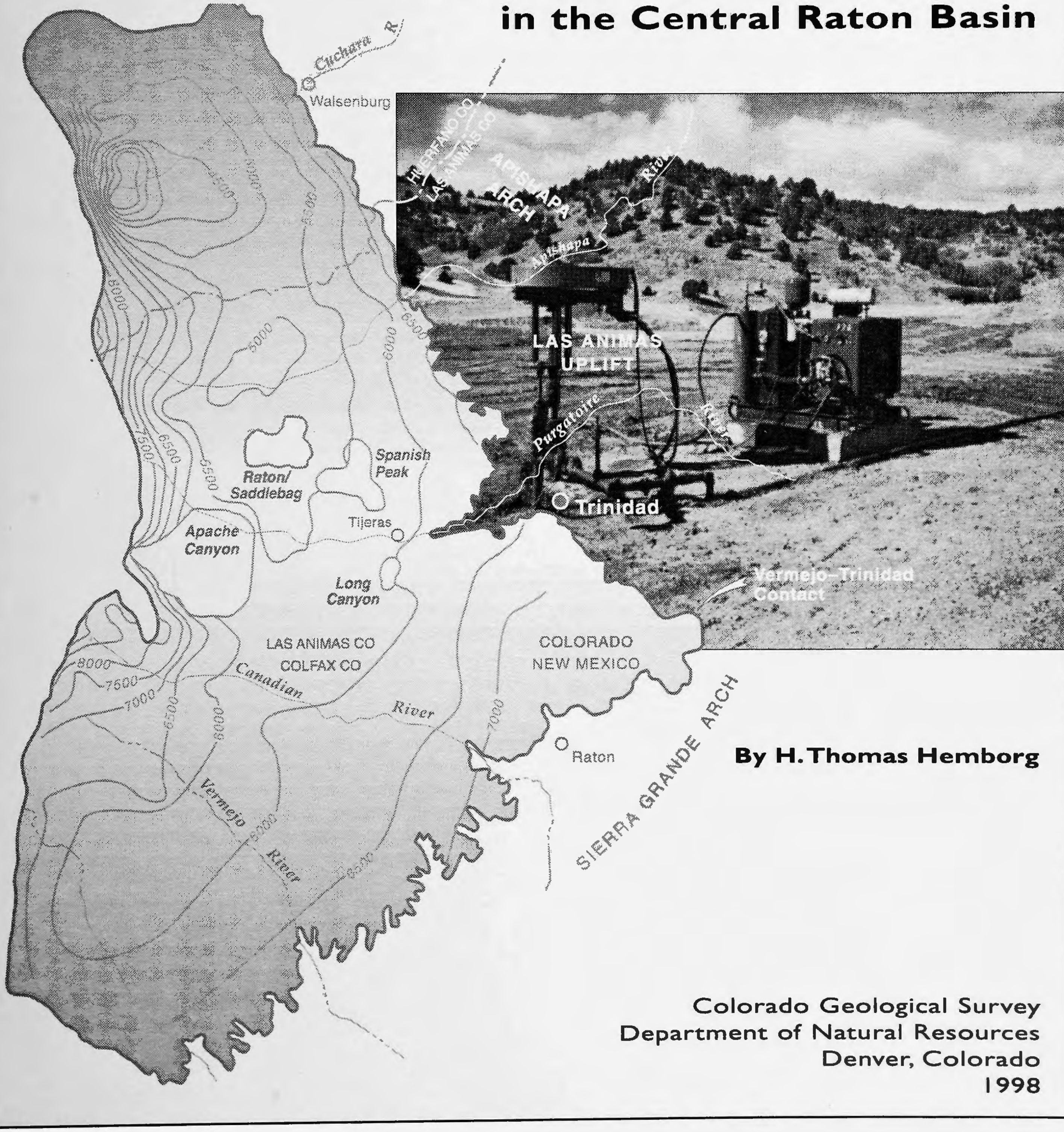
Spanish Peak Field, Las Animas County, Colorado:

Geologic Setting and Early Development of a Coalbed Methane Reservoir in the Central Raton Basin



By H. Thomas Hemborg

Colorado Geological Survey
Department of Natural Resources
Denver, Colorado
1998

Resource Series 33

Spanish Peak Field, Las Animas County, Colorado:

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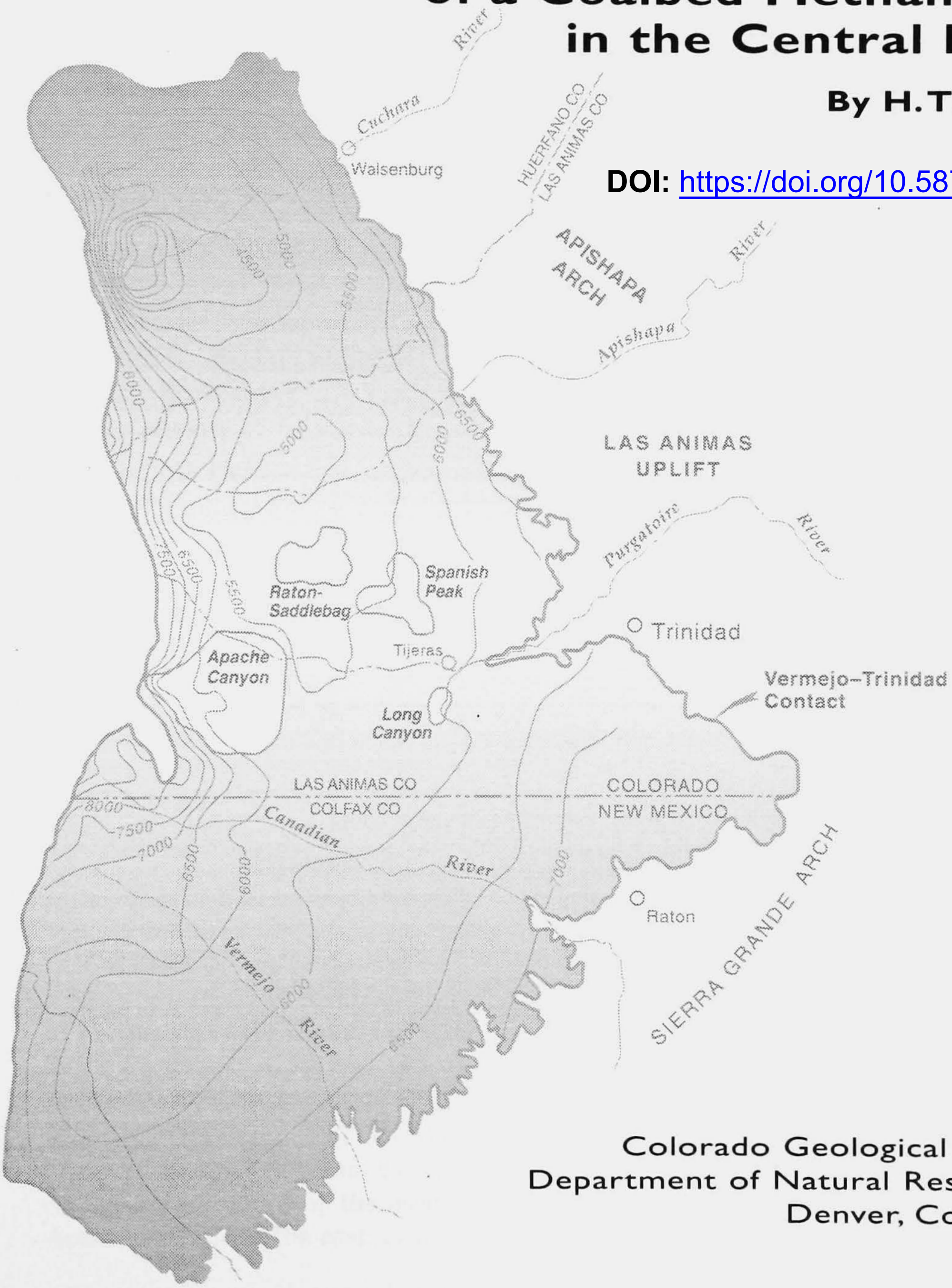
DOI: https://doi.org/10.58783/cgs.rs33.pujt1451



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Acknowledgements

The author thanks the individual operators who generously contributed information for this Raton Basin field study, particularly Dennis R. Carlton, Evergreen Resources, Inc.; Mike Korte, Stroud Oil Properties; Alex Woodruff, Colorado Interstate Gas; and Amoco personnel.

I also express my thanks to reviewers James A. Cappa, Carol Morgans Tremain, Celia Greenman, Allan Larson, Linda Jacobs, D. Keith Murry, and Mary-Margaret Coates for their critical reading and numerous helpful comments; however, the ideas and interpretations presented herein are entirely my own.

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ABSTRACT

The Raton Basin's Spanish Peak coalbed methane (CBM) field was discovered in 1993 by Evergreen Resources, Inc., Denver, Colorado, which drilled and completed a cluster of four exploratory wells located 7 to 8 mi northwest of the small town of Tijeras, Colorado. In January 1995 Evergreen placed three of the wildcats and six additional 1994 field development wells on line. Nearly 4.1 billion cu ft (BCF) of CBM was produced from 45 wells through 1996. In the fall of 1996 Evergreen accelerated its field development program. (December 1996 field production volume averaged 12.9 million cu ft (MMCF) of gas per day: March 1997 deliveries exceeded 17 MMCF from 53 active wells). In early March 1997, Evergreen announced plans to drill and complete an additional 40 CBM wells in the Raton Basin during 1997. It is believed that 36 of these wells will be located in the Spanish Peak development area.

The primary source of Spanish Peak field production is coal beds in the Vermejo Formation (Late Maastrichtian). A very small proportion of the field gas is contributed by coals in the overlying Raton Formation (latest Maastrichtian-early Paleocene). The base of the Vermejo Formation and the top of the conformably underlying Trinidad Sandstone in the Spanish Peak field area varies from about 750 to 1,800 ft below ground surface. Part of this range is related to the region's basin structure, but more than half reflects topography dissected by the Purgatoire River and its tributaries. The thickness of the Vermejo Formation in the Spanish Peak field area varies from 350 ft to 225 ft. The average thickness of the Vermejo Formation in the field area is 290 ft. Individual coal seams in the Vermejo Formation range from several inches to more than 14 ft thick, total aggregate coal thickness in the Spanish Peak field area ranges from 19 to 44 ft.

Evergreen drills field wells in about 1 day using an air percussion rotary rig (somewhat like a jackhammer). After reaching total depth of about 200 ft below the base of the Vermejo Formation in the upper Pierre Shale, Evergreen sets 5.5 in. casing on bottom with cement set through the coal reservoir sequence. Individual wells are completed to produce gas from five to fifteen individual coal seams. The coal zones that are opened with perforations are fracture- stimulated in two or three stages, using on the average 75,000 to 100,000 pounds of sand per stage and from 300 to 400 bbl of water mixed with nitrogen as a carrying agent. An occasional well is completed in four stages. The present field spacing is 160 acres per well.

This study of Spanish Peak field in an early stage of development and productive life is significant because it: (1) demonstrates that commercial levels of CBM have been attained in the central Raton Basin area, (2) provides substantial incentive to explore for additional CBM fields along and east of the Raton Basin synclinal axis from Spanish Peak north into the Cucharas River drainage, and (3) suggests a rather simple strategy for locating fairways of enhanced coalbed permeability in the Central Raton development area and northern Raton exploration area. The strategy is based on synthesis of Spanish Peak geologic and reservoir performance data.

INTRODUCTION

The Spanish Peak coalbed methane (CBM) field developed by Evergreen Resources, Inc. is located in the central area of the Raton Basin in Las Animas County, Colorado (Fig. 1). The Spanish Peak field currently covers approximately 6,000 acres and incorporates 53 active wells on 160-acre spacing. It lies within a CBM belt or "fairway" approximately 25 mi long by 15 mi wide that is centered about 20 mi west of Trinidad, Colorado in the headwaters of the Purgatoire River. The fairway includes four producing fields: Spanish Peak, Apache Canyon (operated by Stroud Oil Properties which recently bought this field from Meridian Oil Company), Raton-Saddlebag (operated by Amoco Production Company), and Long Canyon (operated by Consolidated Industrial Services).

The oil and gas companies active in the Purgatoire River area CBM degasification play are producing this gas from two coal-bearing units, the Vermejo Formation (Late Maastrichtian) and the Raton Formation (latest Maastrichtian to early Paleocene). The upper portion of the Raton crops out in the Spanish Peak Field area. The underlying Vermejo Formation crops out 6 mi east of the present eastern boundary of the Spanish Peak field.

The abundance of coal contained in these two formations is visible from State Highway 12 in the Purgatoire Valley west of Trinidad. Erosion and roadcuts have exposed seams ranging from a few inches to 5 or 6 ft thick that can be observed in a number of places on valley walls along a 20 mi stretch of roadway between Trinidad and the eastern edge of the Sangre de Cristo Mountains. These coals are assigned to the Trinidad field of the Raton Mesa Coal Region (central Raton Basin area) and have been mined extensively in western Las Animas County, Colorado and in Colfax County, New Mexico.

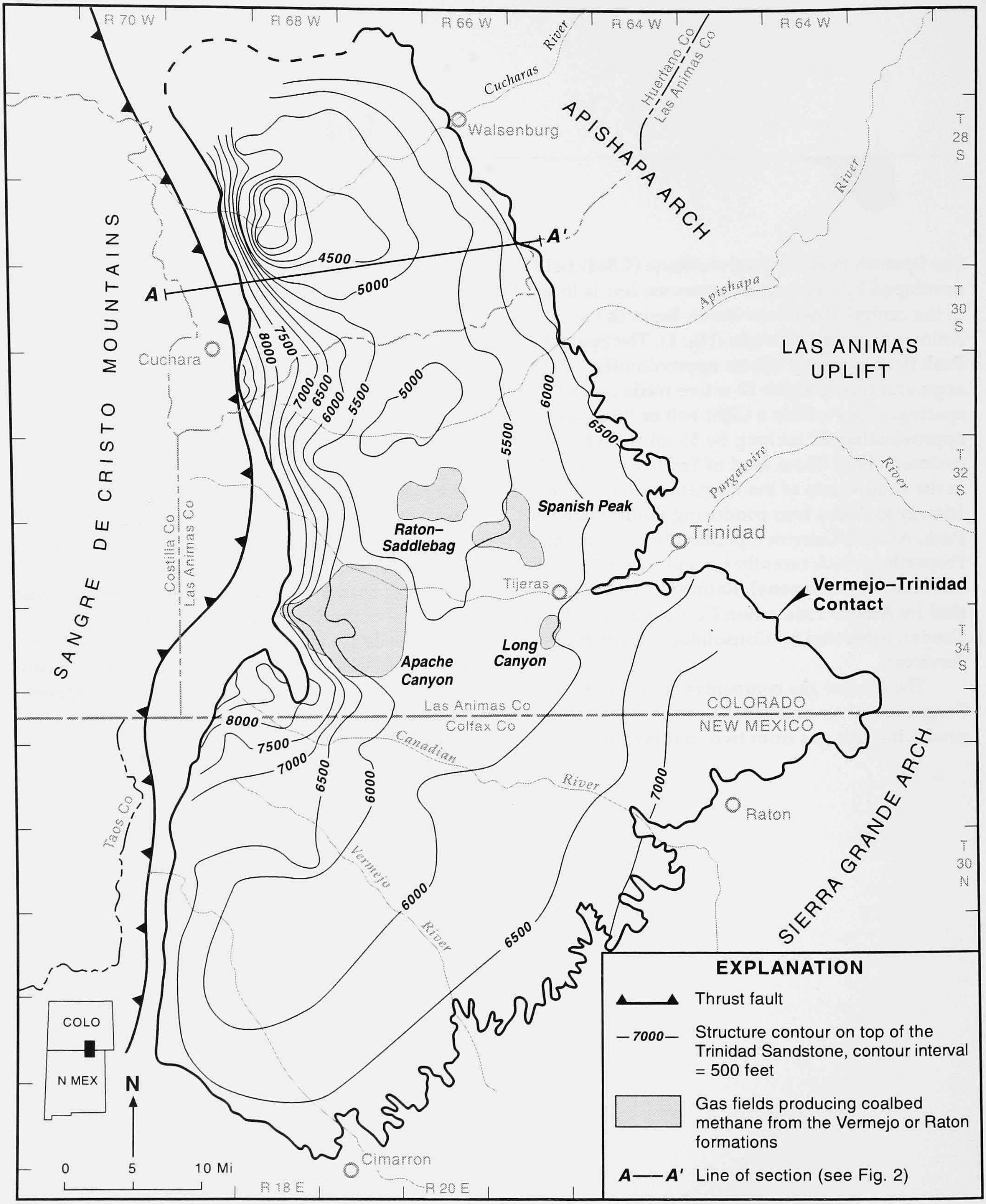

Figure 1. Index map of Raton Basin showing tectonic features, structural configuration of basin on top of the Late Cretaceous Trinidad Sandstone, location of producing coalbed methane fields in the Purgatoire River area of Colorado, and location of cross-section A–A' included in this report as Figure 2. (Modified from Stevens and others, 1992)

Geology and Hydrology of the Spanish Peak Field

Structure and Stratigraphy

The Raton Basin is the southernmost Laramide basin in the Rocky Mountain region. The basin can best be described as an elongate asymmetric synclinorium that extends from southern Colfax County, New Mexico, northward to Huerfano County, Colorado. In this discussion the basin includes the area contained within the outcrop of the Cretaceous Trinidad Sandstone. By this definition the Raton Basin is 80 mi long from north to south and up to 50 mi wide from east to west, and its area is about 2,200 sq mi. Sedimentary rocks may be 15,000–20,000 ft thick in the deepest part of the basin, which is located approximately 15 mi southwest of Walsenburg, Colorado (Keighin, 1996). The basin is bounded by the Sangre de Cristo Mountains to the west, the south edge of the Wet Mountains to the north, the Apishapa Arch to the northeast, the Las Animas Arch to the east, and the Sierra Grande Arch to the south and southeast. The asymmetrical axial trace of the Raton basin (La Veta Syncline), lies approximately 5 to 12 mi east of and parallel to the Sangre de Cristo Mountains. Sedimentary rocks on the west limb, adjacent to the Sangre de Cristo Mountains, dip steeply eastward and gently westward on the east limb (Tyler and others, 1995). The sedimentary rocks along the west edge of the Raton Basin are extensively deformed by steeply dipping thrust faults and several major folds. Normal faulting within the basin generally displaces strata less than 50 ft (Rice and Finn, 1996). At least 15,500 ft of structural relief exists between the deepest part of the Raton Basin and the adjacent Sangre de Cristo uplift (Fig. 2).

The stratigraphy of the Raton Basin is typical of the southern Rocky Mountains (Fig. 3). A thin carbonate succession (Devonian and Mississippian) overlies the Precambrian basement. Overlying this sequence are 5,000–10,000 ft of terrigenous Permian-Pennsylvanian strata, largely sandstones and redbeds. The Permian beds in the Raton basin are unconformably overlain by the upper Triassic Dockum group, a body of fluvial sandstone and shale as much as 1,200 ft thick (Baltz, 1965). The upper Triassic rocks are unconformably overlain by middle and upper Jurassic strata, which consist of continental and shallow-marine siliciclastic and carbonate rocks that are 200–600 ft thick. The Cretaceous section includes 200 ft of the basal clastic sequence of the Purgatoire and Dakota Formation, followed by 1,000–2,000 ft of marine chalks, marls, and organic-rich shales of the Benton and Niobrara Groups. This sequence is overlain by approximately 2,500 ft of marine Pierre Shale. The marginal marine and partly deltaic Trinidad Sandstone overlies the Pierre, and is in turn overlain by the coal-bearing Vermejo Formation. The Late Cretaceous and Paleocene Raton Formation which is also coal-bearing overlies the Vermejo. Tertiary sediments of the Poison Canyon Formation overlying these strata are highly variable and represent continental terrigenous sedimentation during the end of the Laramide orogeny. Perhaps 10,000 ft of Tertiary sediments were originally deposited, but erosion has removed much of them, especially around the basin margins.

Young igneous rocks (early Miocene to recent) occur over a wide area of the Colorado portion of the Raton Basin. These rocks were emplaced as stocks, laccoliths, flows, plugs, dikes, and sills. Prominent stocks include the two early Miocene granitic intrusives which form the core of East Spanish Peak (12,683 ft) and West Spanish Peak (13,626 ft). These much photographed, perennially snowcapped peaks, from which Evergreen's Spanish Peak field took its name, are located about 18 mi northwest of Spanish Peak field.

Hundreds of dikes, 2–60 ft thick, radiate from the Spanish Peaks. A second dike set is oriented approximately normal to the convex front of the

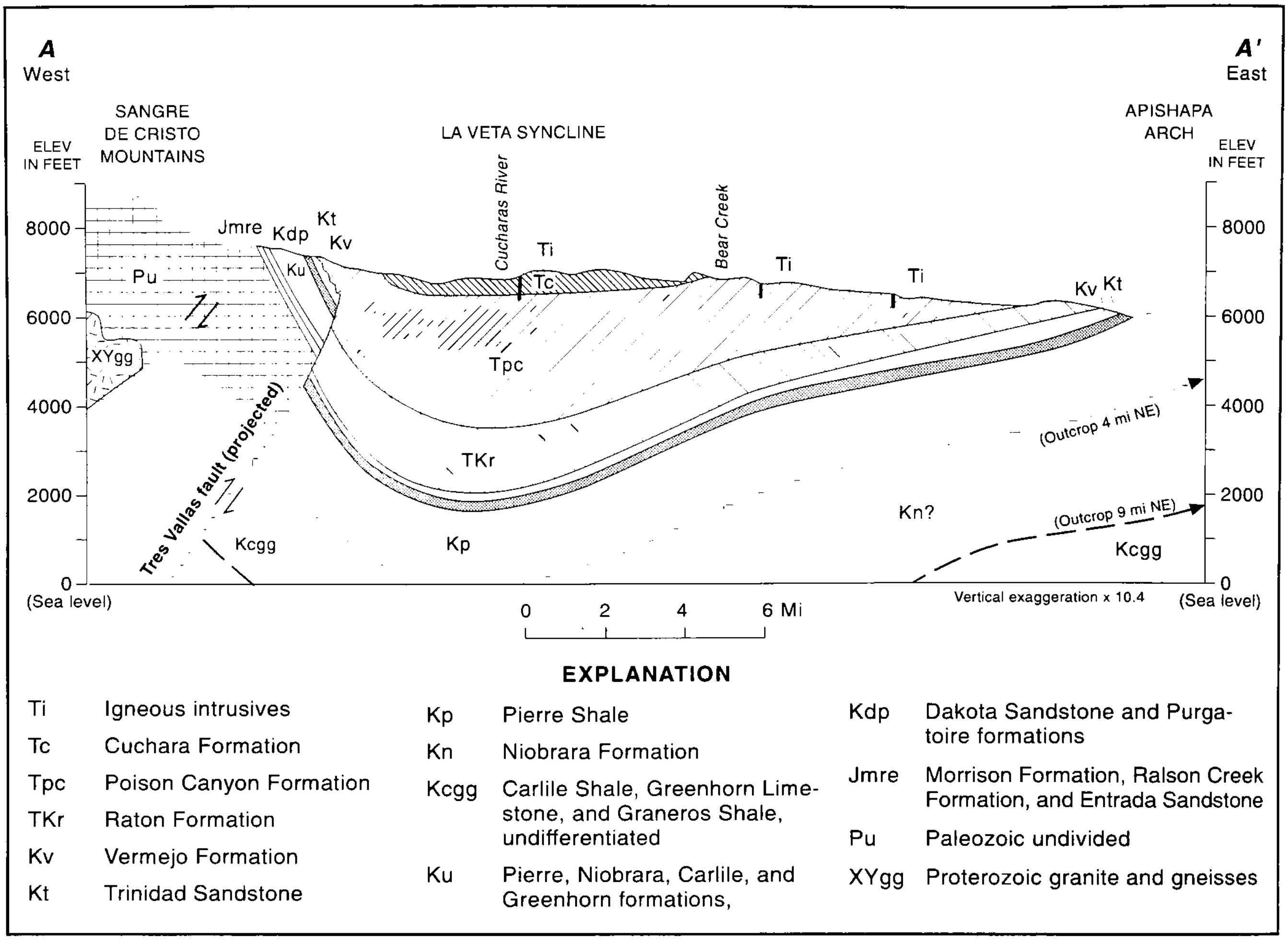

Figure 2. West-east cross section across the northern Raton Basin from Sangre de Cristo Mountains on the west to Apishapa Arch on the east. The location of the cross section is shown on Figure 1. (Modified from Stevens and others, 1992)

Sangre de Cristo Mountains in an east-west direction. According to Ode (1957), Johnson (1961), and Muller and Pollard (1977) the radial dikes were intruded into domed and fractured host rock which was deformed during the intrusion of the Spanish Peaks stocks. The east-west oriented dikes, in contrast, intruded fractures formed during east-west compression, which predate by a few million years the 23–27 ma age-dated Spanish Peaks intrusives. Dike-fed sills and small laccoliths are also common. They range in composition from gabbroic to rhyolitic.

Vermejo Formation

Stratigraphy

The Vermejo Formation, whose coals currently contribute most of the Spanish Peak field gas stream, is named after exposures in the Vermejo Park area of New Mexico. W. T. Lee first described the formation in 1913 (Mitchell and others, 1956). Harbour and Dixon (1959) described the formation as 60 percent shale, 30 percent sandstone, and 10 percent coal. These components are shown on a type log from the Spanish Peak field's Evergreen-Laura well 41-12, NE1/4NE1/4 sec. 12, T. 33 S., R. 66 W. (Fig. 4). Tremain (1980) characterized the appearance of these components as described below:

Shales—gray, dark gray, and nearly black; carbonaceous and silty

Sandstones—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

ERA	PERIOD / EPOCH	FORMATION	THICKNESS (FT)	LITHOLOGY
CENOZOIC	Recent		0—30	Alluvium, basalt flows
CENOZOIC	Miocene	Devils Hole Formation	25–1,300	Light-gray conglomeratic tuff and conglomerate
CENOZOIC	Oligocene	Farisita Formation	0–1,200	Buff conglomerate and sandstone
CENOZOIC	Eocene	Huerfano Formation	0–2,000	Variegated maroon shale and red, gray, and tan claystone
CENOZOIC	Eocene	Cuchara Formation	0–5,000	Red, pink, and white sandstone, and red, gray, and tan claystone
CENOZOIC	Paleocene	Poison Canyon Formation	0–2,500	Buff arkosic conglomerate and sandstone, yellow siltstone, and shale
CENOZOIC	Paleocene	Raton Formation	0–2,075	Light-gray to buff sandstone, dark-gray siltstone, shale, and coal; conglomerate at base
MESOZOIC	Upper Cretaceous	Raton Formation		
MESOZOIC	Upper Cretaceous	Vermejo Formation	0–360	Dark-gray silty and coaly shale, buff to gray carbonaceous siltstone, and sandstone beds; coal
MESOZOIC	Upper Cretaceous	Trinidad Sandstone	0–255	Light-gray to buff sandstone
MESOZOIC	Upper Cretaceous	Pierre Shale	1,300–2,900	Dark-gray fissile shale and siltstone
MESOZOIC	Upper Cretaceous	Niobrara Group: Smokey Hill Marl	560–850	Yellow chalk, marine gray shale and thin white limestone; and light-gray limestone at base
MESOZOIC	Upper Cretaceous	Niobrara Group: Fort Hayes Limestone	0–55	
MESOZOIC	Upper Cretaceous	Benton Group: Codell Sandstone	0–30	Brownish sandstone, dark-gray shale, gray limestone and gray shale
MESOZOIC	Upper Cretaceous	Benton Group: Carlile Shale	165–225	
MESOZOIC	Upper Cretaceous	Benton Group: Greenhorn Limestone	30–80	
MESOZOIC	Upper Cretaceous	Benton Group: Graneros Shale	185–400	
MESOZOIC	Lower Cretaceous	Dakota Sandstone	100–200	Buff sandstone, buff conglomerate sandstone, and dark-gray shale
MESOZOIC	Lower Cretaceous	Purgatoire Formation	100–150	
MESOZOIC	Jurassic	Morrison Formation	150–400	Variegated maroon shale, gray limestone, red siltstone, gypsum, and gray sandstone
MESOZOIC	Jurassic	Ralston Creek Formation	30–100	
MESOZOIC	Jurassic	Entrada Sandstone	40–100	
MESOZOIC	Triassic	Dockum Group	0–1,200	Red sandstone, calcareous shales, and thin limestones
PALEOZOIC UNDIVIDED			5,000–10,000	Variegated shales, arkose, conglomerates, and thin marine limestone

Figure 3. Generalized stratigraphy of Cenozoic and Mesozoic units in the central and northern Raton Basin. (After Tremain, 1980)

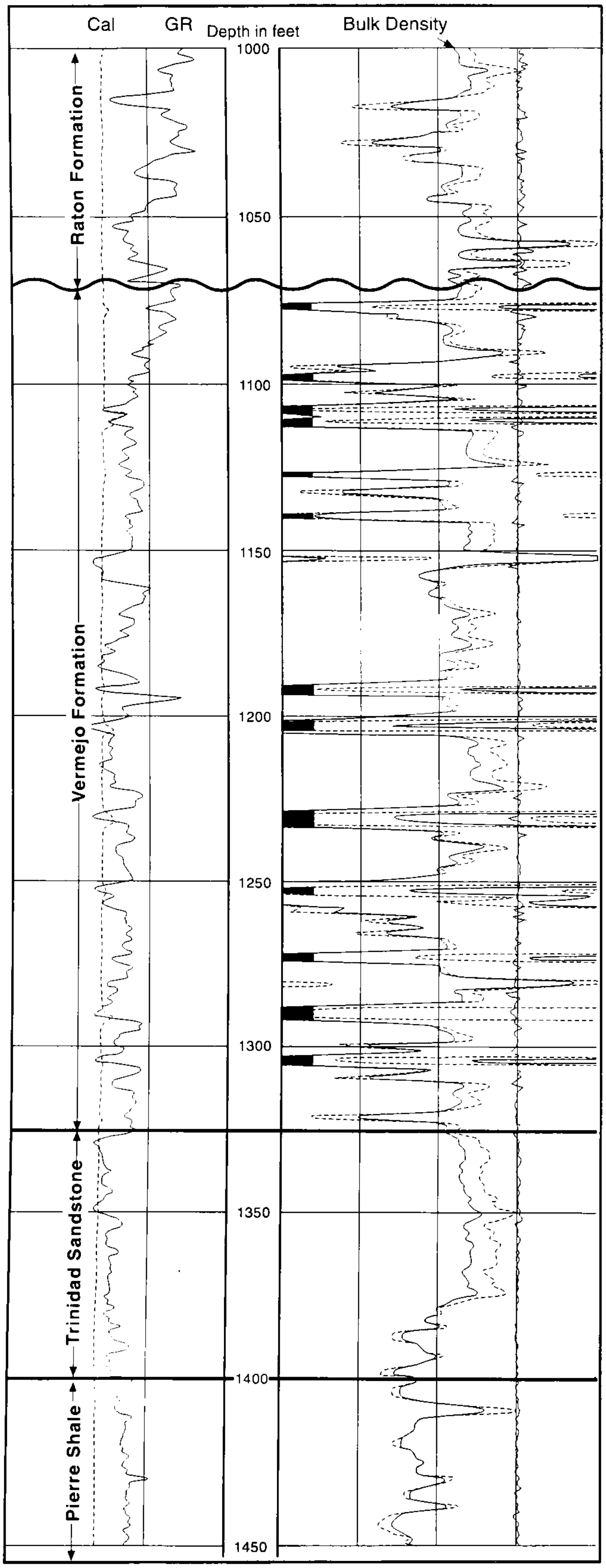

Figure 4. Type log, Spanish Peak field, showing gamma-ray and bulk density patterns. Solid black areas indicate coal seams.

Coals—black; friable; bright luster; platy cleavage; cubic or prismatic cleats; 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, 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.

The thickness of the Vermejo Formation in the Spanish Peak field area ranges from 350 ft to 225 ft. and averages 290 ft. The gross thickness of coals in the formation here ranges from 19 to 44 ft.

Uplift of the Sierra Grande occurred following deposition of the Vermejo Formation and is documented by the Late Cretaceous erosional beveling of the Vermejo Formation and part of the Trinidad Sandstone in the southeastern part of the basin. Concurrently, Laramide orogenic activity began to the west. Erosion during uplift of the Sangre de Cristo Mountains supplied the clastic sediments for the Raton Formation basal conglomerate that marks the contact between the Vermejo and overlying Raton Formation (Stevens and others, 1992). The Raton Formation is as much as 1,600 ft thick and has a net coal isopach thickness in the range of 10 to 140 ft (Stevens and others, 1992). Although the Raton Formation contains more coal than the Vermejo, individual coal seams are thinner and more discontinuous, and they are distributed over 1,200 ft of section. The nature of the coal seams in the two formations was controlled by depositional environment: the Vermejo was deposited in a lagoon, whereas the Raton was deposited in a fluvial setting.

Coal Rank in the Purgatoire Fairway

The rank of coals in the Vermejo Formation ranges from high-volatile C bituminous along the margins of the basin to low-volatile bituminous in the central part of the basin. The rank generally correlates with present-day depth of burial and structural configuration, and it probably reflects the maximum depth of burial and structural configuration extant in Tertiary time (Rice and Finn, 1995). However, the highest ranks (low-volatile bituminous) occur along the Purgatoire River where present day depths of burial are less than 1,800 ft. These high ranks may be the result of heat flow from the crust, upper mantle or deep igneous intrusions whose heat was transferred laterally by groundwater in middle Tertiary time (Rice and Finn, 1995).

Numerous sills up to 2 ft thick can be recognized in the Spanish Peak field Vermejo section on wire line log traces of the compensated neutron-density log, which Evergreen Resources uses as their primary well bore evaluation tool. Rice and Finn (1995), however, report the thermal maturity of coal beds is only locally affected (one sill width) by the intrusions.

Coal-bed gases from production tests in the Raton Basin are composed mostly of methane with minor amounts of ethane, carbon dioxide, and nitrogen (each less than 1 percent). Isotopic analyses indicate that the gases are predominantly of thermogenic origin and were probably generated during the time of maximum burial, which may correlate with maximum heat flow. Some mixing of relatively recent biogenic gas may have occurred in areas of groundwater flow (Rice and Finn, 1995).

Regional Groundwater

Regional ground water flow in the Purgatoire area is eastward (Fig. 5). Recharge is along the elevated western outcrops which receive more rain and snowfall. Discharge is primarily along the Purgatoire River. The total dissolved salt concentrations in the fairway are relatively low for

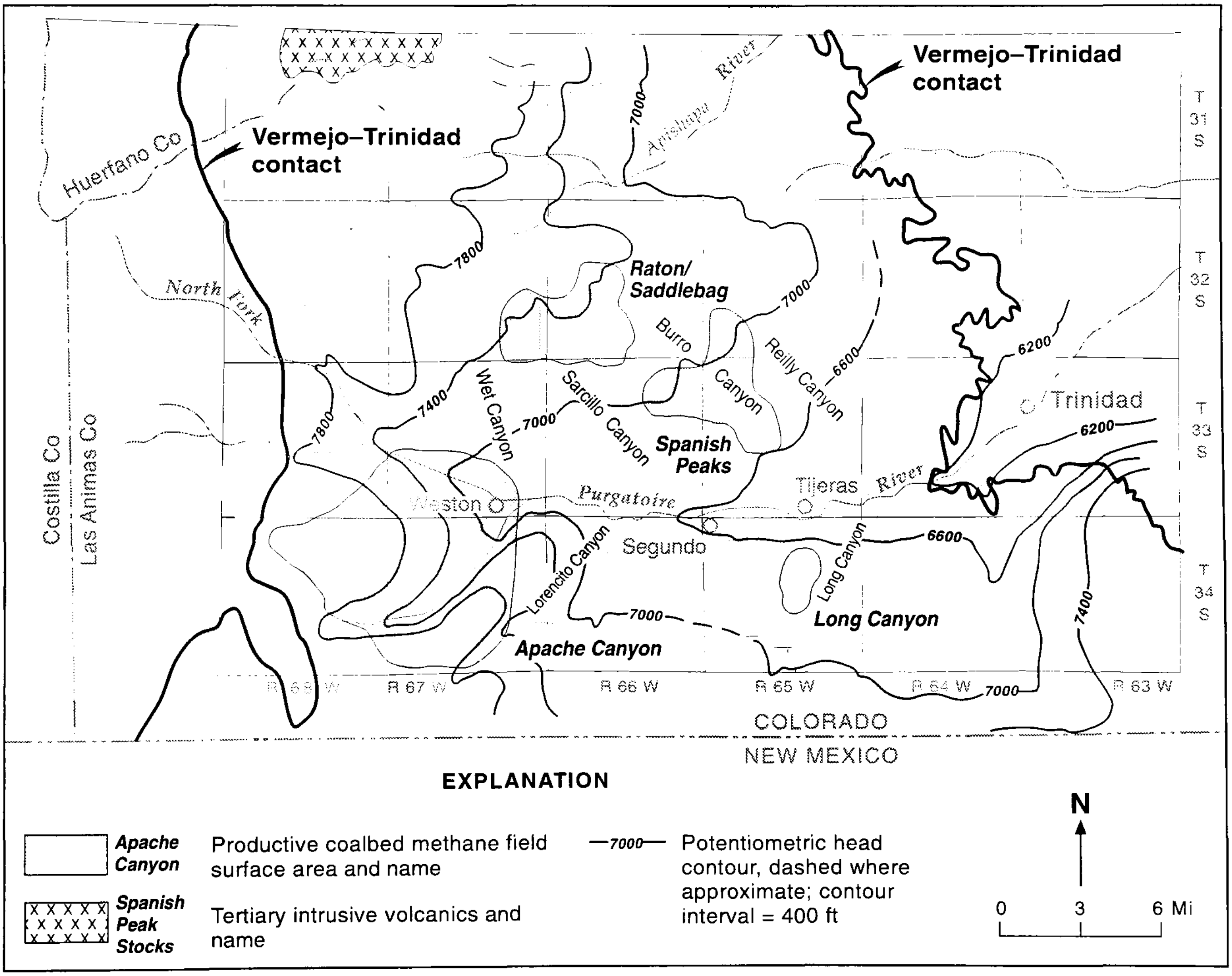

Figure 5. Potentiometric surface map of aquifers in the upper Purgatoire River and Apishapa River drainages. Data obtained from files on record with Las Animas County. Study was conducted for the county by Rocky Mountain Consultants Inc. in 1975.

coalbed waters (< 2,500 part per million), indicating a short residence time and continuous recharge from adjacent sandstones, dikes, sills, or the coals themselves. Evergreen, operating under permits issued by the Colorado Department of Public Health and Environment, has been discharging produced water into stream beds and stock ponds.

Coalbed Methane Development

Early Studies by the Colorado Geological Survey

The United States Bureau of Mines in 1975 granted $50,000 to the Colorado Geological Survey (CGS) in support of a research project entitled "Data Accumulation on the Methane Potential of the Coal Beds of Colorado."

The objectives of the project were as follows: (1) to search the literature and available historic records for references pertaining to the occurrence of methane gas in Colorado coal beds and mines; (2) to calculate the methane gas content of coal in freshly cut cores by means of desorption measurements; (3) to acquire geological data needed to prepare stratigraphic cross sections and structure and isopach maps of coal beds in selected areas; and (4) to collect data on faults, fractures, cleats, etc. related to the coal beds studied.

The overall goal was to locate an area in Colorado in which gassy coal beds could be penetrated by a vertically drilled hole and subsequently stimulated by the hydraulic fracture method currently being employed by the petroleum industry to enhance the production of oil and gas. Stimulation treatments of coal beds in other areas of the country have in some instances increased the flow of methane several fold. Degasification of coal beds before they are mined could add needed new reserves of pipeline-quality gas, improve mine safety, and increase mine productivity.

Open file report CGS 78-2 (Fender and Murray, 1978) reports the results of this study. The authors concluded from a study of historical mining records and recorded methane emission rates at active mines that, "The coal-bearing areas of Colorado exhibiting the highest concentrations of methane in coal are (a) the southeastern Uinta region (Carbondale field) in Pitkin and Gunnison Counties; and (b) the Raton Mesa Region (Trinidad field) in western Las Animas County." Although unable to obtain fresh cores for desorption testing, Fender and Murray (1978) identified 16 mines in the Purgatoire CBM fairway as gassy, a site of a underground methane explosion, or a site of a dust explosion that may have been methane related (Fig. 6). The Colorado portion of the coal region covers approximately 1,100 sq mi in Las Animas and Huerfano counties. Commercial mining of the Raton Mesa Vermejo and Raton Formations coals in Colorado began in 1870 (Pillmore, 1969). Reports of methane gas in the region's coal mines date back to the same period (Fender and Murray, 1978). At least 371 mines have operated in the region (Boreck and Murray, 1979). Currently there are no active mines in the Colorado portion of the Raton Mesa Coal Region. The final mine to be closed was the Golden Eagle, which was sealed by the mine operator (Basin Resources) in December 1995. This shutdown effectively ended 125 years of continuous coal mining activity in the district. The district closure is not a result of resource depletion, but rather that the district could not compete economically with the lower unit operating costs obtained by operators in other Rocky Mountain coal regions.

The United States Department of Energy in 1978 awarded a second grant to the CGS in support of its continued research on the gas content of Colorado coals. This latter research project was entitled "Evaluation of the Methane Potential of Unmined/Unminable coalbeds in Colorado." The objectives of this study were to locate the gassiest coals in the Raton Mesa Coal Region, determine why they are gassy, and estimate the amount of gas they contain. CGS Open File Report 80-4 (Tremain, 1980), reported the results of 38 "direct method" desorption tests (method of MaCullough and others, 1975) completed by the CGS on fresh coal cores collected from both Vermejo and Raton Formation seams. Desorption analysis included coal cores from four United States Geological

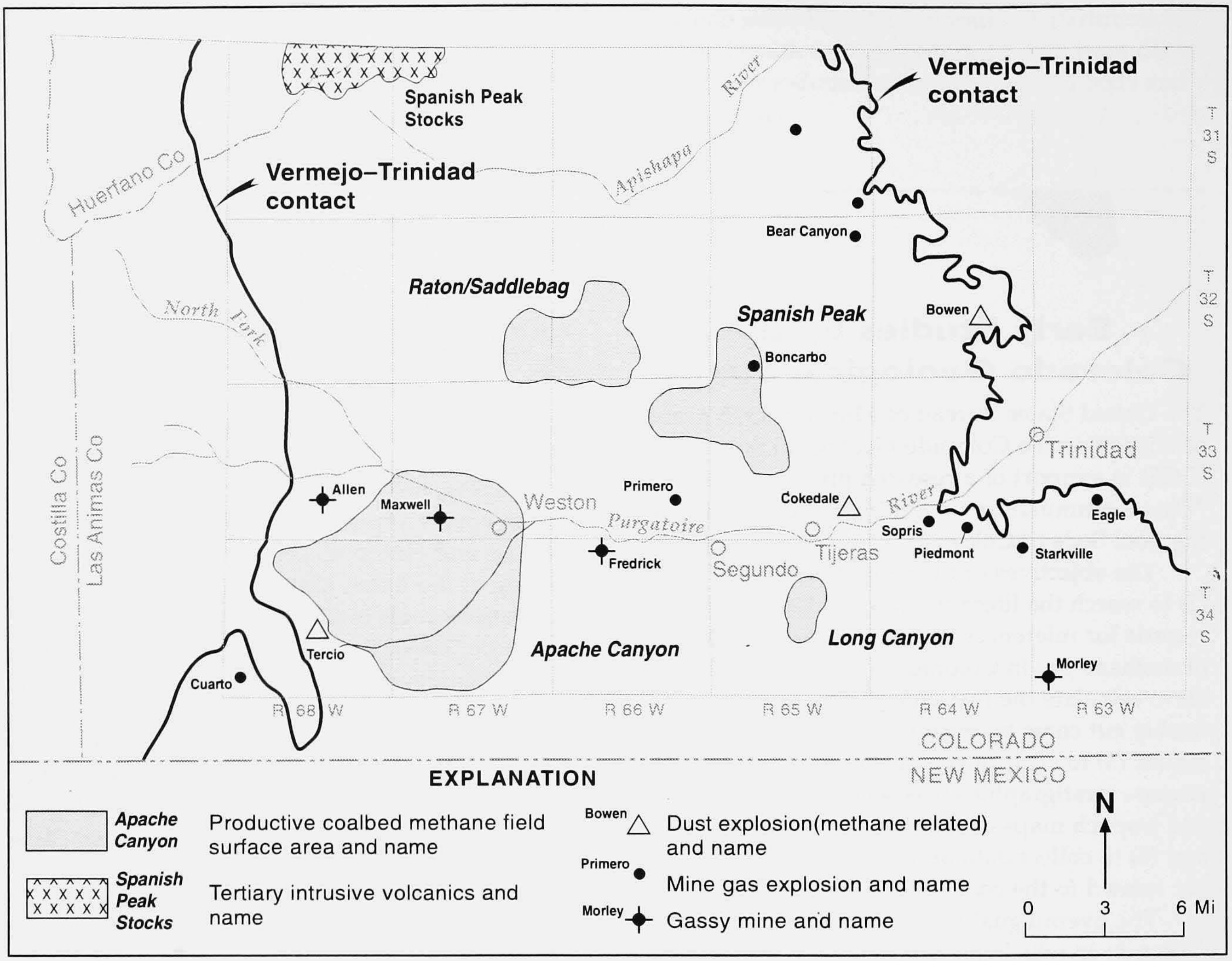

Figure 6. Location of Las Animas County, Colorado coal mines in the Vermejo or Raton Formation reported as gassy, as a site of an underground methane explosion, or as a site of a methane-related coal dust explosion. (After Fender and Murray, 1978)

Survey test holes that were drilled within the Purgatoire fairway in June 1978.

The author concluded that a 179-sq mi area containing 1.56 trillion cu ft of gas in Vermejo coal beds (Fig. 7) could be defined by coal rank data, data from the desorption of coal core samples, structure mapping of the Trinidad Sandstone, isopach mapping of the Vermejo coal beds, coal mine emission data, and records of oil and gas tests in the region (Tremain, 1980). 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 area. These coals contain up to 514 cu ft of gas per ton and are less than 2,000 ft below the surface in the high-potential area.

This high-potential area proposed essentially mirrors the Purgatoire River CBM fairway now under active development by Evergreen Resources, Stroud Oil Properties, Amoco Production Company and Consolidated Industrial Services.

CGS Open File Report 81-4 (Tremain and Toomy, 1983) reports desorption data from the 1978 test holes and from coal samples collected from seven additional test holes advanced in the Purgatoire fairway from late 1978 through 1980 (Fig. 8 and Table 1). This latter report also includes drilling information, sample descriptions, petrographic analysis, proximate analysis, ash content, heating value, and apparent rank of each of the samples analyzed.

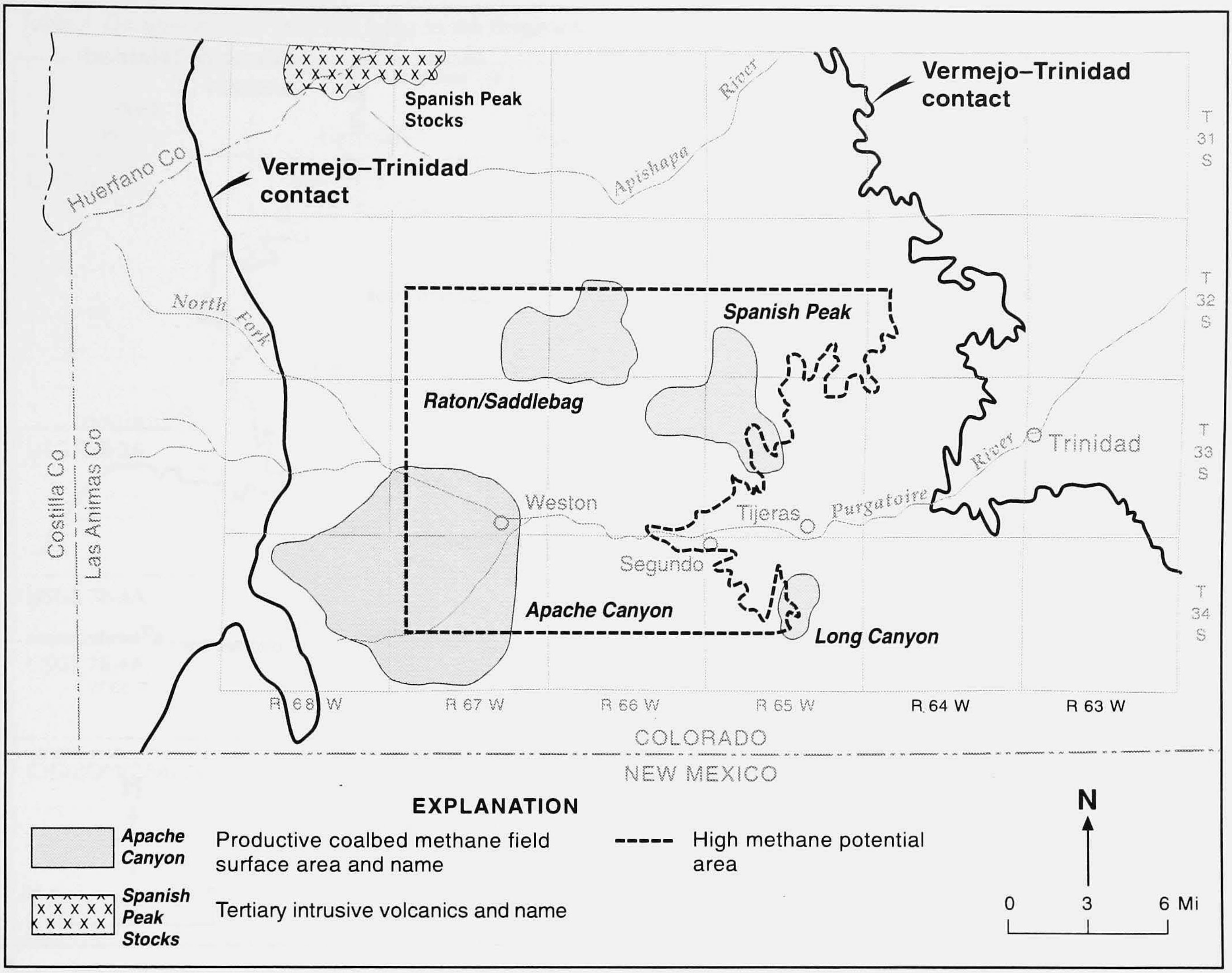

Figure 7. High potential CBM development area in the Raton Mesa Coal Region. (Tremain, 1980)

The gas content is notable in the Vermejo coal core collected from 1192.1 to 1194.7 ft in the Mobil CT-79-8-9c. This 1979 test hole lies within the Spanish Peak field. Gas in place (GIP) for this 2.6 ft seam was calculated at 385 MMCF, based on a seam extent of 160 acres, the current Spanish Peak field spacing. The equation used to calculate the gas in place is as follows:

$$GIP = GC \times h \times A \times P;$$

Where GIP = gas in place (cu ft),
GC = gas content (cu ft),
h = total coal thickness (ft),
A = drillable area/well spacing (acres),
and P = coal density (tons/acre-ft).

A density of 1,800 tons per acre foot was applied to this seam (Stevens and others, 1992).

Drilling History

CBM exploration in the Purgatoire fairway began in 1982 when Woods-McShane-Thomas drilled three wells in the Raton-Saddlebag field area (Fig. 1). In late 1982 through early 1984 seven wells were drilled by HBB, Inc. north of the Raton-Saddlebag area (T. 31 S., R. 66 W., T. 31 S., R 67 W., and T. 32 S., R. 67 W). Amoco Production Company, in a period from 1984–1989, drilled about 20 wells. Amoco activity was divided between the Raton-Saddlebag area and an area east of Apache Canyon field in T. 34 S., R. 66 W. Casing was run on most of these early wells and completion was attempted in both the Raton and Vermejo Formations.

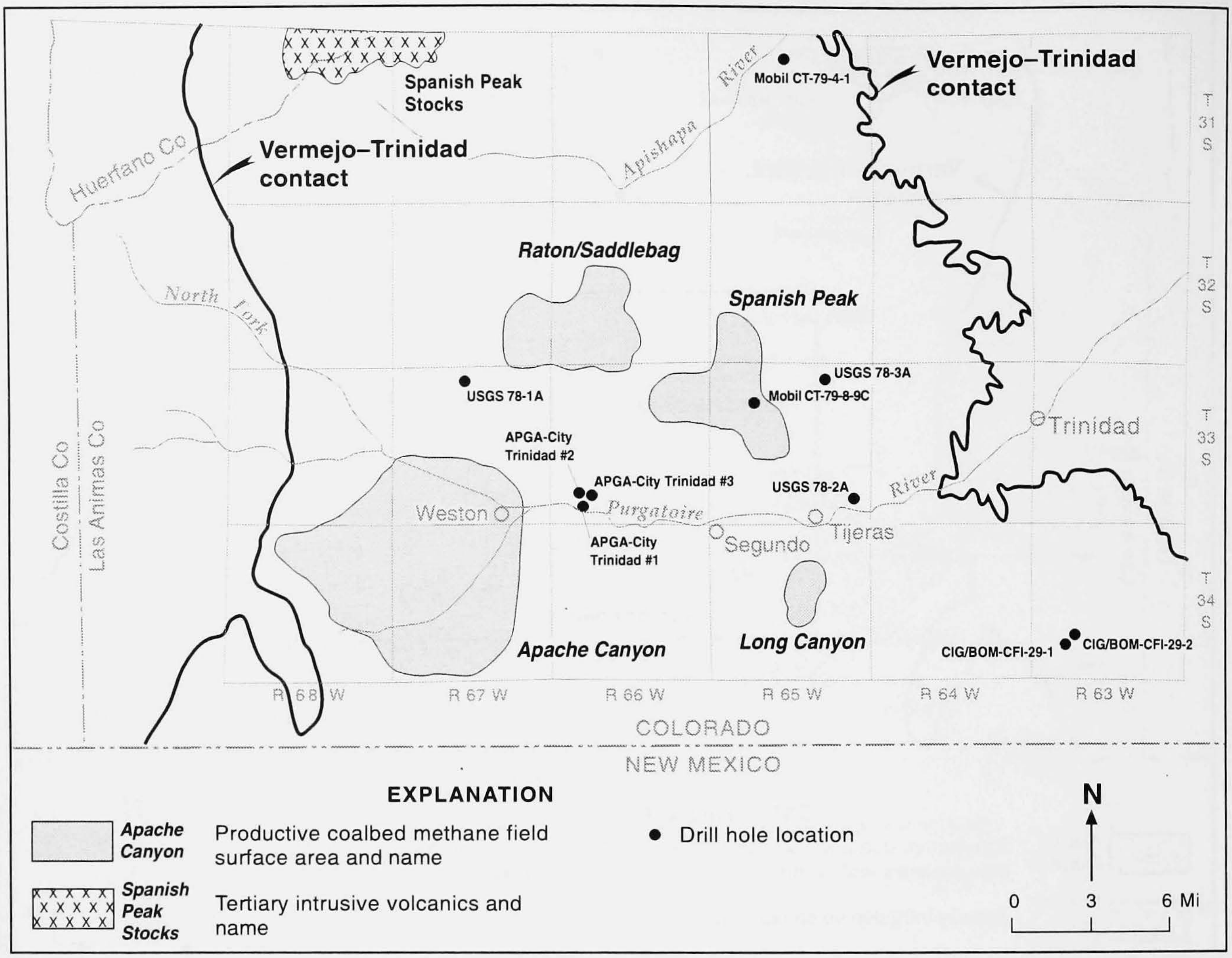

Figure 8. Las Animas County, Colorado drill holes that cored Vermejo or Raton Formation coal seams for desorption testing by the Colorado Geological Survey. Gas content data individual cores is reported in Table 1.

In 1990 Meridian Oil Company commenced a 22-well program of CBM production test wells in the central and eastern portion of the Apache Canyon area. Western Oil in 1991 drilled an additional series of 11 production test holes in the northwestern part of the Apache Canyon field area. Three other oil and gas operators (Pennzoil, Precisione O'Neal, K N Production) drilled either one or two CBM tests in the southern part of Purgatoire fairway in the late 1980s or early 1990s.

Traditional completion techniques were employed during the 1982–92 exploratory period. Five and one-half inch casing was run to total depth, and the coal seams were shot with from two to eight perforations per foot. The Raton basin coals generally seem to exhibit fair to good permeability. However, in order to maximize production rates operators usually hydraulically stimulated the pay zones. Because of the wide intervals through which the coal seams occur, most of the wells were stimulated in two stages, or occasionally three. The treatment averaged about 200,000 lbs of 10/20 or 20/40 sand with 100,000 gal of cross-linked gel per job (Stevens and other, 1992).

Wood-McShane-Thomas and HBB Inc. have never released information on the results of the production testing of their collective 10 CBM tests. Amoco in 1989 released data from a well in the Raton- Saddlebag field. It reported that the #1 State of Colorado-AT (SE1/4SE1/4 sec. 16, T. 32 S., R. 66 W) had an initial production (IP) rate of 239 Mcf/d and no water. This well was a workover of one of the Wood-McShane-Thomas tests. Amoco completed the well in 1987. Amoco, without being specific as to location, also reported at the same

Table 1. Desorption data from test holes in the Purgatoire fairway from 1978–1980.

Well Name	Location	Sample Date	Formation	Cored Interval	Total Gas Content Cu Ft/Ton
USGS 78-1A	SESE Sec. 4 T. 33 S., R. 67 W.	6/6/78	Raton	810–811.3	51
		6/6/78	Raton	828.2–828.65	26
		6/7/78	Raton	1,053.5–1,053.9	72
		6/7/78	Raton	1,062.9–1,065	193
		6/9/78	Vermejo	1,691.2–1,695.4	354
		6/10/78	Vermejo	1,792–1,795	492
USGS 78-2A	T. 33 S., R. 66 W. SWSE Sec. 27	6/12/78	Raton	308.3–310.5	83
		6/12/78	Raton	482.2–484.7	88
		6/13/78	Raton	499–501	160
USGS 78-3A	NWSW Sec. 2 T. 33 S., R. 65 W.	6/15/78	Vermejo	729.4–732.6	254
USGS 78-4A	Center Sec. 36 T. 33 S., R. 65 W.	6/16/78	Vermejo	1,00.5–102.65	23
		6/16/78	Vermejo	1,67.9–169.85	114
CIG/BOM/CF&I 29-1	7941.38 ft at 263° 33' 59.7" from USGS "Berg" Marker—Sec. 29 T. 34 S., R. 63 W.	7/14/78	Vermejo	715.6–717.6	46
		7/17/78	Vermejo	810–815	6
		7/18/78	Vermejo	857.5–858.7	155
		7/18/78	Vermejo	869.5–871.9	147
		7/18/78	Vermejo	875–875.5 878.7–879.1	102
CIG/BOM/CF&I 29-2	1669.91 ft at 62°-14' 42" from drill hole CIG/BOM/CF&I 29-1—Sec. 29. T. 34 S., R. 63 W.	8/2/78	Vermejo	868–870.1	37
		8/2/78	Vermejo	872.5–873	13
		8/4/78	Vermejo	961.7–966.5	36
		8/7/78	Vermejo	1,005.5–100.95	38
		8/7/78	Vermejo	1,012.75–1,014.35	86
		8/7/78	Vermejo	1,029.1–1,032.3	89
Mobil CT-79-8-9c	NENW Sec. 8 T. 33 S., R. 65 W.	7/23/79	Vermejo	1,192.1–1,194.7	514
Mobil CT-79-4-1	SESW Sec. 4 T. 31 S., R. 65 W.	7/26/79	Raton	223.8–226.6	51
		7/26/79	Raton	343–346	90

Table 1. Continued.

Well Name	Location	Sample Date	Formation	Cored Interval	Total Gas Content Cu Ft/Ton
APGA Incorporated City of Trinidad #2	T. 33 S., R. 66 W. NWNW Sec. 32	6/22/80	Vermejo	1,184–1,185	131
		6/27/80	Vermejo	1,190–1,190.5	271
		6/27/80	Vermejo	1,205–1,209	364
APGA Incorporated City of Trinidad #3	NENW Sec. 32 T. 33 S., R. 66 W.	7/23/80	Vermejo	1,092.6–1,094.6	339
		7/24/80	Vermejo	1,099.3–1,100.3	345
		7/24/80	Vermejo	1,108–1,109	414
		7/25/80	Vermejo	1,157–1,158	515
APGA Incorporated City of Trinidad #3	NWNW Sec. 32 T. 33 S., R. 66 W.	9/23/80	Vermejo	1,360–1,363	407

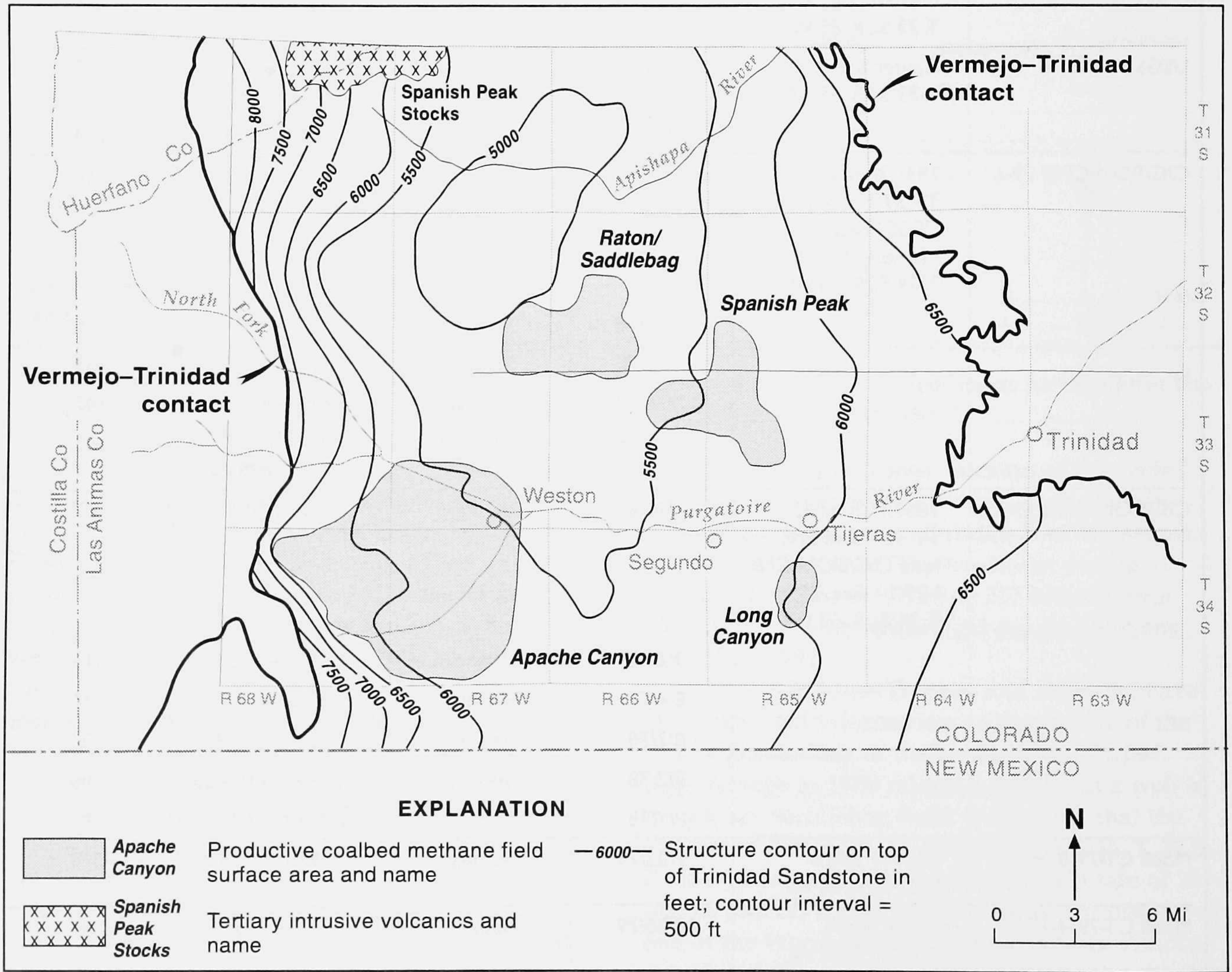

Figure 9. Structure contour map on top of the Trinidad Sandstone in Las Animas County, Colorado.

time that five other wells in their series of CBM tests in the Purgatoire fairway had been flared at between 68 to 500 Mcf/d per well before they were shut-in owing to low gas prices and the absence of a pipeline infrastructure (Gas Research Institute, 1989; Stevens, 1993; Taylor and others, 1995).

Meridian Oil, after stimulating the best well in its Apache Canyon development area, reported that the Apache Canyon 14-1, NE1/4NE1/4 sec. 14, R. 34 S., T. 68 W., initially produced 340 Mcf/d of gas and 368 bbl of water (BW) per day (Tyler and others, 1995).

Data obtained from the Colorado Oil and Gas Conservation Commission files indicate that Western Oil in 1991 production-tested 10 of their wells in the northwestern Apache Canyon development area. These wells (secs, 28, 29, 30, 31, 33, and 34, T. 33 S., R. 67 W) collectively flared 44 MMCF of gas and produced 1,189,869 BW, an average of 27,042 BW per MMCF of gas.

In summary, results were mixed in the 1982–92 series of CBM exploration and production test wells in the Purgatoire fairway. Poor well performance can be credited to some combination of the following three factors: (1) sub-optimal well siting; (2) drilling practices that expose the Raton Basin coals to drilling mud, which appears to significantly lower seam permeability; and (3) excessive or poorly contained hydrologic stimulations which have led to completions in out-of-zone water-prone igneous sills or dikes and sandstones within the Raton and/or Vermejo Formations (Stevens and others, 1996). The poorly sited wells are along the steeply dipping western margin of the play, where because of the high recharge excessive water is produced. The 1991 production testing by Western Oil of their CBM wells located in the northwestern portion of the Apache Canyon (Fig. 9) clearly supports this observation. While at present (1997) Stroud Oil Properties is actively developing and expanding the areal extent of Apache Canyon field, the Western Oil CBM properties, which are now owned by Tom Brown Inc., remain shut-in.

Spanish Peak Field

Development History

Beginning in December 1991, Evergreen acquired 120,000 acres of oil and gas leases in the Purgatoire CBM fairway. The initial 70,000 acres were acquired from Amoco Production Company by direct purchase without overriding royalties. The remainder of the acreage was purchased from individual owners under various lease terms. Evergreen's acreage generally encircles Amoco's Raton-Saddlebag field development area. The majority of the lands under lease by Evergreen are fee, and state and federal leases make up the balance.

In March 1995, the Bureau of Land Management (BLM) approved Evergreen placing approximately 67,000 acres of its Las Animas County acreage position in a federal unit called Spanish Peak. In May 1966 Amoco placed 32,000 acres of the Raton-Saddlebag field development area into a federal unit called Cottontail Pass. In January 1997 Evergreen placed an additional 32,000 acres of its Purgatoire fairway oil and gas leases in a federal unit called Sangre de Cristo (see Fig. 10). Currently all Spanish Peak field productive acreage lies within the Spanish Peak Unit.

In March 1997 Evergreen permitted four exploratory wells for drilling (Fig. 10). four exploratory All four were to be Vermejo Formation tests. Evergreen's Sangre de Cristo unit obligation requires it to establish commercial production through the drilling of two new wells in the unit in 1997. The newly staked Evergreen-Hank Canyon 34-12 (projected total depth 3,300 ft) and the Evergreen-Cimarron 32-18 (projected depth 3,100 ft), which are located in the center of the Sangre de Cristo Unit, are the 1997 unit obligation wells. The Evergreen-Dave 21-31 (projected depth 1,598 ft) and the Evergreen-Zele 41-5 (projected depth 1,545 ft) represent an effort to establish commercial production in the northern portion of the Spanish Peak Unit.

Evergreen Resources,Inc., Denver, Colorado, opened Spanish Peak field with a four-well wildcat drilling program carried out in August of 1993. The four wells, ranging from 0.5 to 2.5 mi from the northwest corner of T. 33 S., R. 65 W. (Fig. 11), were spudded in the Raton Formation and penetrated a full section of the Vermejo Formation and underlying Trinidad Sandstone before bottoming in the upper Pierre Shale. The total depth of the wells ranged from 1,550 ft to 1,953 ft, and the average depth was 1,747 ft. The drilling time from spud to setting casing was approximately 2 days. Two of the wells (Garcia #14-30, SW1/4SW1/4 sec. 30, T. 32 S., R. 65 W.) and Ozzello #42-1 (SE1/4NE1/4 sec. 1, T. 33 S., R. 66 W.)

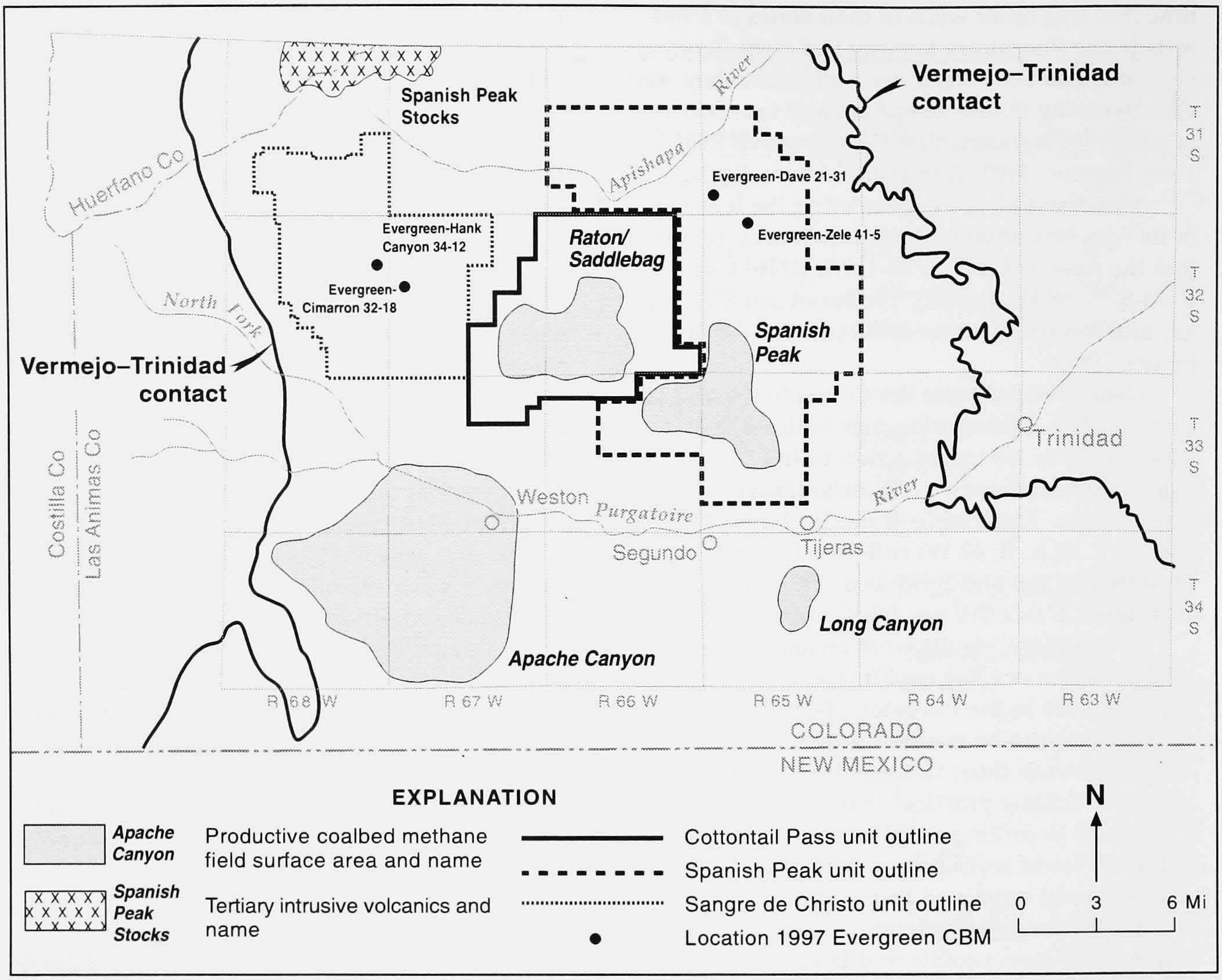

Figure 10. Unit outlines of Cottontail Pass, Sangre de Cristo, and Spanish Peak federal drilling units on record in May 1997.

were perforated in October 1993, fraced with an average of 55,000 gallons of water and 154,00 pounds of sand each, and then opened up for production testing by flaring to the atmosphere. Subsequently, the Taylor #44-1 (SE1/4SE1/4 sec. 1, T. 33 S., R. 66 W.) and the Taylor #42-10 (SE1/4NE1/4 sec. 10, T. 33 S., R 66 W.) were perforated in December 1993, fraced with an average of 83,000 gallons of water and 116,000 pounds of sand and then also opened up for production testing by flaring. The four wells were completed by selectively perforating 5 to 11 Vermejo Formation coal seams averaging 2.5 to 3.5 ft in thickness through an average interval thickness of 293 ft. The average well depth to the top of the pay zone was 1,327 ft.

The production results were mixed. During February and March 1994 the Ozzello #42-1 averaged 968,000 cu ft of gas per day (Mcfg/d). The two Taylor wells, #44-1 and #42-10, averaged 262 Mcfg/d and 290 Mcfg/d, respectively. The Garcia #14-30, however, managed a flow rate of only 62 Mcfg/d. Flaring was terminated for the Ozzello and Taylor wells in April 1994. Intermittent flaring continued with Garcia #14-30 until June 1994. During the time that Evergreen conducted the initial production tests on the four Spanish Peak discovery wells, the lack of a pipeline outlet prevented Evergreen from placing the Spanish Peak field openers on production. Consequently, the four wells were shut-in after testing was completed.

Colorado Interstate Gas (CIG) company in 1994, working with Amoco Production Company and Meridian Oil Incorporated, "fixed" the region's gas marketing problem by laying

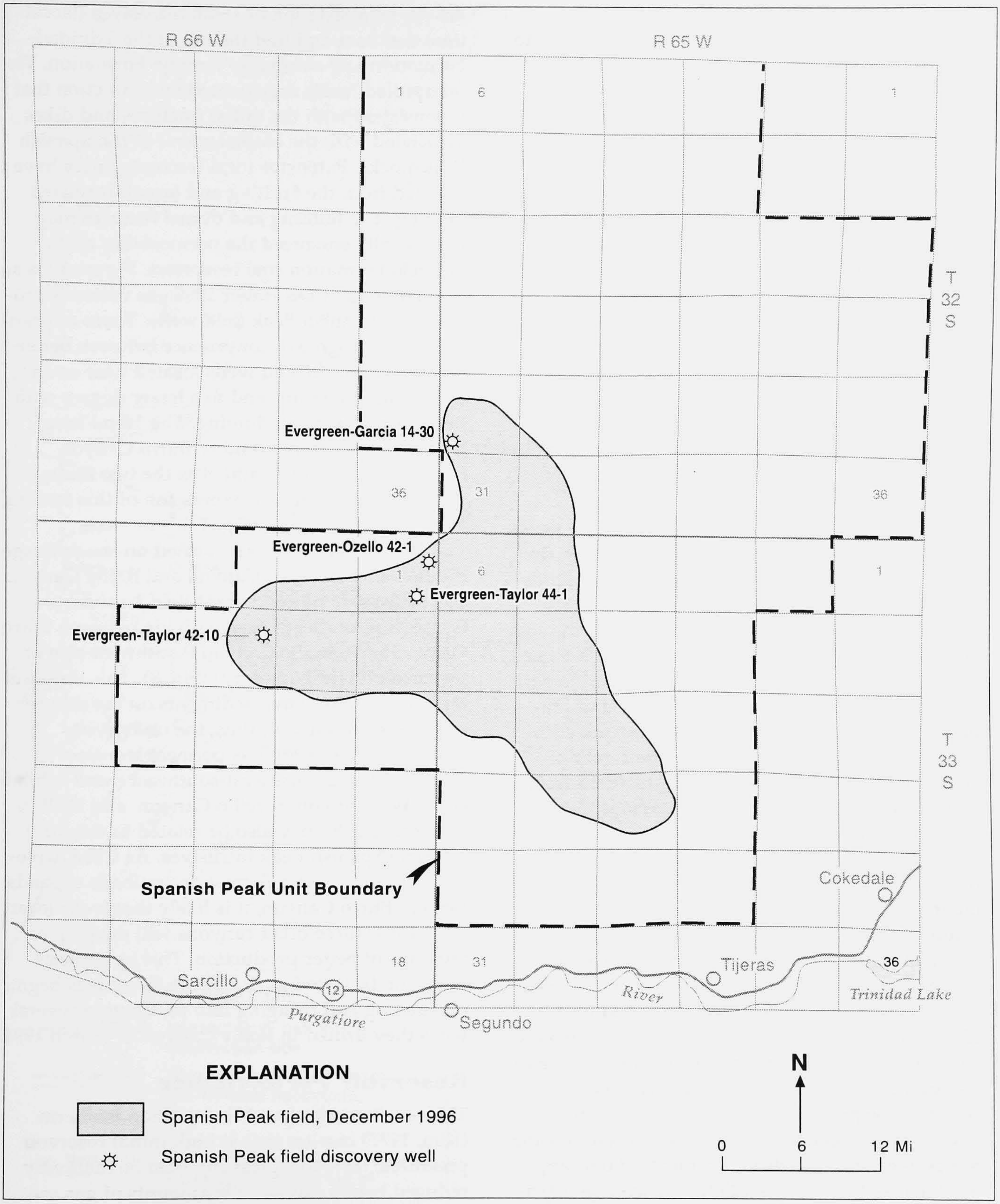

Figure 11. Location of Spanish Peak field discovery wells.

approximately 35 mi of pipeline west from Trinidad, Colorado into the central Raton Basin to bring onstream the shut-in gas wells that the two operators had completed, previous to the Evergreen activity, in Vermejo and Raton Formation coals. CIG refers to this line as the Picketwire Lateral. This new pipeline provided the first regional outlet for natural gas from the Vermejo-Raton Formation CBM fairway in the headwater area of the Purgatoire River that had been delineated by Amoco, Meridian and other operators in the 1980s.

The first sales began in November of 1994 from two wells in Amoco's Raton-Saddlebag field.

Evergreen Resources connected into CIG's line and began deliveries by placing nine Spanish Peak field wells on line in January of 1995. Meridian also began sales in January 1995 from its Apache Canyon field by placing 14 wells on line.

Permeability

Coal itself is essentially impermeable. Cleats, the natural fractures which form during the coalification process, provide the primary permeability network for desorbed gas to flow through the coal seam to the well bore. The degree to which these cleats are open and permeable depends on in situ stress and coal compressibility (McKee and others, 1984). Tectonic fracturing may provide additional flow paths and, more important, relieve stress along structural flexures or shattered fault zones, thereby locally enhancing permeability.

A detailed structure contour map on the top of the Trinidad Formation in the Spanish Peak field area (Fig. 12) was constructed in an effort to identify permeability-enhancement features. The resulting map indicates that the top of the Trinidad Formations, in a gross sense, exhibits a moderate northwest dip of 100 ft per mi. All well control was used and the area contoured on a 25-foot interval. Two northwest-southeast striking faults are interpreted to cut through the middle of the present field. Both of these interpreted faults appear to be primarily normal faults with the downthrown block to the southwest. There is some component of strike-slip movement. Maximum relief across the faults is 125 ft. The average vertical separation appears to be approximately 50 ft.

In addition, the Spanish Peak field structure map includes two closed highs with perhaps 25 ft of relief. It is very possible that these two highs are the manifestation of small intrusives (laccoliths) that have uplifted the top of the Trinidad Formation and overlying Vermejo Formation. The interpreted faults are oriented in a direction that is consistent with the radial fractures and dikes associated with the emplacement of the Spanish Peak stocks. Extensive local fracturing may have resulted from the faulting and laccolith-related doming. The faulting and domal features may have locally enhanced the permeability of the Vermejo Formation coal reservoirs. Figure 13 is an isopleth map of December 1996 gas volumes produced by Spanish Peak field wells. There appears to be a fair degree of congruence between better field performance and wells located near or on trend with the faults, and to a lesser degree with the inferred laccolith doming. The 10-mi long northwest-southeast trend of Burro Canyon (Fig. 8) between and parallel to the two faults is believed to be a surface expression of this faulting and related fracturing (Fig. 12).

Poorer field wells are located on the drainage divide between Burro Canyon and Reilly Canyon (northeast side of the current field boundary) (Fig. 8) and on the drainage divide between Burro Canyon and Sarcillo Canyon (southwest side of the current field boundary) (Fig. 8). This suggests that the more resistant sediments on the divides are less fractured and, thus, the underlying Vermejo coalbeds are less permeable.

The strong northwest-southeast trend exhibited by Wet Canyon, Sarcillo Canyon, and Reilly Canyon (Fig. 8) may also be related to the early Miocene Spanish Peak intrusives. As CBM exploration from Vermejo Formation coalbeds expands beyond Burro Canyon, it is likely that wells located in these three other canyons will develop as fairways of better production. This hypothesis will soon be tested as Evergreen Resources begins completing and bringing into production several wells they drilled in Reilly Canyon in March 1996.

Reservoir Performance

The non-linear shape of the sorption isotherm (Kim, 1977) implies that at high initial reservoir pressures, reservoir pressure must be markedly reduced before measurable amounts of gas are desorbed from the coal matrix. In a water-saturated reservoir, water must be reduced (dewatering) to reduce reservoir pressure. As water is removed and the reservoir pressure

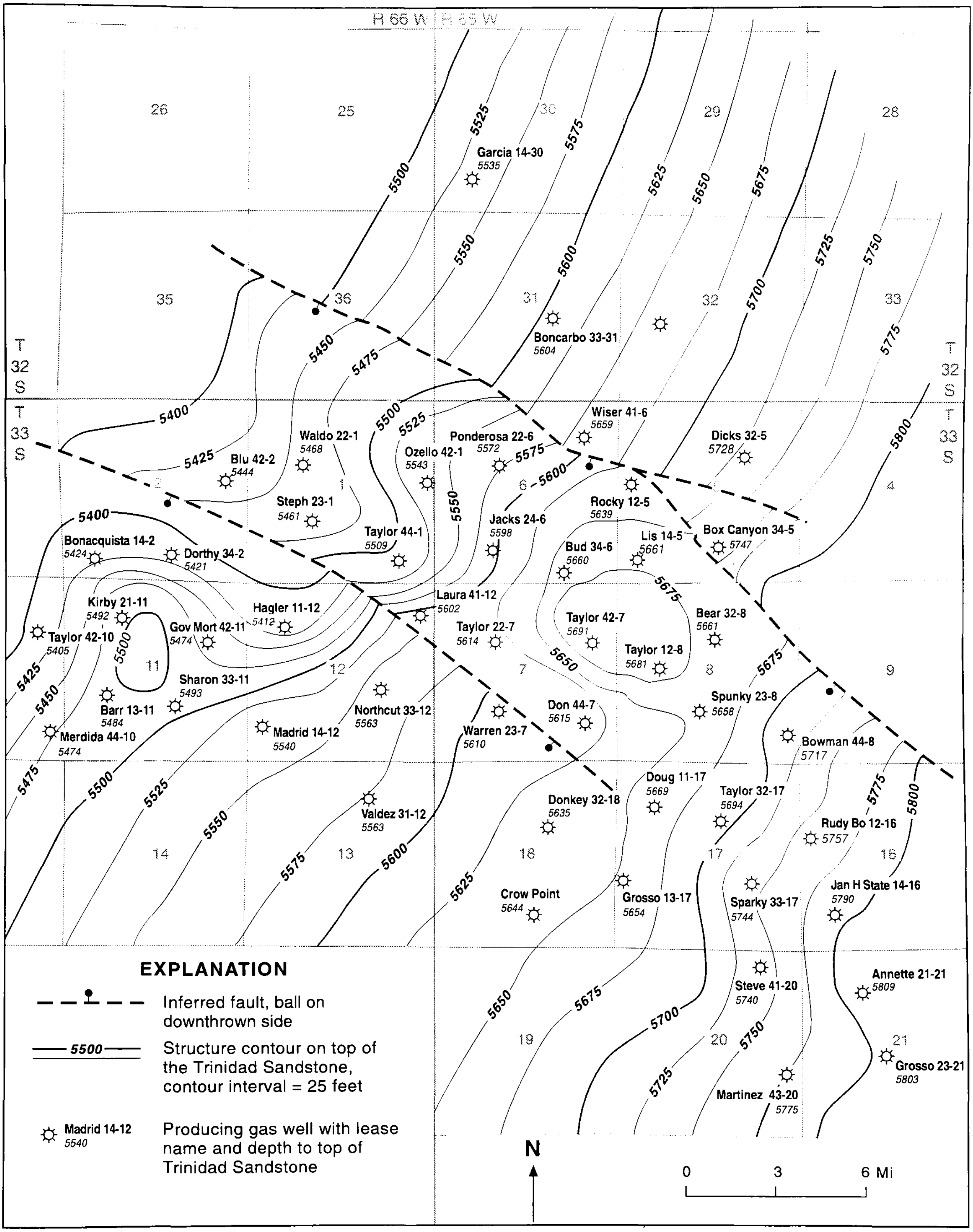

Figure 12. Structure contour map of the area around Spanish Peak field; contours on the top of the Trinidad Sandstone.

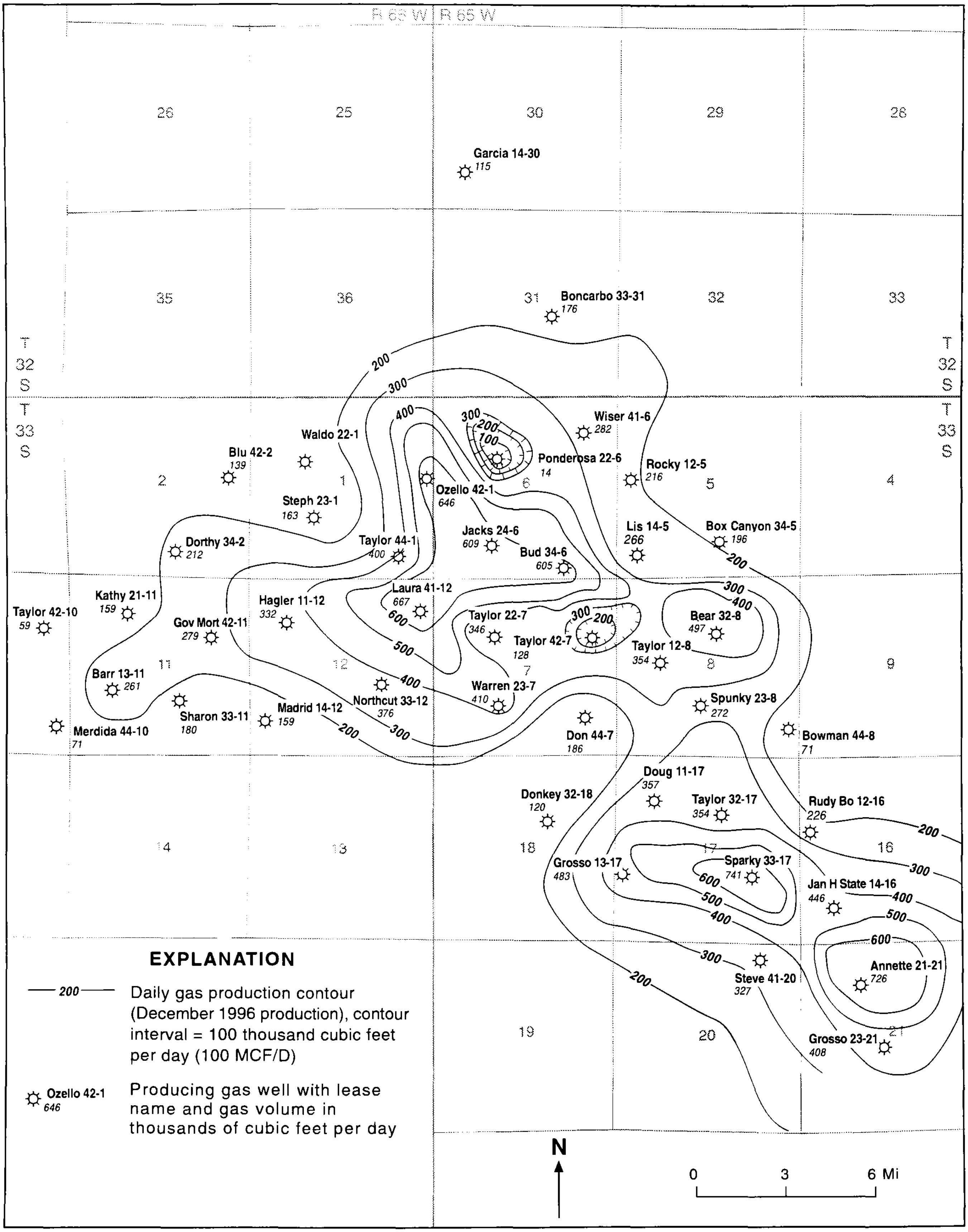

Figure 13. Isopleth map of December 1996 Spanish Peak field gas volumes.

declines, gas desorbed from the coal saturates the cleats. As the gas concentration increases, gas flow increases, thereby increasing production volumes. The non-linear shape of the sorption isotherm indicates that at lower reservoir pressures, ever-increasing amounts of gas will desorb for the same amount of pressure drop. Thus, as reservoir depletion occurs, the rate of gas desorption actually increases. This leads to the negative decline in production rates observed in most CBM wells as opposed to the constant decline in production rates that characterize conventional gas wells (Decker and other, 1988).

A comparison of monthly CBM production with the number of producing well from January 1995 through December 1996 suggests that dewatering of the coalbed reservoirs in the Spanish Peak field lowered reservoir pressures sufficiently to trigger the "classic" negative decline curves observed in other CBM fields (Fig. 14 and Table 2). Twenty eight of the 43 Spanish Peak field wells produced at a higher daily rate in December 1996 than during the first month the well was on line (Table 2). Water rates per MMCF were lower in December 1996 compared to first month of production for 29 of the 43 wells.

Figures 15 through 20 are production profiles of six representative Spanish Peak field wells. Four (Grosso 23-21, Taylor 12-8, Govt 42-11, and Sparky 33-170) (Figures 15–18); exhibit typical CBM production profiles: increasing gas production and declining water production. In two wells (Ozzello 42-1 and Rudy Bo 12–16) Figures 19 and 20), gas production rose while water production rose slightly also. Two factors could account for the water production failing to decline: (1) well stimulation failed to stay in zone and connected the well to water-bearing sills or sandstones that are hydraulically connected to recharge areas, and (2) hydraulic connection between coal seams and the underlying water bearing Trinidad Sandstone.

The hydrostatic pressure gradient of the Spanish Peak reservoir is about 38 lbs per sq in. (psi) per 100 ft of depth (Evergreen staff member, oral communication, 1996). Average reservoir depth below the potentiometric surface in the Spanish Peak field area is approximately 750 ft, and, accordingly, the average pay zone reservoir pressure is about 285 psi. Well-head back pressure on Spanish Peak producers varied in 1997 between 25 and 67 psi. Line pressure on the CIG Picketwire Lateral varies between 700 and 725 psi. Evergreen,

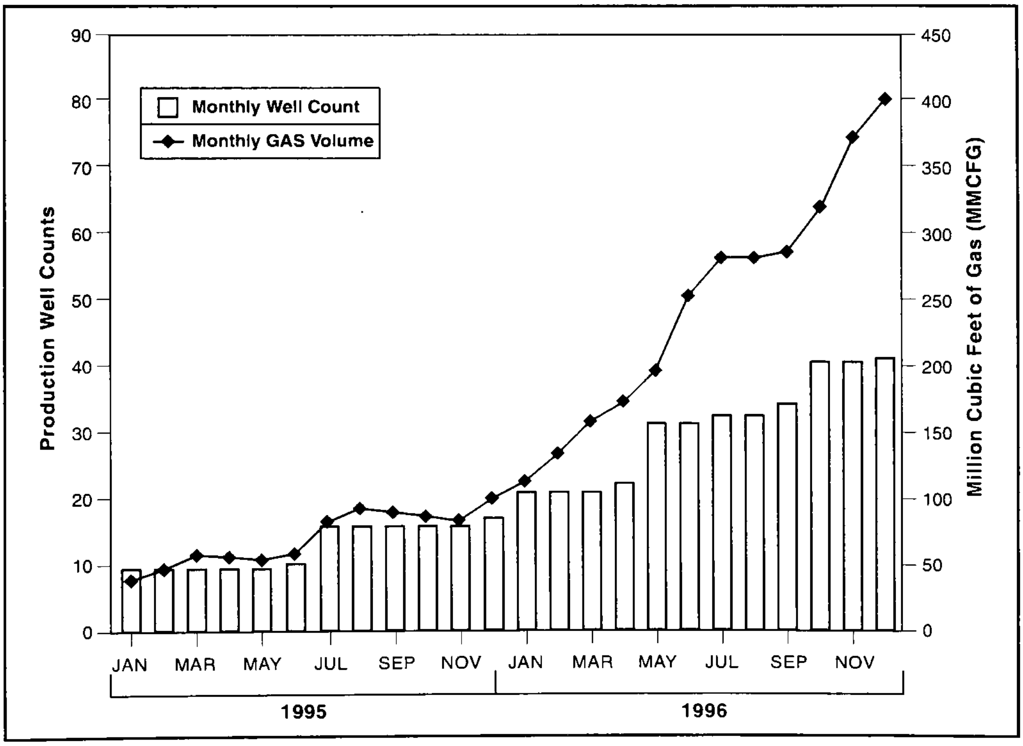

Figure 14. Spanish Peak field monthly CBM production volumes and monthly count of productive wells from date of first production to the end of 1996.

Table 2. Spanish Peak field producing wells from Juanry 1995 through December 1996 with monthly CBM production.

Well Name	Location	Spud Date	Date First Prod.	Daily Gas Rate First Month on Line in MCF	Bbl of Water per MMCF of Gas When First on Prod.	Daily Gas Rate Dec. 1996 in MCF	Bbls of Water per MMCF of Gas Dec. 1996
Evergreen- Garcia #14-30	SWSW Sec. 30 T. 32 S., R. 65 W.	8/04/93	12-96	115	1,931	115	1,931
Evergreen- Taylor #44-1	SESE Sec. 1 T. 33 S., R. 66 W.	8/07/93	1-95	131	494	400	194
Evergreen- Ozzello #42-1	SENE Sec. 1 T. 33 S., R. 66 W.	8/10/93	1-95	315	30	646	210
Evergreen- Taylor #42-10	T. 33 S., R. 66 W. SENE Sec. 10	8/12/93	1-95	133	96	59	413
Evergreen- Taylor #32-17	T. 33 S., R. 65 W. SWNE Sec. 17	10/05/94	1-95	221	313	354	155
Evergreen- Taylor #12-8	T. 33 S., R. 65 W. SWNW Sec. 8	10/07/94	1-95	181	2,905	354	169
Evergreen- Taylor #42-7	T. 33 S., R. 65 W. SENE Sec. 7	10/09/94	1-95	40	702	128	302
Evergreen- Taylor #22-7	T. 33 S., R. 65 W. SENW Sec. 7	10/11/94	1-95	222	325	346	165
Evergreen- Hagler #11-12	T. 33 S., R. 66 W. NWNW Sec. 12	10-13-94	1-95	199	439	332	220
Evergreen- Govt. Mort #42-11	T. 33 S., R. 66 W. SENE Sec. 11	10-15-94	1-95	345	89	279	160
Evergreen- Grosso #23-21	T. 33 S., R. 65 W. NESW Sec. 21	3-30-95	7-95	14	45,386	408	608
Evergreen- Jan H. State #14-16	T. 33 S., R. 65 W. SWSW Sec. 16	4-01-95	7-95	138	6,614	446	851
Evergreen- Rudy Bo #12-16	T. 33 S., R. 65 W. SWNW Sec. 16	4-03-95	7-95	99	1,574	226	1,624
Evergreen- Laura #41-12	T. 33 S., R. 66 W. NENE Sec. 12	4-05-95	6-95	120	354	667	55
Evergreen- Jacks #24-6	T. 33 S., R. 65 W. SESW Sec. 6	4-07-95	7-95	360	679	609	132
Evergreen- Don #44-7	T. 33 S., R. 65 W. SESE Sec. 7	4-09-95	7-95	118	1,113	186	249
Evergreen- Kathy #21-11	T. 33 S., R. 66 W. NENW Sec. 11	4-19-95	7-95	47	8,592	159	7,381
Evergreen- Steph #23-1	T. 33 S., R. 66 W. NESW Sec. 1	10-06-95	1-96	303	352	163	665
Evergreen- Bud #34-6	T. 33 S., R. 65 W. SWSE Sec. 6	10-09-95	1-96	173	1,405	605	434
Evergreen- Ponderosa #22-6	T. 33 S., R. 65 W. SENW Sec. 6	10-11-95	1-96	39	12,689	14	30,000
Evergreen- Lis #14-5	T. 33 S., R. 65 W. SWSW Sec. 5	10-12-95	12-95	326	659	226	290

Table 2. Continued.

Well Name	Location	Spud Date	Date First Prod.	Daily Gas Rate First Month on Line in MCF	Bbl of Water per MMCF of Gas When First on Prod.	Daily Gas Rate Dec. 1996 in MCF	Bbls of Water per MMCF of Gas Dec. 1996
Evergreen- Spunky #23-8	T. 33 S., R. 65 W. NENW Sec. 8	10-14-95	1-96	324	800	272	246
Evergreen- Barr #13-11	T. 33 S., R. 66 W. NWSW Sec. 11	2-18-96	6-96	240	758	261	529
Evergreen- Sharon #33-11	T. 33 S., R. 66 W. NWSE Sec. 11	2-19-96	5-96	167	6,224	180	458
Evergreen- Madrid #14-12	T. 33 S., R. 66 W. SWSW Sec. 12	2-21-96	5-96	226	1,515	159	665
Evergreen- Dorothy #34-2	T. 33 S., R. 66 W. SWSE Sec. 2	2-22-96	5-96	482	626	212	687
Evergreen- Wiser #41-6	T. 33 S., R. 65 W. NENE Sec. 6	2-25-96	5-96	233	1,915	282	1,340
Evergreen- Rocky #12-5	T. 33 S., R65 W. SWNW Sec. 5	2-26-96	5-96	388	422	216	518
Evergreen- Box Canyon #34-5	SWSE Sec. 5	2-27-96	5-96	106	9,347	196	663
Evergreen- Bowman #44-8	SESE Sec. 8	2-29-96	5-96	40	36,208	71	3,681
Evergreen- Sparky #33-17	NWSE Sec. 17	3-02-96	5-96	644	493	741	273
Evergreen- Doug #11-17	NWNW Sec. 17	3-02-96	5-96	385	534	357	553
Evergreen- Medida #44-10	SESE Sec. 10	7-08-96	9-96	83	462	71	475
Evergreen- Warren #23-7	NESW Sec. 7	7-13-96	10-96	298	1,390	410	940
Evergreen- Donkey #32-18	SWNE Sec. 18	7-15-96	10-96	66	13,923	120	10,529
Evergreen- Grosso #13-17	NWSW Sec. 17	7-17-96	10-96	339	1,008	483	612
Evergreen- Blu #42-2	SENE Sec. 2	7-18-96	10-96	137	3,245	139	3,346
Evergreen- Northcut #33-12	NWSE Sec. 12	7-19-96	10-96	498	246	376	646
Evergreen- Boncarbo #33-31	NWSE Sec. 31	7-20-96	10-96	283	794	176	801
Evergreen- Steve #41-20	NENE Sec. 20	7-21-96	9-96	133	968	327	737
Evergreen- Annette #21-21	NENW Sec. 21	7-22-96	9-96	258	2,082	726	415
Evergreen- Bear #32-8	SWNE Sec. 8	7-24-96	10-96	211	1,175	497	279

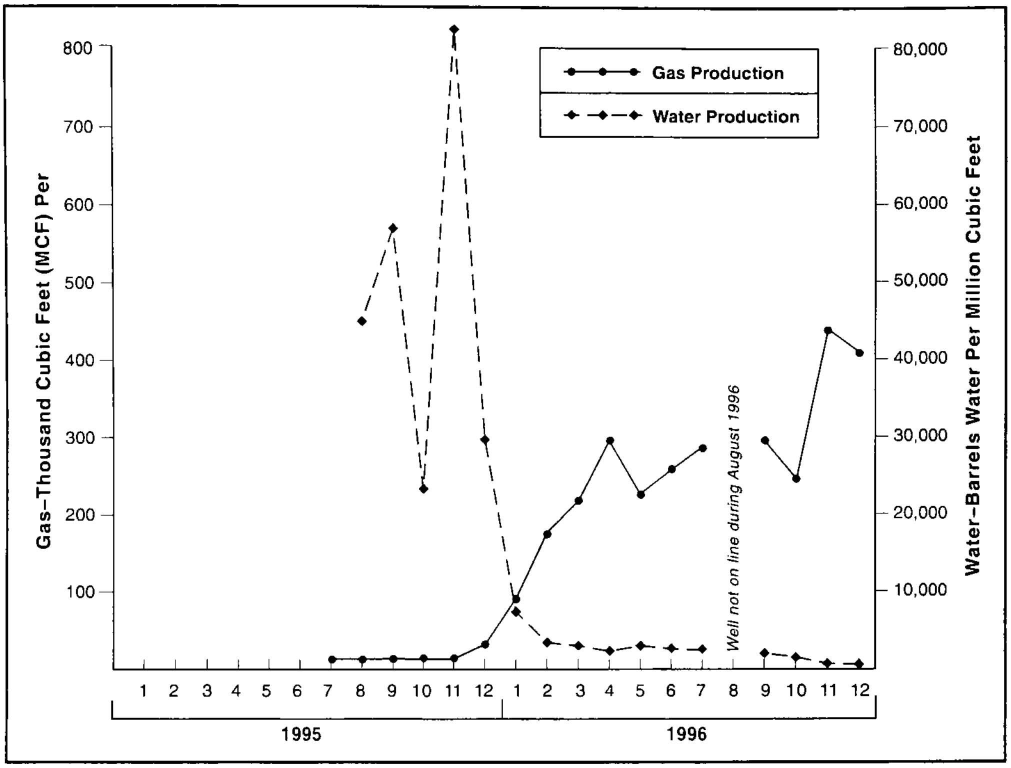

Figure 15. Historical gas and water production for the Grosso 23-21 from August 1995 through December 1996.

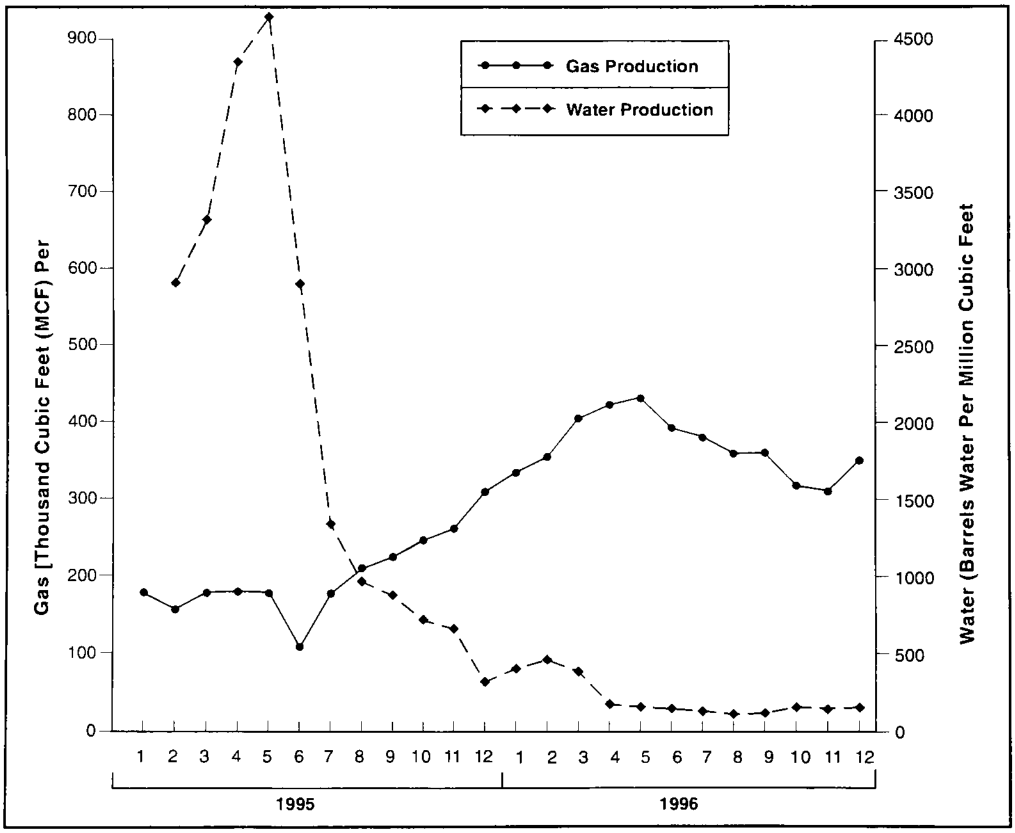

Figure 16. Historical gas and water production for the Taylor 12-8 from January 1995 through December 1996.

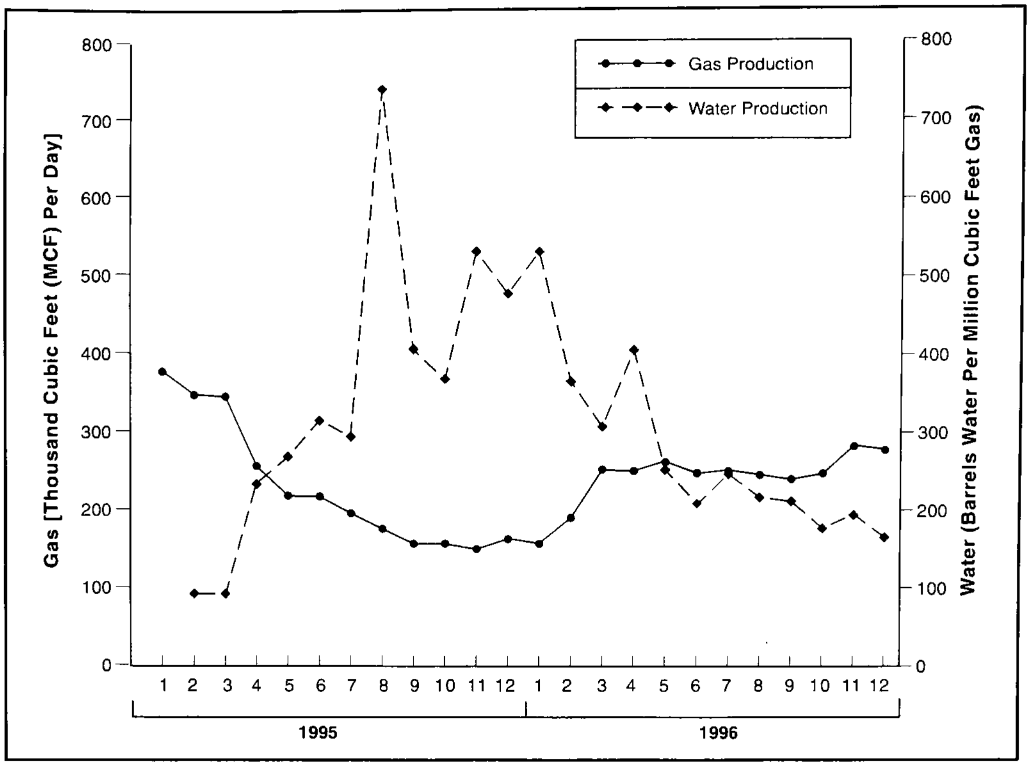

Figure 17. Historical gas and water production for the Govt-Mort 42-11 from January 1995 through December 1996.

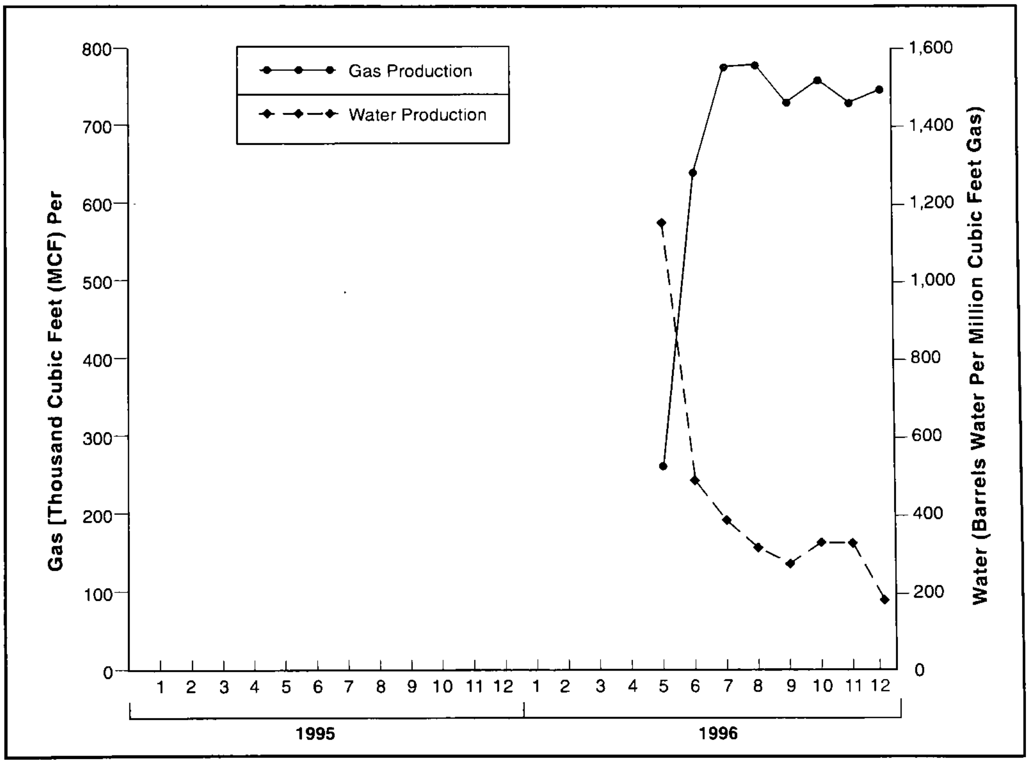

Figure 18. Historical gas and water production for the Sparky 33-17 from May 1996 through December 1996.

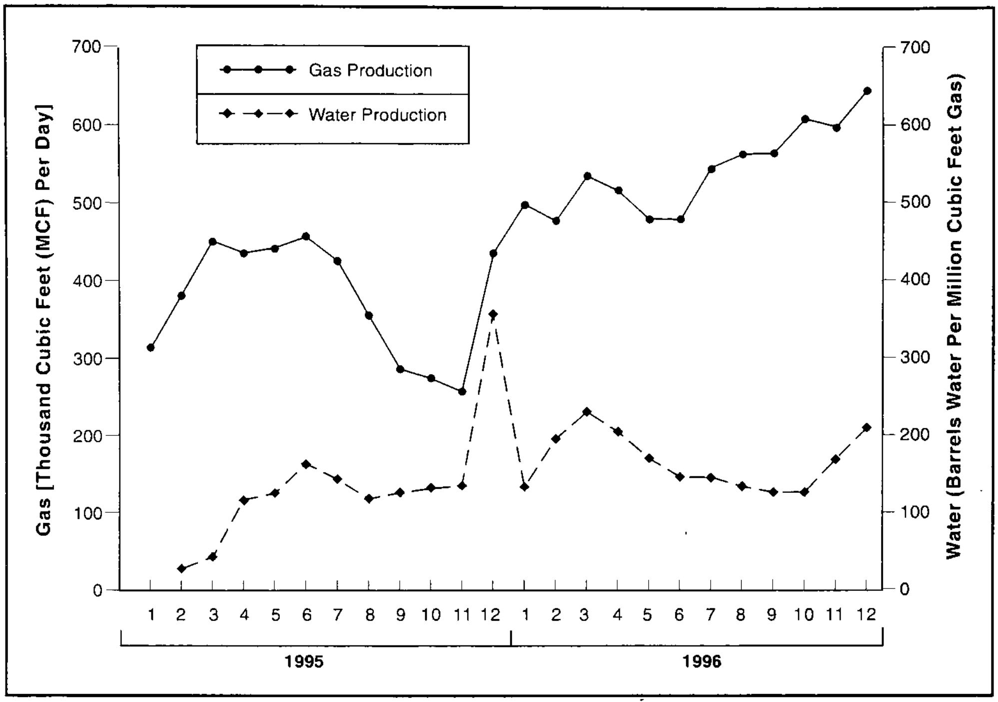

Figure 19. Historical gas and water production for the Ozzello 42-1 from January 1995 through December 1996.

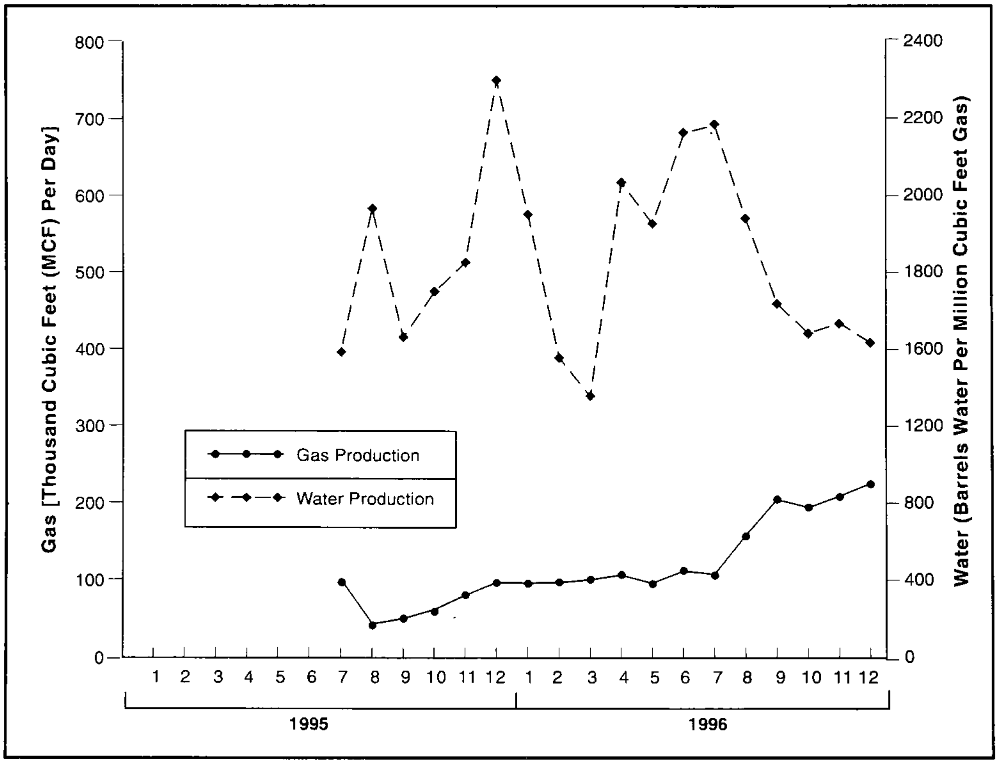

Figure 20. Historical gas and water production for the Rudy-BO 12-16 from July 1995 through December 1996.

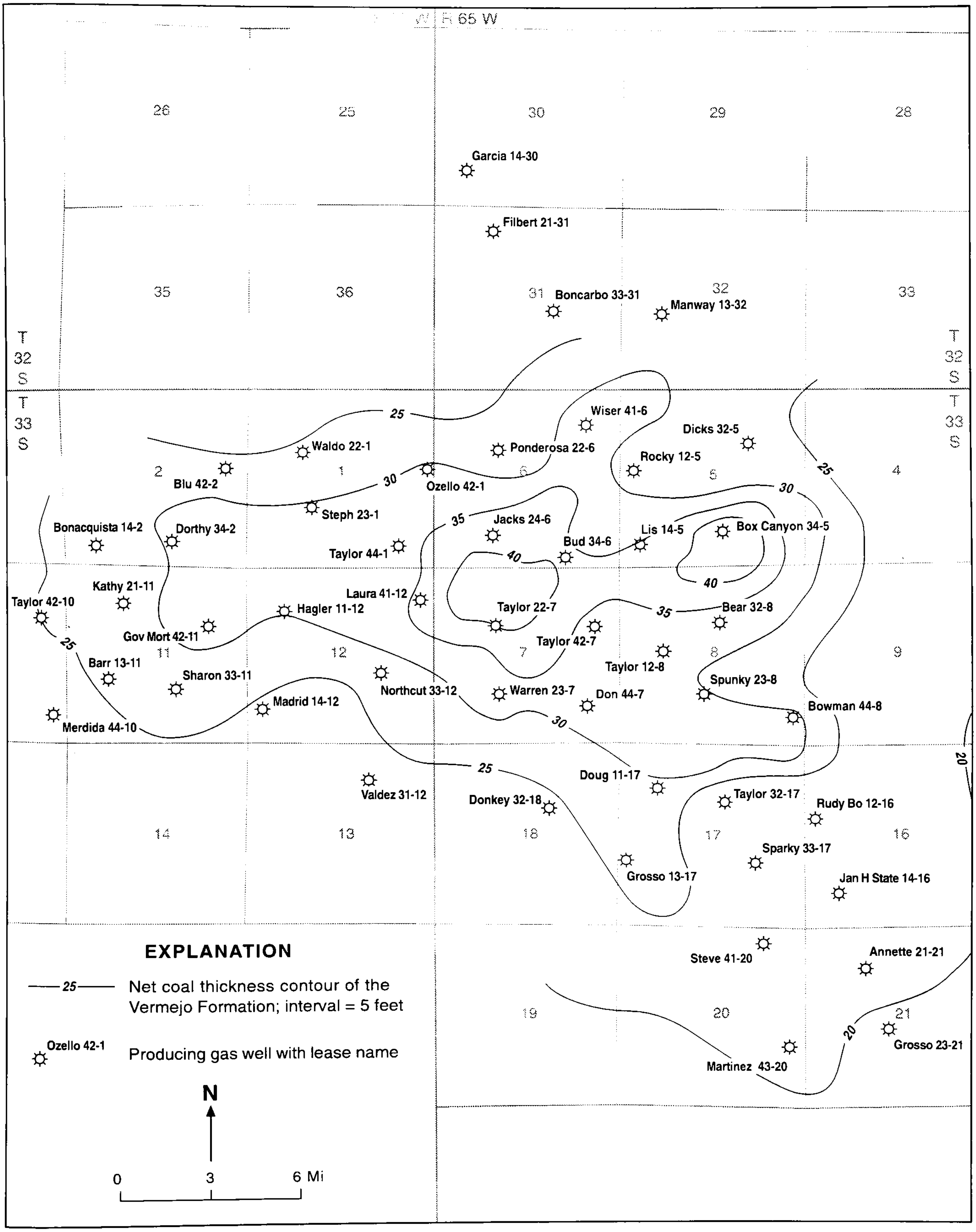

Figure 21. Net coal thickness map of the Vermejo Formation in the Spanish Peak field.

accordingly, has been required to build a compression station on the southeast edge of Spanish Peak field to boost gathering system line pressures to the CIG's pressure requirement. Currently they are adding compression to maintain gathering system line pressures in the same range as more development wells are brought on stream.

Reserves

Stevens et al (1992) statistically averaged public desorption data incorporating 49 samples from 14 wells in the Colorado portion of the basin. Although the data available for analysis display a very high degree of scatter, he showed that coal seam gas content in the Vermejo and Raton Formation coals generally increased with depth. Stevens et al (1992) reported that basin operators who have much larger proprietary data sets collectively have concluded that depth below the potentiometric surface, rather than depth below ground surface, exerts the greater control on gas content. This approach resulted in markedly better statistical correlation of gas content versus depth.

Stevens found that at a depth between 750 ft and 1,700 ft below the potentiometric surface the gas content of medium- and low-volatile bituminous coals in the Purgatoire fairway should average 300 to 400 cu ft per ton. Fig. 21 is an isopach map of gross coal thickness in the Spanish Peak field. Assuming the average gross Vermejo coal thickness within the field to be 30 ft and the average gas content is 350 cu ft in the field area, and applying the 160-acre spacing pattern on which Evergreen is developing Spanish Peak field, the GIP per well is calculated as 3 BCF of gas per spacing unit. [3 BCF (GIP) = 350 (GC) $\times$ 30 (h) $\times$ 160 (A) $\times$ 1,800 (P)] Evergreen estimates recoverable reserves per well in Spanish Peak at 1.5 to 2.0 BCF. Assuming the 3 BCF GIP is an accurate assessment, Evergreen's 1.5 to 2.0 BCF of reserve per well would represent a reservoir recovery factor between of 50 and 67 percent. By extrapolation Evergreen's 53 completed wells have developed gas reserves of between 79.5 BCF and 106 BCF.

Future

Evergreen in a March 10, 1997 press release stated that Spanish Peak production now exceeded 17 MMCF of gas per day from 53 wells. It also announced plans to drill an additional 40 wells during the remainder of 1997. Evergreen believes its acreage can support 500 wells on 160-acre spacing. By the end of 1997 Evergreen could be selling 27 MMCF of gas into the CIG Picketwire Lateral. Assuming a somewhat constant or slightly accelerated development by Evergreen during 1998 and 1999 by the year 2000 the firm could be operating 200–225 wells in Spanish Peak field, producing some 80 to 100 MMCF of gas per day.

SUMMARY

Tyler and others (1991), Stevens and others (1992), Close and Dutcher (1990), and Rice and Finn (1996) have described the geologic controls and potential of coal bed gas in the Raton Basin. Consideration of their work and the characterization of the Spanish Peak field data presented here strongly suggest that opportunities exist to develop Vermejo CBM reserves in Colorado within the Trinidad Sandstone outcrop area from the New Mexico state line to the northern side of the Cucharas River drainage. Within this fairway, experience gained from Western Oil in the northwest portion of Apache Canyon field indicates that the steeply dipping western edge of the basin is not a good exploration target. It also appears that canyon bottoms are surface expressions of fairways where subsurface fractures of Vermejo Formation coal seams are more abundant. Focusing acreage acquisition and initial exploratory drilling in these areas should be advantageous because of the potential for improved CBM reservoir permeability.

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