Chapter 2

Petroleum Systems and Assessment of Undiscovered Oil and Gas in the Raton Basin–Sierra Grande Uplift Province, Colorado and New Mexico

By Debra K. Higley

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Volume Title Page

Chapter 2 of
Petroleum Systems and Assessment of Undiscovered Oil and Gas in the Raton Basin–Sierra Grande Uplift Province, Colorado and New Mexico—USGS Province 41
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Contents

Figures

Table

Petroleum Systems and Assessment of Undiscovered Oil and Gas in the Raton Basin–Sierra Grande Uplift Province, Colorado and New Mexico

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Abstract

Using Total Petroleum System-based assessment methods, the U.S. Geological Survey estimated a mean of 2.35 trillion cubic feet (TCF) of undiscovered natural gas and 28.1 million barrels (MMB) of undiscovered natural gas liquids (NGL) in the Raton Basin-Sierra Grande Uplift Province of Colorado and New Mexico. This is a gas-prone province with limited oil production or potential; consequently, oil resources were not assessed.

Approximately 3.864 TCF of hydrocarbon and nonhydrocarbon (carbon dioxide, helium) gases, 4,325 barrels of oil (BO), and 389 million barrels of water (MMBW) were produced from the Raton Basin-Sierra Grande Uplift Province through 2003. Primary production was carbon dioxide (3.570 TCFG), and 2 MMBW produced through 2003. More than 287 billion cubic feet of natural gas (BCFG) and 387 MMBW have been produced from the coal beds of the Upper Cretaceous Vermejo Formation and Upper Cretaceous–Tertiary Raton Formation; coalbed methane from these formations provides most of the petroleum production in the province. Estimated ultimate recovery of coalbed methane from 1,621 wells is 1.087 TCFG; 5.41 percent of this total is from the Raton Formation, 14.9 percent is commingled Raton-Vermejo production, and 79.6 percent is from the Vermejo Formation. Mean undiscovered resources associated with coalbed methane in the Raton Coalbed Gas, Vermejo Coalbed Gas, and Upper Cretaceous–Tertiary Sandstones assessment units (AU) of the Upper Cretaceous-Tertiary Coalbed Gas Total Petroleum System (TPS) are 611.26 BCFG, 979.32 BCFG, and 58.53 BCFG, respectively.

Sandstone and shale of Jurassic through Cretaceous age in the Raton Basin and Las Vegas subbasin have potential resources and minor production of natural gas. Mean undiscovered resources from the Jurassic–Cretaceous Composite TPS are 88.76 BCFG and 3.54 MMBNGL from the Fractured Reservoirs AU, and 615.09 BCFG and 24.58 MMBNGL from the Jurassic–Lower Cretaceous Reservoirs AU.

Introduction

The U.S. Geological Survey (USGS) recently completed an assessment of the undiscovered oil and gas potential of the Raton Basin–Sierra Grande Uplift Province of northeastern New Mexico and southeastern Colorado (fig. 1). This is hereafter referred to as the 2005 assessment, which corresponds to the publication release date of the results of the assessment (Higley and others, 2005). Assessed areas include the Raton Basin, the Las Vegas subbasin, and the Sierra Grande uplift. The assessment is based on the geologic elements of each Total Petroleum System (TPS) that is defined within the province. The TPS approach groups reservoir and potential reservoir formations with common hydrocarbon source rocks (source rock maturation, hydrocarbon generation and migration), reservoir rocks (depositional setting and petrophysical properties), and hydrocarbon traps (trap types and timing of trap formation and petroleum migration). Using these geologic elements, the USGS defined (1) the Jurassic–Cretaceous Composite TPS, containing two oil and gas assessment units (Fractured Reservoirs Assessment Unit (AU) and Jurassic–Cretaceous Reservoirs AU), which were assessed as conventional accumulations, and (2) the Upper Cretaceous–Tertiary Coalbed Gas TPS containing one conventional AU (Upper Cretaceous–Tertiary Sandstones AU) and two continuous oil and gas assessment units (Raton Coalbed Gas AU and Vermejo Coalbed Gas AU). The AU boundaries shown in figure 1 were determined primarily on the basis of (1) vertical and lateral extent and geologic characteristics of the respective reservoir and source intervals, (2) the presence of igneous intrusions and their potential influences on trap formation, reservoirs, and heating history, and (3) timing of onset of oil and gas generation of petroleum source rocks and current levels of thermal maturation. Undiscovered oil, gas, and natural gas liquids resources were assessed within the five AUs and results are presented in table 1.

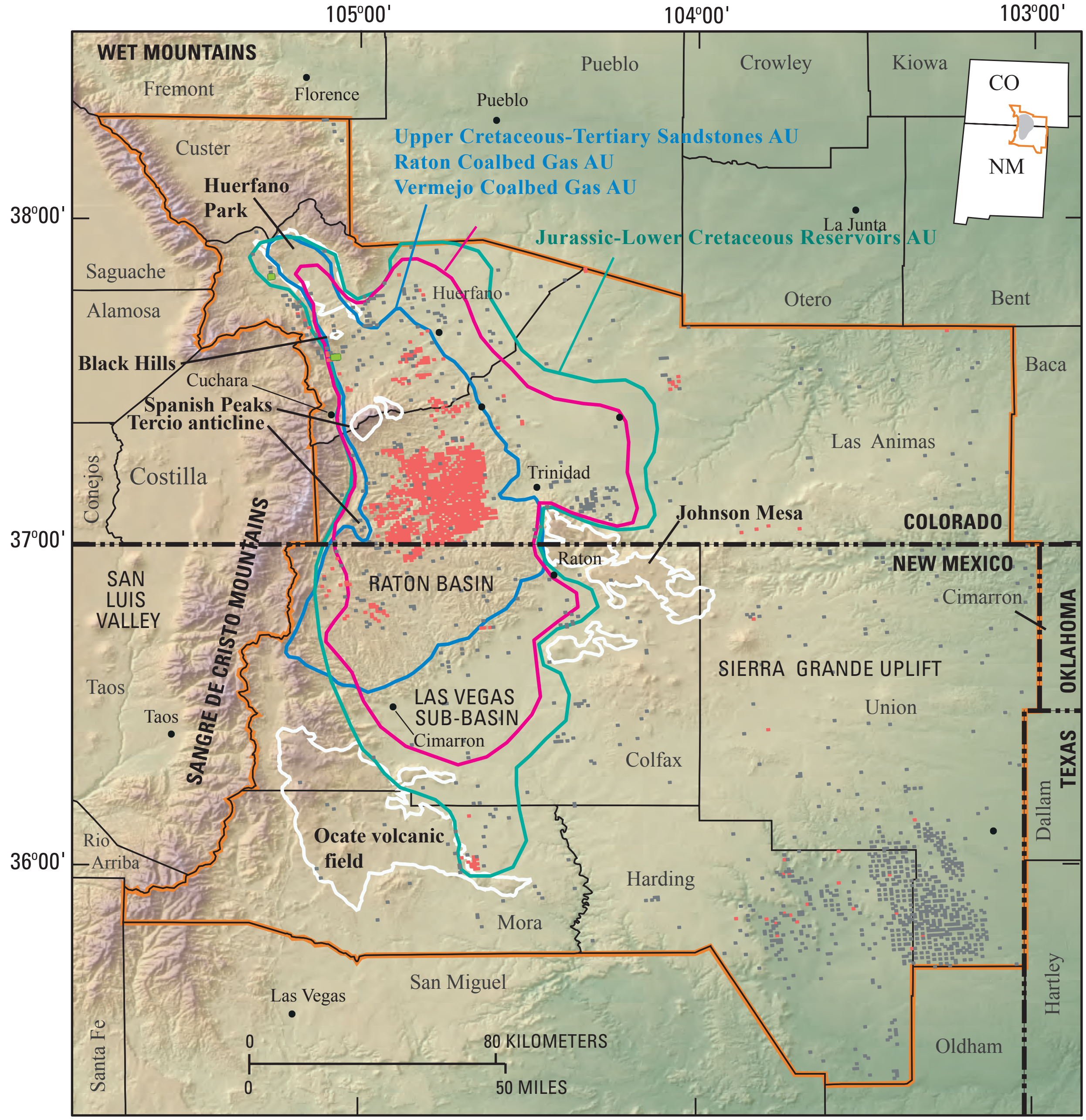

Figure 1. Raton Basin–Sierra Grande Uplift Province (orange line) of northeastern New Mexico and southeastern Colorado, modified from Higley and others (2005). The Upper Cretaceous–Tertiary Coalbed Gas Total Petroleum System (TPS) (blue line) contains the Upper Cretaceous–Tertiary Sandstones, Raton Coalbed Gas, and Vermejo Coalbed Gas AUs. The Jurassic–Cretaceous Composite TPS (green line) contains the Fractured Reservoirs AU (pink line) and the Jurassic–Lower Cretaceous Reservoirs AU (green line). Some of the igneous intrusions and volcanic fields are outlined in white. Red and gray squares within the AU boundaries are cells that produce hydrocarbon gas and those that are nonproductive of hydrocarbons, respectively. Two green cells near the northwest boundary of the AUs were oil productive. Cell sizes are about 1 mi square. Gas-productive cells contain at least one well that is gas productive and may also include nonproductive wells. Red and gray cells outside the Jurassic–Lower Cretaceous Reservoirs AU boundary are not productive of hydrocarbons; they are dry or productive of carbon dioxide, nitrogen, and (or) helium.

Table 1. Raton Basin–Sierra Grande Uplift Province assessment results listed by name and code of Total Petroleum System (TPS) and Assessment Unit (AU) (Higley and others, 2005).

[Resources are undiscovered oil, gas, and (or) natural gas liquids. MMBO, million barrels of oil; BCFG, billion cubic feet of gas; MMBNGL, million barrels of natural gas liquids. Type refers to mainly oil or gas accumulations in the assessment unit. CBG is coalbed gas. Fractiles are fully risked estimates. F95 represents a 95-percent chance of at least the amount tabulated. Other fractiles are defined similarly. Fractiles are additive under the assumption of perfect positive correlation]

	Total Petroleum Systems and Assessment Units (AU)	Type	RESOURCES											
			Oil (MMBO)				Gas (BCFG)				NGL (MMBNGL)			
			F95	F50	F5	Mean	F95	F50	F5	Mean	F95	F50	F5	Mean
Conventional oil and gas	**Upper Cretaceous-Tertiary Coalbed Gas, Total Petroleum System 504101**													
	Upper Cretaceous-Tertiary Sandstones AU (50410101)	**Oil**	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
		Gas	0.00	0.00	0.00	0.00	17.52	54.00	113.12	58.53	0.54	3.00	0.00	0.00
	Jurassic-Cretaceous Composite, Total Petroleum System 504102													
	Fractured Reservoirs AU (50410201)	**Oil**	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
		Gas	0.00	0.00	0.00	0.00	14.64	78.04	199.31	88.76	6.86	23.29	8.35	3.54
	Jurassic-Lower Cretaceous Reservoirs AU (50410202)	**Oil**	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
		Gas	0.00	0.00	0.00	0.00	184.48	605.39	1,073.12	615.09	0.00	0.00	46.45	24.58
Continuous oil and gas	**Upper Cretaceous-Tertiary Coalbed Gas, Total Petroleum System 504101**													
	Raton Coalbed Gas AU (50410181)	**Oil**	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
		CBG	0.00	0.00	0.00	0.00	316.65	572.83	1,036.25	611.26	0.00	0.00	0.00	0.00
	Vermejo Coalbed Gas AU (50410182)	**Oil**	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
		CBG	0.00	0.00	0.00	0.00	584.10	939.31	1,510.54	979.32	0.00	0.00	0.00	0.00
	TOTAL CONVENTIONAL RESOURCES		**0.00**	**0.00**	**0.00**	**0.00**	**216.64**	**737.43**	**1,385.55**	**762.39**	**7.40**	**26.29**	**54.81**	**28.12**
	TOTAL CONTINUOUS RESOURCES		**0.00**	**0.00**	**0.00**	**0.00**	**900.75**	**1,512.14**	**2,546.79**	**1,590.58**	**0.00**	**0.00**	**0.00**	**0.00**
	TOTAL RESOURCES		**0.00**	**0.00**	**0.00**	**0.00**	**1,117.39**	**2,249.57**	**3,932.34**	**2,352.97**	**7.40**	**26.29**	**54.81**	**28.12**

Geologic Setting of the Raton Basin–Sierra Grande Uplift Province

The Raton Basin and Las Vegas subbasin parts of the Raton Basin–Sierra Grande Uplift Province are Laramide-age asymmetric foreland basins that extend about 175 mi in a north-south direction and about 65 mi in an east-west direction; total area is approximately 18,800 mi^2 (Keighin, 1995). Although province boundaries correspond to county lines, the province is defined on the basis of geologic features: (1) the western boundary is the Sangre de Cristo Mountains (fig. 2), the east flank of which is thrust faults that trend approximately parallel to the axes of the Raton Basin and Las Vegas subbasin; (2) part of the northern boundary is formed from the Wet Mountains and the Apishapa arch, a northwest-southeast extension of the Wet Mountains structure; (3) the southern boundary is defined by the Tucumcari Basin; and (4) the eastern boundary is the eastern limit of the Sierra Grande uplift. There is 4,000–7,000 ft of structural relief between the Sierra Grande arch and the axis of the Raton Basin (Woodward and Snyder, 1976). Maximum aggregate thickness of sedimentary rocks in the Las Vegas subbasin is 12,700 ft, and an estimated 16,000–20,000 ft of sedimentary rocks is preserved along the Raton Basin axis (Baltz, 1965).

The Sierra Grande uplift is a broad regional feature that was active during Precambrian time; the characteristics of Pennsylvanian and older beds on its flanks indicate it has been a positive feature since Paleozoic time (Speer, 1976). The Sierra Grande arch, the axis of which extends northeast to merge with the Las Animas arch (fig. 2), represents a Laramide rejuvenation of part of the Sierra Grande uplift (Speer, 1976). Uplift of the area during the Paleozoic is indicated by the eastward pinchout of Pennsylvanian strata in the Sierra Grande arch area (Woodward, 1987). Sedimentary strata east of the arch are primarily Early Cretaceous and older; younger strata are missing due to either nondeposition or erosion.

Baltz (1965) indicated that the Raton Basin has been a basin since Early Pennsylvanian time, and that latest Cretaceous and Tertiary tectonic elements of the Raton Basin and Las Vegas subbasin are rejuvenated structures that originally formed mainly in Pennsylvanian and Permian time, contemporaneous with uplift of the ancestral Rocky Mountains. The west edge of the Raton Basin northward from the Las Vegas subbasin is composed of strata that are mostly vertical or overturned and generally broken by west-dipping high-angle reverse faults and thrusts (fig. 2) (Northrop and others, 1946; Baltz and Bachman, 1956; Johnson and others, 1958; Bolyard, 1959; Bachman and Dane, 1962). Figure 3 is a generalized stratigraphic column of the Colorado and New Mexico part of the Raton Basin; most of the stratigraphic units are also present in the Las Vegas subbasin and the Sierra Grande uplift, except where removed by erosion. Timing of intrusion is applicable across the province. Strata along the western margin of the basin and subbasin are extensively deformed (Merin and others, 1988) and are associated with Tertiary igneous intrusions in some areas. Strata in other areas of the province may also contain Tertiary intrusions and basalt flows, some of which are shown on the geologic map of the Raton Basin and Las Vegas subbasin (fig. 4) and in figure 1; not shown are dike swarms, such as those that radiate outward from the middle Tertiary intrusions of West and East Spanish Peaks, located in the northwestern part of the Raton Basin (figs. 1, 4). Figure

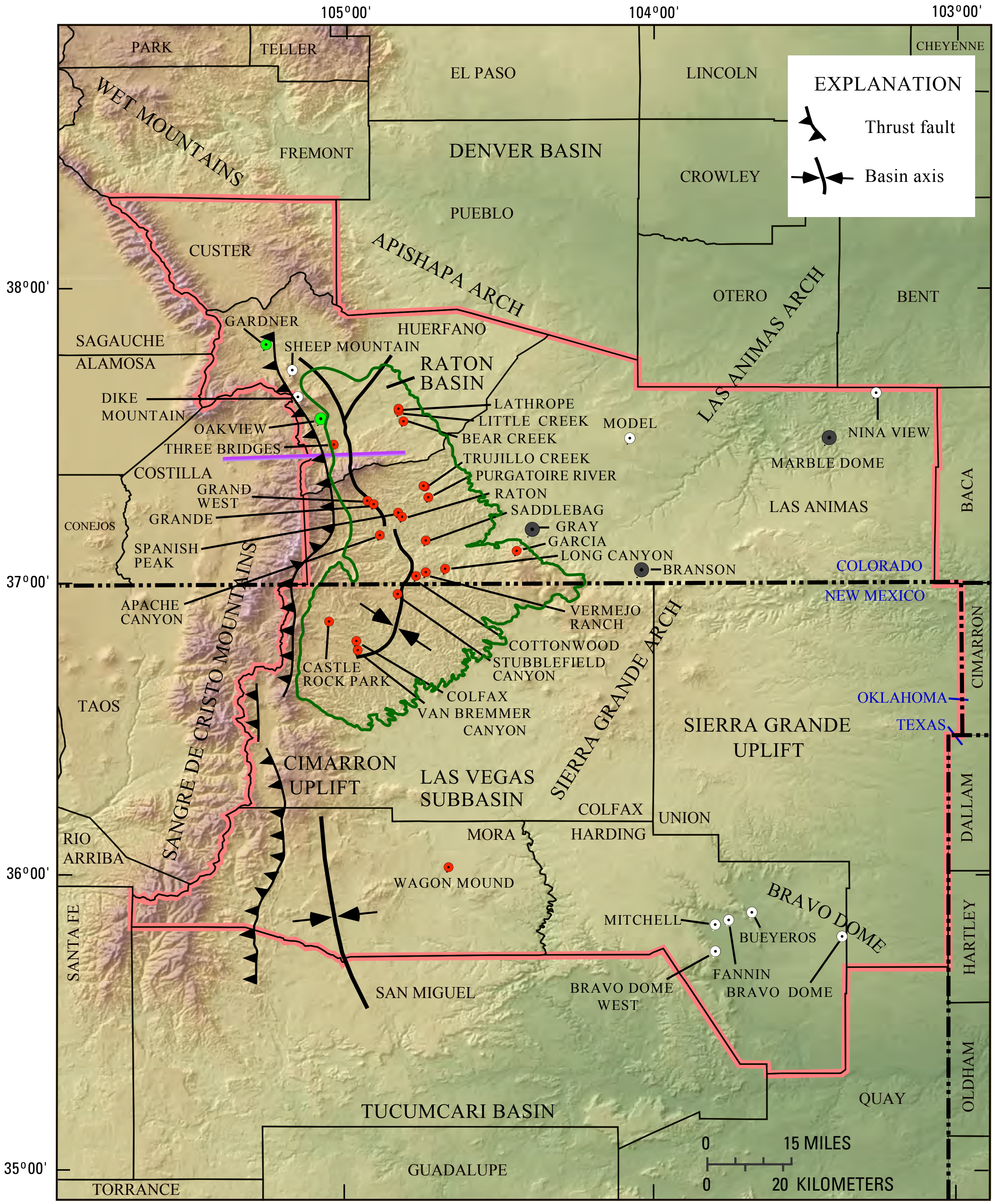

Figure 2. Raton Basin–Sierra Grande Uplift Province (red line). Shown are synclinal axes of the Raton Basin and Las Vegas subbasin. Symbols for generalized locations of fields are red (natural gas), green (oil), white (CO_2), and dark gray (helium and unknown). Structural information and outline of the Vermejo Formation (green line) are derived from Roberts and others (1976), Tyler and others (1995), Flores and Bader (1999), and Johnson and Finn (2001). Purple line is generalized location of cross section shown in figure 6.

5 shows one of the igneous dikes radiating from the northern slope of the West Spanish Peak. Spanish Peaks stocks and radial dikes were emplaced 20-25 million years ago (Ma), synchronous with the beginning of rifting in the San Luis Valley segment of the Rio Grande rift (Smith, 1979), which borders the Sangre de Cristo Mountains on the west.

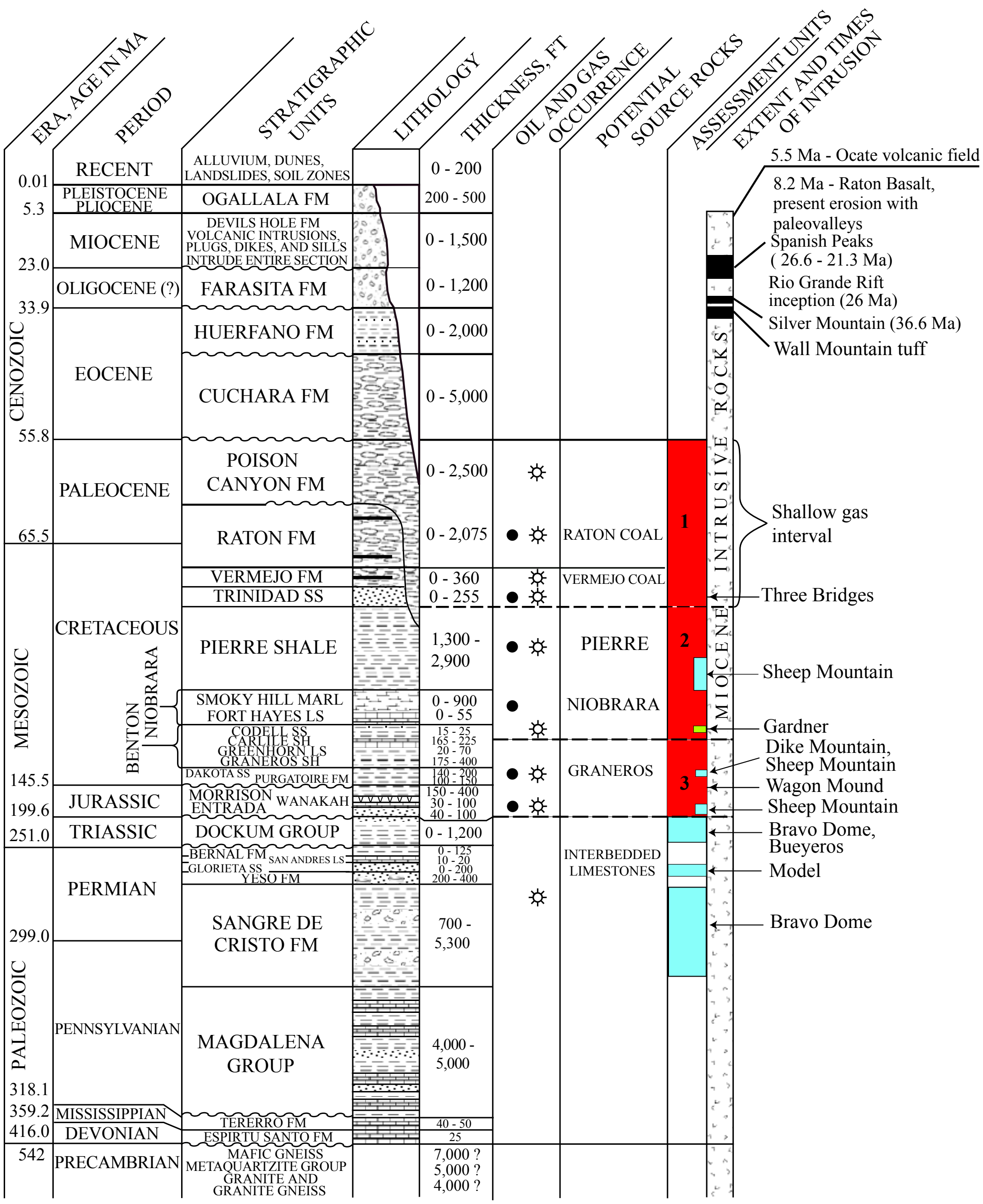

Figure 3. Generalized stratigraphic column for the Raton Basin, Colorado and New Mexico. Divisions within the assessment units column are (1) Raton Coalbed Gas, Vermejo Coalbed Gas, and Upper Cretaceous–Tertiary Sandstones; (2) Fractured Reservoirs; and (3) Jurassic–Lower Cretaceous Reservoirs. Associated potential productive intervals are indicated by red (natural gas), blue (carbon dioxide and (or) helium), and green (oil). Arrows point to producing formations of listed non-coalbed methane fields. "Oil and gas occurrence" means production and (or) well or outcrop shows of petroleum within the province. The black dots represent production or shows of oil and the open circles with radiating lines indicate production or shows of petroleum gas. Modified from Ewing and Kues (1976) and Johnson and Finn (2001). Ages of geologic events are from O'Neil (1988), Stormer and others (1990), O'Neill and Mehnert (1988), and Close and Dutcher (2002). Unconformities (wavy lines) are from Johnson and others (1966). Abbreviations: FM, formation; LS, limestone; SH, shale; SS, sandstone

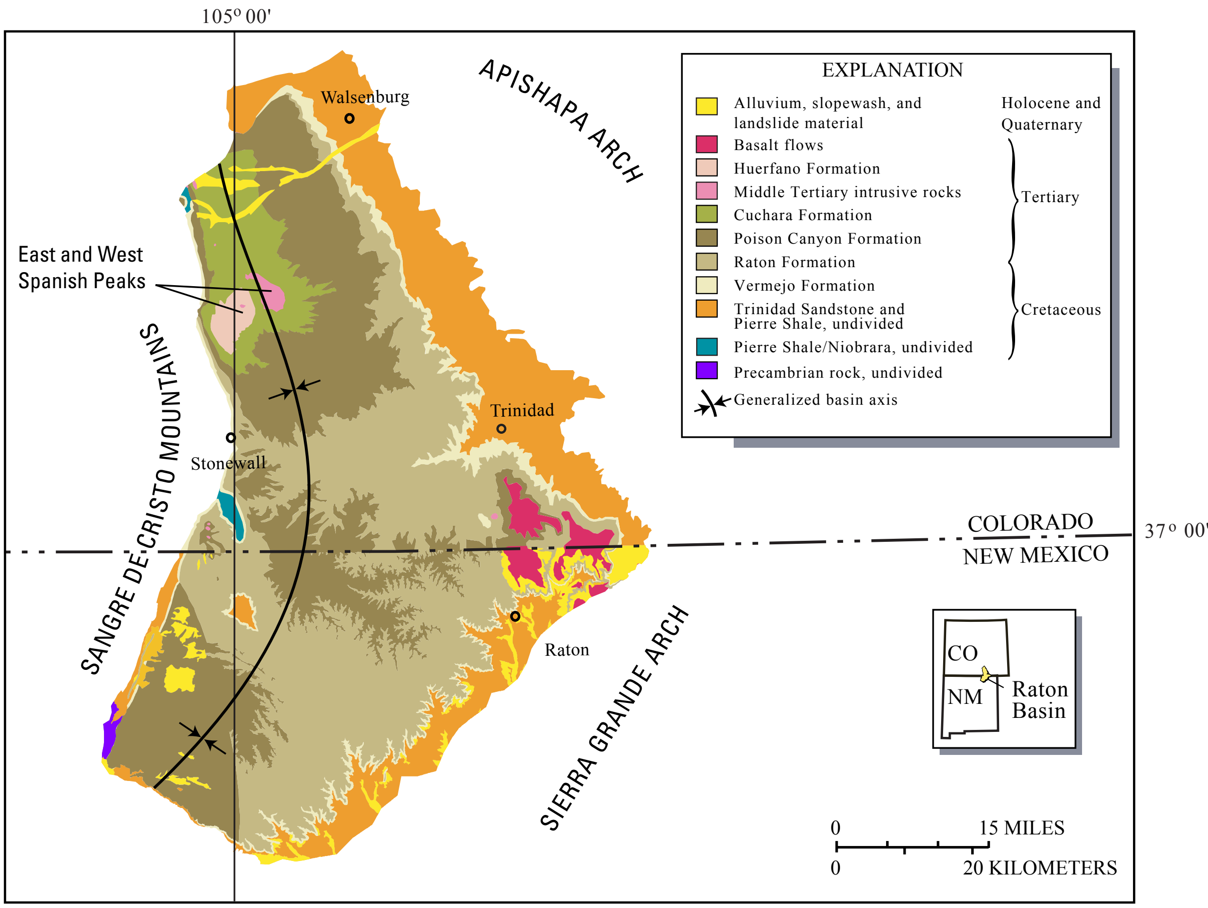

Figure 4. Generalized geologic map of most of the Raton Basin and Las Vegas subbasin, Colorado and New Mexico. Modified from Flores and Bader (1999) and Johnson and Finn (2001).

Figure 5. View looking south to West Spanish Peak (fig. 4). Arrows point to an igneous dike that radiates from the peak. Small white squares in front of the foremost dike exposure are buildings. Small, dark-green dots in front of the peak are evergreen trees. Photograph was taken on May 2006.

The Laramide orogeny in the area of the southern Rocky Mountains began about 67.5 Ma and ended about 50 Ma (Tweto, 1975). Laramide-age structures of the central Sangre de Cristo Mountains were interpreted by Lindsey (1998) as west-dipping thrusts and reverse faults that are associated with basement structures. Figure 6 shows the Merin and others (1988) structural interpretations of Laramide fault movement along the northwest flank of the Raton Basin. The tectonic elements that were established in the late Paleozoic influenced later sedimentation and structural deformation. Chapin and Cather (1981) showed that the Laramide orogeny began with maximum compressive stress oriented to the east-northeast during Late Cretaceous to Paleocene time and ended with maximum compression oriented to the northeast in Eocene time. In general, north-south- to northwest-trending compressional structures formed during the early phase of the tectonism and most northwest- to east-west-trending compressional structures formed during the late phase (Merin and others, 1988). Coal cleats and joints in the Vermejo and Raton Formations were initiated during the Laramide and the associated folding of the La Veta syncline, located north of Cuchara (fig. 1) (Close and Dutcher, 2002). The post-Laramide, east-directed lateral compressional stress that controlled the West and East Spanish Peaks dike emplacement reversed polarity about 22 Ma (Muller, 1986). Butt cleats and secondary joints (and inferred fracture-permeability zones) in the Vermejo-Raton stratigraphic interval may have been further dilated during rift inception and later extensional tectonism (Close and Dutcher, 1990). On the basis of both regional and local stratigraphic evidence, Lindsey (1998) determined that Laramide deformation in the Sangre de Cristo Mountains (Culebra Range) and accompanying synorogenic sedimentation in the western Raton Basin probably took place from latest Cretaceous through early middle Eocene time.

Views differ as to sedimentologic evidence in the Raton Basin for the onset of the Laramide orogeny. Johnson and others (1966) stated that the onset of deformation is recorded in the upper 100–300 ft of the Pierre Shale by alternating fine-grained sandstone and shale beds that were eroded from newly uplifted areas. Lindsay (1998) indicated that the lower Eocene Cuchara Formation contains the youngest record of the orogeny in the Spanish Peaks area. Close and Dutcher (2002) stated that notable Laramide folding and thrusting of the Raton Formation and underlying rocks occurred prior to the deposi-

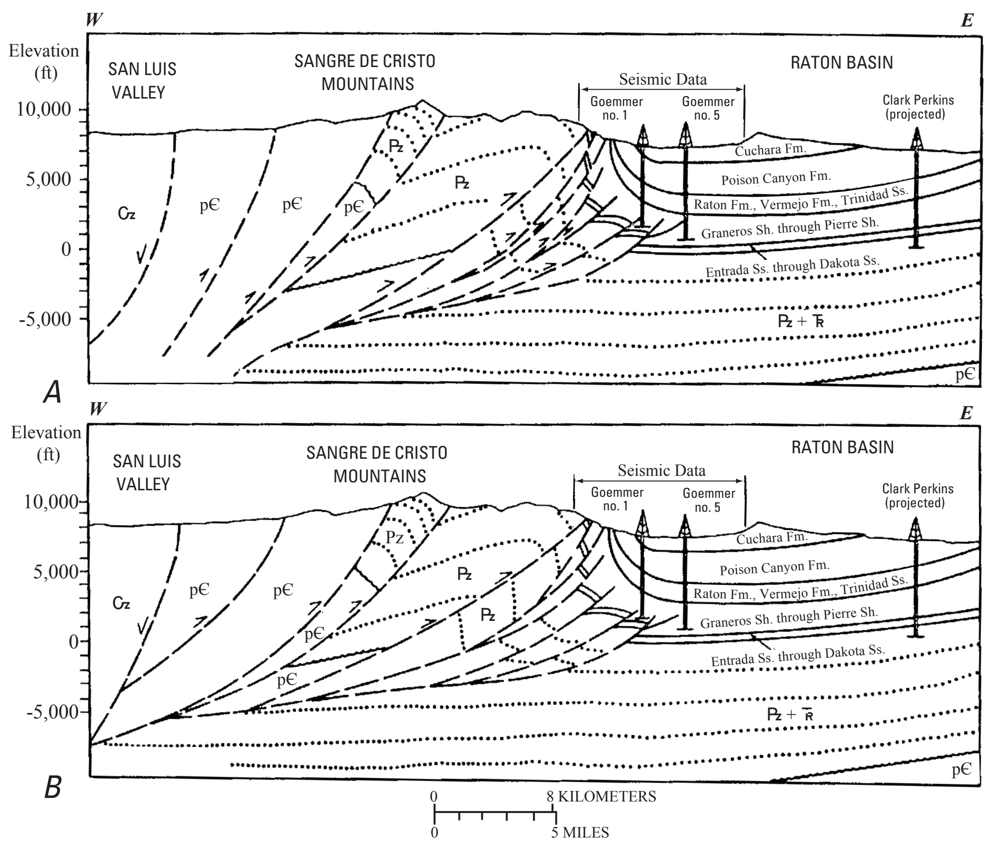

Figure 6. Two possible structural interpretations of west-to-east Laramide wrench fault movement along the northwest flank of the Raton Basin (Merin and others, 1988). Generalized location is shown in figure 2. Merin and others (1988) hypothesized (*A*) a positive flower structure, and (*B*) a series of low-angle, oblique-slip thrust faults; the faults are shown as solid lines where confirmed by seismic data and dashed where inferred (Rose and others, 1984; Applegate and Rose, 1985). Fault dips were modeled after analogous features mapped by Gries (1981). Directions of fault movement are indicated by arrows. Contacts between formations are shown as solid lines where confirmed and as dotted lines where estimated. Abbreviations: Fm, Formation; Ss, Sandstone; TR, Triassic; Cz, Cenozoic; Pz, Paleozoic; pЄ, Precambrian

tion during late Paleocene of the Poison Canyon Formation. The angular unconformity at the base of the Poison Canyon is well exposed near the northern and southern limits of Trinidad Sandstone outcrops (Johnson and Stevens, 1954; Robinson and others, 1964; Lindsey, 1995).

Paleocene through Miocene time included intensive and waning stages of the Laramide orogeny, periods of igneous intrusions and volcanism, and the onset of the Rio Grande Rift system. Ash fall of the Wall Mountain Tuff, radiometrically dated at 36.64 ± 0.06 Ma (McIntosh and others, 1992) covers a large area of the exposed late Eocene surface, indicating that the Laramide orogeny had essentially ended by that time (Epis and others, 1980). Silver (Dike) Mountain igneous dikes cross-cut Laramide structures in Huerfano Park (Johnson and others, 1958); Dike Mountain is located directly east of the Dike Mountain field (fig. 2). Samples from the Black Hills (fig. 1) east of Dike Mountain were dated by Ar^{40}/Ar^{39} analyses at 36.2 ± 0.12 Ma (Penn, 1994; Penn and Lindsey, 1996).

A period of volcanism and intrusions in the province, with magmas probably sourced from the upper mantle beginning at 26.6 Ma and extending to 21.3 ± 0.25 Ma, is represented by the West and East Spanish Peaks stocks (fig. 1) and associated radial and subparallel dikes (Penn, 1994; Penn and others, 1994; Penn and Lindsey, 1996). These events were associated with hydrothermal alteration. Onset of the Rio Grande Rift system, dated at 26 Ma by Chapin (1988), resulted in uplift of the Sangre de Cristo Mountains and concomitant subsidence of the San Luis and other Rio Grande Rift valleys located west of the mountains (Lindsey and others, 1986; Kelley, 1990; Kelley and others, 1992). A regionally widespread geomorphic surface then developed in late Miocene time in central Colorado and adjacent areas, including the Raton Basin (Levings, 1951; Epis and others, 1980; Scott and others, 1990; Scott and Pillmore, 1993). The oldest flow of the Raton Basalt on Johnson Mesa (fig. 1) was radiometrically K-Ar dated at 8.19 ± 0.31 Ma (Stormer and Dungan, 1990). The last period of volcanism is the Ocate volcanic field (fig. 1), dated at about 5.5 Ma (O'Neill, 1988; O'Neill and Mehnert, 1988), which forms the south and southwest borders of the Jurassic–Lower Cretaceous Reservoirs AU (fig. 1). The Ocate volcanic field is a probable source of local heating for Lower Cretaceous source and reservoir rocks of the proximal Wagon Mound gas field (fig. 2).

Petroleum Production History

Coalbed methane AUs were assessed as continuous resources; the other AUs were assessed as conventional resources (table 1). Oil resources were not assessed because of limited potential for accumulations of 0.5 million barrels of oil (MMBO) and greater. The only reported oil production is from the Codell Sandstone Member of the Carlile Shale (fig. 3) in one well in the Gardner field (fig. 2); production from 1974 through 1988 yielded 4,325 BO and 3.179 million cubic feet (MMCF) of hydrocarbon gas (Lawson and Hemborg, 1999; IHS Energy, 2004b).

More than 2,900 wells were drilled in the Raton Basin–Sierra Grande Uplift Province through March, 2003 (IHS Energy, 2004a); the cumulative number of drillholes versus completion date is shown in figure 7; not shown are several hundred wells for which geographic location and production data were unavailable (most of these are located in New Mexico and were drilled since 2000). Vertical white bars mark time periods of no well completions. The number of

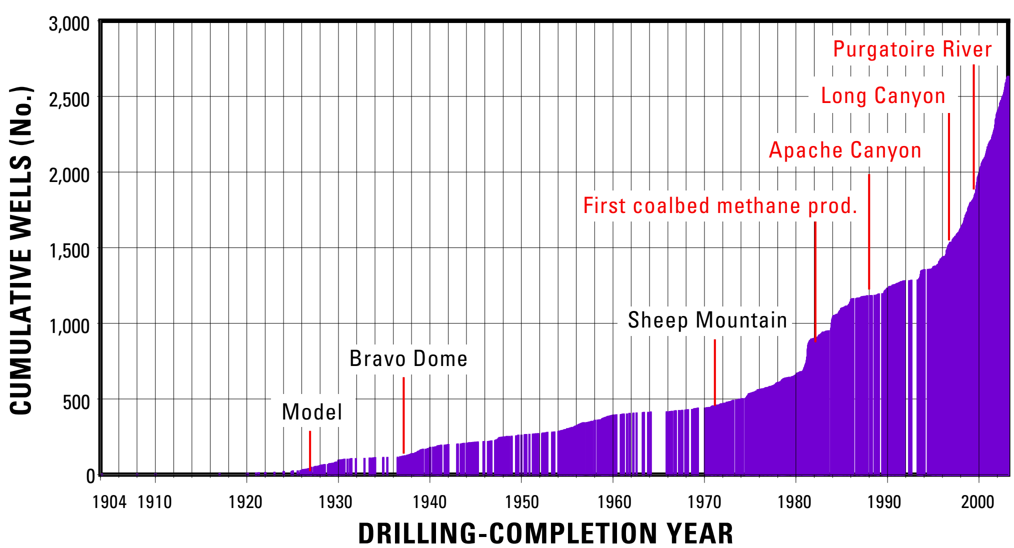

Figure 7. Cumulative number of drilled wells versus completion date starting in 1904. Black type marks some of the fields that have produced helium and nitrogen (Model) or carbon dioxide (Bravo Dome, Sheep Mountain). Red leaders mark onset of coalbed methane (CBM) production in 1984, and onset for listed fields. More than 2,900 wells were drilled in the province from 1904 through 2003, and greater than 2,300 wells drilled for CBM from 1984 through 2003 (IHS Energy, 2004a).

completed wells through September 2005 is reported at 4,007 (IHS Energy, 2006), including 80 or more duplicate wells; approximately 63 percent of the total wells were drilled in the Colorado part of the Raton Basin.

Approximately 4,325 barrels of oil (BO), 3,864 billion cubic feet (BCF) of hydrocarbon and non-hydrocarbon gas, and 389 million barrels of water (MMBW) were produced from the Raton Basin–Sierra Grande Uplift Province through 2003 (IHS Energy, 2004b). Initial and primary production is carbon dioxide, with 3.570 trillion cubic feet of gas (TCFG) and 2 MMBW (IHS Energy, 2004b); included are minor amounts of helium and nitrogen. First recorded CO_2 production was from two wells in the Nina View field (fig. 2). Production is primarily from structural traps in eight fields with variable amounts of water production and no recorded hydrocarbon shows. There are numerous unnamed fields with no reported production. Productive formations range in age from the Pennsylvanian-Permian Sangre de Cristo Formation "Tubb sandstone" to the Upper Cretaceous Pierre Shale (fig. 3).

Hydrocarbon production from the province is mainly coalbed methane (CBM) from the Upper Cretaceous to middle Paleocene Vermejo and Raton Formations (fig. 3). Since the start of commercial CBM production in 1984, through 2003, approximately 286 BCF of CBM and 387 MMBW have been produced from more than 1,620 wells in the Raton Basin part of the province (IHS Energy, 2004b). About 90 percent of the CBM production is from the Vermejo Formation, with the remainder from the Raton Formation and commingled Raton-Vermejo production. Individual coalbed methane wells in the Colorado part of the province are completed in 5 to 15 individual coal beds in the Raton and Vermejo Formations (Hemborg, 1996). Carlton (2006) indicated the Raton Formation has as many as 40 coal seams with net coal thickness locally approaching 100 ft, however, individual coal beds are generally 1–10 ft thick with limited lateral continuity. Most of the coal is high in volatiles, ranging from about 25.8 to 38.7 percent (Amuedo and Bryson, 1977). Depths of CBM tests and production range from about 230–5,000 ft. Sandstones interbedded with the coals contain gas resources, but assessment of this gas may be complicated by commingled recovery with CBM. This is particularly true if the perforated zones include sandstone beds. Potential gas resources are also in sandstone in both the overlying Poison Canyon Formation and underlying Trinidad Sandstone. Total production from the Trinidad Sandstone in the province is 31 MMCFG, with no reported water from two leases in the Three Bridges field.

Hydrocarbon gas from the Dakota Formation is produced from the Wagon Mound field (fig. 2). More than 97 MMCF of natural gas was produced from the Dakota Sandstone and Morrison Formation in the Wagon Mound field (fig. 2) from 1940 through 1981 (IHS Energy, 2004b).

Oil shows have been observed in wells in the central part of the Raton Basin and in outcrops of the Trinidad, Pierre, Niobrara, and Dakota formations at the basin margins (Baltz, 1965; Dolly and Meissner, 1977). Numerous wells across the province have reports of fluorescence from oil shows and odor, or other indicators of gas shows from Permian through Tertiary formations (fig. 3). There are shows of oil and gas in the Sangre de Cristo Mountains, and in wells on the Graham anticline, north of Las Vegas, N. Mex. (western San Miguel County, fig. 1), and asphaltic residues have been observed in the Sangre de Cristo Mountains at outcrops northwest of Las Vegas (Northrop and others, 1946).

Comparison of USGS 2005 Total Petroleum System Assessment to the 1995 USGS National Oil and Gas Play-Based Assessment

Estimates of undiscovered oil and gas resources can vary widely at reservoir to basin scales due to various methods of analysis used by different organizations and individuals, as well as the quality, quantity, and areal distribution of available geologic, geochemical, and production data. Provinces that have minimal subsurface information from drilling or seismic sections, termed "frontier," generally are assigned wide ranges of confidence levels in USGS assessments to reflect this lack of information. As research and exploration develop within a province, the additional data leads to greater confidence in assessment results. Dolly and Meissner (1977) estimated that 23 TCFG has been generated in Vermejo and Raton Formation coals in the Colorado part of the Raton Basin, based on their analysis of coal thickness, volume, density, and rank; they further assumed that 50 percent of the generated gas is retained within coals or lost to the surface, and that only 50 percent of the gas trapped within sandstone reservoirs in the target intervals will be producible. Based on these qualifiers, their estimated "potential reserve volume" from the sandstones is 5.8 TCFG. Tremain (1980) estimated 1.56 TCF of CBM resources for the Vermejo Formation in the Colorado part of the province. Tyler and others (1995) estimated in-place CBM in the Vermejo and Raton Formations for the province at 8–12 TCF, based on projections of local estimates by Danilchik and others (1979), Tremain (1980), and Stevens and others (1992a).

Undiscovered petroleum resources of the Raton Basin–Sierra Grande Uplift Province were assessed by the USGS oil and gas resource assessment team in 1995 (Keighin, 1995; U.S. Geological Survey, 1995); this will hereafter be referred to as the "1995 assessment." USGS assessments of conventional and continuous resources are based on analysis of the volumes of oil, gas, and natural gas liquids (NGL) that have the potential to be produced in the next 30 yr, assuming continued application of the current methods of exploration and development. The 1995 assessment of total oil and gas resources was based on minimum accumulation sizes of 1 MMBO or 6 BCFG within each play. Minimum accumulation size in the 2005 assessment for conventional assessment units is 0.5 MMBO or 3 BCFG, and minimum estimated ultimate recovery per cell for continuous assessment units is 0.02 BCFG. Mean estimates of undiscovered, technically recoverable conventional resources from the 1995 assessment of the province were 0 BO, 40 BCFG, and less than 10 MMBNGL; estimated mean undiscovered CBM resources were 1.78 TCF (USGS, 1995). Shown in figure 8 are 1995 assessment play names and boundaries and dry or petroleum-productive cells across the province. Geographic information system (GIS) data files that contain the play boundaries and cell information for this and other provinces from the 1995 assessment are located at Beeman and others (1996) and *http://energy.cr.usgs.gov/oilgas/noga/1995.html*. A link to the 1995 assessment data and results is also at *http://energy.cr.usgs.gov/oilgas/noga/index.htm*. This site also contains downloadable GIS for cells and petroleum system boundaries, fact sheets and other publications, and results and methodology for provinces evaluated in the 2005 assessment.

Exploration and development of coalbed gas has expanded outside the play boundaries defined in the 1995 assessment (figs. 1, 8). AU boundaries in the 2005 assessment include almost the entire areal extent of the Upper Cretaceous Vermejo and Upper Cretaceous–Tertiary Raton Formations. Boundaries of other AUs in the 2005 assessment (fig. 1) were modified from 1995 boundaries (fig. 8) based on geologic and production data. The irregular shapes of the current Fractured Reservoirs and Jurassic–Lower Cretaceous Reservoirs AUs reflect the extent of potentially producing formations. Excluded are peripheral areas of decreased potential due to the presence of igneous intrusions. Petroleum resources may be present in these areas, but are probably below the minimum sizes of 6 BCFG for conventional accumulations. For example, based on a cross section by Tremain (1980), a laccolithic intrusion is present in the upper half of the Jurassic Morrison Formation through the lower half of the Lower Cretaceous Dakota Sandstone in the area of the basalt flows south of Trinidad, Colo. (figs. 1, 4). Petroleum source rocks that are proximal to the intrusion are probably overmature for hydrocarbon generation. Table 1 lists F5 to F95 confidence levels for undiscovered petroleum resources in the province based on the 2005 assessment. Oil resources of 0 BO for the province in the 2005 assessment agrees with that of the 1995 assessment. For the 1995 assessment, resources were not assigned for the Jurassic–Lower Cretaceous play (4102) because there were too few wells that penetrated the Jurassic Morrison Formation and Lower Cretaceous Dakota Sandstone that composed this play (Keighin, 1995). The play was also high risk because discoveries would probably be smaller than 6 BCFG or 1 MMBO in the probable sandstone reservoirs of lenticular marine bar and fluvial channel depositional environments (Keighin, 1995). This play was roughly equivalent to the Jurassic–Lower Cretaceous Reservoirs AU (50410202) of the Jurassic–Cretaceous Composite TPS (504102) (table 1), for which assessed mean recoverable resources are 615.09 BCFG and 24.58 MMBNGL.

The 2005 assessment of Fractured Reservoirs (AU 50410201) of the Jurassic–Cretaceous Composite TPS (504102) has no counterpart in the 1995 assessment. The Fractured Reservoirs AU has estimated mean resources of 88.78 BCFG and 3.54 MMBNGL (table 1) from fractured shale of the Cretaceous Pierre Shale and Carlile Shale, sandstone of the Codell Sandstone Member, and marl of the Niobrara Formation (fig. 3).

The 1995 conventional and hypothetical Upper Cretaceous–Tertiary play (4101) is roughly equivalent to the 2005 Upper Cretaceous–Tertiary Sandstones AU (50410101) of the Upper Cretaceous–Tertiary Coalbed Gas TPS (504101) (table 1). Both the 1995 and 2005 assessments evaluated conventional resources for sandstone of the Cretaceous Trinidad Sandstone and Vermejo Formation, and the Cretaceous–Tertiary Raton Formation and Poison Canyon Formation. The 1995 assessment estimated mean recoverable resources for these formations are 34 BCFG and 0.9 MMBNGL, and the 2005 assessment estimated mean recoverable resources are 58.53 BCFG and 0 MMBNGL.

D.D. Rice and T.M. Finn (as reported in Keighin, 1995) divided continuous CBM plays into the Northern Raton Basin play (4150), the Raton Basin–Purgatoire River play (4151), and the Southern Raton Basin Play (4152) (fig. 8), based partly on coal rank and depths. Mean recoverable resources for these three plays were estimated to be 914.39, 289.41, and 571.39 BCFG, respectively, for a total of 1.78 TCF. Reservoirs for both the 1995 and 2005 assessments are coal beds of the Vermejo Formation and the Raton Formation. In the 2005 assessment, mean recoverable resources for the Vermejo Coalbed Gas AU (50410182) and Raton Coalbed Gas AU (50410181) are estimated at 979.32 BCFG, and 611.26 BCFG, respectively; cumulative recoverable resources are 1.59 TCFG (table 1). Rice and Finn (in Keighin, 1995) indicated that (1) more that 110 exploration wells had been drilled for CBM in the province, (2) results of production tests were variable, but rates of more than 300 MCFG per day have been reported, and (3) all wells were shut in due to the lack of gas pipelines. Between the 1995 and 2005 assessments, gas pipelines were constructed and more than 2,100 exploration and development wells were drilled into or below the Raton Formation. As of 2004, more than 287 BCFG and 387 MMB water were produced from more than 1,700 wells from coal beds of the Vermejo and Raton Formations (IHS Energy, 2004b).

Total Petroleum System Elements of the Raton Basin–Sierra Grande Uplift Province

Paleozoic Potential for Oil and Gas

Devonian through Triassic strata were not assessed for petroleum resources. Although some oil and gas potential exists based on published records of shows in outcrops (fig. 3), there is no production. These strata are a frontier explora-

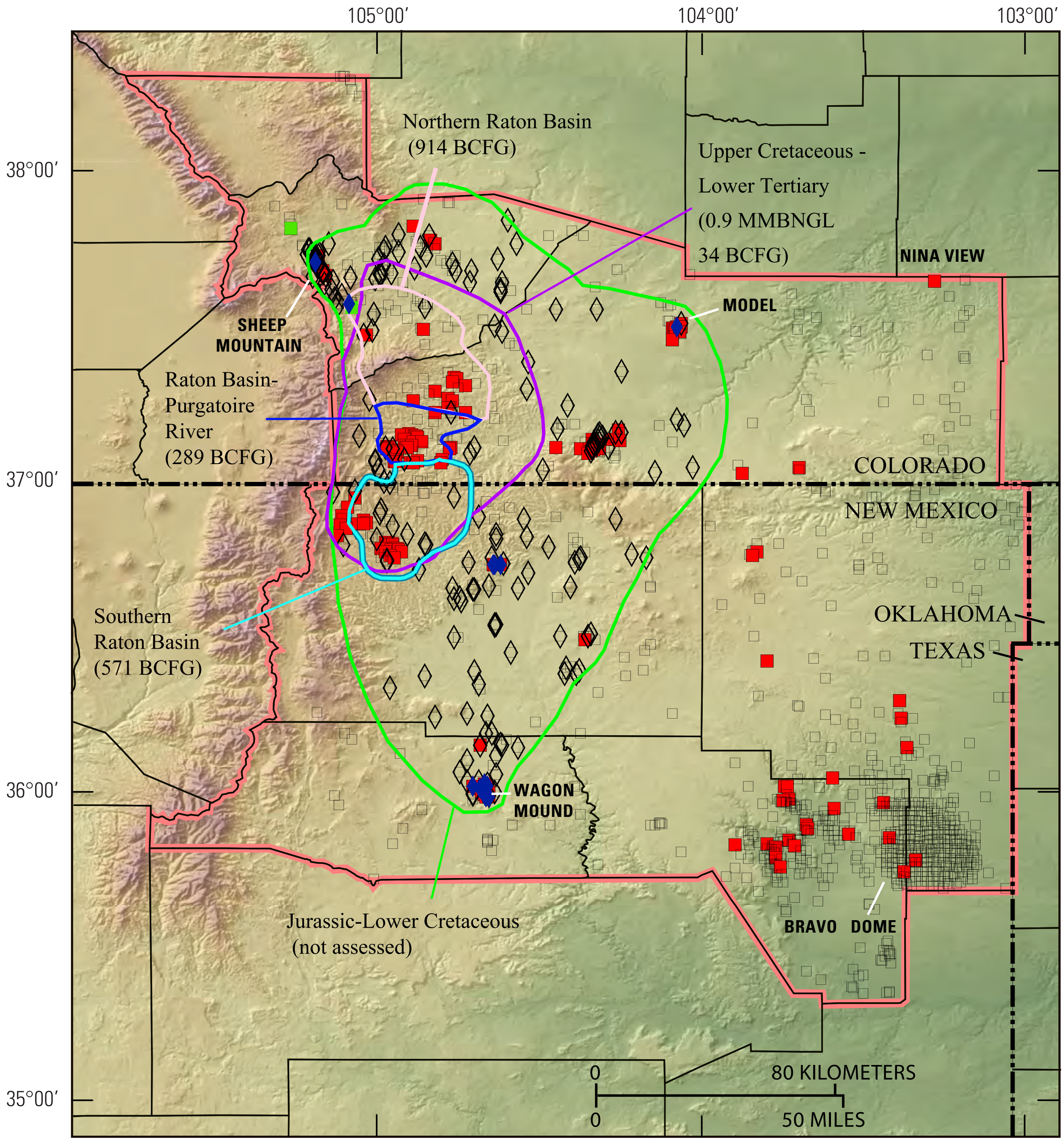

Figure 8. Play names and boundaries, and estimated mean undiscovered resources from the 1995 assessment of the Raton Basin–Sierra Grande Uplift Province. Coalbed methane plays are Northern Raton Basin, Purgatoire River, and Southern Raton Basin. Conventional plays are Jurassic–Lower Cretaceous and Upper Cretaceous–Lower Tertiary. Diamond symbols are gas (dark blue) and nonproductive (black) cells for the Jurassic–Lower Cretaceous play. Square symbols are gas (red) and nonproductive (black) cells for the coalbed methane and Upper Cretaceous–lower Tertiary plays. The two green squares near the northwest border of the province are oil cells. Red and black cells outside of the Upper Cretaceous–lower Tertiary play, and within the Model field, are productive of carbon dioxide and (or) helium, or are nonproductive. Abbreviations: BCFG, billion cubic feet of gas; MMBNGL, million barrels of natural gas liquids.

tion target because there are only about a dozen wells that penetrate Triassic and older formations within the Raton Basin and Las Vegas subbasin. Lower Permian and Pennsylvanian rocks are 13,000 to 15,000 ft thick in the Sangre de Cristo uplift and thin or absent along the east flanks of most of the Raton Basin and Las Vegas subbasin; Ordovician, Devonian, and Mississippian rocks crop out in the northern Sangre de Cristo Mountains, but wedge out southward and may not be present in the subsurface in the northern part of the Raton Basin (Baltz, 1965).

Wells that penetrate Paleozoic through Mesozoic strata outside TPS boundaries (fig. 1) are productive of CO_2 and (or) helium, and nitrogen, or are nonproductive (dry). Vitrinite reflectance (R_o) data on Cretaceous and Tertiary coals and burial history reconstructions in the Raton Basin and Las Vegas subbasin indicate that the Paleozoic section here is probably overmature for gas generation, but because of the paucity of wells and information on source rock occurrence and levels of maturation, this cannot be confirmed at this time.

Helium and Carbon Dioxide Production

Overview

Primary production of gas in the province has been CO_2 from several fields located on the Sierra Grande uplift and along the northwest border of the Raton Basin (fig. 2); helium and nitrogen are also produced in some fields. More than 635 wells produce CO_2, from formations that range from the Pennsylvanian-Permian Sangre de Cristo Formation to the Lower Cretaceous Dakota Sandstone; one well in the Sheep Mountain field has commingled CO_2 production from the Dakota Sandstone and from the Codell Sandstone Member of the Carlile Shale (IHS Energy, 2004a,b) (figs. 2, 3). There is CO_2 gas production from the Entrada Sandstone in the Sheep Mountain and Dike Mountain fields, and also production from sills or igneous intrusions from one well each in the Oakview and Sheep Mountain fields (fig. 2). In the southeastern quarter of the province CO_2 is mainly produced from the Sangre de Cristo Formation; six wells are also productive from Triassic strata. The ranges in thickness of strata in the Raton Basin are shown in figure 3.

Cumulative production of CO_2 is about 3.57 TCF from the Bravo Dome, Bravo Dome West, Bueyeros, Dike Mountain, Fannin, Nina View, Sheep Mountain, Mitchell, and Model fields (fig. 2) (Lawson and Hemborg, 1999; IHS Energy, 2004b). Helium and CO_2 were produced from the Nina View (1948-1965) and Model (1927-1940) fields; respective CO_2 production was 53 MMCF and 776.121 MMCF (Lawson and Hemborg, 1999). Clair and Bradish (1956) estimated a total reserve of helium from the Model field at 261.56 MMCFG. Sheep Mountain field CO_2 production through 1996 was 1.009 TCF, of which 825 BCFG was from the Dakota Sandstone, and 184 BCFG was from the Entrada Sandstone (Lawson and Hemborg, 1999). Reported volumes of produced water from helium and CO_2 wells are variable.

Source Rocks and Gas Migration

The CO_2 is mainly produced from chemical reactions between Paleozoic and Mesozoic limestones and hydrothermal fluids. The fluids are associated with fault and fracture systems that are the result of tectonic activity. Carbon isotopic data from a wellhead gas sample in the Sheep Mountain field indicates a nonbiogenic upper-mantle source for the CO_2 (Penn, 1994).

Helium and associated gases are produced primarily from the decay of uranium and thorium isotopes trapped within stratigraphic occurrences, and from vertical and lateral advection from Precambrian and other deep igneous rock sources along permeable fault and fracture systems. Helium is also transported through ground water. Analysis of gas from the Model field yields 8 percent helium, 15 percent CO_2, and 77 percent nitrogen (Clair and Bradish, 1956). A study of helium migration within the Vasto Basin gas province in central Italy indicated that the concentration of helium is controlled by the distribution of fault and fracture systems in the shallow crust, and all types of faults and fractures may act as preferential pathways for the ascent of deep gases and fluids (Ciotoli and others, 2004). The timing of formation of these largely structural traps in the Raton Basin–Sierra Grande Uplift Province is associated with Paleozoic and Laramide tectonism and Tertiary igneous activity.

Jurassic–Cretaceous Composite Total Petroleum System

Jurassic–Lower Cretaceous Reservoirs Assessment Unit (50410202)

Overview

Mean resources of the Jurassic–Lower Cretaceous Reservoirs AU are estimated at 615.09 BCFG and 24.58 MMBNGL (table 1); AU boundaries (fig. 1) correspond generally to the areal extent of the reservoirs and potential reservoir formations. This AU, assessed as conventional, includes the interval from the base of the Jurassic Entrada Sandstone through the Cretaceous Greenhorn Limestone (figs. 3, 9). Appendix 1 contains input data used in the assessment of undiscovered resources for the Jurassic–Cretaceous Composite AU; explanation of the data sheets and assessment model are in Schmoker and Klett (2000). Appendix 2 is the forecast for natural gas and NGL distributions of undiscovered resources that is based on the Monte Carlo simulation method described in Charpentier and Klett (2000).

A widespread blanket of shallow-marine and overlying terrestrial deposits was laid down across the area of the Raton Basin–Sierra Grande Uplift Province in Late Jurassic time; the total thickness of these strata ranges from about 100–600 ft, with the variation being attributable mainly to an erosional surface at the top of the Jurassic rocks (Baltz, 1965). More than 3,500 ft (Baltz, 1965) of mostly Cretaceous marine shale and limestone then accumulated, with the Pierre Shale at the top of the sequence capped by nonmarine sandstone and shale of the Trinidad Sandstone.

Source Rocks

The Graneros Shale is the likely hydrocarbon source rock for the Jurassic–Lower Cretaceous Reservoirs AU (fig. 9). The formation conformably overlies the Dakota Sandstone and consists of dark gray shale and a minor amount of fine-grained sandstone, with thin beds of bentonite, and a few thin beds of limestone; it is 185–380 ft thick in the northern Raton Basin and 215–250 ft thick in the Las Vegas subbasin (Baltz, 1965). Shows of oil and gas have been reported from Graneros Shale outcrops in the northern Raton Basin (Baltz, 1965). High total organic carbon (TOC) intervals of the Graneros Shale in the Denver Basin are important sources of petroleum for Lower Cretaceous reservoirs. There are no TOC or other data on marine shales within and bounding the Dakota Sandstone in the Raton Basin–Sierra Grande Uplift Province. Cretaceous shales below the Dakota Sandstone in the Denver Basin are not considered to be petroleum source rocks because of low TOC contents.

It is unknown as to whether limestones or shales of the Jurassic Wanakah Formation contain sufficient organic matter to be petroleum source rocks for the Jurassic Entrada Sandstone or Morrison Formation. The Entrada Sandstone west of Las Vegas, N. Mex., is overlain by, and intertongues with, the 50- to 100-ft thick Wanakah, which is mainly composed of gray, finely laminated, fetid limestone; it is correlated with the Todilto Limestone of western New Mexico (Northrop and others, 1946; Baltz and Bachman, 1956). The Todilto (Wanakah) grades northward and eastward into a sequence of locally gypsiferous, reddish to waxy-green shale that contains interbedded thin, fine- to medium-grained sandstone and red chalcedony beds (Baltz, 1965).

Laramide reactivation of the Las Animas and Sierra Grande arches may have served as barriers to eastward migration of petroleum from Cretaceous and older source rocks in the Raton Basin and Las Vegas subbasin. Cretaceous through Tertiary formations are the principle petroleum source and reservoir rocks across the province; most of these strata were eroded from, or were not deposited within, the Sierra Grande uplift.

Burial History

The degree of thermal maturation of coals and other petroleum source rocks is controlled by numerous factors, most importantly by depth of burial and the associated temperature history. The heating history of the Raton Basin

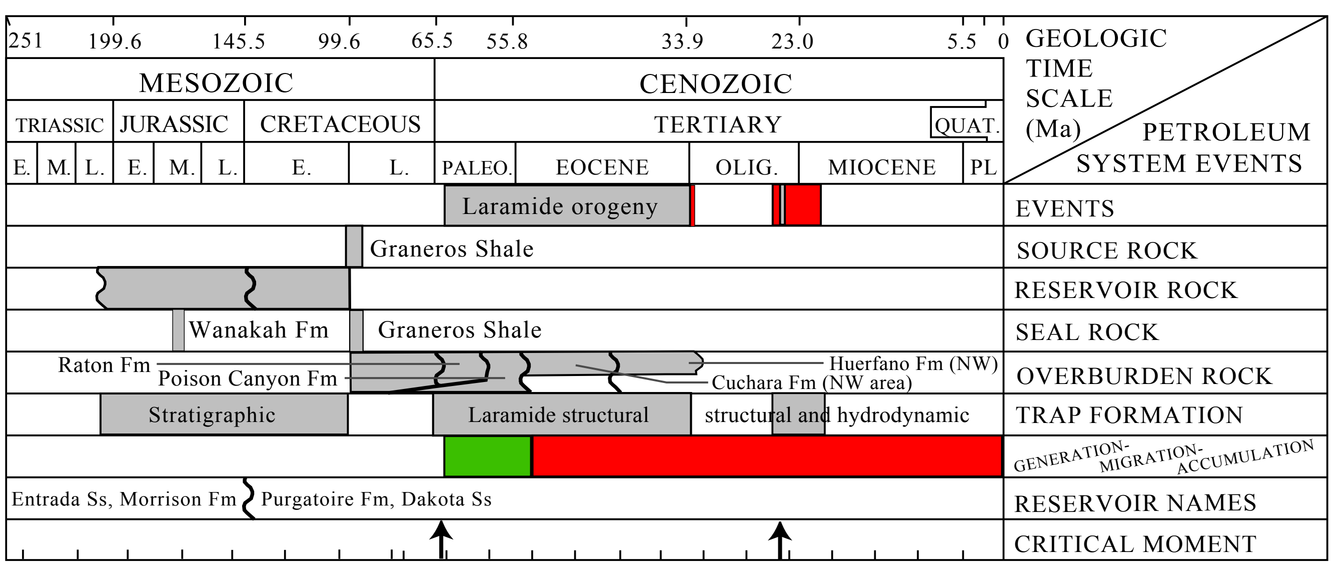

Figure 9. Events chart for the Jurassic–Lower Cretaceous Reservoirs Assessment Unit (50410202) of the Jurassic–Cretaceous Composite Total Petroleum System (504102). There is potential for conventional gas resources from sandstone beds of the Entrada Sandstone, Morrison Formation, Purgatoire Formation, and Dakota Sandstone. Gray and red on the events bar are used to differentiate intrusive/tectonic events that may have influenced oil and gas accumulations. Wavy lines mark unconformities. Generalized time intervals for onset of oil (green) and gas (red) generation are based on burial history reconstructions. Abbreviations: E., Early; M., Middle; L., Late; PALEO, Paleocene; OLIG., Oligocene; PL., Pliocene; QUAT., Quaternary; FM, Formation; SS, Sandstone

and Las Vegas subbasin is increased by the thermal blanket effects of coals within the Vermejo and Raton Formations, and shales within these and other formations. The TPS events chart for the Jurassic–Lower Cretaceous Reservoirs AU (fig. 9) shows the major tectonic events that influenced deposition, erosion, and heating history in the province, and the associated oil and gas generation, migration, and accumulation. Most of the Cretaceous through Paleocene petroleum source rocks in the Raton Basin and Las Vegas subbasin are within the gas generation window based on coal-rank values estimated from R_o data (fig. 10), and the burial history reconstructions that are presented later. Potential Triassic and older source rocks are currently overmature for gas generation based on the results of the burial histories. Stevens and others (1992b) indicated that the composition of gas in Raton and Vermejo coal seams averages more than 90 percent methane, less than 5 percent nitrogen, and less than 1 percent CO_2.

The burial and thermal history in this province is difficult to model; additional and accurate R_o and temperature data for Cretaceous and older formations are required before conclusions can be reached. Vitrinite reflectance data on coals are of good quality, but temperatures may have been locally elevated in areas near igneous intrusions. Available source rock data are for Upper Cretaceous and Tertiary formations, and there are no analyses on potential Paleozoic to Lower Cretaceous petroleum source rocks. Total depth within most wells in the Raton Basin and Las Vegas subbasin is in the Trinidad Sandstone or shallower formations. There are multiple erosional events (fig. 3) but little documentation on the extent and thickness of removed strata. Few wells have recorded drillstem test (DST) or other temperature data. Charles Spencer (oral commun., 2004) indicated that available temperature data were generally of poor quality, due partly to the shallow drill depths; in addition, wells drilled in summer commonly had warmer recorded temperatures than those drilled in winter due to the higher temperature of drilling fluids. Drillstem test temperatures available for the present study (IHS Energy, 2004a) are all located in the northern part of the Raton Basin (fig. 10), and these values may have been suppressed by the hydrologic effects of downward-moving water from the Wet and Sangre de Cristo Mountains. Because of these factors, the burial history plots should be viewed as hypothetical.

The levels of thermal maturity at the base of the Vermejo Formation vary from 0.57 percent R_o around the margins in the northern part of the basin to 1.58 percent in the central part (Johnson and Finn, 2001). Anthracite or higher coal ranks are proximal to intrusions (Jurich and Adams, 1984). The high coal ranks along the Purgatoire River are unusual in that the coal beds are not near the major intrusions that are farther to the north in the basin. Wells drilled near the river have, however, encountered some sills (ARI, Inc., 1991) that may have played a role in elevating the coal ranks. Almost all coalbed methane wells drilled in the West and East Spanish Peaks area exhibit some degree of coal replacement by igneous sills (Carlton, 2006).

Bostick and Pawlewicz (1984b) measured percent R_o of the Pierre Shale in Colorado and northern New Mexico. Results from 14 outcrop samples from the Raton Basin were rated at fair to good quality, including 2 north of Walsenburg, Colo. (0.40 and 0.50 percent R_o), 6 near Raton, N. Mex., that ranged from 0.45 to 0.64 percent R_o, and 6 spread across the western boundary of the basin in Colorado that ranged from 0.40 to 1.35 percent R_o, the latter sample being located near an igneous dike. Bostick and Pawlewicz (1984a) indicated that Pierre Shale samples in thermal alteration zones adjacent to igneous dikes in and north of Walsenburg rose from a regional level of 0.5 percent R_o to more than 4.0 percent R_o; maximum paleotemperatures ranged from less than 100 °C outside the influence of the Walsenburg dike, to as much as 500 °C or higher near the dike. The dikes increased the R_o value for a distance of slightly more than their width. On the basis of the sample results of both studies, Bostick and Pawlewicz (1984a) concluded that there was no evidence that post-Pierre deformation was accompanied by elevated heat flow (“hot spots”) except in the immediate vicinity of known volcanic intrusions. Interpretations of apatite fission-track analyses and conodont alteration indices (CAI) indicate that the northern Sangre de Cristo Mountains were abruptly cooled to temperatures below 120 °C at about 19 Ma (Lindsey and others, 1986), shortly after cessation of West and East Spanish Peaks and associated magmatism, and following the onset of Rio Grande rifting. Cooling in the basin probably commenced in response to rapid uplift and erosion of the northern mountains during early rift development (Lindsey and others, 1986; Kelley and others, 1992) and may also have been influenced by hydrologic factors. Downward flowing water along the western and northern boundary of the Raton Basin would cool aquifers, and the upward flow of water along the eastern flank of the basin would contribute heat. Volcanic activity in the province occurred from 26.6 to 21.3 Ma (Penn, 1994; Penn and others, 1994; Penn and Lindsey, 1996). Smith (1978) reported the age of some West and East Spanish Peaks dikes at 20–27 Ma. The Walsenburg dikes are of the same complex (Johnson, 1968), so the associated heating would have occurred after maximum burial about 40 Ma.

Edwards and others (1978) created 65 temperature logs from wells in northeastern New Mexico and southeastern Colorado and used this information to generate heat flow data at 53 sites; a best heat flow value was normally chosen by averaging heat flow throughout the drill hole. They assigned three regional trends to the data: (1) areas of extensive volcanic activity do not necessarily exhibit high-heat flow, (2) a narrow, north-south-trending high-heat flow anomaly located between lat 35.5° and 34° is apparently associated with the Rio Grande rift, and (3) a broad high heat flow anomaly is located over the southern Rocky Mountains and extends 200–300 km onto the Great Plains of northeastern New Mexico and southeastern Colorado. Measurements of crustal radioactivity in the vicinity of the Rio Grande rift (Edwards and others, 1978) suggest that the radioactive heat generation contributes uniformly to the surface heat flow, which indicates tectonic and volcanic sources rather than anomalously high crustal radioactivity.

The Raton Basin and Las Vegas subbasin have high heat flows equal to or greater than 2.0 $cal/cm^2/sec$ (83.7 milliWatts

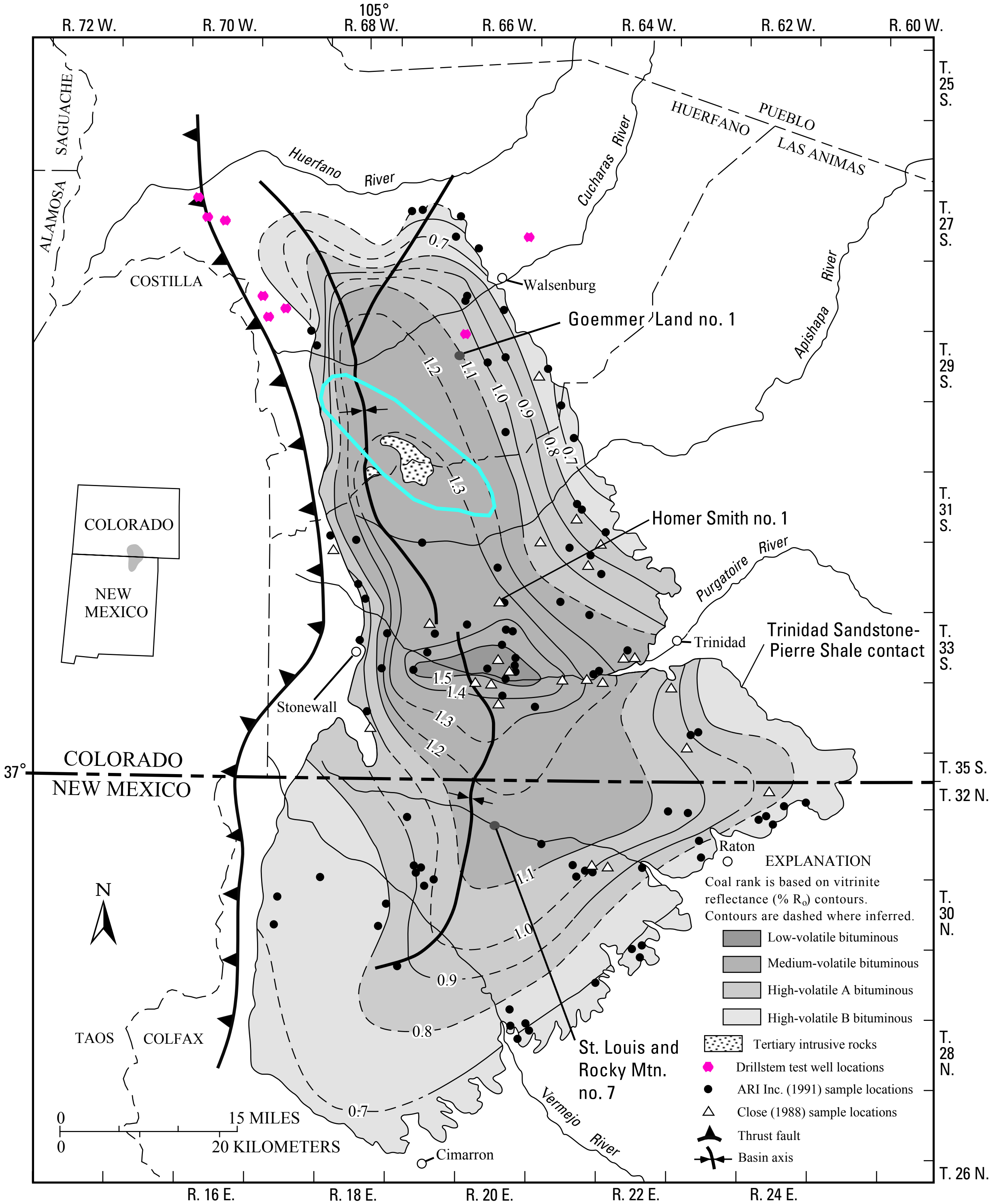

Figure 10. Map showing vitrinite reflectance contours and interpreted coal rank at the base of the Vermejo Formation, Raton Basin, Colorado and New Mexico. Modified from Johnson and Finn (2001), Hemborg (1996), and Tyler and others (1995). Drillstem test (DST) well locations are approximate. Blue oval in the West and East Spanish Peak intrusions area is the generalized outline of the postulated Trinidad Sandstone basin-centered gas accumulation of Rose and others (1986).

per meter squared (mW/m^2)), which is in contrast to the Great Plains where cratonic heat flow values are equal to or less than 1.5 $cal/cm^2/sec$ (62.8 mW/m^2) (Edwards and others, 1978). The central Raton Basin high heat flow is also supported by elevated levels of R_o in coals; these measurements are subject to local heating by intrusions and also the heating and cooling effects of hydrologic and (or) hydrothermal flow. Present heat flow for the burial history plots (figs. 11–14) is derived from regional heat flow maps by Goolsby and others (1979) and Close (1988). Age constraints on the onset of high heat flow were based on timing of the Laramide orogeny and on Tertiary tectonic events that are listed in figure 3. Timing and magnitude of potential heat flow events is unknown. However, burial history reconstructions indicate that heat pulses that lasted 10 million years or more near the time of maximum burial would significantly increase levels of thermal maturation.

One-dimensional burial history plots were constructed for three wells in the Raton Basin by using Integrated Exploration Services PetroMod® software (figs. 11–14). The Sweeney and Burnham (1990) Easy%R_o algorithm was used in the burial history constructions and the results were compared to measured R_o values. Most Upper Cretaceous and Tertiary petroleum source and potential source rocks within the Raton Basin and Las Vegas subbasin are within the gas generation window, as indicated by R_o values of 0.5 percent and greater for humic coals; the threshold for the generation of sufficient gas to form economic accumulations or overpressuring is between 0.8 and 1.0 percent R_o (Scott, 1993; Tang and others, 1996; Law, 2002; Roberts and others, 2004). Based on hydrous pyrolysis and initial and subsequent R_o analysis of lignite to semianthracite samples from Poland, Kotarba and Lewan (2004) determined that 75 percent of the maximum potential of the coals to generate thermogenic methane was expended at 1.7 percent R_o. End of gas generation from the type-III kerogen in coal is between 1.8 and 2.0 percent R_o (Rohrback and others, 1984; Saxby and others, 1986; Roberts and others, 2004). The type-III kerogen ranges were based partly on burial history reconstructions by Roberts and others (2004) for wells in southwestern Wyoming, in which R_o ranges were assigned partly based on modeled transformation ratios. These ranges do not include contributions of biogenic methane within the coals.

Type-II kerogen is concentrated in the Cretaceous shale and limestone petroleum source rocks. For modeling purposes, onset of gas generation from type-II kerogen is placed at 0.9 percent R_o, and source rocks are considered overmature for primary or secondary hydrocarbon generation at 2.5 percent R_o. Vitrinite reflectance (R_o) analyses are used to estimate the maximum temperature experienced by the vitrinite macerals, and this information is used to evaluate levels of thermal maturation of petroleum source rocks. In contrast, timing of primary and secondary generation of oil and gas can be calculated using results of hydrous and (or) anhydrous pyrolysis of samples of source rocks. Transformation ratios are the fraction of reaction that is completed for conversion of kerogen to oil and gas or cracking of oil to gas; minimum gas generation is 1 percent and maximum is 99 percent with peak generation at 50 percent (Roberts and others, 2004).

Vitrinite reflectance data in the Homer Smith no. 1 well were from coals of the Vermejo and Raton Formations (figs. 10–12) (Close, 1988). Mean random R_o data were based on an average of 50 measurements on each coal sample, and the data were not modified on the basis of sample composition because of the high ratio of vitrinite to pseudovitrinite (Close, 1988). The Homer Smith no. 1 well reached total depth in the Trinidad Sandstone, and thicknesses of deeper formations were incorporated from the nearby Horn Springs no. 1, Manway 13-32, and Filbert 21-31 wells. Modeled parameters in the burial history included 1,500 m of erosion from 40 Ma to present, heat flow of 55 mW/m^2 from about 290 Ma to 65 Ma, and 121 mW/m^2 from 65 Ma to the present (blue lines, fig. 11). The curves can also be matched by modeling 1,600 m of erosion from 40 Ma to the present and the 121 mW/m^2 from 40 to 10 Ma. The onset of oil generation was about 65 Ma and gas generation was about 60 Ma for the Pierre Shale, the oldest formation that is still within the gas generation window. The onset of oil generation from the Niobrara was almost 70 Ma, on the basis of modeled R_o (fig. 11) and transformation ratios (fig. 12).

To approximately fit the R_o data for the Homer Smith no. 1 well by using the 55 mW/m^2 heat flow through time, 5,000 meters of erosion from 40 Ma to present is required. This amount of erosion is not defendable. In figure 11, red lines on the temperature and R_o by depth plots are based on a stable cratonic heat flow of 55 mW/m^2 through time and 1,600 m of erosion from 40 Ma to present. Using this heat flow, the Graneros Shale at 0.7 percent R_o is presently thermally mature for oil generation. The Graneros Shale in this well is probably overmature for gas generation.

The transformation ratios of kerogen in coals to petroleum (fig. 12A) are based on applying the Pepper and Corvi (1995) type-III H(DE) hydrous pyrolysis kinetic algorithm to coal sequences. Used in the analysis were a 200 mg hydrocarbons/g TOC hydrocarbon index of coals, the frequency factor is 6.09x 10^{29}/million years for dry gas and 1.57x 10^{28}/million years for medium oil, and activation energies are variable. The transformation level for coals of the Raton and Vermejo are 45–75 percent, indicating that the coals still have thermogenic gas potential in the unlikely event of future deep burial.

Ideally, thermally immature samples of petroleum source rocks in the province should be sampled and analyzed using pyrolysis techniques. Because these data are not available, we applied Woodford type II hydrous pyrolysis kinetics (Lewan and Ruble, 2002) to Pierre Shale and Niobrara Formation intervals (fig 12B). The onset of petroleum generation, based on a transformation ratio of 4 percent, with 1,500 m of erosion from 40 Ma to present and heat flow of 121 mW/m^2 from 65 Ma to present, was about 70 Ma, and peak generation at 50 percent was about 60 Ma; generation potential is 100 percent for all formations below the Vermejo. This indicates that the Pierre and deeper formations are probably overmature for gas generation. Application of 1,600 m of erosion from 40 Ma

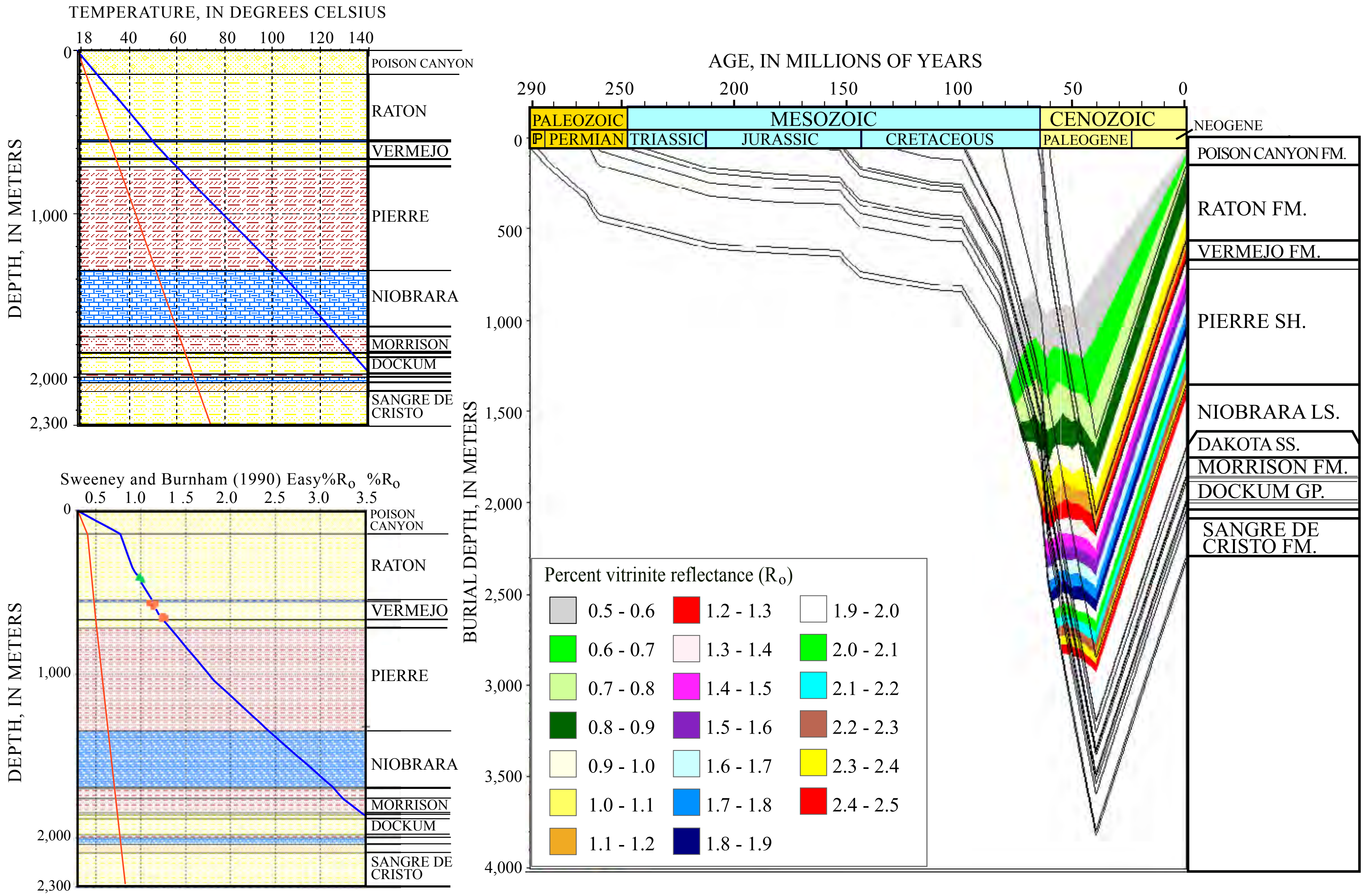

Figure 11. Burial history of the Homer Smith no. 1 well. Onset of oil and gas generation are about 70 Ma and 66 Ma, respectively, for the Graneros Shale and overlying Niobrara Formation. Charts of depth compared to temperature and vitrinite reflectance (R_o) (blue lines) and burial history were calibrated to R_o data using (1) 1,500 m of erosion from 40 Ma to present (2) a heat flow of 55 milliWatts per square meter (mW/m^2) from 290 Ma to 65 Ma, at which time it changed to 121 mW/m^2. Red lines on the depth plots represent modeled temperature and vitrinite reflectance based on a constant 55 mW/m^2 through time. Well location is shown in figure 10. Formation depths below the Trinidad Sandstone were constructed by using data from wells located at Sec. 33, T. 32 S., R. 66 W. Vitrinite reflectance data are from coals of the Vermejo and Raton Formations (Close, 1988). Abbreviations: IP, Pennsylvanian; FM, formation; LS, limestone; SH, shale; SS, sandstone

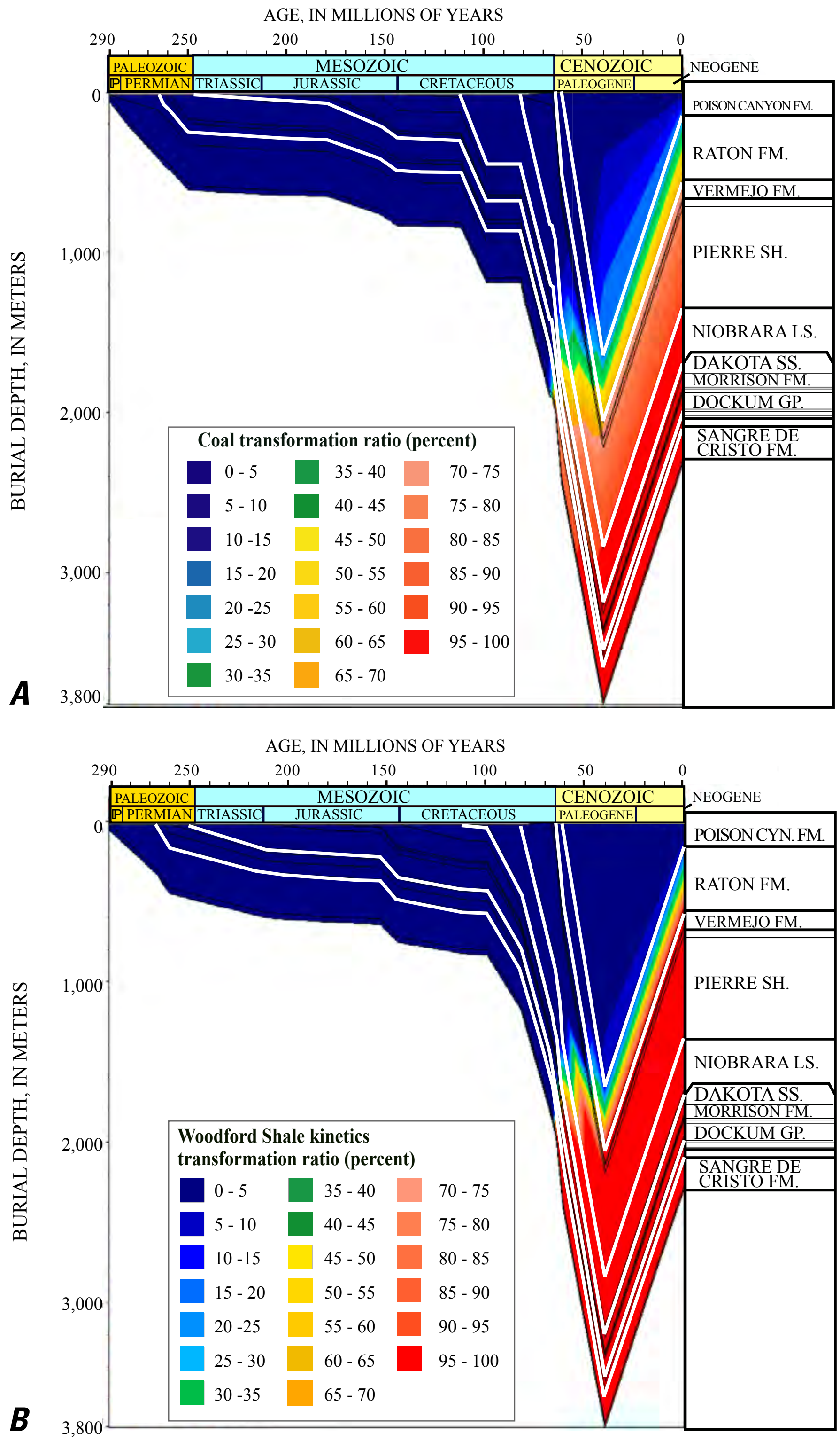

Figure 12. Transformation history of the Homer Smith no. 1 well. Transformation ratio calculations incorporate (1) 1,500 m of erosion from 40 Ma to present and (2) a heat flow of 55 milliWatts per square meter (mW/m^2) from 290 Ma to 65 Ma, at which time it changed to 121 mW/m^2. Transformation ratios are based on (*A*) coal (Pepper and Corvi, 1995) and (*B*) Woodford Shale (Lewan and Ruble, 2002) hydrous pyrolysis kinetics. (*A*) Onset of gas generation from coals of the Raton and Vermejo started about 50 Ma; kerogen is 45–75 percent transformed to gas. (*B*) Onset of oil and gas generation was about 70 Ma for the Pierre Shale and 60 Ma for the Niobrara Formation. Well location is shown in figure 10. Abbreviations: P, Pennsylvanian; FM, formation; LS, limestone; SH, shale; SS, sandstone

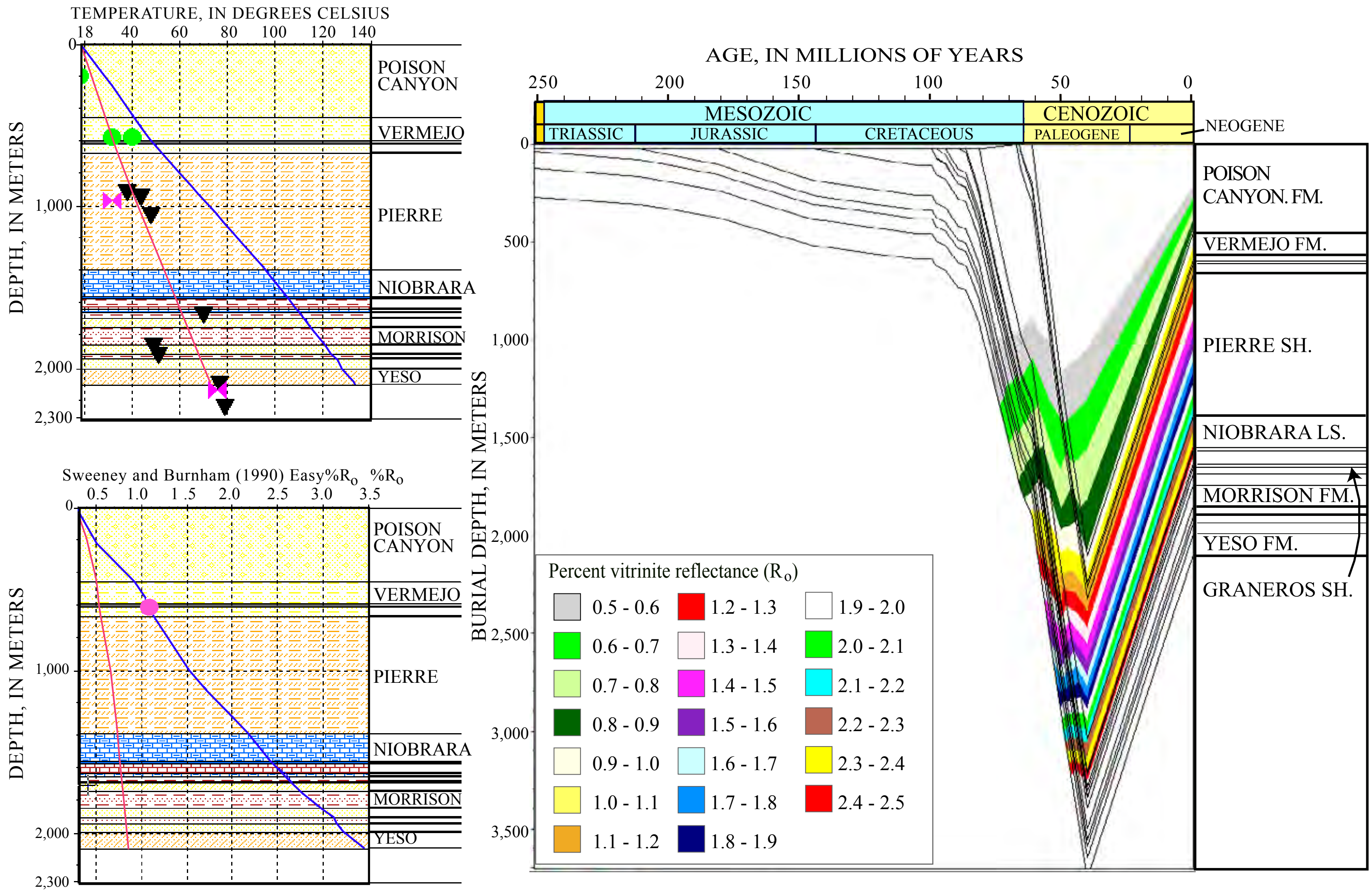

Figure 13. Burial history of the Goemmer Land no. 1 well. Vitrinite reflectance (R_o) values are extrapolated from contours shown in figure 10. Burial history, and the blue lines on charts showing temperature and vitrinite reflectance by depth, represent heat flow of 55 milliWatts per square meter (mW/m^2) from onset to 65 Ma, and 108.8 mW/m^2 from 65 Ma to present. Based on these parameters, the estimated amount of erosion is about 1,650 m from 40 Ma to present. Onset of oil generation was about 65 Ma, and onset of gas generation was about 55 Ma for the Graneros Shale and Niobrara Formation. All symbols on the temperature by depth plot are drillstem test values from the northern Raton Basin (fig. 10); green symbols are from wells on the east flank of the basin, and pink symbols are from wells from the Sheep Mountain CO2 field (fig. 2). Red lines on the depth charts represent curves based on 55 mW/m^2 heat flow through time; both temperature and R_o data can be matched only if 4,500 m of strata has been eroded from 40 Ma to present. Abbreviations: FM, formation; LS, limestone; SH, shale; SS, sandstone

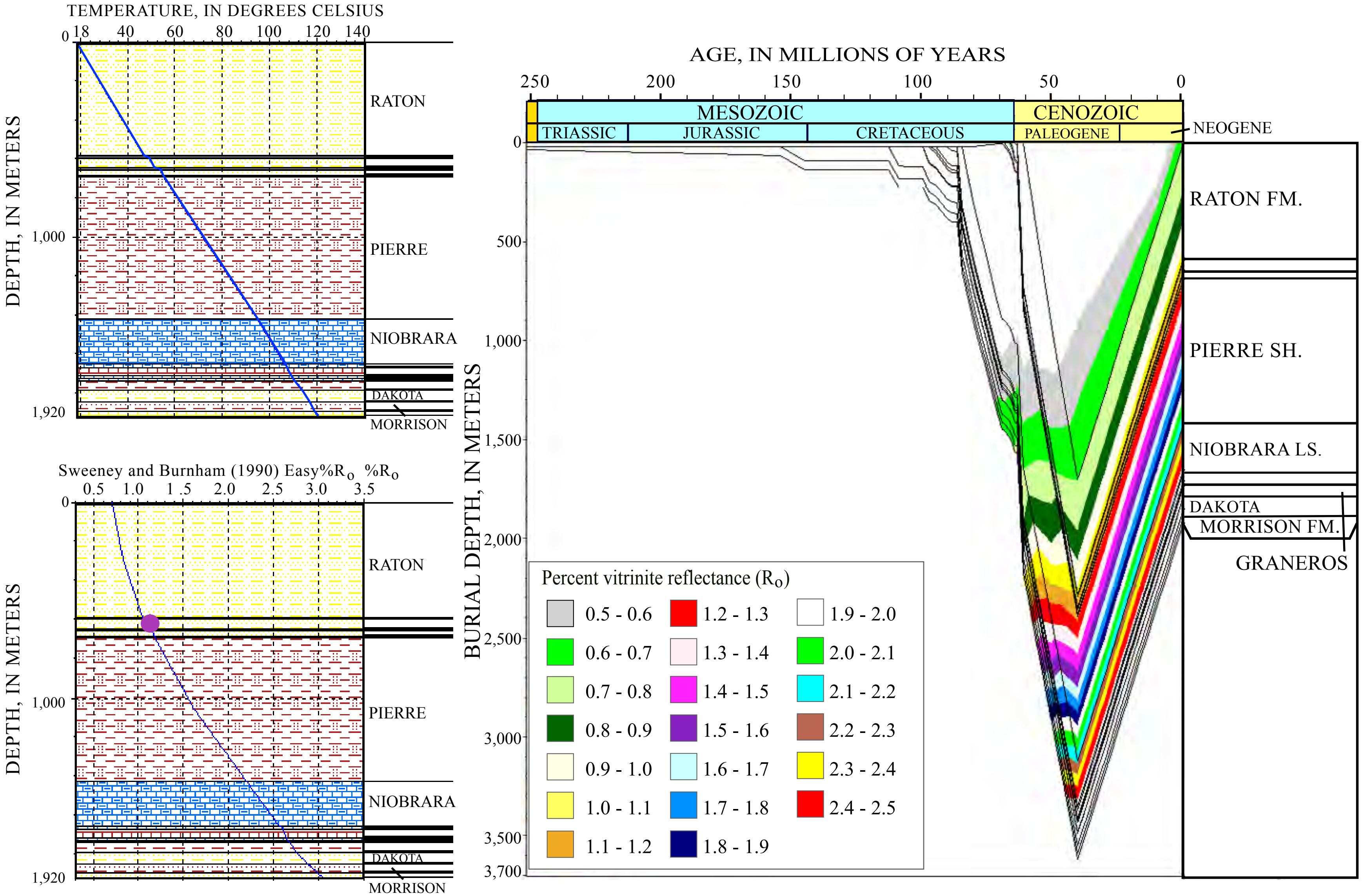

Figure 14. Burial history of the St. Louis and Rocky Mountain no. 7 well (fig. 10). Burial history, and blue lines on charts showing temperature and vitrinite reflectance (R_o) by depth, were calculated using (1)1,700 m of erosion from 40 Ma to present, (2) heat flow of 55 mW/m^2 from 250 Ma to 65 Ma, and (3) 105 mW/m^2 from 65 Ma to present. Based on these parameters, onset of oil generation was about 65 Ma and gas generation about 60 Ma in the Graneros Shale and Niobrara Formation. Vitrinite reflectance data (pink symbol) (Close, 1988; ARI, 1991) are from Vermejo Formation coals. Abbreviations: FM, formation; LS, limestone; SH, shale; SS, sandstone

to present and 121 mW/m^2 heat flow from 40 Ma to present resulted in approximately the same present-day transformation ratio but had the result of shifting the onset of petroleum generation to about 55 Ma for the Niobrara and Pierre. The Homer Smith no. 1 well is located near East Spanish Peak, with its related intrusions and dike swarms. Although these intrusions may have caused localized heating of coals and other source rocks, as previously discussed, alteration zones near the dikes are narrow, and it is assumed that sampled coals were outside the alteration zones.

Neither measured R_o nor well-temperature data were available for the Goemmer Land no. 1 or St. Louis Rocky Mountain no. 7 wells (figs. 13, 14), which adds another level of uncertainty to results. The R_o values at the base of the Vermejo Formation were estimated for both wells using extrapolated contour values (fig. 10). These wells were selected because they reached a total depth that was within or below the Morrison Formation. The Goemmer Land no. 1 well was also chosen because of proximity to DST temperature data (fig. 10) that were recorded from surrounding wells; tests were taken from the Dakota Formation to the Poison Canyon Formation. Posted drillstem test values (fig. 13) are based on depth, rather than formation, and associated formations generally do not correspond to those labeled for the Goemmer Land no. 1 well. Calibration of modeled to measured R_o requires a prolonged period of high heat flow from 65 Ma to the present and approximately 1,700 m of erosion from 40 Ma to the present. This, however, results in temperatures that are significantly greater than the measured DST values. Calibration to both the present-day well temperature and the estimated R_o can be modeled by using a stable 55 mW/m^2 heat flow through time and 4,500 m or greater erosion. This results in considerably lower heat flow than is currently measured and the thickness of erosion is not defendable.

The general trends for the Goemmer Land no. 1 and St. Louis Rocky Mountain no. 7 well burial history plots (figs. 13, 14) correspond to those of the Homer Smith no. 1 well (figs. 11, 12). These trends are the respective onsets of oil and gas generation about 65 Ma and 55 Ma for the Niobrara through Graneros interval, and Raton and Vermejo coals were within the gas generation window at about 55 Ma. Reservoirs could be sourced from proximal petroleum source rocks in areas where they are within the gas generation window. This is applicable for conventional and for continuous resources, which commonly have bounding source rocks that are thermally mature for oil and (or) gas. Some lateral and vertical migration of oil and gas did occur within the province, based on the presence of oil stains in outcrops along its western boundary.

One primary conclusion using the variable burial history results is that the Pierre Shale and deeper source rocks within the central Raton Basin should be more critically analyzed for levels and timing of thermal maturity. There is minor production of petroleum gas in the central Raton Basin from several wells in the Niobrara Formation from the Saddlebag, Long Canyon, Colfax Undesignated, and Apache Canyon fields, and Pierre Shale production from two wells in the Purgatoire River field (fig. 2) (IHS Energy, 2004b); this suggests that (1) actual levels of thermal maturity are lower than those calculated (using present-day heat flows) for Cretaceous and deeper formations, (2) gas migrated into the reservoir formations from cooler areas of the basin, and (or) (3) the upper limit of 2.5 percent R_o that indicates sources are overmature for gas generation is actually higher than this. Vermejo coals near the western margin of the Raton Basin and Las Vegas subbasin appear to exhibit lower levels of thermal maturation than those in the modeled wells (fig. 10); there is the potential for hydrocarbon gas from Mesozoic source rocks near the western boundary of the province.

Reservoirs

Sandstone beds of the Jurassic Entrada Sandstone and Morrison Formation and the Lower Cretaceous Purgatoire Formation and Dakota Sandstone are the potential petroleum reservoirs for the Jurassic–Lower Cretaceous Reservoirs AU (figs. 3, 9). There are approximately 21 hydrocarbon gas leases in this AU (IHS Energy, 2004a). More than 97 MMCF of natural gas was produced from the Dakota Sandstone and Morrison Formation in the Wagon Mound field (fig. 2) from 1940 through 1981 (IHS Energy, 2004b). The only lease outside the Wagon Mound field that recorded Dakota Sandstone petroleum production is one well within the Long Canyon field that has 2.3 MMCFG and 8.3 MBW (IHS Energy, 2004b); this production is suspect due to the large volume of water produced. Large volumes of produced water may be characteristic of wells that produce from the Dakota Sandstone in the southern half of the Raton Basin (Speer, 1976), or could represent water associated with coalbed methane production from the Vermejo Formation. Several wells within the Long Canyon, Purgatoire River, and Spanish Peak fields list the Dakota Sandstone as a producing formation. One well in the Spanish Peak field lists the producing interval as the Purgatoire River Formation.

There is no recorded petroleum production from Triassic formations. However, traces of asphaltic residue have been observed in outcrops of the Triassic Dockum Group in the northern Raton Basin. Although some of the Triassic sandstones are moderately porous and permeable, they are not favorably situated with respect to source beds in most of the Raton Basin (Baltz, 1965). Burial history reconstructions within the Raton Basin indicate that Jurassic and older shales and limestones are overmature for gas generation; gas potential in shallower and cooler areas of the basin and Las Vegas subbasin are unknown, but source rocks would probably be overmature for oil generation.

The Entrada Sandstone has favorable porosity and permeability to qualify as a reservoir, but it has low potential as a petroleum reservoir because it is not proximal to petroleum source rocks. Speer (1976) indicated that possible reservoir rocks might include the Entrada Sandstone, the Permian Glorieta Sandstone, and the Pennsylvanian Madera Formation; however, only the latter is associated with possible (marine) petroleum source rocks. Within the province, the thickness of the Entrada Sandstone ranges from 20–120 ft, with considerable local variation; it generally thins northward toward the Wet Mountains, and is absent from the Sierra Grande uplift (Baltz, 1965). The Entrada is a white to pink and red, fine- to coarse-grained, moderately well-sorted sandstone that was probably deposited on and near beaches and in nearshore marine environments during the transgression of a shallow sea (Baltz, 1965). Stratification in Entrada sandstones is mainly tangential or parallel, and the strata intertongue with overlying limestone, fine-grained clastics, and evaporites of the Wanaka Formation (Baltz, 1965). The Entrada unconformably overlies Triassic rocks (Baltz, 1965) in most of the Raton Basin and Las Vegas subbasin; it is absent over most of the Sierra Grande uplift. There are dead oil stains in the Entrada at Tercio anticline (fig. 1) in the northern Raton Basin (Baltz, 1965).

The Jurassic Morrison Formation is comprised of interbedded sandstone and shale that were deposited in fluvial and lacustrine environments. There is considerable local variation in thickness, which ranges from about 150–400 ft; it is generally thickest in the western Raton Basin and thins eastward onto the Sierra Grande and Apishapa arches and the Wet Mountains (Baltz, 1965). Sandstone beds within the formation have low potential as reservoir rocks primarily because of the distance from potential petroleum source rocks. Any petroleum resources would probably be stratigraphically trapped within the sandstone beds. There is the possible production of natural gas from the Morrison in several wells in the Wagon Mound field (IHS Energy, 2004b). This could not be verified, but it is unlikely because some of the wells in the field with reported “Dakota-Morrison” production reached total depth within the Dakota Sandstone, and there is no record of the wells being deepened.

The Purgatoire Formation of Early Cretaceous age rests unconformably on the Morrison Formation and is present in most of the Raton Basin, Las Vegas subbasin, and on the Sierra Grande and Apishapa arches; it consists of a lower conglomeratic sandstone member and an upper member containing varied proportions of gray carbonaceous to coaly shale and interbedded thin sandstone (Baltz, 1965). Well completion cards in the New Mexico part of the province do not commonly identify the Purgatoire (Woodward, 1987). Baltz (1965) noted that the formation on the west margin of the Raton Basin cannot be differentiated from the overlying Dakota Sandstone. The Purgatoire has favorable reservoir properties, but no current petroleum production.

The Dakota Sandstone is commonly 30–60 ft thick in New Mexico; it thickens northward to 100–150 ft in Colorado (Baltz, 1965). At the southeast side of the Wet Mountains, the Dakota and Purgatoire have a combined thickness of as much as 650 ft of strata that is of deltaic origin (Waage, 1953). Much of the Dakota was deposited in marine environments, but in the western part of the basin it contains fluvial sandstones and in places may be mostly terrestrial; the upper part of the Dakota grades into the marine rocks of the overlying Graneros Shale (Baltz, 1965). There is also the potential for gas resources within the low-permeability, primarily marine strata of the Dakota.

The Dakota Sandstone has the greatest potential for natural gas resources in the Jurassic–Lower Cretaceous Reservoirs AU because of proximity to Graneros Shale source rocks and favorable reservoir lithologies. However, burial history models in the central Raton Basin indicate that the potential source rocks are overmature for gas generation, but additional research is needed. Shows of oil are found in the Dakota at a few places in the Las Vegas subbasin and in many places where it has been tested in the northern Raton Basin; Baltz (1965) stated “the Cheyenne Sandstone Member (of the Dakota Sandstone) is porous and permeable and generally yields large amounts of water in wells. At a few places in the northern part of the basin the Cheyenne has produced “shows” of oil, but these were flooded out by water.” Widespread presence of water in the Dakota in the south half of the Raton Basin indicates that the sandstone units are in hydraulic communication and that stratigraphic entrapment of petroleum is generally unfavorable (Speer, 1976). Speer (1976) indicated that the Dakota is water-bearing in almost all sandstones in their study area; measurable water flows on the order of 20 BPH were encountered with salinities ranging from a relatively fresh 5,000 ppm chloride and 9,800 ppm total dissolved solids, up to 14,500 ppm and 22,339 ppm, respectively.

Seal Rock

The Graneros Shale is both petroleum source and seal for the Jurassic–Cretaceous Reservoirs assessment unit (fig. 9). Seals for the Dakota Sandstone, Purgatoire Formation, and Morrison Formation include overlying, interbedded, and updip shales. The primary seal for the Entrada Sandstone is probably evaporites of the overlying Wanakah Formation.

Fractured Reservoirs Assessment Unit (50410201)

Overview

The Fractured Reservoirs AU assessed mean resources are 88.76 BCFG and 3.54 MMBNGL (table 1). The AU boundary (fig. 1) is approximately the areal extent of the reservoir and potential reservoir formations, with modifications based on location of major igneous intrusions that are proximal to outcrops. This was assessed as a conventional AU; Appendix 3 contains input data used in the assessment of undiscovered resources. Explanations of the data sheets and assessment model are in Schmoker and Klett (2000). Appendix 4 is the forecast for natural gas and NGL distributions of undiscovered resources based on the Monte Carlo simulation method (Charpentier and Klett, 2000).

Source Rocks

Rose and others (1986) stated that the Benton (Graneros) Shale and Niobrara Formation shales and chalks contain oil and gas source rocks, and that the thick prodeltaic Pierre Shale contains gas-prone source rock (fig. 15), but they did not provide supporting evidence. These strata are within the gas generation window over almost the entire Raton Basin and Las Vegas subbasin, based on R_o data from Close (1988) and Bostick and Pawlewicz (1984a, b), and from burial history reconstructions. There is low potential for oil production within this AU because of its thermal history. The same formations are also considered petroleum source rocks in the Denver Basin to the north. For example, the Pierre Shale (Lillis and other, 1998) and Niobrara Formation (Pollastro, 1992) are the probable hydrocarbon source rocks for the Florence field in southeastern Fremont County, Colo., which borders the Raton Basin on the north.

Reservoirs

Potential reservoirs are the Cretaceous Carlile Shale, including the Codell Sandstone Member, the Niobrara Formation, and the Pierre Shale (figs. 3, 15). Reservoir facies are primarily low-permeability marine shale, limestone, and minor sandstone. There are several fields in the province with reported production from this AU—the Gardner field in northwestern Raton Basin and the Garcia field in eastern Raton Basin (fig. 2). Gardner field production (1974–1988) was 4,325 BO and 3.179 MMCF of natural gas from the Codell; Garcia field production (1896–1943) was 1.56 BCF of natural gas from the Niobrara and Pierre (Lawson and Hemborg, 1999). There is also minor production of natural gas from the Pierre Shale (2001–2003) in two wells in the Purgatoire River field and one wildcat near or in the Oakview field, and from the Niobrara Formation (1993–2003) in several wells in the Saddlebag, Long Canyon, Colfax Undesignated, and Apache Canyon fields (fig. 2) (IHS Energy, 2004b).

The Carlile Shale is dark-gray marine shale that contains thin limestone beds and septarian concretions; included in the upper part are sandy shale and thin calcareous sandstone beds (Baltz, 1965). The Codell Sandstone Member occurs where the upper calcareous sandstones form a distinct unit and are fairly thick (15–25 ft) (Baltz, 1965).

The Niobrara is present over the Raton Basin and northern Las Vegas subbasin; the assessment unit boundaries approximate the extent of the Niobrara. It is absent because of Quaternary erosion in the southern part of the Las Vegas subbasin (Baltz, 1965). The Niobrara is comprised of as much as 955 ft of interbedded marine shale and limestone and conformably overlies the Carlile Shale (fig. 3). The Niobrara is about 560 ft thick at outcrops on the flanks of the Wet Mountains (Johnson and Stephens, 1954) and as much as 630 ft thick in the subsurface of the northern Raton Basin (Baltz, 1965). It is divided into two members: (1) the lower, Fort Hays Limestone Member, is interbedded thin limestone and shale beds which range in thickness from 25 to 55 ft in the northern Raton Basin (Cobban, 1956) and from10 to 20 ft in the Las Vegas subbasin; and (2) the overlying Smoky Hill Marl Member is marly shale with interbedded thin limestone and sandy shale; the middle

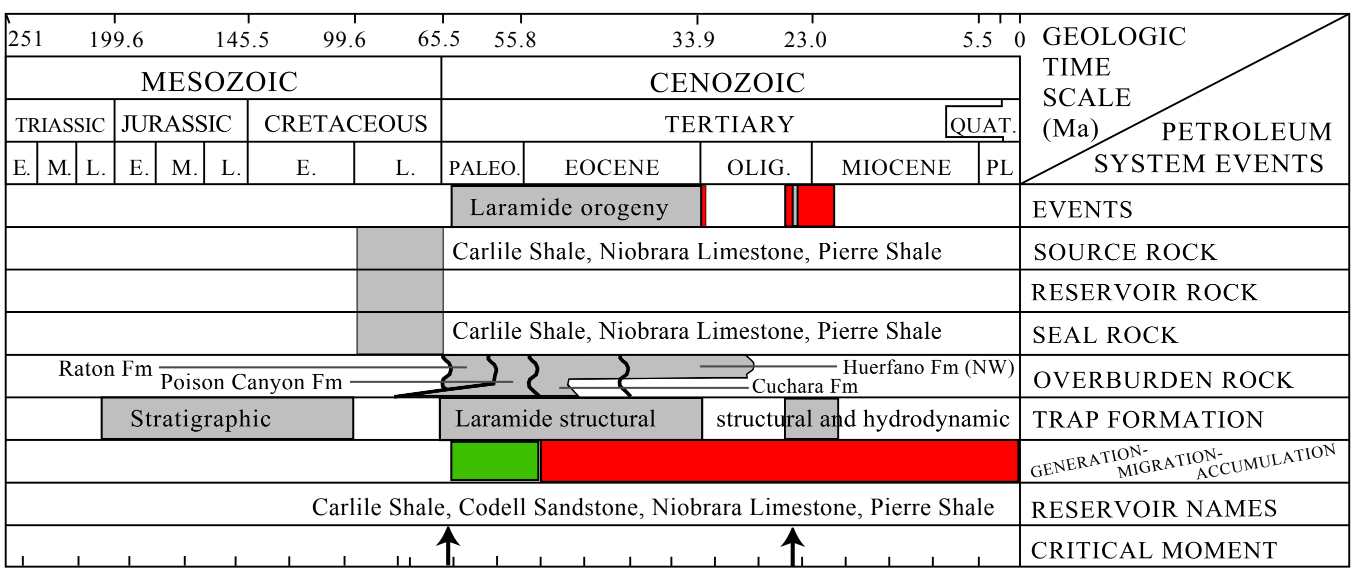

Figure 15. Events chart for Fractured Reservoirs Assessment Unit (50410201) of the Jurassic–Cretaceous Composite Total Petroleum System (504102). There is potential for conventional gas resources from sandstone, shale, and limestone of the Cretaceous Carlile Shale, Codell Shale, Pierre Shale, and Niobrara Formation. Gray and red on the events bar are used to differentiate intrusive/tectonic events that may have influenced oil and gas accumulations. Wavy lines mark unconformities. Generalized time intervals for onset of oil (green) and gas (red) generation are based on burial history reconstructions. Abbreviations: E., Early; M., Middle; L., Late; OLIG., Oligocene; PL, Pliocene; QUAT., Quaternary; Fm, formation.

part of which contains some distinct beds of fairly clean sandstone that are as much as 10–30 ft thick (Baltz, 1965).

The Pierre Shale overlies the Niobrara Formation over much of the Raton Basin, but has been completely eroded off the Sierra Grande uplift. Quaternary erosion has removed all but the lower part of the Pierre in the southern Las Vegas subbasin (Baltz, 1965). The formation is about 1,600 ft thick near the southern margin of the Raton Basin; it thickens to 2,100 ft near the Colorado–New Mexico border (Johnson and Wood , 1956) and to about 2,300 ft in Huerfano Park (fig. 1) (Johnson and others, 1966). The Pierre, deposited in marine environments, consists mainly of dark-gray non-calcareous shale with a few thin beds of limestone, sandy shale, and sandstone; the upper 200–300 ft consists of interbedded shale and thin sandstone that grade into and intertongue with the overlying Trinidad Sandstone (Baltz, 1965).

Seal Rock

Seals for the Fractured Reservoirs assessment unit are primarily marine shale beds that are interbedded with and overlie other lithofacies of the Carlile Shale, the Niobrara Formation, and the Pierre Shale.

Upper Cretaceous–Tertiary Coalbed Gas Total Petroleum System

Vermejo Coalbed Gas Assessment Unit (50410182) and Raton Coalbed Gas Assessment Unit (50410181)

Overview

The Cretaceous–Tertiary Coalbed Gas TPS (fig. 1) is divided into three assessment units: (1) the Vermejo Coalbed Gas AU; and (2) the Raton Coalbed Gas AU, and (3) the Upper Cretaceous–Tertiary Sandstone AU. AU boundaries (fig. 1) approximate the areal extent of the Vermejo Formation (fig. 4); excluded is the area under and proximal to the Johnson Mesa basalt flows (fig. 1, 4). While coalbed gas may be present, the volume would be decreased due to lower levels of thermal maturation in this area, thinning of Raton and Vermejo coals, and local heating and replacement of coals by igneous intrusions. Coalbed methane may exhibit a greater biogenic input than for areas deeper in the basin. Mean undiscovered resources for the Vermejo Coalbed Gas (979.32 BCFG), Raton Coalbed Gas (611.26 BCFG), and Upper Cretaceous–Tertiary Sandstones (58.52 BCFG) AUs are included with other statistics in Table 1. Input data used in the assessment of undiscovered resources are in Appendix 5 (Raton Coalbed Gas AU) and Appendix 6 (Vermejo Coalbed Gas AU); explanation of the data sheets and assessment models are in Schmoker and Klett (2000). The events chart for the Upper Cretaceous–Tertiary Coalbed Gas TPS (fig. 16) shows the primary events that resulted in accumulations of biogenic and thermogenic gas in the AUs. The stratigraphic column for the formations in this TPS (fig. 17) include generalized lithologies, interval thicknesses, and primary CBM-productive zones.

Coal was first reported in the Raton Basin in 1848, and mining began in 1873; peak cumulative production for the 10-yr period from 1911 to 1920 was 71 million tons, which included average production of 5.6 million tons/yr in Colorado and 1.5 million tons/yr in New Mexico (Amuedo and Bryson, 1977). Cumulative coal production through 1975 for the basin is estimated at 325.5 million tons—247.5 million tons from Colorado and 78 million tons from New Mexico (Amuedo and Bryson, 1977). There are about 2,100 mi^2 of Upper Cretaceous and lower Tertiary coal-bearing rocks in the basin (above the top of the Upper Cretaceous Trinidad Sandstone); coals in the Vermejo and Raton Formations are exposed in some outcrops and are buried to depths of 3,000 ft or more along basin axes, with estimated thickness of individual coal beds ranging from 10 to 14 ft (Amuedo and Bryson, 1977; Flores and Bader, 1999; Close and Dutcher, 2002). Figures 18 and 19 are total-coal isopach maps for the Raton and Vermejo, respectively.

Reported gas contents in coal beds of the Vermejo Formation range from 115 to 492 ft^3/short ton (3.6 to 15.5 cm^3/g), and coals in the Raton Formation contain from 23 to 193 ft^3/short ton (0.72 to 6.07 cm^3/g) (Tyler and others, 1995). Coals in the West and East Spanish Peaks area that are below the localized potentiometric head, or groundwater table, have gas contents that range from 250 to 450 standard ft^3/ton for the Vermejo and from 130 to 280 standard ft^3/ton for the Raton (Carlton, 2006). Produced gas is very dry; the $C_1/C_{1\text{-}5}$ ratio is between 0.96 and 1.0 (Carlton, 2006). More than 287 BCFG and 387 MMB water was produced from these coal beds through 2003 (IHS Energy, 2004b). Coalbed gas sales in 2006 are almost 240 MMCFG per day from approximately 1,950 wells (Carlton, 2006). Estimated ultimate recovery (EUR) calculations and data were provided by Troy A. Cook, U.S. Geological Survey. EUR from the 1,621 wells used in this study is 1.087 trillion cubic feet of gas; 5.41 percent of this total is from the Raton Formation, 14.9 percent is commingled Raton-Vermejo production, and 79.6 percent is from the Vermejo Formation. Average EUR for all wells is 663.9 MMCFG, and average EURs for wells from the Raton, Raton-Vermejo, and Vermejo Formations are 444.4, 488.9, and 738.3 MMCFG, respectively. Smaller EURs for the commingled Raton-Vermejo production indicates that decreased production from one or the other formation in each well is the probable reason for perforating both intervals. Minimum EUR for inclusion is 20 MMCFG/cell. Figures 20–23 are contoured EUR values for the Vermejo and (or) Raton, and commingled production. D.D. Rice and T.M. Finn (in Keighin, 1995) indicated that the gas composition for the Raton and Vermejo Formations is 98 percent C_1 (methane), 1.0 percent C_2, 0.6 percent CO_2, and

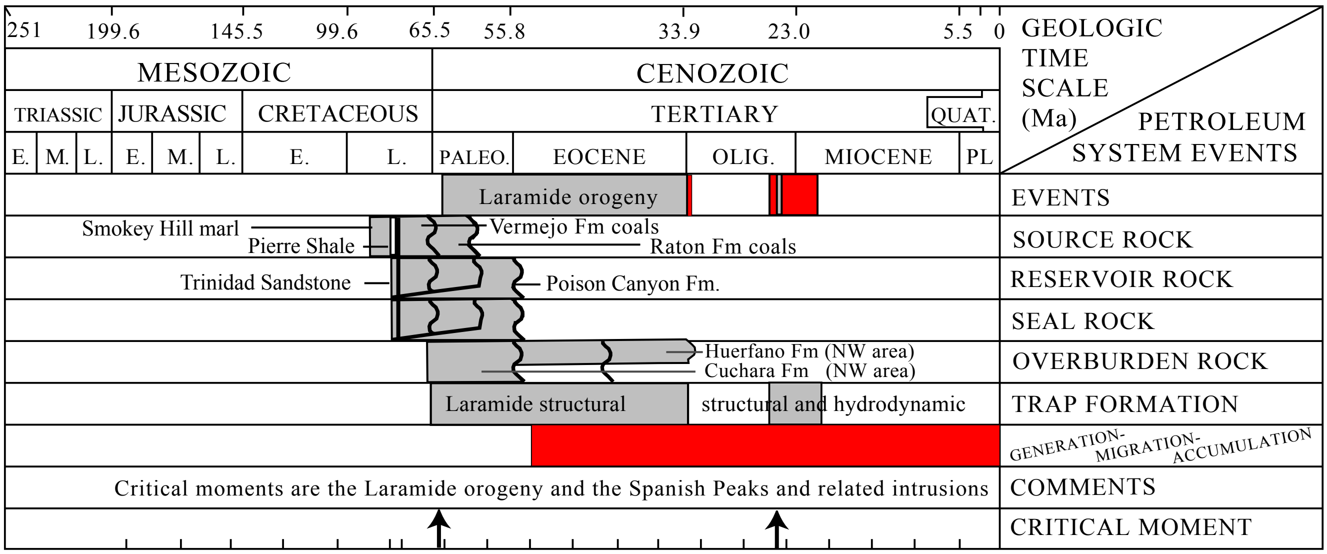

Figure 16. Events chart for the Upper Cretaceous–Tertiary Coalbed Gas Total Petroleum System (504101). Primary reservoirs are coal beds in the Vermejo and Raton Formations. There is also potential gas production from interbedded sandstones of the Vermejo and Raton Formations and from sandstones of the Trinidad Sandstone and Poison Canyon Formation. Gray and red on the events bar are used to differentiate intrusive/tectonic events that may have influenced accumulations of oil and gas. Wavy lines mark unconformities. Generalized time interval for onset of gas (red) generation is based on burial history reconstructions. Abbreviations: E., Early; M., Middle; L., Late; OLIG., Oligocene; PL, Pliocene; QUAT., Quaternary; Fm, formation.

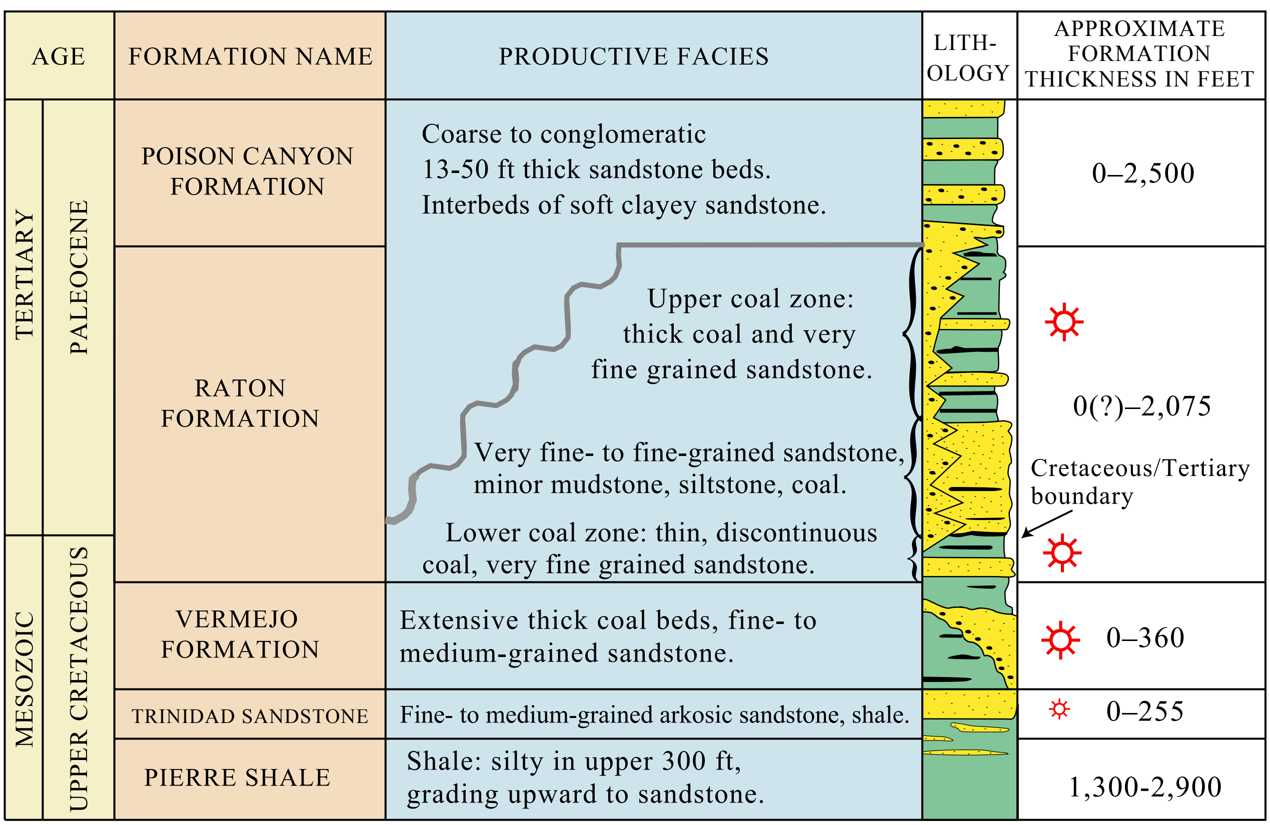

Figure 17. Generalized stratigraphic column of Cretaceous and Tertiary rocks in the Raton Basin part of the Raton Basin–Sierra Grande Uplift Province. Wavy gray line marks erosional unconformity between Vermejo and Raton Formations. Gas-productive formations and intervals are marked with red symbols for gas wells. Modified from Johnson and Finn (2001), Flores and Bader (1999), Pillmore (1969), Pillmore and Flores (1987), and Flores (1987).

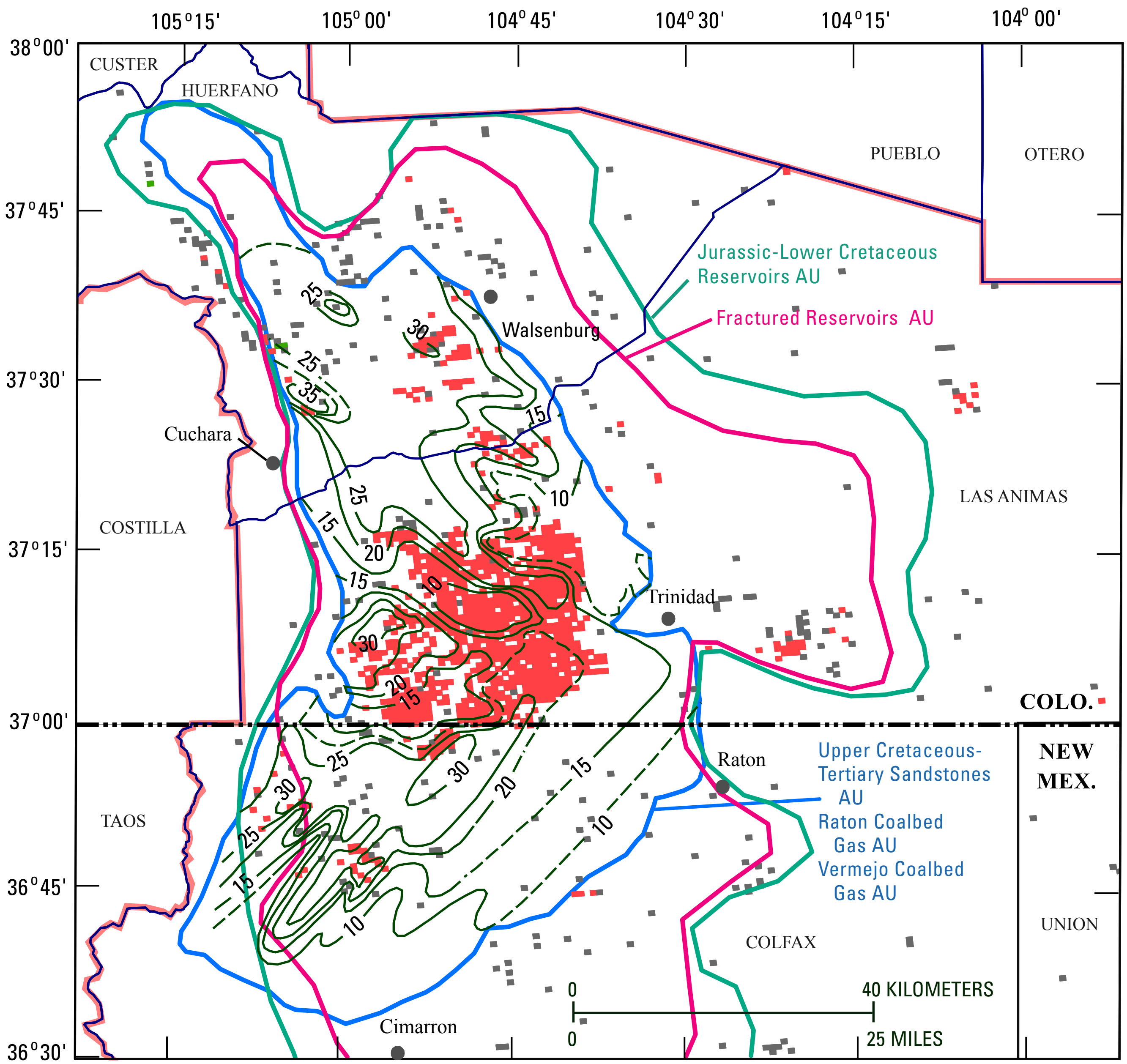

Figure 18. Total-coal isopach for the Vermejo Formation (thin green line, dashed where inferred), modified from Stevens and others (1992a, b). Contour interval is 20 ft. Outline of the Upper Cretaceous–Tertiary Total Petroleum System (thick blue line) is the approximate limit of coal. Also shown are all oil (green), gas (red), and dry (gray) cells for the province (thick orange line), and county boundaries (thin dark-blue line). Abbreviations: AU, assessment unit

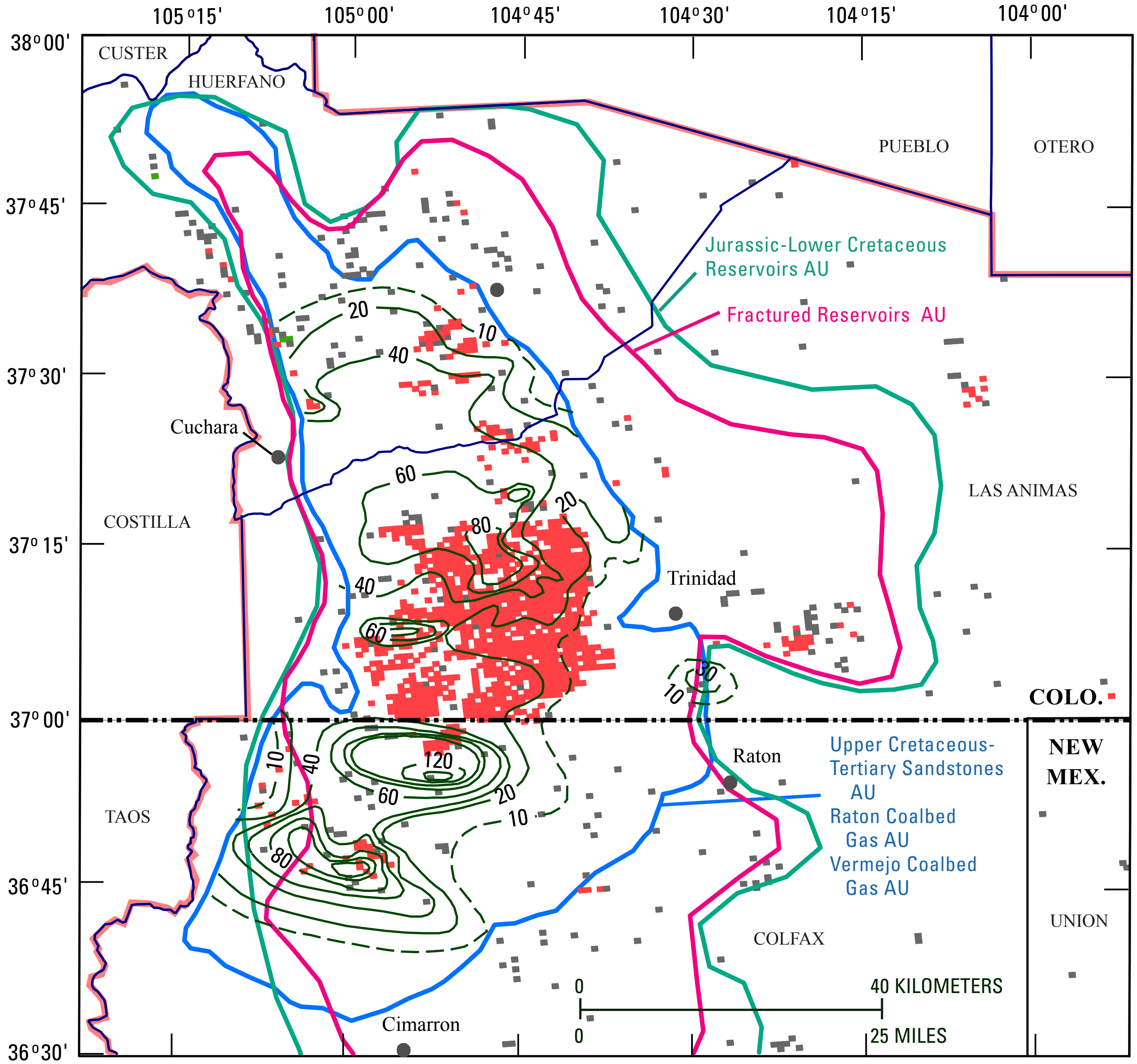

Figure 19. Total-coal isopach for the Raton Formation (thin green lines, dashed where inferred), modified from Stevens and others (1992a, b). Contour interval is 20 ft. Outline of the Upper Cretaceous–Tertiary Total Petroleum System (thick blue line) is the approximate limit of coal. Also shown are all oil (green), gas (red), and dry (gray) cells for the province (thick orange line), and county boundaries (thin dark-blue line). Abbreviations: AU, assessment unit

0.4 percent N_2; BTU value is 1,049, and total dissolved solids in produced water is 5,000 parts per million. Carlton (2006) indicated that water quality from these wells is among the highest for any coalbed methane project in the world. He also stated that initial water disposal from wells consisted of surface impoundments and discharge that were permitted by the Colorado Department of Public Health and Environment. The Colorado Oil and Gas Conservation Commission regulated surface water discharge points, and hauling by tanker truck, water impoundments for discharge, water quality blending and evaporation, and a simple buried water gathering-pipeline system to deeper (Dakota Formation) disposal wells (Carlson, 2006). He states that discharge to the Dakota Formation disposal wells proved to be the most efficient method of produced water disposal, and it would have reduced both lease operating expenses and litigation resulting from surface discharge or other processes of water disposal.

Source Rocks

Coals in the Raton and Vermejo Formations are the primary hydrocarbon source rocks for biogenic and thermogenic gas in the Upper Cretaceous–Tertiary Coalbed Gas TPS; open fault systems within the basin could also have contributed gas from deeper source rocks. Total net-coal thickness for the Vermejo Formation typically ranges from 5 to 35 ft (Stevens and others, 1992b). Figure 18 and 19 show cumulative thickness of coal across the province for the Vermejo and Raton Formations, respectively. Figure 18 contours are based on 92 data points that were constructed from well logs and measured sections and include all coal seams thicker than 1 ft (Stevens and others, 1992b). Generalized northeast trends mimic depositional trends of sandstones in the underlying Trinidad Sandstone. Estimates of cumulative thickness and that of individual coal beds vary. Dolly and Meissner (1977) indicated that the Vermejo and Raton coals are as much as 14.5 ft thick with an estimated average aggregate thickness of 15 ft. Estimated thickness of individual coal beds in the Vermejo Formation ranges from 0.5 to 6 ft (Dolly and Meissner, 1977) to a few inches to more than 14 ft (Hemborg, 1996).

Coals of the Raton Formation are generally thinner and less continuous than those of the Vermejo Formation, are distributed over a stratigraphic interval of as much as 1,600 ft (Close and Dutcher, 2002), and are concentrated in the upper and lower thirds of the formation. Total coal thickness ranges from 10 ft to more than 140 ft (Stevens and others, 1992b) (fig. 19); isopach contours are based on 87 data points that were constructed from well logs and measured sections and that include all coal seams thicker than 1 ft (Stevens and others, 1992b). Estimated thickness of individual coal beds in the Raton Formation ranges from a several inches to more than 10 ft (Stevens and others, 1992b), a few inches to more than 11 ft (Hemborg, 1996), and 0.5–12 ft (Dolly and Meissner, 1977).

Burial History

Vitrinite reflectance data (fig. 10) and burial history modeling (figs. 11–14) indicate that Raton and Vermejo coals across the province are thermally mature for gas generation, as indicated by R_o values of 0.5 percent and greater for humic coals. The highest levels of thermal maturity are along the Purgatoire River drainage system, west of Trinidad, Colo. (fig. 10). Stevens and others (1992b) indicated that gas composition averages more than 90 percent methane, less than 5 percent nitrogen, and less than 1 percent CO_2. Results are based on 19 samples from the Raton Basin that include the Vermejo Formation in 6 wells and the Raton Formation in 1 well; several samples have relatively low methane concentrations, probably because of sampling and (or) analytical error (Stevens and others, 1992b). Isotopic analysis was used by Carlton (2006) to determine the gas is primarily thermogenic, with average $\delta^{13}C$ values of -44.8 percent.

Reservoirs

Coal beds are reservoirs within the Vermejo and Raton Formations (figs. 18, 19). Vermejo and Raton coals are of bituminous rank, averaging about 13,000 Btu/lb; the coal is of steam quality north of a line just south of West and East Spanish Peaks (figs. 1, 4); south of this it is high quality, metallurgical-grade coking coal (Amuedo and Bryson, 1977). Dolly and Meissner (1977), using a medium-volatile bituminous coal average coal rank containing 26 percent volatile matter, estimated that coals in the Vermejo and Raton Formations have generated 1,121 standard cubic ft of gas per ton. Methane storage capacity varies for different types of coal (Juntgen and Karweil, 1966; Meissner, 1984). Adsorption capacity for methane commonly increases with increasing coal rank, temperature, and pressure. Charles Barker (written commun., 2006) stated that "the consensus is that adsorption (of methane) does generally increase with rank for say a coal of constant maceral composition on a dry, ash-free basis, isotherm measured on an equilibrium moisture basis, a rank above about medium-volatile bituminous, and moderate pressures. So there are plenty of caveats. Generally the higher the vitrinite content the higher the adsorption capacity. Under an as-received basis, the lower the ash and moisture, the higher the adsorption capacity." Barker also indicated there are cases where decreases in adsorption capacity from high-volatile bituminous to medium-volatile bituminous were interpreted to result from petroleum generation affecting the surface area available for desorption, and other instances where a decrease in adsorption capacity occurred at high pressure. Romeo Flores (oral commun., 2006) verified that adsorption of methane generally increases with increased coal rank. Other factors that influence reservoir quality include type, patterns, and density of fractures, pressure, and volume of water. Dewatering of coals before gas can be produced is required because hydrostatic pressure keeps the methane adsorbed on the coal through

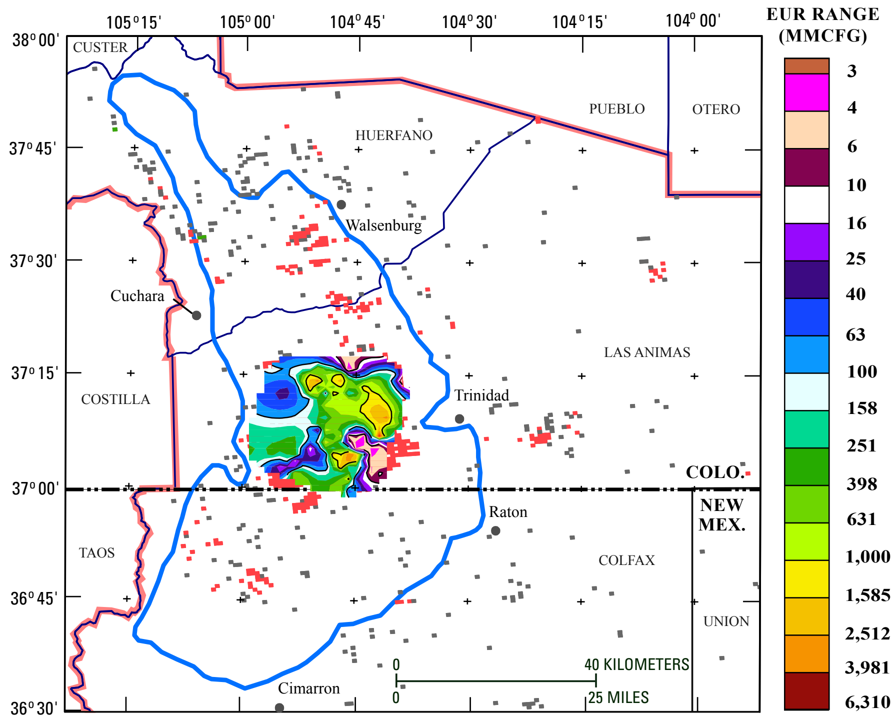

Figure 20. Estimated ultimate recovery (EUR) of (commingled) natural gas production from Vermejo and Raton Formation coals, Raton Basin; data from Troy Cook (written commun., 2004). Red and blue lines are province and Upper Cretaceous–Tertiary Coalbed Gas Total Petroleum System boundaries, respectively. Squares are cells that are productive of gas (red), oil (green), or nonproductive (gray) for all formations. MMCFG, million cubic feet of gas.

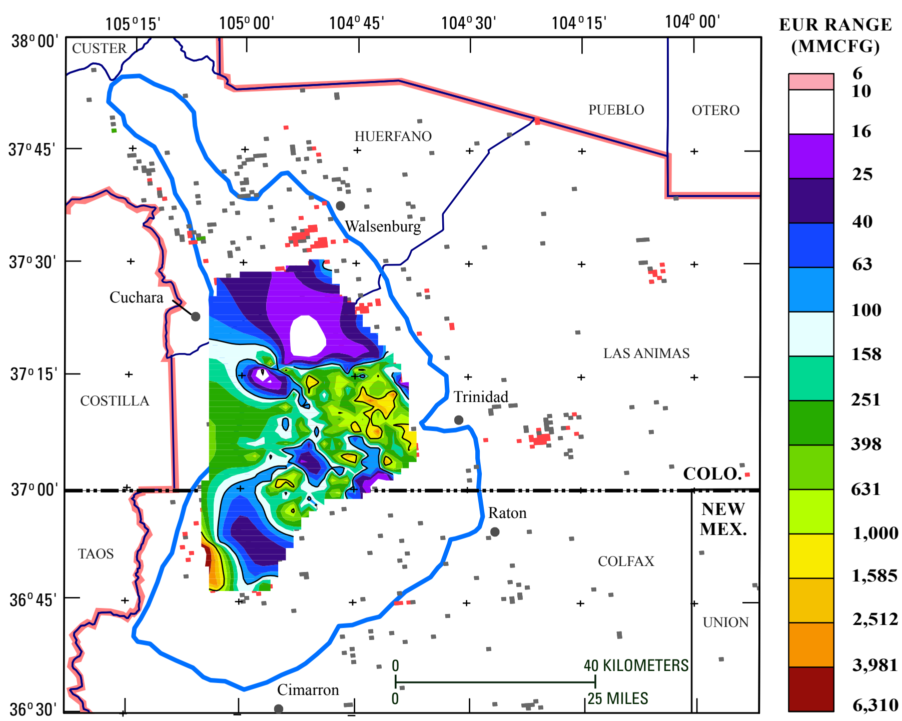

Figure 21. Estimated ultimate recovery (EUR) of natural gas from all reported production from Vermejo and Raton Formation coals, Raton Basin; data from Troy Cook (written commun., 2004). Red and blue lines are province and Upper Cretaceous–Tertiary Coalbed Gas Total Petroleum System boundaries, respectively. Squares are cells that are productive of gas (red), oil (green), or nonproductive (gray) for all formations. Abbreviations: MMCFG, million cubic feet of gas

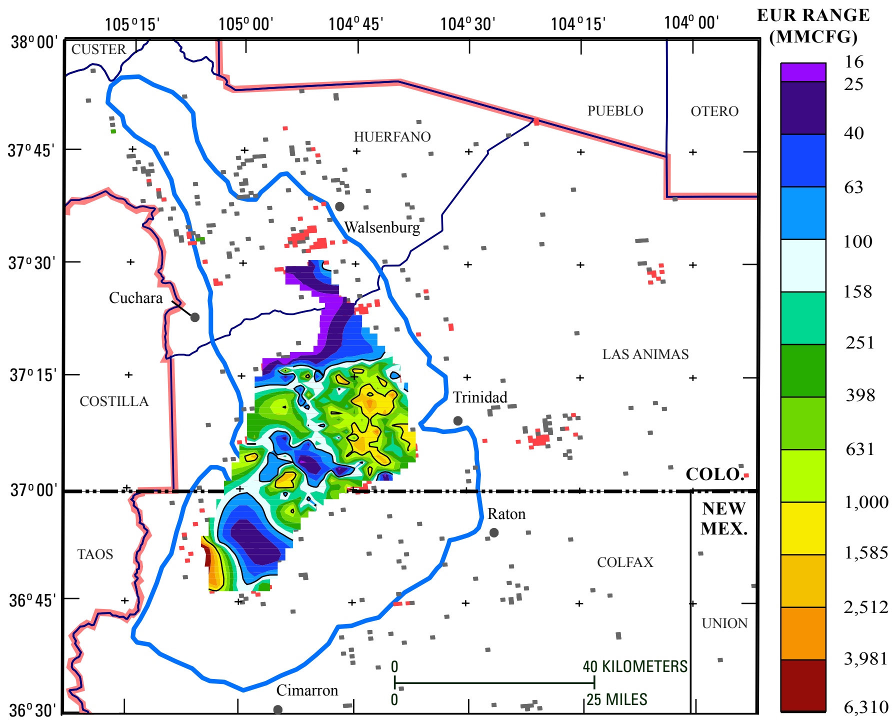

Figure 22. Estimated ultimate recovery (EUR) of natural gas from all reported production from Vermejo Formation coals, Raton Basin; data from Troy Cook (written commun., 2004). Red and blue lines are province and Upper Cretaceous–Tertiary Coalbed Gas Total Petroleum System boundaries, respectively. Squares are cells that are productive of gas (red), oil (green), or nonproductive (gray) for all formations. Abbreviations: MMCFG, million cubic feet of gas

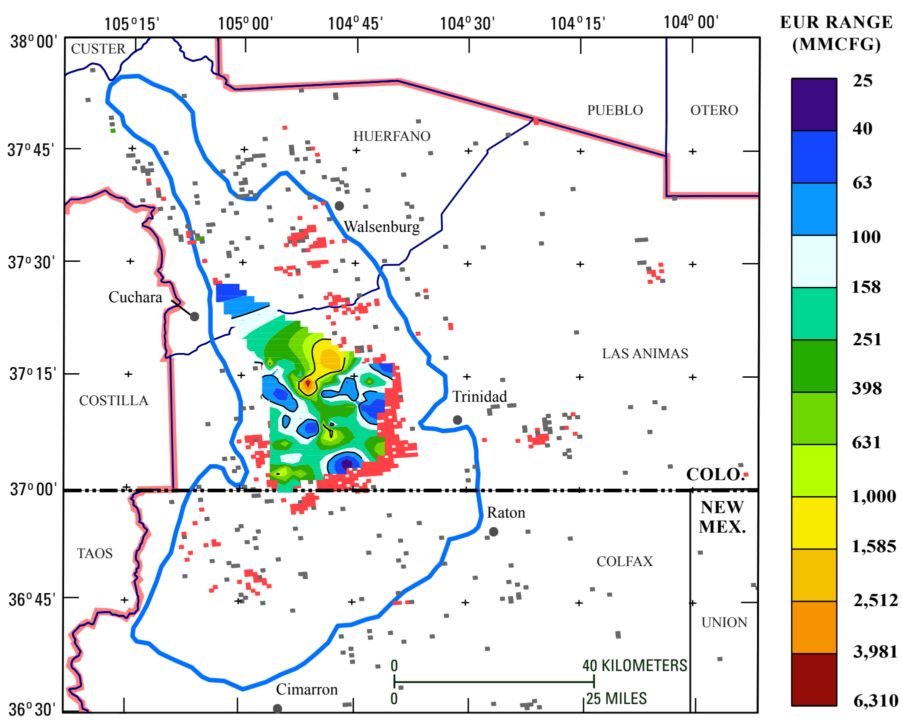

Figure 23. Estimated ultimate recovery (EUR) of natural gas from all reported production from Raton Formation coals, Raton Basin; data from Troy Cook (written commun., 2004). Red and blue lines are province and Upper Cretaceous–Tertiary Coalbed Gas Total Petroleum System boundaries, respectively. Squares are cells that are productive of gas (red), oil (green), or nonproductive (gray) for all formations. Abbreviations: MMCFG, million cubic feet of gas.

physical/chemical equilibrium between the carbon matrix and the methane molecules (Gas Research Institute, 1985).

There is no clear correlation between coal rank (fig. 10) and EUR of coalbed methane (figs. 20–23) in the province, a conclusion that is based on visual comparison of the maps. The area west of Trinidad, Colo. does contain both increased coal rank and EUR of coalbed methane from the Vermejo and Raton Formations relative to other areas of the Raton Basin, but EUR is also variable at well scales as indicated by bulls-eyes in figures 20–23.

Seal Rock

Seals for the Vermejo Coalbed Gas and Raton Coalbed Gas AUs include shales that are interbedded with and overlie reservoir intervals, clinker beds in which the associated heat did not destroy reservoir properties of bounding coals, and water within the coal beds that prevents escape of the methane.

Upper Cretaceous–Tertiary Sandstones Assessment Unit (50410101)

Overview

There is the potential for conventional gas resources in the Upper Cretaceous–Tertiary Sandstones AU that are trapped in sandstone beds of the Trinidad Sandstone and Vermejo, Raton, and Poison Canyon Formations. Sandstone beds in the Trinidad Sandstone were postulated by Dolly and Meissner (1977) as having potential for hydrodynamically trapped hydrocarbon gas.

Mean undiscovered resources for this AU are 58.53 BCFG and 0 MMBNGL (table 1). The F5 to F95 fractiles confidence levels are based on assessment of undiscovered petroleum resources. The range from the F95 to F5 is large due to the largely hypothetical nature of this AU; numerous wells have penetrated potential reservoir intervals, but current production is limited. Reported hydrocarbon gas production is 31.4 MMCF through 2001 from the Trinidad Sandstone in two wells in the Three Bridges field (IHS Energy, 2004b); production through 1996 from Raton coal and Trinidad sandstone in the field were 8.313 and 27.029 MMCF, respectively (Lawson and Hemborg, 1999).

Appendix 7 contains input data used in the assessment of undiscovered resources for this AU; explanation of the data sheets and assessment models are in Schmoker and Klett (2000). Appendix 8 is the forecast for natural gas and NGL distributions of undiscovered resources based on the Monte Carlo simulation method (Charpentier and Klett, 2000). Potential trap types are structures and (or) updip pinchout of reservoir sandstones against shales. Reporting of production from sandstones of the Vermejo and Raton Formations is complicated by the commingling of gas from coal beds and the bounding sandstones. A problem with the petroleum potential of this AU in the West and East Spanish Peaks area is that the sandstone beds may be cut by Tertiary igneous intrusions and radial dikes of Silver Mountain and West and East Spanish Peaks. These intrusions would have caused local heating, but their influence on trapping and sealing are unknown. Dolly and Meissner (1977) indicated that sandstone intervals of the lower part of the Poison Canyon Formation are potential reservoirs, and gas shows have been recorded in wells. However, drilling in the Poison Canyon has not encountered economically recoverable gas; if gas were present it would be underpressured and difficult to detect.

Source Rocks

Potential petroleum source rocks are coals within the Vermejo and Raton Formations. Burial history reconstructions and R_o data (fig. 10) indicate that the coals have reached generative maturity for thermogenic gas. Carlton (2006) stated that the coalbed gas is primarily thermogenic with average $\delta^{13}C$ values of -44.8 percent. Coals are also a source for biogenic gas.

Reservoirs

Dolly and Meissner (1977) stated that "[hydrocarbon] gas is trapped in a complex series of overlapping and discontinuous channel sandstone units that are interbedded with water-bearing zones within the lower Vermejo, Raton, and Poison Canyon Formations. A gas-accumulation may also be present in a basin-bottom hydrodynamic trap within the Trinidad Sandstone." The Trinidad Sandstone was deposited in paralic and littoral environments and represents the final withdrawal to the northeast of the Cretaceous seas from the area (Weimer, 1960; Dolly and Meissner, 1977). Rose and others (1986) mapped the formation in the Colorado part of the Raton Basin and delineated two northwest-southeast-trending deltas in the northern half of their mapped area. The Trinidad Sandstone ranges in thickness from about 300 ft in the East Spanish Peak area to less than 100 ft in the interdeltaic areas (Rose and others, 1986). It consists of buff to gray, slightly arkosic sandstone with local thin interbeds of tan to gray silty shale (Johnson and others, 1966).

More than 1,300 wells within the Raton Basin and northern Las Vegas subbasin reach total depth within or below the Trinidad Sandstone (IHS Energy, 2004a). Well depth to the top of the Trinidad ranges from about 200 ft near the east margin (fig. 4) to 5,000 ft along the northwest border, with a median depth of 1,900 ft in the central part of the Raton Basin. The variation in depth is due mainly to post-Laramide erosion and associated downcutting by fluvial systems, and by uplift of the western flank of the Raton Basin. The Vermejo Formation conformably overlies the Trinidad Sandstone over most of the northern basin and consists of (1) thin- to massive-bedded gray siltstone, buff, gray, and gray-green, slightly arkosic sandstone; (2) nearly black, carbonaceous coaly and silty shale; and (3) numerous coal beds (Johnson and others, 1966). The Vermejo Formation is as much as 350 ft thick in the province (Close and Dutcher, 2002); it thickens to the west-northwest from about 50 ft at the Colorado–New Mexico border southeast of Trinidad, to more than 300 ft near the Costilla–Las Animas County line (Dolly and Meissner, 1977).

The Raton Formation is characterized by a thin basal sequence of gray to dark-purple-gray, siliceous conglomeratic sandstone, overlain by buff, gray, and olive-gray very fine- to coarse-grained arkose, greywacke, and quartzose sandstone beds, gray to dark-gray siltstone and silty shale beds, and numerous coal beds (Johnson and others, 1966). Sandstone beds within the Raton Formation range in thickness from about 3 to 40 ft (Dolly and Meissner, 1977) and were deposited in fluvial channel and crevasse splay environments in an alluvial plain setting (Flores and Bader, 1999). Channel sandstone beds trend generally northeast-southwest; the formation ranges in thickness from 500 ft on the eastern side of the basin to nearly 2,000 ft on the western side (Dolly and Meissner, 1977).

Variation in thickness of the Raton Formation is primarily due to the unconformity at the base of the Poison Canyon Formation; erosion and subsequent Poison Canyon deposition is greatest near the northwest margin of the Raton Basin (Johnson and Wood, 1956). Greatest thickness of the Poison Canyon is believed to be more than 2,500 ft in the deepest part of the basin, surrounding the Spanish Peaks (Dolly and Meissner, 1977). To the southeast, the Poison Canyon conformably overlies and intertongues with the Raton Formation (Johnson and Wood, 1956; Dolly and Meissner, 1977; Flores, 1987); it consists of interbedded coarse-grained conglomeratic sandstone, mudstone, and siltstone (Hills, 1888; Johnson and others, 1966) that become finer grained toward the east in the Raton Basin; there is little coal or carbonaceous shale (Johnson and Finn, 2001).

Rose and others (1986) postulated a basin-centered (continuous) gas accumulation in the Trinidad Sandstone that corresponds to their southern delta system (fig. 10) and contains high-depositional-energy sandstone having low clay content; their estimate of 750 BCF of recoverable gas assumed an average gas-in-place of 250 MCF/acre-ft and an average recovery factor of 70 percent for this 130,000-acre area. The west-east cross section (fig. 6) across the northern third of their hypothetical continuous reservoir area shows a steeply dipping west flank and gently dipping east flank. Although a production test was run on the Trinidad Sandstone in the Goemmer no. 1 well, there were no reported results and the well was abandoned; the IHS Energy databases (2004a, b) did not contain information on the Goemmer no. 5 well. There is minor production of gas from the Trinidad in the Three Bridges field that is located north of these wells. Petroleum source rocks were subject to localized heating that resulted from Tertiary sill and dike intrusions of the West and East Spanish Peaks; the associated effects on reservoir and seal integrity are indeterminate, particularly since there are few wells in the area. Another complicating factor is the possible incursion of meteoric water in the Trinidad and overlying formations, which would probably be most pronounced close to outcrops flanking the mountain ranges. This would be expected particularly in the northwestern Raton Basin near the convergence of the Sangre de Cristo and Wet Mountains (fig. 1). Meteoric water could either function as an updip trap for gas in continuous accumulations or could flush potential conventional reservoirs.

Johnson and Finn (2001) based their evaluation of continuous gas in this AU partly on reported oil and gas shows from Dolly and Meissner (1977) and Rose and others (1986) and on analogs with other Rocky Mountain basins. They state, "The Raton Basin appears to contain a significant continuous or basin-centered gas accumulation in sandstones of the Upper Cretaceous Trinidad Sandstone and Vermejo Formation and Upper Cretaceous and Paleocene Raton Formation. The accumulation is underpressured and occurs at comparatively shallow (<3,500 ft) depths. The sandstones are interbedded with coal beds that are currently being developed for coal-bed methane, and the coals are the likely source for gas found in the sandstones."

Seal Rock

Primary seals for the Upper Cretaceous–Tertiary Sandstones AU are shale beds of the Trinidad, Poison Canyon, Raton, and Vermejo formations that are interbedded with and updip of reservoir intervals.

Summary

The Raton Basin–Sierra Grande Uplift Province is predominately a gas province, with production limited almost entirely to natural gas, carbon dioxide (CO_2), nitrogen, and helium. Coalbed methane from the Vermejo and Raton Formations accounts for most petroleum production and resources. There are potential conventional gas resources in the Raton Basin and Las Vegas subbasin that include sandstone beds of (1) the Jurassic Entrada Sandstone and (2) Morrison Formation, (3) the Cretaceous Purgatoire Formation, (4) Dakota Sandstone, (5) Codell Member of the Carlile Shale, (6) Trinidad Sandstone, and (7) Vermejo Formation, (8) the Cretaceous-Tertiary Raton Formation, and (9) the Tertiary Poison Canyon Formation. Also included are shale and limestone beds of (1) the Cretaceous Carlile Shale and Niobrara Formation, and (2) shale intervals of the Cretaceous Pierre Shale.

The Raton Basin and Las Vegas subbasin have low potential for oil resources as Cretaceous and older petroleum source rocks are mature to overmature for gas generation. Total oil production from the province is 4,325 barrels from 1 well in the Gardner field. Production that is proximal to the west boundary is mainly CO_2 from Jurassic through Cretaceous formations. Production from the Sierra Grande uplift is non-hydrocarbon gases (helium and CO_2) from Pennsylvanian through Upper Cretaceous sandstone, limestone, shale, and igneous rocks.

Probable petroleum source rocks are the Cretaceous Graneros Shale, Carlile Shale, Niobrara Formation, Pierre Shale, and coals of the Cretaceous Vermejo Formation and Cretaceous-Tertiary Raton Formation. The Permian San Andres Limestone is a possible petroleum source rock; Baltz (1965) indicated that the limestone was the probable source rock for traces of asphaltic residues in well samples from the lower part of the Triassic Santa Rosa Sandstone of the Dockum Group in the Las Vegas subbasin. However, Paleozoic rocks are probably overmature for gas generation in all or most of the Raton Basin and Las Vegas subbasin, on the basis of vitrinite reflectance analyses and burial history models. Burial history reconstructions are complicated by the absence of vitrinite reflectance analyses from units older than Upper Cretaceous and Tertiary, by the generally poor quality of temperatures from well tests, and by localized heating by Tertiary igneous intrusions. The heating history has clearly been influenced by anomalously high heat flows. Timing of this heating event (or events) has not been determined, but it is likely associated with Tertiary tectonic events.

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Appendix 1. Basic input data for the Jurassic–Lower Cretaceous Reservoirs Assessment Unit (50410202). SEVENTH APPROXIMATION DATA FORM (NOGA, Version 5, 6–30–01). [AU, assessment unit; bcfg, billion cubic feet of gas; bliq/mmcfg, barrels of liquid per million cubic feet of gas; bngl/mmcfg, barrels of natural gas liquids per million cubic feet of gas; cfg/bo, cubic feet of gas per barrel of oil; m, meters; min., minimum; mmboe, million barrels of oil equivalent; ngl, natural gas liquids]

SEVENTH APPROXIMATION
DATA FORM FOR CONVENTIONAL ASSESSMENT UNITS (Version 6, 9 April 2003)

IDENTIFICATION INFORMATION

Assessment Geologist:	D.K. Higley-Feldman	Date:	9/15/2004
Region:	North America	Number:	5
Province:	Raton Basin-Sierra Grande Uplift	Number:	5041
Total Petroleum System:	Jurassic-Cretaceous Composite	Number:	504102
Assessment Unit:	Jurassic-Lower Cretaceous Reservoirs	Number:	50410202
Based on Data as of:	IHS Energy (PI/Dwights) 2004 (data current through 1 January 2004)		
Notes from Assessor:	Dakota Group and D Sandstone (50390401) assessment unit as analog.		

CHARACTERISTICS OF ASSESSMENT UNIT

Oil (<20,000 cfg/bo overall) **or** Gas (≥20,000 cfg/bo overall): Gas

What is the minimum accumulation size? 0.5 mmboe grown
(the smallest accumulation that has potential to be added to reserves)

No. of discovered accumulations exceeding minimum size: Oil: 0 Gas: 0
Established (>13 accums.) ____ Frontier (1-13 accums.) ____ Hypothetical (no accums X

Median size (grown) of discovered oil accumulations (mmbo):
1st 3rd ____ 2nd 3rd ____ 3rd 3rd ____
Median size (grown) of discovered gas accumulations (bcfg):
1st 3rd ____ 2nd 3rd ____ 3rd 3rd ____

Assessment-Unit Probabilities:

Attribute	Probability of occurrence (0-1.0)
1. **CHARGE:** Adequate petroleum charge for an undiscovered accum. ≥ minimum size:	1.0
2. **ROCKS:** Adequate reservoirs, traps, and seals for an undiscovered accum. ≥ minimum size:	1.0
3. **TIMING OF GEOLOGIC EVENTS:** Favorable timing for an undiscovered accum. ≥ minimum siz	1.0

Assessment-Unit GEOLOGIC Probability (Product of 1, 2, and 3): 1.0

UNDISCOVERED ACCUMULATIONS

No. of Undiscovered Accumulations: How many undiscovered accums. exist that are ≥ min. size?:
(uncertainty of fixed but unknown values)

Oil Accumulations:	minimum (>0)	0	mode	0	maximum	0
Gas Accumulations:	minimum (>0)	1	mode	60	maximum	120

Sizes of Undiscovered Accumulations: What are the sizes (**grown**) of the above accums?:
(variations in the sizes of undiscovered accumulations)

Oil in Oil Accumulations (mmbo):	minimum		median		maximum	
Gas in Gas Accumulations (bcfg):	minimum	3	median	6	maximum	200

Appendix 1. Basic input data for the Jurassic–Lower Cretaceous Reservoirs Assessment Unit (50410202). SEVENTH APPROXIMATION DATA FORM (NOGA, Version 5, 6–30–01). [AU, assessment unit; bcfg, billion cubic feet of gas; bliq/mmcfg, barrels of liquid per million cubic feet of gas; bngl/mmcfg, barrels of natural gas liquids per million cubic feet of gas; cfg/bo, cubic feet of gas per barrel of oil; m, meters; min., minimum; mmboe, million barrels of oil equivalent; ngl, natural gas liquids]—Continued

Assessment Unit (name, no.)
Jurassic-Lower Cretaceous Reservoirs, 50410202

AVERAGE RATIOS FOR UNDISCOVERED ACCUMS., TO ASSESS COPRODUCTS
(uncertainty of fixed but unknown values)

Oil Accumulations:	minimum	mode	maximum
Gas/oil ratio (cfg/bo)			
NGL/gas ratio (bngl/mmcfg)			

Gas Accumulations:	minimum	mode	maximum
Liquids/gas ratio (bliq/mmcfg)	20	40	60
Oil/gas ratio (bo/mmcfg)			

SELECTED ANCILLARY DATA FOR UNDISCOVERED ACCUMULATIONS
(variations in the properties of undiscovered accumulations)

Oil Accumulations:	minimum	mode	maximum
API gravity (degrees)			
Sulfur content of oil (%)			
Depth (m) of water (if applicable)			

	minimum	F75	mode	F25	maximum
Drilling Depth (m)					

Gas Accumulations:	minimum	mode	maximum
Inert gas content (%)			
CO_2 content (%)			
Hydrogen-sulfide content (%)			
Depth (m) of water (if applicable)			

	minimum	F75	mode	F25	maximum
Drilling Depth (m)	150	915	972	1798	3000

Appendix 1. Basic input data for the Jurassic–Lower Cretaceous Reservoirs Assessment Unit (50410202). SEVENTH APPROXIMATION DATA FORM (NOGA, Version 5, 6–30–01). [AU, assessment unit; bcfg, billion cubic feet of gas; bliq/mmcfg, barrels of liquid per million cubic feet of gas; bngl/mmcfg, barrels of natural gas liquids per million cubic feet of gas; cfg/bo, cubic feet of gas per barrel of oil; m, meters; min., minimum; mmboe, million barrels of oil equivalent; ngl, natural gas liquids]—Continued

Assessment Unit (name, no.)
Jurassic-Lower Cretaceous Reservoirs, 50410202

ALLOCATIONS OF POTENTIAL ADDITIONS TO RESERVES TO STATES
Surface Allocations (uncertainty of a fixed value)

1. Colorado represents 55.55 area % of the AU

Oil in Oil Accumulations:	minimum	mode	maximum
Volume % in entity			
Gas in Gas Accumulations:			
Volume % in entity		40	

2. New Mexico represents 45.45 area % of the AU

Oil in Oil Accumulations:	minimum	mode	maximum
Volume % in entity			
Gas in Gas Accumulations:			
Volume % in entity		60	

3. ______ represents ______ area % of the AU

Oil in Oil Accumulations:	minimum	mode	maximum
Volume % in entity			
Gas in Gas Accumulations:			
Volume % in entity			

4. ______ represents ______ area % of the AU

Oil in Oil Accumulations:	minimum	mode	maximum
Volume % in entity			
Gas in Gas Accumulations:			
Volume % in entity			

5. ______ represents ______ area % of the AU

Oil in Oil Accumulations:	minimum	mode	maximum
Volume % in entity			
Gas in Gas Accumulations:			
Volume % in entity			

6. ______ represents ______ area % of the AU

Oil in Oil Accumulations:	minimum	mode	maximum
Volume % in entity			
Gas in Gas Accumulations:			
Volume % in entity			

Appendix 1. Basic input data for the Jurassic–Lower Cretaceous Reservoirs Assessment Unit (50410202). SEVENTH APPROXIMATION DATA FORM (NOGA, Version 5, 6–30–01). [AU, assessment unit; bcfg, billion cubic feet of gas; bliq/mmcfg, barrels of liquid per million cubic feet of gas; bngl/mmcfg, barrels of natural gas liquids per million cubic feet of gas; cfg/bo, cubic feet of gas per barrel of oil; m, meters; min., minimum; mmboe, million barrels of oil equivalent; ngl, natural gas liquids]—Continued

Assessment Unit (name, no.)
Jurassic-Lower Cretaceous Reservoirs, 50410202

7. ____________________ represents ________ area % of the AU

	minimum	mode	maximum
Oil in Oil Accumulations:			
Volume % in entity			
Gas in Gas Accumulations:			
Volume % in entity			

8. ____________________ represents ________ area % of the AU

	minimum	mode	maximum
Oil in Oil Accumulations:			
Volume % in entity			
Gas in Gas Accumulations:			
Volume % in entity			

9. ____________________ represents ________ area % of the AU

	minimum	mode	maximum
Oil in Oil Accumulations:			
Volume % in entity			
Gas in Gas Accumulations:			
Volume % in entity			

10. ____________________ represents ________ area % of the AU

	minimum	mode	maximum
Oil in Oil Accumulations:			
Volume % in entity			
Gas in Gas Accumulations:			
Volume % in entity			

11. ____________________ represents ________ area % of the AU

	minimum	mode	maximum
Oil in Oil Accumulations:			
Volume % in entity			
Gas in Gas Accumulations:			
Volume % in entity			

12. ____________________ represents ________ area % of the AU

	minimum	mode	maximum
Oil in Oil Accumulations:			
Volume % in entity			
Gas in Gas Accumulations:			
Volume % in entity			

Appendix 1. Basic input data for the Jurassic–Lower Cretaceous Reservoirs Assessment Unit (50410202). SEVENTH APPROXIMATION DATA FORM (NOGA, Version 5, 6–30–01). [AU, assessment unit; bcfg, billion cubic feet of gas; bliq/mmcfg, barrels of liquid per million cubic feet of gas; bngl/mmcfg, barrels of natural gas liquids per million cubic feet of gas; cfg/bo, cubic feet of gas per barrel of oil; m, meters; min., minimum; mmboe, million barrels of oil equivalent; ngl, natural gas liquids]—Continued

Assessment Unit (name, no.)
Jurassic-Lower Cretaceous Reservoirs, 50410202

ALLOCATIONS OF POTENTIAL ADDITIONS TO RESERVES TO LAND ENTITIES

Surface Allocations (uncertainty of a fixed value)

1. Federal Lands represents 3.81 area % of the AU

Oil in Oil Accumulations:	minimum	mode	maximum
Volume % in entity			
Gas in Gas Accumulations:			
Volume % in entity		0.9	

2. Private Lands represents 92.49 area % of the AU

Oil in Oil Accumulations:	minimum	mode	maximum
Volume % in entity			
Gas in Gas Accumulations:			
Volume % in entity		97.6	

3. Tribal Lands represents ____ area % of the AU

Oil in Oil Accumulations:	minimum	mode	maximum
Volume % in entity			
Gas in Gas Accumulations:			
Volume % in entity			

4. Other Lands represents ____ area % of the AU

Oil in Oil Accumulations:	minimum	mode	maximum
Volume % in entity			
Gas in Gas Accumulations:			
Volume % in entity			

5. Colorado State Lands represents 2.43 area % of the AU

Oil in Oil Accumulations:	minimum	mode	maximum
Volume % in entity			
Gas in Gas Accumulations:			
Volume % in entity		1	

6. New Mexico State Lands represents 1.27 area % of the AU

Oil in Oil Accumulations:	minimum	mode	maximum
Volume % in entity			
Gas in Gas Accumulations:			
Volume % in entity		0.5	

Appendix 1. Basic input data for the Jurassic–Lower Cretaceous Reservoirs Assessment Unit (50410202). SEVENTH APPROXIMATION DATA FORM (NOGA, Version 5, 6–30–01). [AU, assessment unit; bcfg, billion cubic feet of gas; bliq/mmcfg, barrels of liquid per million cubic feet of gas; bngl/mmcfg, barrels of natural gas liquids per million cubic feet of gas; cfg/bo, cubic feet of gas per barrel of oil; m, meters; min., minimum; mmboe, million barrels of oil equivalent; ngl, natural gas liquids]—Continued

Assessment Unit (name, no.)
Jurassic-Lower Cretaceous Reservoirs, 50410202

7. ____________________ represents ________ area % of the AU

	minimum	mode	maximum
Oil in Oil Accumulations:			
Volume % in entity			
Gas in Gas Accumulations:			
Volume % in entity			

8. ____________________ represents ________ area % of the AU

	minimum	mode	maximum
Oil in Oil Accumulations:			
Volume % in entity			
Gas in Gas Accumulations:			
Volume % in entity			

9. ____________________ represents ________ area % of the AU

	minimum	mode	maximum
Oil in Oil Accumulations:			
Volume % in entity			
Gas in Gas Accumulations:			
Volume % in entity			

10. ____________________ represents ________ area % of the AU

	minimum	mode	maximum
Oil in Oil Accumulations:			
Volume % in entity			
Gas in Gas Accumulations:			
Volume % in entity			

11. ____________________ represents ________ area % of the AU

	minimum	mode	maximum
Oil in Oil Accumulations:			
Volume % in entity			
Gas in Gas Accumulations:			
Volume % in entity			

12. ____________________ represents ________ area % of the AU

	minimum	mode	maximum
Oil in Oil Accumulations:			
Volume % in entity			
Gas in Gas Accumulations:			
Volume % in entity			

Appendix 1. Basic input data for the Jurassic–Lower Cretaceous Reservoirs Assessment Unit (50410202). SEVENTH APPROXIMATION DATA FORM (NOGA, Version 5, 6–30–01). [AU, assessment unit; bcfg, billion cubic feet of gas; bliq/mmcfg, barrels of liquid per million cubic feet of gas; bngl/mmcfg, barrels of natural gas liquids per million cubic feet of gas; cfg/bo, cubic feet of gas per barrel of oil; m, meters; min., minimum; mmboe, million barrels of oil equivalent; ngl, natural gas liquids]—Continued

Assessment Unit (name, no.)
Jurassic-Lower Cretaceous Reservoirs, 50410202

ALLOCATIONS OF POTENTIAL ADDITIONS TO RESERVES TO FEDERAL LAND SUBDIVISIONS
Surface Allocations (uncertainty of a fixed value)

1. Bureau of Land Management (BLM) represents 1.35 area % of the AU

	minimum	mode	maximum
Oil in Oil Accumulations:			
Volume % in entity			
Gas in Gas Accumulations:			
Volume % in entity		0.3	

2. BLM Wilderness Areas (BLMW) represents ____ area % of the AU

	minimum	mode	maximum
Oil in Oil Accumulations:			
Volume % in entity			
Gas in Gas Accumulations:			
Volume % in entity			

3. BLM Roadless Areas (BLMR) represents ____ area % of the AU

	minimum	mode	maximum
Oil in Oil Accumulations:			
Volume % in entity			
Gas in Gas Accumulations:			
Volume % in entity			

4. National Park Service (NPS) represents ____ area % of the AU

	minimum	mode	maximum
Oil in Oil Accumulations:			
Volume % in entity			
Gas in Gas Accumulations:			
Volume % in entity			

5. NPS Wilderness Areas (NPSW) represents ____ area % of the AU

	minimum	mode	maximum
Oil in Oil Accumulations:			
Volume % in entity			
Gas in Gas Accumulations:			
Volume % in entity			

6. NPS Protected Withdrawals (NPSP) represents ____ area % of the AU

	minimum	mode	maximum
Oil in Oil Accumulations:			
Volume % in entity			
Gas in Gas Accumulations:			
Volume % in entity			

Appendix 1. Basic input data for the Jurassic–Lower Cretaceous Reservoirs Assessment Unit (50410202). SEVENTH APPROXIMATION DATA FORM (NOGA, Version 5, 6–30–01). [AU, assessment unit; bcfg, billion cubic feet of gas; bliq/mmcfg, barrels of liquid per million cubic feet of gas; bngl/mmcfg, barrels of natural gas liquids per million cubic feet of gas; cfg/bo, cubic feet of gas per barrel of oil; m, meters; min., minimum; mmboe, million barrels of oil equivalent; ngl, natural gas liquids]—Continued

Assessment Unit (name, no.)
Jurassic-Lower Cretaceous Reservoirs, 50410202

7. US Forest Service (FS) represents 2.14 area % of the AU

	minimum	mode	maximum
Oil in Oil Accumulations:			
Volume % in entity			
Gas in Gas Accumulations:			
Volume % in entity		0.5	

8. USFS Wilderness Areas (FSW) represents ____ area % of the AU

	minimum	mode	maximum
Oil in Oil Accumulations:			
Volume % in entity			
Gas in Gas Accumulations:			
Volume % in entity			

9. USFS Roadless Areas (FSR) represents ____ area % of the AU

	minimum	mode	maximum
Oil in Oil Accumulations:			
Volume % in entity			
Gas in Gas Accumulations:			
Volume % in entity			

10. USFS Protected Withdrawals (FSP) represents ____ area % of the AU

	minimum	mode	maximum
Oil in Oil Accumulations:			
Volume % in entity			
Gas in Gas Accumulations:			
Volume % in entity			

11. US Fish and Wildlife Service (FWS) represents 0.12 area % of the AU

	minimum	mode	maximum
Oil in Oil Accumulations:			
Volume % in entity			
Gas in Gas Accumulations:			
Volume % in entity		0.03	

12. USFWS Wilderness Areas (FWSW) represents ____ area % of the AU

	minimum	mode	maximum
Oil in Oil Accumulations:			
Volume % in entity			
Gas in Gas Accumulations:			
Volume % in entity			

Appendix 1. Basic input data for the Jurassic–Lower Cretaceous Reservoirs Assessment Unit (50410202). SEVENTH APPROXIMATION DATA FORM (NOGA, Version 5, 6–30–01). [AU, assessment unit; bcfg, billion cubic feet of gas; bliq/mmcfg, barrels of liquid per million cubic feet of gas; bngl/mmcfg, barrels of natural gas liquids per million cubic feet of gas; cfg/bo, cubic feet of gas per barrel of oil; m, meters; min., minimum; mmboe, million barrels of oil equivalent; ngl, natural gas liquids]—Continued

Assessment Unit (name, no.)
Jurassic-Lower Cretaceous Reservoirs, 50410202

13. USFWS Protected Withdrawals (FWSP) represents ______ area % of the AU

	minimum	mode	maximum
Oil in Oil Accumulations: Volume % in entity			
Gas in Gas Accumulations: Volume % in entity			

14. Wilderness Study Areas (WS) represents ______ area % of the AU

	minimum	mode	maximum
Oil in Oil Accumulations: Volume % in entity			
Gas in Gas Accumulations: Volume % in entity			

15. Department of Energy (DOE) represents ______ area % of the AU

	minimum	mode	maximum
Oil in Oil Accumulations: Volume % in entity			
Gas in Gas Accumulations: Volume % in entity			

16. Department of Defense (DOD) represents 0.13 area % of the AU

	minimum	mode	maximum
Oil in Oil Accumulations: Volume % in entity			
Gas in Gas Accumulations: Volume % in entity		0.05	

17. Bureau of Reclamation (BOR) represents 0.06 area % of the AU

	minimum	mode	maximum
Oil in Oil Accumulations: Volume % in entity			
Gas in Gas Accumulations: Volume % in entity		0.02	

18. Tennessee Valley Authority (TVA) represents ______ area % of the AU

	minimum	mode	maximum
Oil in Oil Accumulations: Volume % in entity			
Gas in Gas Accumulations: Volume % in entity			

Appendix 1. Basic input data for the Jurassic–Lower Cretaceous Reservoirs Assessment Unit (50410202). SEVENTH APPROXIMATION DATA FORM (NOGA, Version 5, 6–30–01). [AU, assessment unit; bcfg, billion cubic feet of gas; bliq/mmcfg, barrels of liquid per million cubic feet of gas; bngl/mmcfg, barrels of natural gas liquids per million cubic feet of gas; cfg/bo, cubic feet of gas per barrel of oil; m, meters; min., minimum; mmboe, million barrels of oil equivalent; ngl, natural gas liquids]—Continued

Assessment Unit (name, no.)
Jurassic-Lower Cretaceous Reservoirs, 50410202

19. Other Federal ______ represents ______ area % of the AU

	minimum	mode	maximum
Oil in Oil Accumulations:			
Volume % in entity			
Gas in Gas Accumulations:			
Volume % in entity			

20. ______ represents ______ area % of the AU

	minimum	mode	maximum
Oil in Oil Accumulations:			
Volume % in entity			
Gas in Gas Accumulations:			
Volume % in entity			

Appendix 1. Basic input data for the Jurassic–Lower Cretaceous Reservoirs Assessment Unit (50410202). SEVENTH APPROXIMATION DATA FORM (NOGA, Version 5, 6–30–01). [AU, assessment unit; bcfg, billion cubic feet of gas; bliq/mmcfg, barrels of liquid per million cubic feet of gas; bngl/mmcfg, barrels of natural gas liquids per million cubic feet of gas; cfg/bo, cubic feet of gas per barrel of oil; m, meters; min., minimum; mmboe, million barrels of oil equivalent; ngl, natural gas liquids]—Continued

Assessment Unit (name, no.)
Jurassic-Lower Cretaceous Reservoirs, 50410202

ALLOCATIONS OF POTENTIAL ADDITIONS TO RESERVES TO ECOSYSTEMS
Surface Allocations (uncertainty of a fixed value)

1. Arkansas Tablelands (ARTL) represents 26.38 area % of the AU

	minimum	mode	maximum
Oil in Oil Accumulations: Volume % in entity			
Gas in Gas Accumulations: Volume % in entity		25	

2. Pecos Valley (PCVA) represents 7.83 area % of the AU

	minimum	mode	maximum
Oil in Oil Accumulations: Volume % in entity			
Gas in Gas Accumulations: Volume % in entity		4	

3. Sacremento-Monzano Mountain (SMMT) represents 7.86 area % of the AU

	minimum	mode	maximum
Oil in Oil Accumulations: Volume % in entity			
Gas in Gas Accumulations: Volume % in entity		10	

4. Southern Parks and Ranges (SPRA) represents 57.92 area % of the AU

	minimum	mode	maximum
Oil in Oil Accumulations: Volume % in entity			
Gas in Gas Accumulations: Volume % in entity		61	

5. ______ represents ______ area % of the AU

	minimum	mode	maximum
Oil in Oil Accumulations: Volume % in entity			
Gas in Gas Accumulations: Volume % in entity			

6. ______ represents ______ area % of the AU

	minimum	mode	maximum
Oil in Oil Accumulations: Volume % in entity			
Gas in Gas Accumulations: Volume % in entity			

Appendix 1. Basic input data for the Jurassic–Lower Cretaceous Reservoirs Assessment Unit (50410202). SEVENTH APPROXIMATION DATA FORM (NOGA, Version 5, 6–30–01). [AU, assessment unit; bcfg, billion cubic feet of gas; bliq/mmcfg, barrels of liquid per million cubic feet of gas; bngl/mmcfg, barrels of natural gas liquids per million cubic feet of gas; cfg/bo, cubic feet of gas per barrel of oil; m, meters; min., minimum; mmboe, million barrels of oil equivalent; ngl, natural gas liquids]—Continued

Assessment Unit (name, no.)
Jurassic-Lower Cretaceous Reservoirs, 50410202

7. ______________________ represents ________ area % of the AU

	minimum	mode	maximum
Oil in Oil Accumulations: Volume % in entity			
Gas in Gas Accumulations: Volume % in entity			

8. ______________________ represents ________ area % of the AU

	minimum	mode	maximum
Oil in Oil Accumulations: Volume % in entity			
Gas in Gas Accumulations: Volume % in entity			

9. ______________________ represents ________ area % of the AU

	minimum	mode	maximum
Oil in Oil Accumulations: Volume % in entity			
Gas in Gas Accumulations: Volume % in entity			

10. ______________________ represents ________ area % of the AU

	minimum	mode	maximum
Oil in Oil Accumulations: Volume % in entity			
Gas in Gas Accumulations: Volume % in entity			

11. ______________________ represents ________ area % of the AU

	minimum	mode	maximum
Oil in Oil Accumulations: Volume % in entity			
Gas in Gas Accumulations: Volume % in entity			

12. ______________________ represents ________ area % of the AU

	minimum	mode	maximum
Oil in Oil Accumulations: Volume % in entity			
Gas in Gas Accumulations: Volume % in entity			

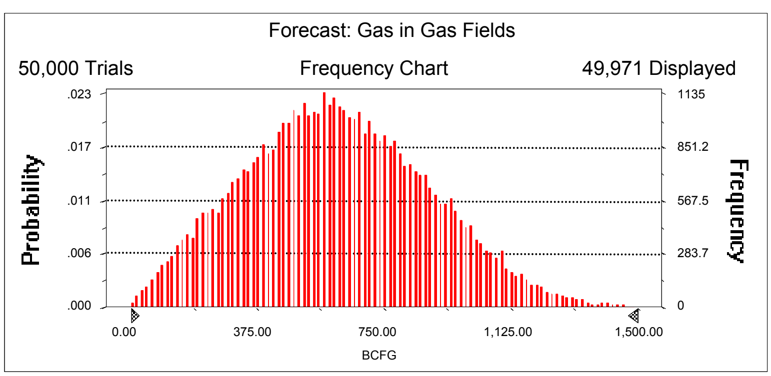
Appendix 2. Monte Carlo Assessment Output—Jurassic–Lower Cretaceous Reservoirs Assessment Unit (50410202). Contained in this appendix are detailed descriptions of the probability distributions of the results of the assessment of the Jurassic–Lower Cretaceous Reservoirs AU (50410202). These details may be of use to those conducting further analysis of the results. All distributions in this appendix are fully risked. They include the probability that there are no gas or NGL fields of minimum size or larger. Each distribution is documented by two pages. The first page contains distribution parameters, most importantly the mean, as well as a graph of the probability density function. The second page lists the percentiles (fractiles) of the distribution at 5-percent intervals. Also included are the descriptions of probability distributions of the input based on the input parameters documented in appendix 1. Each of the distributions used in calculating the results is documented by its parameters and a graph of the probability density function. Note that, for the distribution of size of undiscovered oil fields and for the distribution of size of undiscovered gas fields, the parameters of both the shifted and unshifted lognormal distributions are given. Each accompanying graph is that of the unshifted distribution.

50410202
Jurassic-Lower Cretaceous Reservoirs
Monte Carlo Results

Forecast: Gas in Gas Fields

Summary:
Display range is from 0.00 to 1,500.00 BCFG
Entire range is from 3.23 to 1,837.95 BCFG
After 50,000 trials, the standard error of the mean is 1.20

Statistics:	Value
Trials	50000
Mean	615.09
Median	605.39
Mode	---
Standard Deviation	268.44
Variance	72,062.15
Skewness	0.20
Kurtosis	2.65
Coefficient of Variability	0.44
Range Minimum	3.23
Range Maximum	1,837.95
Range Width	1,834.73
Mean Standard Error	1.20



Appendix 2. Monte Carlo Assessment Output—Jurassic–Lower Cretaceous Reservoirs Assessment Unit (50410202). Contained in this appendix are detailed descriptions of the probability distributions of the results of the assessment of the Jurassic–Lower Cretaceous Reservoirs AU (50410202). These details may be of use to those conducting further analysis of the results. All distributions in this appendix are fully risked. They include the probability that there are no gas or NGL fields of minimum size or larger. Each distribution is documented by two pages. The first page contains distribution parameters, most importantly the mean, as well as a graph of the probability density function. The second page lists the percentiles (fractiles) of the distribution at 5-percent intervals. Also included are the descriptions of probability distributions of the input based on the input parameters documented in appendix 1. Each of the distributions used in calculating the results is documented by its parameters and a graph of the probability density function. Note that, for the distribution of size of undiscovered oil fields and for the distribution of size of undiscovered gas fields, the parameters of both the shifted and unshifted lognormal distributions are given. Each accompanying graph is that of the unshifted distribution.—Continued.

50410202
Jurassic-Lower Cretaceous Reservoirs
Monte Carlo Results

Forecast: Gas in Gas Fields (cont'd)

Percentiles:

Percentile	BCFG
100%	3.23
95%	184.48
90%	262.71
85%	324.11
80%	375.22
75%	420.39
70%	461.69
65%	499.08
60%	534.71
55%	571.29
50%	605.39
45%	640.51
40%	677.40
35%	715.84
30%	756.70
25%	799.82
20%	849.14
15%	905.46
10%	972.67
5%	1,073.12
0%	1,837.95

End of Forecast

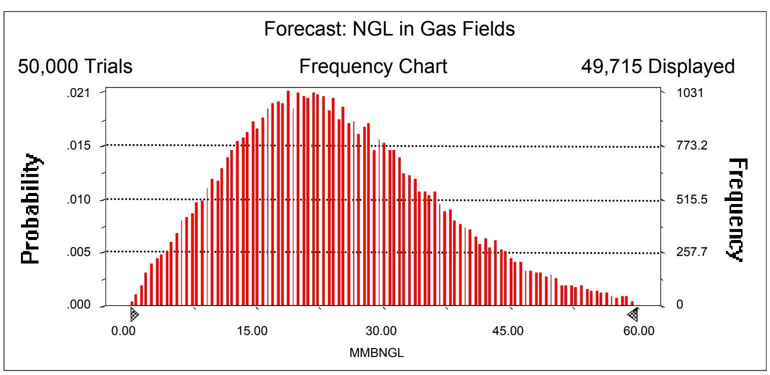
Appendix 2. Monte Carlo Assessment Output—Jurassic–Lower Cretaceous Reservoirs Assessment Unit (50410202). Contained in this appendix are detailed descriptions of the probability distributions of the results of the assessment of the Jurassic–Lower Cretaceous Reservoirs AU (50410202). These details may be of use to those conducting further analysis of the results. All distributions in this appendix are fully risked. They include the probability that there are no gas or NGL fields of minimum size or larger. Each distribution is documented by two pages. The first page contains distribution parameters, most importantly the mean, as well as a graph of the probability density function. The second page lists the percentiles (fractiles) of the distribution at 5-percent intervals. Also included are the descriptions of probability distributions of the input based on the input parameters documented in appendix 1. Each of the distributions used in calculating the results is documented by its parameters and a graph of the probability density function. Note that, for the distribution of size of undiscovered oil fields and for the distribution of size of undiscovered gas fields, the parameters of both the shifted and unshifted lognormal distributions are given. Each accompanying graph is that of the unshifted distribution.—Continued.

50410202
Jurassic-Lower Cretaceous Reservoirs
Monte Carlo Results

Forecast: NGL in Gas Fields

Summary:
Display range is from 0.00 to 60.00 MMBNGL
Entire range is from 0.18 to 89.53 MMBNGL
After 50,000 trials, the standard error of the mean is 0.05

Statistics:	Value
Trials	50000
Mean	24.58
Median	23.29
Mode	---
Standard Deviation	12.07
Variance	145.60
Skewness	0.57
Kurtosis	3.20
Coefficient of Variability	0.49
Range Minimum	0.18
Range Maximum	89.53
Range Width	89.35
Mean Standard Error	0.05



Appendix 2. Monte Carlo Assessment Output—Jurassic–Lower Cretaceous Reservoirs Assessment Unit (50410202). Contained in this appendix are detailed descriptions of the probability distributions of the results of the assessment of the Jurassic–Lower Cretaceous Reservoirs AU (50410202). These details may be of use to those conducting further analysis of the results. All distributions in this appendix are fully risked. They include the probability that there are no gas or NGL fields of minimum size or larger. Each distribution is documented by two pages. The first page contains distribution parameters, most importantly the mean, as well as a graph of the probability density function. The second page lists the percentiles (fractiles) of the distribution at 5-percent intervals. Also included are the descriptions of probability distributions of the input based on the input parameters documented in appendix 1. Each of the distributions used in calculating the results is documented by its parameters and a graph of the probability density function. Note that, for the distribution of size of undiscovered oil fields and for the distribution of size of undiscovered gas fields, the parameters of both the shifted and unshifted lognormal distributions are given. Each accompanying graph is that of the unshifted distribution.—Continued.

50410202
Jurassic-Lower Cretaceous Reservoirs
Monte Carlo Results

Forecast: NGL in Gas Fields (cont'd)

Percentiles:

Percentile	MMBNGL
100%	0.18
95%	6.86
90%	9.86
85%	12.11
80%	13.99
75%	15.73
70%	17.31
65%	18.84
60%	20.34
55%	21.81
50%	23.29
45%	24.82
40%	26.50
35%	28.24
30%	30.10
25%	32.06
20%	34.47
15%	37.32
10%	40.97
5%	46.45
0%	89.53

End of Forecast

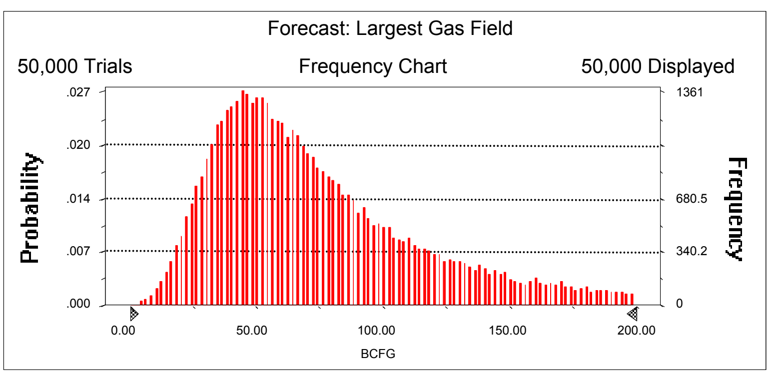
Appendix 2. Monte Carlo Assessment Output—Jurassic–Lower Cretaceous Reservoirs Assessment Unit (50410202). Contained in this appendix are detailed descriptions of the probability distributions of the results of the assessment of the Jurassic–Lower Cretaceous Reservoirs AU (50410202). These details may be of use to those conducting further analysis of the results. All distributions in this appendix are fully risked. They include the probability that there are no gas or NGL fields of minimum size or larger. Each distribution is documented by two pages. The first page contains distribution parameters, most importantly the mean, as well as a graph of the probability density function. The second page lists the percentiles (fractiles) of the distribution at 5-percent intervals. Also included are the descriptions of probability distributions of the input based on the input parameters documented in appendix 1. Each of the distributions used in calculating the results is documented by its parameters and a graph of the probability density function. Note that, for the distribution of size of undiscovered oil fields and for the distribution of size of undiscovered gas fields, the parameters of both the shifted and unshifted lognormal distributions are given. Each accompanying graph is that of the unshifted distribution.—Continued.

50410202
Jurassic-Lower Cretaceous Reservoirs
Monte Carlo Results

Forecast: Largest Gas Field

Summary:
Display range is from 0.00 to 200.00 BCFG
Entire range is from 3.23 to 199.95 BCFG
After 50,000 trials, the standard error of the mean is 0.18

Statistics:	Value
Trials	50000
Mean	73.17
Median	63.92
Mode	---
Standard Deviation	39.47
Variance	1,557.87
Skewness	0.98
Kurtosis	3.50
Coefficient of Variability	0.54
Range Minimum	3.23
Range Maximum	199.95
Range Width	196.73
Mean Standard Error	0.18



Appendix 2. Monte Carlo Assessment Output—Jurassic–Lower Cretaceous Reservoirs Assessment Unit (50410202). Contained in this appendix are detailed descriptions of the probability distributions of the results of the assessment of the Jurassic–Lower Cretaceous Reservoirs AU (50410202). These details may be of use to those conducting further analysis of the results. All distributions in this appendix are fully risked. They include the probability that there are no gas or NGL fields of minimum size or larger. Each distribution is documented by two pages. The first page contains distribution parameters, most importantly the mean, as well as a graph of the probability density function. The second page lists the percentiles (fractiles) of the distribution at 5-percent intervals. Also included are the descriptions of probability distributions of the input based on the input parameters documented in appendix 1. Each of the distributions used in calculating the results is documented by its parameters and a graph of the probability density function. Note that, for the distribution of size of undiscovered oil fields and for the distribution of size of undiscovered gas fields, the parameters of both the shifted and unshifted lognormal distributions are given. Each accompanying graph is that of the unshifted distribution.—Continued.

50410202
Jurassic-Lower Cretaceous Reservoirs
Monte Carlo Results

Forecast: Largest Gas Field (cont'd)

Percentiles:

Percentile	BCFG
100%	3.23
95%	24.83
90%	31.20
85%	35.92
80%	40.04
75%	43.95
70%	47.62
65%	51.44
60%	55.28
55%	59.46
50%	63.92
45%	68.51
40%	73.63
35%	79.41
30%	86.03
25%	93.72
20%	103.45
15%	115.67
10%	131.84
5%	155.62
0%	199.95

End of Forecast

Appendix 2. Monte Carlo Assessment Output—Jurassic–Lower Cretaceous Reservoirs Assessment Unit (50410202). Contained in this appendix are detailed descriptions of the probability distributions of the results of the assessment of the Jurassic–Lower Cretaceous Reservoirs AU (50410202). These details may be of use to those conducting further analysis of the results. All distributions in this appendix are fully risked. They include the probability that there are no gas or NGL fields of minimum size or larger. Each distribution is documented by two pages. The first page contains distribution parameters, most importantly the mean, as well as a graph of the probability density function. The second page lists the percentiles (fractiles) of the distribution at 5-percent intervals. Also included are the descriptions of probability distributions of the input based on the input parameters documented in appendix 1. Each of the distributions used in calculating the results is documented by its parameters and a graph of the probability density function. Note that, for the distribution of size of undiscovered oil fields and for the distribution of size of undiscovered gas fields, the parameters of both the shifted and unshifted lognormal distributions are given. Each accompanying graph is that of the unshifted distribution.—Continued.

50410202
Jurassic-Lower Cretaceous Reservoirs
Monte Carlo Results

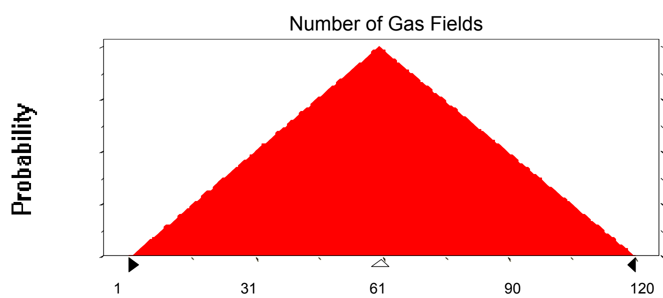
Assumptions

Assumption: Number of Gas Fields

Triangular distribution with parameters:

Minimum	1
Likeliest	60
Maximum	120

Selected range is from 1 to 120



Assumption: Sizes of Gas Fields

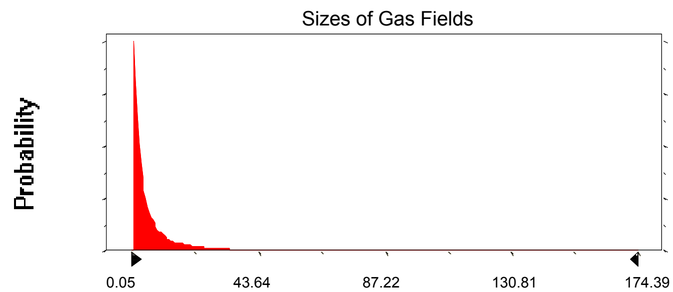
Lognormal distribution with parameters:		Shifted parameters
Mean	7.51	10.51
Standard Deviation	17.21	17.21

Selected range is from 0.00 to 197.00 3.00 to 200.00

Appendix 2. Monte Carlo Assessment Output—Jurassic–Lower Cretaceous Reservoirs Assessment Unit (50410202). Contained in this appendix are detailed descriptions of the probability distributions of the results of the assessment of the Jurassic–Lower Cretaceous Reservoirs AU (50410202). These details may be of use to those conducting further analysis of the results. All distributions in this appendix are fully risked. They include the probability that there are no gas or NGL fields of minimum size or larger. Each distribution is documented by two pages. The first page contains distribution parameters, most importantly the mean, as well as a graph of the probability density function. The second page lists the percentiles (fractiles) of the distribution at 5-percent intervals. Also included are the descriptions of probability distributions of the input based on the input parameters documented in appendix 1. Each of the distributions used in calculating the results is documented by its parameters and a graph of the probability density function. Note that, for the distribution of size of undiscovered oil fields and for the distribution of size of undiscovered gas fields, the parameters of both the shifted and unshifted lognormal distributions are given. Each accompanying graph is that of the unshifted distribution.—Continued.

50410202
Jurassic-Lower Cretaceous Reservoirs
Monte Carlo Results

Assumption: Sizes of Gas Fields (cont'd)

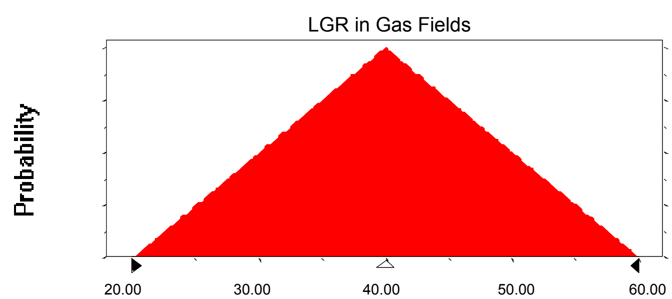


Assumption: LGR in Gas Fields

Triangular distribution with parameters:

Minimum	20.00
Likeliest	40.00
Maximum	60.00

Selected range is from 20.00 to 60.00



End of Assumptions

Simulation started on 9/17/04 at 16:05:30
Simulation stopped on 9/17/04 at 16:09:11

Appendix 3. Basic input data for the Fractured Reservoirs Assessment Unit (50410201). SEVENTH APPROXIMATION DATA FORM (NOGA, Version 5, 6–30–01). [AU, assessment unit; bcfg, billion cubic feet of gas; bliq/mmcfg, barrels of liquid per million cubic feet of gas; bngl/mmcfg, barrels of natural gas liquids per million cubic feet of gas; cfg/bo, cubic feet of gas per barrel of oil; m, meters; min. minimum; mmboe, million barrels of oil equivalent; ngl, natural gas liquids]

SEVENTH APPROXIMATION
DATA FORM FOR CONVENTIONAL ASSESSMENT UNITS (Version 6, 9 April 2003)

IDENTIFICATION INFORMATION

Assessment Geologist:	D.K. Higley-Feldman	Date:	9/15/2004
Region:	North America	Number:	5
Province:	Raton Basin-Sierra Grande Uplift	Number:	5041
Total Petroleum System:	Jurassic-Cretaceous Composite	Number:	504102
Assessment Unit:	Fractured Reservoirs	Number:	50410201
Based on Data as of:	IHS Energy (PI/Dwights) 2004 (data current through 1 January 2004)		
Notes from Assessor:	Pierre Shale Sandstones (50390601) assessment unit as partial analog.		

CHARACTERISTICS OF ASSESSMENT UNIT

Oil (<20,000 cfg/bo overall) **or** Gas (≥20,000 cfg/bo overall): Gas

What is the minimum accumulation size? 0.5 mmboe grown
(the smallest accumulation that has potential to be added to reserves)

No. of discovered accumulations exceeding minimum size: Oil: 0 Gas: 0
Established (>13 accums.) ____ Frontier (1-13 accums.) ____ Hypothetical (no accums X

Median size (grown) of discovered oil accumulations (mmbo):
1st 3rd ____ 2nd 3rd ____ 3rd 3rd ____
Median size (grown) of discovered gas accumulations (bcfg):
1st 3rd ____ 2nd 3rd ____ 3rd 3rd ____

Assessment-Unit Probabilities:

Attribute	Probability of occurrence (0-1.0)
1. **CHARGE:** Adequate petroleum charge for an undiscovered accum. ≥ minimum size:	1.0
2. **ROCKS:** Adequate reservoirs, traps, and seals for an undiscovered accum. ≥ minimum size:	1.0
3. **TIMING OF GEOLOGIC EVENTS:** Favorable timing for an undiscovered accum. ≥ minimum siz	1.0

Assessment-Unit GEOLOGIC Probability (Product of 1, 2, and 3): 1.0

UNDISCOVERED ACCUMULATIONS

No. of Undiscovered Accumulations: How many undiscovered accums. exist that are ≥ min. size?:
(uncertainty of fixed but unknown values)

	minimum (>0)	mode	maximum
Oil Accumulations:	0	0	0
Gas Accumulations:	1	2	30

Sizes of Undiscovered Accumulations: What are the sizes (**grown**) of the above accums?:
(variations in the sizes of undiscovered accumulations)

	minimum	median	maximum
Oil in Oil Accumulations (mmbo):			
Gas in Gas Accumulations (bcfg):	3	6	80

Appendix 3. Basic input data for the Fractured Reservoirs Assessment Unit (50410201). SEVENTH APPROXIMATION DATA FORM (NOGA, Version 5, 6–30–01). [AU, assessment unit; bcfg, billion cubic feet of gas; bliq/mmcfg, barrels of liquid per million cubic feet of gas; bngl/mmcfg, barrels of natural gas liquids per million cubic feet of gas; cfg/bo, cubic feet of gas per barrel of oil; m, meters; min. minimum; mmboe, million barrels of oil equivalent; ngl, natural gas liquids]—Continued

Assessment Unit (name, no.)
Fractured Reservoirs, 50410201

AVERAGE RATIOS FOR UNDISCOVERED ACCUMS., TO ASSESS COPRODUCTS
(uncertainty of fixed but unknown values)

Oil Accumulations:	minimum	mode	maximum
Gas/oil ratio (cfg/bo)			
NGL/gas ratio (bngl/mmcfg)			

Gas Accumulations:	minimum	mode	maximum
Liquids/gas ratio (bliq/mmcfg)	20	40	60
Oil/gas ratio (bo/mmcfg)			

SELECTED ANCILLARY DATA FOR UNDISCOVERED ACCUMULATIONS
(variations in the properties of undiscovered accumulations)

Oil Accumulations:	minimum	mode	maximum
API gravity (degrees)			
Sulfur content of oil (%)			
Depth (m) of water (if applicable)			

	minimum	F75	mode	F25	maximum
Drilling Depth (m)					

Gas Accumulations:	minimum	mode	maximum
Inert gas content (%)			
CO_2 content (%)			
Hydrogen-sulfide content (%)			
Depth (m) of water (if applicable)			

	minimum	F75	mode	F25	maximum
Drilling Depth (m)	150	960	1220	1681	2600

Appendix 3. Basic input data for the Fractured Reservoirs Assessment Unit (50410201). SEVENTH APPROXIMATION DATA FORM (NOGA, Version 5, 6–30–01). [AU, assessment unit; bcfg, billion cubic feet of gas; bliq/mmcfg, barrels of liquid per million cubic feet of gas; bngl/mmcfg, barrels of natural gas liquids per million cubic feet of gas; cfg/bo, cubic feet of gas per barrel of oil; m, meters; min. minimum; mmboe, million barrels of oil equivalent; ngl, natural gas liquids]—Continued

Assessment Unit (name, no.)
Fractured Reservoirs, 50410201

ALLOCATIONS OF POTENTIAL ADDITIONS TO RESERVES TO STATES
Surface Allocations (uncertainty of a fixed value)

1. Colorado ______ represents 59.76 area % of the AU

	minimum	mode	maximum
Oil in Oil Accumulations:			
Volume % in entity			
Gas in Gas Accumulations:			
Volume % in entity		65	

2. ______ represents 40.24 area % of the AU

	minimum	mode	maximum
Oil in Oil Accumulations:			
Volume % in entity			
Gas in Gas Accumulations:			
Volume % in entity		35	

3. ______ represents ______ area % of the AU

	minimum	mode	maximum
Oil in Oil Accumulations:			
Volume % in entity			
Gas in Gas Accumulations:			
Volume % in entity			

4. ______ represents ______ area % of the AU

	minimum	mode	maximum
Oil in Oil Accumulations:			
Volume % in entity			
Gas in Gas Accumulations:			
Volume % in entity			

5. ______ represents ______ area % of the AU

	minimum	mode	maximum
Oil in Oil Accumulations:			
Volume % in entity			
Gas in Gas Accumulations:			
Volume % in entity			

6. ______ represents ______ area % of the AU

	minimum	mode	maximum
Oil in Oil Accumulations:			
Volume % in entity			
Gas in Gas Accumulations:			
Volume % in entity			

Appendix 3. Basic input data for the Fractured Reservoirs Assessment Unit (50410201). SEVENTH APPROXIMATION DATA FORM (NOGA, Version 5, 6–30–01). [AU, assessment unit; bcfg, billion cubic feet of gas; bliq/mmcfg, barrels of liquid per million cubic feet of gas; bngl/mmcfg, barrels of natural gas liquids per million cubic feet of gas; cfg/bo, cubic feet of gas per barrel of oil; m, meters; min. minimum; mmboe, million barrels of oil equivalent; ngl, natural gas liquids]—Continued

Assessment Unit (name, no.)
Fractured Reservoirs, 50410201

7. ______ represents ______ area % of the AU

	minimum	mode	maximum
Oil in Oil Accumulations: Volume % in entity			
Gas in Gas Accumulations: Volume % in entity			

8. ______ represents ______ area % of the AU

	minimum	mode	maximum
Oil in Oil Accumulations: Volume % in entity			
Gas in Gas Accumulations: Volume % in entity			

9. ______ represents ______ area % of the AU

	minimum	mode	maximum
Oil in Oil Accumulations: Volume % in entity			
Gas in Gas Accumulations: Volume % in entity			

10. ______ represents ______ area % of the AU

	minimum	mode	maximum
Oil in Oil Accumulations: Volume % in entity			
Gas in Gas Accumulations: Volume % in entity			

11. ______ represents ______ area % of the AU

	minimum	mode	maximum
Oil in Oil Accumulations: Volume % in entity			
Gas in Gas Accumulations: Volume % in entity			

12. ______ represents ______ area % of the AU

	minimum	mode	maximum
Oil in Oil Accumulations: Volume % in entity			
Gas in Gas Accumulations: Volume % in entity			

Appendix 3. Basic input data for the Fractured Reservoirs Assessment Unit (50410201). SEVENTH APPROXIMATION DATA FORM (NOGA, Version 5, 6–30–01). [AU, assessment unit; bcfg, billion cubic feet of gas; bliq/mmcfg, barrels of liquid per million cubic feet of gas; bngl/mmcfg, barrels of natural gas liquids per million cubic feet of gas; cfg/bo, cubic feet of gas per barrel of oil; m, meters; min. minimum; mmboe, million barrels of oil equivalent; ngl, natural gas liquids]—Continued

Assessment Unit (name, no.)
Fractured Reservoirs, 50410201

ALLOCATIONS OF POTENTIAL ADDITIONS TO RESERVES TO LAND ENTITIES
Surface Allocations (uncertainty of a fixed value)

1. Federal Lands represents 2.92 area % of the AU

	minimum	mode	maximum
Oil in Oil Accumulations: Volume % in entity			
Gas in Gas Accumulations: Volume % in entity		1	

2. Private Lands represents 94.4 area % of the AU

	minimum	mode	maximum
Oil in Oil Accumulations: Volume % in entity			
Gas in Gas Accumulations: Volume % in entity		97	

3. Tribal Lands represents ____ area % of the AU

	minimum	mode	maximum
Oil in Oil Accumulations: Volume % in entity			
Gas in Gas Accumulations: Volume % in entity			

4. Other Lands represents ____ area % of the AU

	minimum	mode	maximum
Oil in Oil Accumulations: Volume % in entity			
Gas in Gas Accumulations: Volume % in entity			

5. Colorado State Lands represents 2.67 area % of the AU

	minimum	mode	maximum
Oil in Oil Accumulations: Volume % in entity			
Gas in Gas Accumulations: Volume % in entity		2	

6. ____ represents ____ area % of the AU

	minimum	mode	maximum
Oil in Oil Accumulations: Volume % in entity			
Gas in Gas Accumulations: Volume % in entity			

Appendix 3. Basic input data for the Fractured Reservoirs Assessment Unit (50410201). SEVENTH APPROXIMATION DATA FORM (NOGA, Version 5, 6–30–01). [AU, assessment unit; bcfg, billion cubic feet of gas; bliq/mmcfg, barrels of liquid per million cubic feet of gas; bngl/mmcfg, barrels of natural gas liquids per million cubic feet of gas; cfg/bo, cubic feet of gas per barrel of oil; m, meters; min. minimum; mmboe, million barrels of oil equivalent; ngl, natural gas liquids]—Continued

Assessment Unit (name, no.)
Fractured Reservoirs, 50410201

7. ____________________ represents ______ area % of the AU

	minimum	mode	maximum
Oil in Oil Accumulations:			
Volume % in entity			
Gas in Gas Accumulations:			
Volume % in entity			

8. ____________________ represents ______ area % of the AU

	minimum	mode	maximum
Oil in Oil Accumulations:			
Volume % in entity			
Gas in Gas Accumulations:			
Volume % in entity			

9. ____________________ represents ______ area % of the AU

	minimum	mode	maximum
Oil in Oil Accumulations:			
Volume % in entity			
Gas in Gas Accumulations:			
Volume % in entity			

10. ____________________ represents ______ area % of the AU

	minimum	mode	maximum
Oil in Oil Accumulations:			
Volume % in entity			
Gas in Gas Accumulations:			
Volume % in entity			

11. ____________________ represents ______ area % of the AU

	minimum	mode	maximum
Oil in Oil Accumulations:			
Volume % in entity			
Gas in Gas Accumulations:			
Volume % in entity			

12. ____________________ represents ______ area % of the AU

	minimum	mode	maximum
Oil in Oil Accumulations:			
Volume % in entity			
Gas in Gas Accumulations:			
Volume % in entity			

Appendix 3. Basic input data for the Fractured Reservoirs Assessment Unit (50410201). SEVENTH APPROXIMATION DATA FORM (NOGA, Version 5, 6–30–01). [AU, assessment unit; bcfg, billion cubic feet of gas; bliq/mmcfg, barrels of liquid per million cubic feet of gas; bngl/mmcfg, barrels of natural gas liquids per million cubic feet of gas; cfg/bo, cubic feet of gas per barrel of oil; m, meters; min. minimum; mmboe, million barrels of oil equivalent; ngl, natural gas liquids]—Continued

Assessment Unit (name, no.)
Fractured Reservoirs, 50410201

ALLOCATIONS OF POTENTIAL ADDITIONS TO RESERVES TO FEDERAL LAND SUBDIVISIONS
Surface Allocations (uncertainty of a fixed value)

1. Bureau of Land Management (BLM) represents 0.84 area % of the AU

	minimum	mode	maximum
Oil in Oil Accumulations: Volume % in entity			
Gas in Gas Accumulations: Volume % in entity		0.9	

2. BLM Wilderness Areas (BLMW) represents ____ area % of the AU

	minimum	mode	maximum
Oil in Oil Accumulations: Volume % in entity			
Gas in Gas Accumulations: Volume % in entity			

3. BLM Roadless Areas (BLMR) represents ____ area % of the AU

	minimum	mode	maximum
Oil in Oil Accumulations: Volume % in entity			
Gas in Gas Accumulations: Volume % in entity			

4. National Park Service (NPS) represents ____ area % of the AU

	minimum	mode	maximum
Oil in Oil Accumulations: Volume % in entity			
Gas in Gas Accumulations: Volume % in entity			

5. NPS Wilderness Areas (NPSW) represents ____ area % of the AU

	minimum	mode	maximum
Oil in Oil Accumulations: Volume % in entity			
Gas in Gas Accumulations: Volume % in entity			

6. NPS Protected Withdrawals (NPSP) represents ____ area % of the AU

	minimum	mode	maximum
Oil in Oil Accumulations: Volume % in entity			
Gas in Gas Accumulations: Volume % in entity			

Appendix 3. Basic input data for the Fractured Reservoirs Assessment Unit (50410201). SEVENTH APPROXIMATION DATA FORM (NOGA, Version 5, 6–30–01). [AU, assessment unit; bcfg, billion cubic feet of gas; bliq/mmcfg, barrels of liquid per million cubic feet of gas; bngl/mmcfg, barrels of natural gas liquids per million cubic feet of gas; cfg/bo, cubic feet of gas per barrel of oil; m, meters; min. minimum; mmboe, million barrels of oil equivalent; ngl, natural gas liquids]—Continued

Assessment Unit (name, no.)
Fractured Reservoirs, 50410201

7. US Forest Service (FS) represents 0.17 area % of the AU

	minimum	mode	maximum
Oil in Oil Accumulations: Volume % in entity			
Gas in Gas Accumulations: Volume % in entity		0.01	

8. USFS Wilderness Areas (FSW) represents ____ area % of the AU

	minimum	mode	maximum
Oil in Oil Accumulations: Volume % in entity			
Gas in Gas Accumulations: Volume % in entity			

9. USFS Roadless Areas (FSR) represents ____ area % of the AU

	minimum	mode	maximum
Oil in Oil Accumulations: Volume % in entity			
Gas in Gas Accumulations: Volume % in entity			

10. USFS Protected Withdrawals (FSP) represents ____ area % of the AU

	minimum	mode	maximum
Oil in Oil Accumulations: Volume % in entity			
Gas in Gas Accumulations: Volume % in entity			

11. US Fish and Wildlife Service (FWS) represents 0.17 area % of the AU

	minimum	mode	maximum
Oil in Oil Accumulations: Volume % in entity			
Gas in Gas Accumulations: Volume % in entity		0.06	

12. USFWS Wilderness Areas (FWSW) represents ____ area % of the AU

	minimum	mode	maximum
Oil in Oil Accumulations: Volume % in entity			
Gas in Gas Accumulations: Volume % in entity			

Appendix 3. Basic input data for the Fractured Reservoirs Assessment Unit (50410201). SEVENTH APPROXIMATION DATA FORM (NOGA, Version 5, 6–30–01). [AU, assessment unit; bcfg, billion cubic feet of gas; bliq/mmcfg, barrels of liquid per million cubic feet of gas; bngl/mmcfg, barrels of natural gas liquids per million cubic feet of gas; cfg/bo, cubic feet of gas per barrel of oil; m, meters; min. minimum; mmboe, million barrels of oil equivalent; ngl, natural gas liquids]—Continued

Assessment Unit (name, no.)
Fractured Reservoirs, 50410201

13. USFWS Protected Withdrawals (FWSP) represents ______ area % of the AU

	minimum	mode	maximum
Oil in Oil Accumulations:			
Volume % in entity			
Gas in Gas Accumulations:			
Volume % in entity			

14. Wilderness Study Areas (WS) represents ______ area % of the AU

	minimum	mode	maximum
Oil in Oil Accumulations:			
Volume % in entity			
Gas in Gas Accumulations:			
Volume % in entity			

15. Department of Energy (DOE) represents ______ area % of the AU

	minimum	mode	maximum
Oil in Oil Accumulations:			
Volume % in entity			
Gas in Gas Accumulations:			
Volume % in entity			

16. Department of Defense (DOD) represents ______ area % of the AU

	minimum	mode	maximum
Oil in Oil Accumulations:			
Volume % in entity			
Gas in Gas Accumulations:			
Volume % in entity			

17. Bureau of Reclamation (BOR) represents 0.08 area % of the AU

	minimum	mode	maximum
Oil in Oil Accumulations:			
Volume % in entity			
Gas in Gas Accumulations:			
Volume % in entity		0.03	

18. Tennessee Valley Authority (TVA) represents ______ area % of the AU

	minimum	mode	maximum
Oil in Oil Accumulations:			
Volume % in entity			
Gas in Gas Accumulations:			
Volume % in entity			

Appendix 3. Basic input data for the Fractured Reservoirs Assessment Unit (50410201). SEVENTH APPROXIMATION DATA FORM (NOGA, Version 5, 6–30–01). [AU, assessment unit; bcfg, billion cubic feet of gas; bliq/mmcfg, barrels of liquid per million cubic feet of gas; bngl/mmcfg, barrels of natural gas liquids per million cubic feet of gas; cfg/bo, cubic feet of gas per barrel of oil; m, meters; min. minimum; mmboe, million barrels of oil equivalent; ngl, natural gas liquids]—Continued

Assessment Unit (name, no.)
Fractured Reservoirs, 50410201

19. Other Federal represents ______ area % of the AU

	minimum	mode	maximum
Oil in Oil Accumulations:			
Volume % in entity			
Gas in Gas Accumulations:			
Volume % in entity			

20. ______ represents ______ area % of the AU

	minimum	mode	maximum
Oil in Oil Accumulations:			
Volume % in entity			
Gas in Gas Accumulations:			
Volume % in entity			

Appendix 3. Basic input data for the Fractured Reservoirs Assessment Unit (50410201). SEVENTH APPROXIMATION DATA FORM (NOGA, Version 5, 6–30–01). [AU, assessment unit; bcfg, billion cubic feet of gas; bliq/mmcfg, barrels of liquid per million cubic feet of gas; bngl/mmcfg, barrels of natural gas liquids per million cubic feet of gas; cfg/bo, cubic feet of gas per barrel of oil; m, meters; min. minimum; mmboe, million barrels of oil equivalent; ngl, natural gas liquids]—Continued

Assessment Unit (name, no.)
Fractured Reservoirs, 50410201

ALLOCATIONS OF POTENTIAL ADDITIONS TO RESERVES TO ECOSYSTEMS
Surface Allocations (uncertainty of a fixed value)

1. Arkansas Tablelands (ARTL) represents 23.66 area % of the AU

	minimum	mode	maximum
Oil in Oil Accumulations:			
Volume % in entity			
Gas in Gas Accumulations:			
Volume % in entity		10	

2. Pecos Valley (PCVA) represents 4.93 area % of the AU

	minimum	mode	maximum
Oil in Oil Accumulations:			
Volume % in entity			
Gas in Gas Accumulations:			
Volume % in entity		0	

3. Sacremento-Monzano Mountain (SMMT) represents 2.84 area % of the AU

	minimum	mode	maximum
Oil in Oil Accumulations:			
Volume % in entity			
Gas in Gas Accumulations:			
Volume % in entity		0	

4. Southern Parks and Ranges (SPRA) represents 68.57 area % of the AU

	minimum	mode	maximum
Oil in Oil Accumulations:			
Volume % in entity			
Gas in Gas Accumulations:			
Volume % in entity		90	

5. ____________ represents ______ area % of the AU

	minimum	mode	maximum
Oil in Oil Accumulations:			
Volume % in entity			
Gas in Gas Accumulations:			
Volume % in entity			

6. ____________ represents ______ area % of the AU

	minimum	mode	maximum
Oil in Oil Accumulations:			
Volume % in entity			
Gas in Gas Accumulations:			
Volume % in entity			

Appendix 3. Basic input data for the Fractured Reservoirs Assessment Unit (50410201). SEVENTH APPROXIMATION DATA FORM (NOGA, Version 5, 6–30–01). [AU, assessment unit; bcfg, billion cubic feet of gas; bliq/mmcfg, barrels of liquid per million cubic feet of gas; bngl/mmcfg, barrels of natural gas liquids per million cubic feet of gas; cfg/bo, cubic feet of gas per barrel of oil; m, meters; min. minimum; mmboe, million barrels of oil equivalent; ngl, natural gas liquids]—Continued

Assessment Unit (name, no.)
Fractured Reservoirs, 50410201

7. ______________________ represents ______ area % of the AU

	minimum	mode	maximum
Oil in Oil Accumulations:			
Volume % in entity	______	______	______
Gas in Gas Accumulations:			
Volume % in entity	______	______	______

8. ______________________ represents ______ area % of the AU

	minimum	mode	maximum
Oil in Oil Accumulations:			
Volume % in entity	______	______	______
Gas in Gas Accumulations:			
Volume % in entity	______	______	______

9. ______________________ represents ______ area % of the AU

	minimum	mode	maximum
Oil in Oil Accumulations:			
Volume % in entity	______	______	______
Gas in Gas Accumulations:			
Volume % in entity	______	______	______

10. ______________________ represents ______ area % of the AU

	minimum	mode	maximum
Oil in Oil Accumulations:			
Volume % in entity	______	______	______
Gas in Gas Accumulations:			
Volume % in entity	______	______	______

11. ______________________ represents ______ area % of the AU

	minimum	mode	maximum
Oil in Oil Accumulations:			
Volume % in entity	______	______	______
Gas in Gas Accumulations:			
Volume % in entity	______	______	______

12. ______________________ represents ______ area % of the AU

	minimum	mode	maximum
Oil in Oil Accumulations:			
Volume % in entity	______	______	______
Gas in Gas Accumulations:			
Volume % in entity	______	______	______

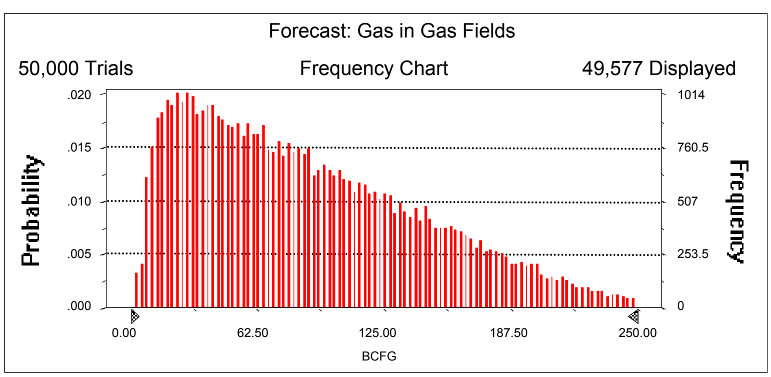
Appendix 4. Monte Carlo Assessment Output—Fractured Reservoirs Assessment Unit (50410201). Contained in this appendix are detailed descriptions of the probability distributions of the results of the assessment of the Fractured Reservoirs AU (50410201). These details may be of use to those conducting further analysis of the results. All distributions in this appendix are fully risked. They include the probability that there are no gas or NGL fields of minimum size or larger. Each distribution is documented by two pages. The first page contains distribution parameters, most importantly the mean, as well as a graph of the probability density function. The second page lists the percentiles (fractiles) of the distribution at 5-percent intervals. Also included are the descriptions of probability distributions of the input based on the input parameters documented in appendix 3. Each of the distributions used in calculating the results is documented by its parameters and a graph of the probability density function. Note that, for the distribution of size of undiscovered oil fields and for the distribution of size of undiscovered gas fields, the parameters of both the shifted and unshifted lognormal distributions are given. Each accompanying graph is that of the unshifted distribution.

50410201
Fractured Reservoirs
Monte Carlo Results

Forecast: Gas in Gas Fields

Summary:
Display range is from 0.00 to 250.00 BCFG
Entire range is from 3.13 to 402.20 BCFG
After 50,000 trials, the standard error of the mean is 0.26

Statistics:	Value
Trials	50000
Mean	88.76
Median	78.04
Mode	---
Standard Deviation	58.59
Variance	3,432.80
Skewness	0.75
Kurtosis	2.99
Coefficient of Variability	0.66
Range Minimum	3.13
Range Maximum	402.20
Range Width	399.07
Mean Standard Error	0.26



Appendix 4. Monte Carlo Assessment Output—Fractured Reservoirs Assessment Unit (50410201). Contained in this appendix are detailed descriptions of the probability distributions of the results of the assessment of the Fractured Reservoirs AU (50410201). These details may be of use to those conducting further analysis of the results. All distributions in this appendix are fully risked. They include the probability that there are no gas or NGL fields of minimum size or larger. Each distribution is documented by two pages. The first page contains distribution parameters, most importantly the mean, as well as a graph of the probability density function. The second page lists the percentiles (fractiles) of the distribution at 5-percent intervals. Also included are the descriptions of probability distributions of the input based on the input parameters documented in appendix 3. Each of the distributions used in calculating the results is documented by its parameters and a graph of the probability density function. Note that, for the distribution of size of undiscovered oil fields and for the distribution of size of undiscovered gas fields, the parameters of both the shifted and unshifted lognormal distributions are given. Each accompanying graph is that of the unshifted distribution.—Continued

50410201
Fractured Reservoirs
Monte Carlo Results

Forecast: Gas in Gas Fields (cont'd)

Percentiles:

Percentile	BCFG
100%	3.13
95%	14.64
90%	21.24
85%	27.49
80%	33.80
75%	40.41
70%	47.24
65%	54.46
60%	61.94
55%	69.66
50%	78.04
45%	86.28
40%	95.45
35%	105.02
30%	115.58
25%	127.07
20%	140.39
15%	155.21
10%	173.28
5%	199.31
0%	402.20

End of Forecast

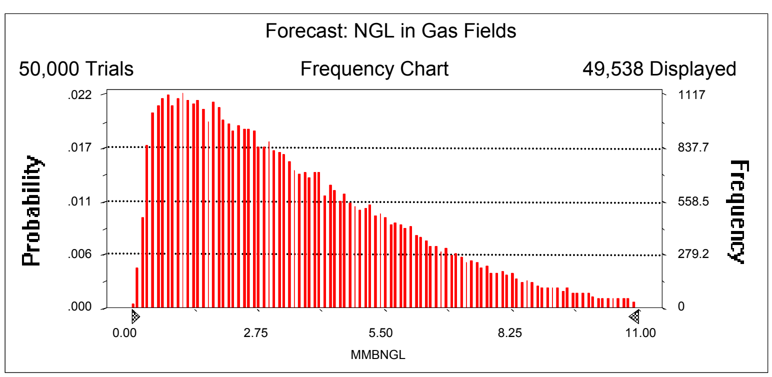
Appendix 4. Monte Carlo Assessment Output—Fractured Reservoirs Assessment Unit (50410201). Contained in this appendix are detailed descriptions of the probability distributions of the results of the assessment of the Fractured Reservoirs AU (50410201). These details may be of use to those conducting further analysis of the results. All distributions in this appendix are fully risked. They include the probability that there are no gas or NGL fields of minimum size or larger. Each distribution is documented by two pages. The first page contains distribution parameters, most importantly the mean, as well as a graph of the probability density function. The second page lists the percentiles (fractiles) of the distribution at 5-percent intervals. Also included are the descriptions of probability distributions of the input based on the input parameters documented in appendix 3. Each of the distributions used in calculating the results is documented by its parameters and a graph of the probability density function. Note that, for the distribution of size of undiscovered oil fields and for the distribution of size of undiscovered gas fields, the parameters of both the shifted and unshifted lognormal distributions are given. Each accompanying graph is that of the unshifted distribution.—Continued

50410201
Fractured Reservoirs
Monte Carlo Results

Forecast: NGL in Gas Fields

Summary:
Display range is from 0.00 to 11.00 MMBNGL
Entire range is from 0.08 to 20.44 MMBNGL
After 50,000 trials, the standard error of the mean is 0.01

Statistics:	Value
Trials	50000
Mean	3.54
Median	3.00
Mode	---
Standard Deviation	2.50
Variance	6.24
Skewness	1.02
Kurtosis	3.93
Coefficient of Variability	0.70
Range Minimum	0.08
Range Maximum	20.44
Range Width	20.36
Mean Standard Error	0.01



Appendix 4. Monte Carlo Assessment Output—Fractured Reservoirs Assessment Unit (50410201). Contained in this appendix are detailed descriptions of the probability distributions of the results of the assessment of the Fractured Reservoirs AU (50410201). These details may be of use to those conducting further analysis of the results. All distributions in this appendix are fully risked. They include the probability that there are no gas or NGL fields of minimum size or larger. Each distribution is documented by two pages. The first page contains distribution parameters, most importantly the mean, as well as a graph of the probability density function. The second page lists the percentiles (fractiles) of the distribution at 5-percent intervals. Also included are the descriptions of probability distributions of the input based on the input parameters documented in appendix 3. Each of the distributions used in calculating the results is documented by its parameters and a graph of the probability density function. Note that, for the distribution of size of undiscovered oil fields and for the distribution of size of undiscovered gas fields, the parameters of both the shifted and unshifted lognormal distributions are given. Each accompanying graph is that of the unshifted distribution.—Continued

50410201
Fractured Reservoirs
Monte Carlo Results

Forecast: NGL in Gas Fields (cont'd)

Percentiles:

Percentile	MMBNGL
100%	0.08
95%	0.54
90%	0.80
85%	1.05
80%	1.30
75%	1.56
70%	1.83
65%	2.09
60%	2.39
55%	2.68
50%	3.00
45%	3.33
40%	3.70
35%	4.09
30%	4.53
25%	5.03
20%	5.58
15%	6.22
10%	7.07
5%	8.35
0%	20.44

End of Forecast

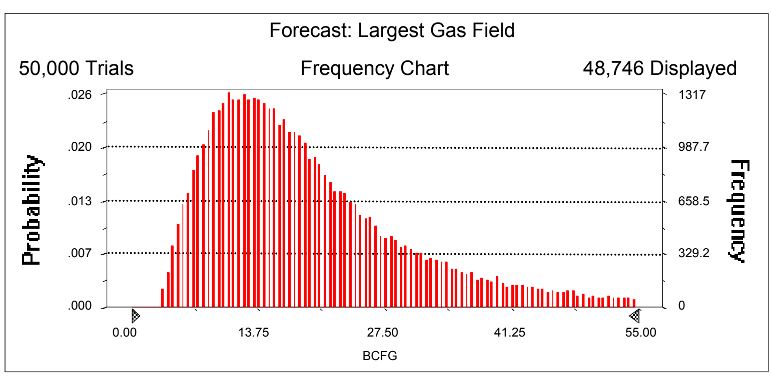
Appendix 4. Monte Carlo Assessment Output—Fractured Reservoirs Assessment Unit (50410201). Contained in this appendix are detailed descriptions of the probability distributions of the results of the assessment of the Fractured Reservoirs AU (50410201). These details may be of use to those conducting further analysis of the results. All distributions in this appendix are fully risked. They include the probability that there are no gas or NGL fields of minimum size or larger. Each distribution is documented by two pages. The first page contains distribution parameters, most importantly the mean, as well as a graph of the probability density function. The second page lists the percentiles (fractiles) of the distribution at 5-percent intervals. Also included are the descriptions of probability distributions of the input based on the input parameters documented in appendix 3. Each of the distributions used in calculating the results is documented by its parameters and a graph of the probability density function. Note that, for the distribution of size of undiscovered oil fields and for the distribution of size of undiscovered gas fields, the parameters of both the shifted and unshifted lognormal distributions are given. Each accompanying graph is that of the unshifted distribution.—Continued

50410201
Fractured Reservoirs
Monte Carlo Results

Forecast: Largest Gas Field

Summary:
Display range is from 0.00 to 55.00 BCFG
Entire range is from 3.13 to 79.92 BCFG
After 50,000 trials, the standard error of the mean is 0.06

Statistics:	Value
Trials	50000
Mean	20.17
Median	16.98
Mode	---
Standard Deviation	12.50
Variance	156.16
Skewness	1.62
Kurtosis	6.19
Coefficient of Variability	0.62
Range Minimum	3.13
Range Maximum	79.92
Range Width	76.79
Mean Standard Error	0.06



Appendix 4. Monte Carlo Assessment Output—Fractured Reservoirs Assessment Unit (50410201). Contained in this appendix are detailed descriptions of the probability distributions of the results of the assessment of the Fractured Reservoirs AU (50410201). These details may be of use to those conducting further analysis of the results. All distributions in this appendix are fully risked. They include the probability that there are no gas or NGL fields of minimum size or larger. Each distribution is documented by two pages. The first page contains distribution parameters, most importantly the mean, as well as a graph of the probability density function. The second page lists the percentiles (fractiles) of the distribution at 5-percent intervals. Also included are the descriptions of probability distributions of the input based on the input parameters documented in appendix 3. Each of the distributions used in calculating the results is documented by its parameters and a graph of the probability density function. Note that, for the distribution of size of undiscovered oil fields and for the distribution of size of undiscovered gas fields, the parameters of both the shifted and unshifted lognormal distributions are given. Each accompanying graph is that of the unshifted distribution.—Continued

50410201
Fractured Reservoirs
Monte Carlo Results

Forecast: Largest Gas Field (cont'd)

Percentiles:

Percentile	BCFG
100%	3.13
95%	6.55
90%	8.06
85%	9.28
80%	10.40
75%	11.46
70%	12.53
65%	13.59
60%	14.67
55%	15.80
50%	16.98
45%	18.25
40%	19.61
35%	21.15
30%	22.98
25%	25.11
20%	27.84
15%	31.43
10%	36.51
5%	45.78
0%	79.92

End of Forecast

Appendix 4. Monte Carlo Assessment Output—Fractured Reservoirs Assessment Unit (50410201). Contained in this appendix are detailed descriptions of the probability distributions of the results of the assessment of the Fractured Reservoirs AU (50410201). These details may be of use to those conducting further analysis of the results. All distributions in this appendix are fully risked. They include the probability that there are no gas or NGL fields of minimum size or larger. Each distribution is documented by two pages. The first page contains distribution parameters, most importantly the mean, as well as a graph of the probability density function. The second page lists the percentiles (fractiles) of the distribution at 5-percent intervals. Also included are the descriptions of probability distributions of the input based on the input parameters documented in appendix 3. Each of the distributions used in calculating the results is documented by its parameters and a graph of the probability density function. Note that, for the distribution of size of undiscovered oil fields and for the distribution of size of undiscovered gas fields, the parameters of both the shifted and unshifted lognormal distributions are given. Each accompanying graph is that of the unshifted distribution.—Continued

50410201
Fractured Reservoirs
Monte Carlo Results

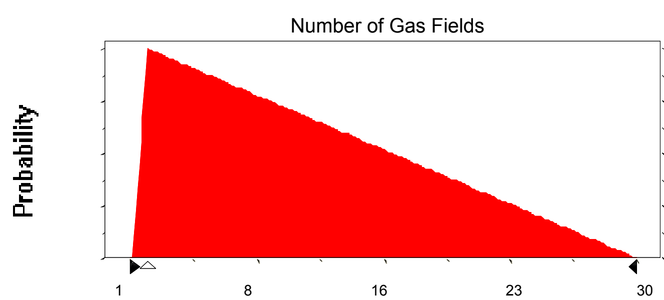
Assumptions

Assumption: Number of Gas Fields

Triangular distribution with parameters:

Minimum	1
Likeliest	2
Maximum	30

Selected range is from 1 to 30



Assumption: Sizes of Gas Fields

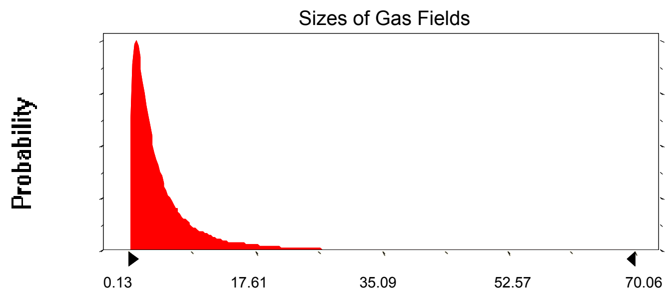
Lognormal distribution with parameters:		Shifted parameters
Mean	5.21	8.21
Standard Deviation	7.39	7.39

Selected range is from 0.00 to 77.00 — 3.00 to 80.00

Appendix 4. Monte Carlo Assessment Output—Fractured Reservoirs Assessment Unit (50410201). Contained in this appendix are detailed descriptions of the probability distributions of the results of the assessment of the Fractured Reservoirs AU (50410201). These details may be of use to those conducting further analysis of the results. All distributions in this appendix are fully risked. They include the probability that there are no gas or NGL fields of minimum size or larger. Each distribution is documented by two pages. The first page contains distribution parameters, most importantly the mean, as well as a graph of the probability density function. The second page lists the percentiles (fractiles) of the distribution at 5-percent intervals. Also included are the descriptions of probability distributions of the input based on the input parameters documented in appendix 3. Each of the distributions used in calculating the results is documented by its parameters and a graph of the probability density function. Note that, for the distribution of size of undiscovered oil fields and for the distribution of size of undiscovered gas fields, the parameters of both the shifted and unshifted lognormal distributions are given. Each accompanying graph is that of the unshifted distribution.—Continued

50410201
Fractured Reservoirs
Monte Carlo Results

Assumption: Sizes of Gas Fields (cont'd)

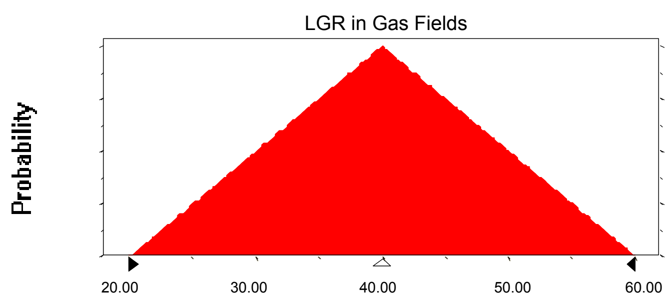


Assumption: LGR in Gas Fields

Triangular distribution with parameters:

Minimum	20.00
Likeliest	40.00
Maximum	60.00

Selected range is from 20.00 to 60.00



End of Assumptions

Simulation started on 9/17/04 at 15:44:56
Simulation stopped on 9/17/04 at 15:46:34

Appendix 5. Basic input data for the Raton Coalbed Gas Assessment Unit (50410181). SEVENTH APPROXIMATION DATA FORM (NOGA, Version 5, 6–30–01). [AU, assessment unit; bcfg, billion cubic feet of gas; bliq/mmcfg, barrels of liquid per million cubic feet of gas; bngl/mmcfg, barrels of natural gas liquids per million cubic feet of gas; cfg/bo, cubic feet of gas per barrel of oil; m, meters; min. minimum; mmboe, million barrels of oil equivalent; ngl, natural gas liquids

FORSPAN ASSESSMENT MODEL FOR CONTINUOUS ACCUMULATIONS--BASIC INPUT DATA FORM (NOGA, Version 9, 2-10-03)

IDENTIFICATION INFORMATION

Assessment Geologist:	D.K. Higley-Feldman	Date:	9/15/2004
Region:	North America	Number:	5
Province:	Raton Basin-Sierra Grande Uplift	Number:	5041
Total Petroleum System:	Upper Cretaceous-Tertiary Coalbed Gas	Number:	504101
Assessment Unit:	Raton Coalbed Gas	Number:	50410181
Based on Data as of:	IHS Energy (PI/Dwights) 2004 (data current through 1 January 2004)		
Notes from Assessor:	Comingled Raton and Vermejo production not included.		

CHARACTERISTICS OF ASSESSMENT UNIT

Assessment-unit type: Oil (<20,000 cfg/bo) **or Gas** (≥20,000 cfg/bo), incl. disc. & pot. additions: Gas

What is the minimum total recovery per cell? 0.02 (mmbo for oil A.U.; bcfg for gas A.U.)

Number of tested cells: 950

Number of tested cells with total recovery per cell ≥ minimum: 430

Established (discovered cells): X Hypothetical (no cells): ____

Median total recovery per cell (for cells ≥ min.): (mmbo for oil A.U.; bcfg for gas A.U.)

1st 3rd discovered 0.25 2nd 3rd 0.3 3rd 3rd 0.25

Assessment-Unit Probabilities:

Attribute	Probability of occurrence (0-1.0)
1. **CHARGE:** Adequate petroleum charge for an untested cell with total recovery ≥ minimum.	1.0
2. **ROCKS:** Adequate reservoirs, traps, seals for an untested cell with total recovery ≥ minimum.	1.0
3. **TIMING:** Favorable geologic timing for an untested cell with total recovery ≥ minimum.	1.0

Assessment-Unit GEOLOGIC Probability (Product of 1, 2, and 3): 1.0

NO. OF UNTESTED CELLS WITH POTENTIAL FOR ADDITIONS TO RESERVES

1. Total assessment-unit area (acres): (uncertainty of a fixed value)

   calculated mean 1,312,000 minimum 1,246,000 mode 1,312,000 maximum 1,378,000

2. Area per cell of untested cells having potential for additions to reserves (acres): (values are inherently variable)

   calculated mean 147 minimum 80 mode 120 maximum 240

   uncertainty of mean: minimum 125 maximum 180

3. Percentage of total assessment-unit area that is untested (%): (uncertainty of a fixed value)

   calculated mean 89 minimum 86 mode 89 maximum 91

Appendix 5. Basic input data for the Raton Coalbed Gas Assessment Unit (50410181). SEVENTH APPROXIMATION DATA FORM (NOGA, Version 5, 6–30–01). [AU, assessment unit; bcfg, billion cubic feet of gas; bliq/mmcfg, barrels of liquid per million cubic feet of gas; bngl/mmcfg, barrels of natural gas liquids per million cubic feet of gas; cfg/bo, cubic feet of gas per barrel of oil; m, meters; min. minimum; mmboe, million barrels of oil equivalent; ngl, natural gas liquids—Continued

Assessment Unit (name, no.)
Raton Coalbed Gas, 50410181

NO. OF UNTESTED CELLS WITH POTENTIAL FOR ADDITIONS TO RESERVES (Continued)

4. Percentage of untested assessment-unit area that has potential for additions to reserves (%):
(a necessary criterion is that total recovery per cell ≥ minimum; uncertainty of a fixed value)

calculated mean 17 minimum 4 mode 13 maximum 34

Geologic evidence for estimates: Infill drilling of existing sweet spots, extension of drilling to east, west, and southeast, and possibility of few new sweet spots in south.

TOTAL RECOVERY PER CELL

Total recovery per cell for untested cells having potential for additions to reserves:
(values are inherently variable; mmbo for oil A.U.; bcfg for gas A.U.)

calculated mean 0.46 minimum 0.02 median 0.25 maximum 8

AVERAGE COPRODUCT RATIOS FOR UNTESTED CELLS, TO ASSESS COPRODUCTS
(uncertainty of fixed but unknown values)

	minimum	mode	maximum
Oil assessment unit:			
Gas/oil ratio (cfg/bo)			
NGL/gas ratio (bngl/mmcfg)			
Gas assessment unit:			
Liquids/gas ratio (bliq/mmcfg)	0	0	0

Appendix 5. Basic input data for the Raton Coalbed Gas Assessment Unit (50410181). SEVENTH APPROXIMATION DATA FORM (NOGA, Version 5, 6–30–01). [AU, assessment unit; bcfg, billion cubic feet of gas; bliq/mmcfg, barrels of liquid per million cubic feet of gas; bngl/mmcfg, barrels of natural gas liquids per million cubic feet of gas; cfg/bo, cubic feet of gas per barrel of oil; m, meters; min. minimum; mmboe, million barrels of oil equivalent; ngl, natural gas liquids—Continued

Assessment Unit (name, no.)
Raton Coalbed Gas, 50410181

SELECTED ANCILLARY DATA FOR UNTESTED CELLS
(values are inherently variable)

Oil assessment unit:	minimum	mode	maximum
API gravity of oil (degrees)			
Sulfur content of oil (%)			
Depth (m) of water (if applicable)			

Drilling depth (m)

minimum	F75	mode	F25	maximum

Gas assessment unit:	minimum	mode	maximum
Inert-gas content (%)			
CO_2 content (%)	0.00	0.50	2.00
Hydrogen sulfide content (%)			
Heating value (BTU)	900	950	1000
Depth (m) of water (if applicable)			

Drilling depth (m)

minimum	F75	mode	F25	maximum
30	213	309	812	1500

Success ratios:	calculated mean	minimum	mode	maximum
Future success ratio (%)	45	20	45	70

Historic success ratio, tested cells (%) 45

Completion practices:

1. Typical well-completion practices (conventional, open hole, open cavity, other) Conventional
2. Fraction of wells drilled that are typically stimulated
3. Predominant type of stimulation (none, frac, acid, other) Possible cavitation
4. Fraction of wells drilled that are horizontal 0

Appendix 5. Basic input data for the Raton Coalbed Gas Assessment Unit (50410181). SEVENTH APPROXIMATION DATA FORM (NOGA, Version 5, 6–30–01). [AU, assessment unit; bcfg, billion cubic feet of gas; bliq/mmcfg, barrels of liquid per million cubic feet of gas; bngl/mmcfg, barrels of natural gas liquids per million cubic feet of gas; cfg/bo, cubic feet of gas per barrel of oil; m, meters; min. minimum; mmboe, million barrels of oil equivalent; ngl, natural gas liquids—Continued

Assessment Unit (name, no.)
Raton Coalbed Gas, 50410181

ALLOCATIONS OF POTENTIAL ADDITIONS TO RESERVES TO STATES
Surface Allocations (uncertainty of a fixed value)

1. Colorado represents 59.14 area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit:			
Volume % in entity			
Gas in gas assessment unit:			
Volume % in entity		60	

2. New Mexico represents 40.86 area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit:			
Volume % in entity			
Gas in gas assessment unit:			
Volume % in entity		40	

3. ________ represents ____ area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit:			
Volume % in entity			
Gas in gas assessment unit:			
Volume % in entity			

4. ________ represents ____ area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit:			
Volume % in entity			
Gas in gas assessment unit:			
Volume % in entity			

5. ________ represents ____ area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit:			
Volume % in entity			
Gas in gas assessment unit:			
Volume % in entity			

6. ________ represents ____ area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit:			
Volume % in entity			
Gas in gas assessment unit:			
Volume % in entity			

Appendix 5. Basic input data for the Raton Coalbed Gas Assessment Unit (50410181). SEVENTH APPROXIMATION DATA FORM (NOGA, Version 5, 6–30–01). [AU, assessment unit; bcfg, billion cubic feet of gas; bliq/mmcfg, barrels of liquid per million cubic feet of gas; bngl/mmcfg, barrels of natural gas liquids per million cubic feet of gas; cfg/bo, cubic feet of gas per barrel of oil; m, meters; min. minimum; mmboe, million barrels of oil equivalent; ngl, natural gas liquids—Continued

Assessment Unit (name, no.)
Raton Coalbed Gas, 50410181

7. ______________ represents ______ area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit:			
Volume % in entity	______	______	______
Gas in gas assessment unit:			
Volume % in entity	______	______	______

8. ______________ represents ______ area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit:			
Volume % in entity	______	______	______
Gas in gas assessment unit:			
Volume % in entity	______	______	______

9. ______________ represents ______ area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit:			
Volume % in entity	______	______	______
Gas in gas assessment unit:			
Volume % in entity	______	______	______

10. ______________ represents ______ area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit:			
Volume % in entity	______	______	______
Gas in gas assessment unit:			
Volume % in entity	______	______	______

11. ______________ represents ______ area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit:			
Volume % in entity	______	______	______
Gas in gas assessment unit:			
Volume % in entity	______	______	______

12. ______________ represents ______ area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit:			
Volume % in entity	______	______	______
Gas in gas assessment unit:			
Volume % in entity	______	______	______

Appendix 5. Basic input data for the Raton Coalbed Gas Assessment Unit (50410181). SEVENTH APPROXIMATION DATA FORM (NOGA, Version 5, 6–30–01). [AU, assessment unit; bcfg, billion cubic feet of gas; bliq/mmcfg, barrels of liquid per million cubic feet of gas; bngl/mmcfg, barrels of natural gas liquids per million cubic feet of gas; cfg/bo, cubic feet of gas per barrel of oil; m, meters; min. minimum; mmboe, million barrels of oil equivalent; ngl, natural gas liquids—Continued

Assessment Unit (name, no.)
Raton Coalbed Gas, 50410181

ALLOCATIONS OF POTENTIAL ADDITIONS TO RESERVES TO GENERAL LAND OWNERSHIPS
Surface Allocations (uncertainty of a fixed value)

1. Federal Lands represents 7.81 area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit: Volume % in entity			
Gas in gas assessment unit: Volume % in entity		5.4	

2. Private Lands represents 89.23 area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit: Volume % in entity			
Gas in gas assessment unit: Volume % in entity		90.4	

3. Tribal Lands represents ____ area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit: Volume % in entity			
Gas in gas assessment unit: Volume % in entity			

4. Other Lands represents ____ area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit: Volume % in entity			
Gas in gas assessment unit: Volume % in entity			

5. Colorado State Lands represents 2.54 area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit: Volume % in entity			
Gas in gas assessment unit: Volume % in entity		4	

6. New Mexico State Lands represents 0.41 area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit: Volume % in entity			
Gas in gas assessment unit: Volume % in entity		0.2	

Appendix 5. Basic input data for the Raton Coalbed Gas Assessment Unit (50410181). SEVENTH APPROXIMATION DATA FORM (NOGA, Version 5, 6–30–01). [AU, assessment unit; bcfg, billion cubic feet of gas; bliq/mmcfg, barrels of liquid per million cubic feet of gas; bngl/mmcfg, barrels of natural gas liquids per million cubic feet of gas; cfg/bo, cubic feet of gas per barrel of oil; m, meters; min. minimum; mmboe, million barrels of oil equivalent; ngl, natural gas liquids—Continued

Assessment Unit (name, no.)
Raton Coalbed Gas, 50410181

7. ________ represents ________ area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit:			
Volume % in entity			
Gas in gas assessment unit:			
Volume % in entity			

8. ________ represents ________ area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit:			
Volume % in entity			
Gas in gas assessment unit:			
Volume % in entity			

9. ________ represents ________ area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit:			
Volume % in entity			
Gas in gas assessment unit:			
Volume % in entity			

10. ________ represents ________ area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit:			
Volume % in entity			
Gas in gas assessment unit:			
Volume % in entity			

11. ________ represents ________ area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit:			
Volume % in entity			
Gas in gas assessment unit:			
Volume % in entity			

12. ________ represents ________ area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit:			
Volume % in entity			
Gas in gas assessment unit:			
Volume % in entity			

Appendix 5. Basic input data for the Raton Coalbed Gas Assessment Unit (50410181). SEVENTH APPROXIMATION DATA FORM (NOGA, Version 5, 6–30–01). [AU, assessment unit; bcfg, billion cubic feet of gas; bliq/mmcfg, barrels of liquid per million cubic feet of gas; bngl/mmcfg, barrels of natural gas liquids per million cubic feet of gas; cfg/bo, cubic feet of gas per barrel of oil; m, meters; min. minimum; mmboe, million barrels of oil equivalent; ngl, natural gas liquids—Continued

Assessment Unit (name, no.)
Raton Coalbed Gas, 50410181

ALLOCATIONS OF POTENTIAL ADDITIONS TO RESERVES TO FEDERAL LAND SUBDIVISIONS
Surface Allocations (uncertainty of a fixed value)

1. Bureau of Land Management (BLM) represents 1.75 area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit:			
Volume % in entity			
Gas in gas assessment unit:			
Volume % in entity		1.4	

2. BLM Wilderness Areas (BLMW) represents ____ area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit:			
Volume % in entity			
Gas in gas assessment unit:			
Volume % in entity			

3. BLM Roadless Areas (BLMR) represents ____ area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit:			
Volume % in entity			
Gas in gas assessment unit:			
Volume % in entity			

4. National Park Service (NPS) represents ____ area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit:			
Volume % in entity			
Gas in gas assessment unit:			
Volume % in entity			

5. NPS Wilderness Areas (NPSW) represents ____ area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit:			
Volume % in entity			
Gas in gas assessment unit:			
Volume % in entity			

6. NPS Protected Withdrawals (NPSP) represents ____ area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit:			
Volume % in entity			
Gas in gas assessment unit:			
Volume % in entity			

Appendix 5. Basic input data for the Raton Coalbed Gas Assessment Unit (50410181). SEVENTH APPROXIMATION DATA FORM (NOGA, Version 5, 6–30–01). [AU, assessment unit; bcfg, billion cubic feet of gas; bliq/mmcfg, barrels of liquid per million cubic feet of gas; bngl/mmcfg, barrels of natural gas liquids per million cubic feet of gas; cfg/bo, cubic feet of gas per barrel of oil; m, meters; min. minimum; mmboe, million barrels of oil equivalent; ngl, natural gas liquids—Continued

Assessment Unit (name, no.)
Raton Coalbed Gas, 50410181

7. US Forest Service (FS) represents 6.06 area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit:			
Volume % in entity			
Gas in gas assessment unit:			
Volume % in entity		4	

8. USFS Wilderness Areas (FSW) represents ______ area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit:			
Volume % in entity			
Gas in gas assessment unit:			
Volume % in entity			

9. USFS Roadless Areas (FSR) represents ______ area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit:			
Volume % in entity			
Gas in gas assessment unit:			
Volume % in entity			

10. USFS Protected Withdrawals (FSP) represents ______ area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit:			
Volume % in entity			
Gas in gas assessment unit:			
Volume % in entity			

11. US Fish and Wildlife Service (FWS) represents ______ area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit:			
Volume % in entity			
Gas in gas assessment unit:			
Volume % in entity			

12. USFWS Wilderness Areas (FWSW) represents ______ area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit:			
Volume % in entity			
Gas in gas assessment unit:			
Volume % in entity			

Appendix 5. Basic input data for the Raton Coalbed Gas Assessment Unit (50410181). SEVENTH APPROXIMATION DATA FORM (NOGA, Version 5, 6–30–01). [AU, assessment unit; bcfg, billion cubic feet of gas; bliq/mmcfg, barrels of liquid per million cubic feet of gas; bngl/mmcfg, barrels of natural gas liquids per million cubic feet of gas; cfg/bo, cubic feet of gas per barrel of oil; m, meters; min. minimum; mmboe, million barrels of oil equivalent; ngl, natural gas liquids—Continued

Assessment Unit (name, no.)
Raton Coalbed Gas, 50410181

13. USFWS Protected Withdrawals (FWSP) represents ______ area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit:			
Volume % in entity	______	______	______
Gas in gas assessment unit:			
Volume % in entity	______	______	______

14. Wilderness Study Areas (WS) represents ______ area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit:			
Volume % in entity	______	______	______
Gas in gas assessment unit:			
Volume % in entity	______	______	______

15. Department of Energy (DOE) represents ______ area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit:			
Volume % in entity	______	______	______
Gas in gas assessment unit:			
Volume % in entity	______	______	______

16. Department of Defense (DOD) represents ______ area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit:			
Volume % in entity	______	______	______
Gas in gas assessment unit:			
Volume % in entity	______	______	______

17. Bureau of Reclamation (BOR) represents ______ area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit:			
Volume % in entity	______	______	______
Gas in gas assessment unit:			
Volume % in entity	______	______	______

18. Tennessee Valley Authority (TVA) represents ______ area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit:			
Volume % in entity	______	______	______
Gas in gas assessment unit:			
Volume % in entity	______	______	______

Appendix 5. Basic input data for the Raton Coalbed Gas Assessment Unit (50410181). SEVENTH APPROXIMATION DATA FORM (NOGA, Version 5, 6–30–01). [AU, assessment unit; bcfg, billion cubic feet of gas; bliq/mmcfg, barrels of liquid per million cubic feet of gas; bngl/mmcfg, barrels of natural gas liquids per million cubic feet of gas; cfg/bo, cubic feet of gas per barrel of oil; m, meters; min. minimum; mmboe, million barrels of oil equivalent; ngl, natural gas liquids—Continued

Assessment Unit (name, no.)
Raton Coalbed Gas, 50410181

19. Other Federal ________ represents ________ area % of the AU

Oil in oil assessment unit:	minimum	mode	maximum
Volume % in entity	________	________	________
Gas in gas assessment unit:			
Volume % in entity	________	________	________

20. ________ represents ________ area % of the AU

Oil in oil assessment unit:	minimum	mode	maximum
Volume % in entity	________	________	________
Gas in gas assessment unit:			
Volume % in entity	________	________	________

Appendix 5. Basic input data for the Raton Coalbed Gas Assessment Unit (50410181). SEVENTH APPROXIMATION DATA FORM (NOGA, Version 5, 6–30–01). [AU, assessment unit; bcfg, billion cubic feet of gas; bliq/mmcfg, barrels of liquid per million cubic feet of gas; bngl/mmcfg, barrels of natural gas liquids per million cubic feet of gas; cfg/bo, cubic feet of gas per barrel of oil; m, meters; min. minimum; mmboe, million barrels of oil equivalent; ngl, natural gas liquids—Continued

Assessment Unit (name, no.)
Raton Coalbed Gas, 50410181

ALLOCATIONS OF POTENTIAL ADDITIONS TO RESERVES TO ECOSYSTEMS
Surface Allocations (uncertainty of a fixed value)

1. Arkansas Tablelands (ARTL) represents 6.03 area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit:			
Volume % in entity			
Gas in gas assessment unit:			
Volume % in entity		6	

2. Southern Parks and Ranges (SPRA) represents 93.97 area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit:			
Volume % in entity			
Gas in gas assessment unit:			
Volume % in entity		94	

3. ______ represents ______ area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit:			
Volume % in entity			
Gas in gas assessment unit:			
Volume % in entity			

4. ______ represents ______ area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit:			
Volume % in entity			
Gas in gas assessment unit:			
Volume % in entity			

5. ______ represents ______ area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit:			
Volume % in entity			
Gas in gas assessment unit:			
Volume % in entity			

6. ______ represents ______ area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit:			
Volume % in entity			
Gas in gas assessment unit:			
Volume % in entity			

Appendix 5. Basic input data for the Raton Coalbed Gas Assessment Unit (50410181). SEVENTH APPROXIMATION DATA FORM (NOGA, Version 5, 6–30–01). [AU, assessment unit; bcfg, billion cubic feet of gas; bliq/mmcfg, barrels of liquid per million cubic feet of gas; bngl/mmcfg, barrels of natural gas liquids per million cubic feet of gas; cfg/bo, cubic feet of gas per barrel of oil; m, meters; min. minimum; mmboe, million barrels of oil equivalent; ngl, natural gas liquids—Continued

Assessment Unit (name, no.)
Raton Coalbed Gas, 50410181

7. ______________________ represents ________ area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit:			
Volume % in entity	________	________	________
Gas in gas assessment unit:			
Volume % in entity	________	________	________

8. ______________________ represents ________ area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit:			
Volume % in entity	________	________	________
Gas in gas assessment unit:			
Volume % in entity	________	________	________

9. ______________________ represents ________ area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit:			
Volume % in entity	________	________	________
Gas in gas assessment unit:			
Volume % in entity	________	________	________

10. ______________________ represents ________ area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit:			
Volume % in entity	________	________	________
Gas in gas assessment unit:			
Volume % in entity	________	________	________

11. ______________________ represents ________ area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit:			
Volume % in entity	________	________	________
Gas in gas assessment unit:			
Volume % in entity	________	________	________

12. ______________________ represents ________ area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit:			
Volume % in entity	________	________	________
Gas in gas assessment unit:			
Volume % in entity	________	________	________

Appendix 6. Basic input data for the Vermejo Coalbed Gas Assessment Unit (50410182). SEVENTH APPROXIMATION DATA FORM (NOGA, Version 5, 6–30–01). [AU, assessment unit; bcfg, billion cubic feet of gas; bliq/mmcfg, barrels of liquid per million cubic feet of gas; bngl/mmcfg, barrels of natural gas liquids per million cubic feet of gas; cfg/bo, cubic feet of gas per barrel of oil; m, meters; min. minimum; mmboe, million barrels of oil equivalent; ngl, natural gas liquids]

FORSPAN ASSESSMENT MODEL FOR CONTINUOUS ACCUMULATIONS--BASIC INPUT DATA FORM (NOGA, Version 9, 2-10-03)

IDENTIFICATION INFORMATION

Assessment Geologist:	D.K. Higley-Feldman	Date:	9/14/2004
Region:	North America	Number:	5
Province:	Raton Basin-Sierra Grande Uplift	Number:	5041
Total Petroleum System:	Upper Cretaceous-Tertiary Coalbed Gas	Number:	504101
Assessment Unit:	Vermejo Coalbed Gas	Number:	50410182
Based on Data as of:	IHS Energy (PI/Dwights) 2004 (data current through 1 January 2004)		
Notes from Assessor:	Comingled Raton and Vermejo production not included.		

CHARACTERISTICS OF ASSESSMENT UNIT

Assessment-unit type: Oil (<20,000 cfg/bo) **or Gas** (≥20,000 cfg/bo), incl. disc. & pot. additions: Gas

What is the minimum total recovery per cell? 0.02 (mmbo for oil A.U.; bcfg for gas A.U.)

Number of tested cells: 1700

Number of tested cells with total recovery per cell ≥ minimum: 1200

Established (discovered cells): X Hypothetical (no cells): ____

Median total recovery per cell (for cells ≥ min.): (mmbo for oil A.U.; bcfg for gas A.U.)

1st 3rd discovered 0.81 2nd 3rd 0.35 3rd 3rd 0.2

Assessment-Unit Probabilities:

Attribute	Probability of occurrence (0-1.0)
1. **CHARGE:** Adequate petroleum charge for an untested cell with total recovery ≥ minimum.	1.0
2. **ROCKS:** Adequate reservoirs, traps, seals for an untested cell with total recovery ≥ minimum.	1.0
3. **TIMING:** Favorable geologic timing for an untested cell with total recovery ≥ minimum.	1.0

Assessment-Unit GEOLOGIC Probability (Product of 1, 2, and 3): 1.0

NO. OF UNTESTED CELLS WITH POTENTIAL FOR ADDITIONS TO RESERVES

1. Total assessment-unit area (acres): (uncertainty of a fixed value)

   calculated mean 1,312,000 minimum 1,246,000 mode 1,312,000 maximum 1,378,000

2. Area per cell of untested cells having potential for additions to reserves (acres): (values are inherently variable)

   calculated mean 147 minimum 80 mode 120 maximum 240

   uncertainty of mean: minimum 125 maximum 180

3. Percentage of total assessment-unit area that is untested (%): (uncertainty of a fixed value)

   calculated mean 80 minimum 75 mode 81 maximum 85

Appendix 6. Basic input data for the Vermejo Coalbed Gas Assessment Unit (50410182). SEVENTH APPROXIMATION DATA FORM (NOGA, Version 5, 6–30–01). [AU, assessment unit; bcfg, billion cubic feet of gas; bliq/mmcfg, barrels of liquid per million cubic feet of gas; bngl/mmcfg, barrels of natural gas liquids per million cubic feet of gas; cfg/bo, cubic feet of gas per barrel of oil; m, meters; min. minimum; mmboe, million barrels of oil equivalent; ngl, natural gas liquids]—Continued

Assessment Unit (name, no.)
Vermejo Coalbed Gas, 50410182

NO. OF UNTESTED CELLS WITH POTENTIAL FOR ADDITIONS TO RESERVES (Continued)

4. Percentage of untested assessment-unit area that has potential for additions to reserves (%):
(a necessary criterion is that total recovery per cell ≥ minimum; uncertainty of a fixed value)

calculated mean 28 minimum 10 mode 25 maximum 50

Geologic evidence for estimates: Infill drilling of existing sweet spots, extension of drilling to east, west, and southeast, and possibility of few new sweet spots in south.

TOTAL RECOVERY PER CELL

Total recovery per cell for untested cells having potential for additions to reserves:
(values are inherently variable; mmbo for oil A.U.; bcfg for gas A.U.)

calculated mean 0.49 minimum 0.02 median 0.25 maximum 9.5

AVERAGE COPRODUCT RATIOS FOR UNTESTED CELLS, TO ASSESS COPRODUCTS
(uncertainty of fixed but unknown values)

	minimum	mode	maximum
Oil assessment unit:			
Gas/oil ratio (cfg/bo)			
NGL/gas ratio (bngl/mmcfg)			
Gas assessment unit:			
Liquids/gas ratio (bliq/mmcfg)	0	0	0

Appendix 6. Basic input data for the Vermejo Coalbed Gas Assessment Unit (50410182). SEVENTH APPROXIMATION DATA FORM (NOGA, Version 5, 6–30–01). [AU, assessment unit; bcfg, billion cubic feet of gas; bliq/mmcfg, barrels of liquid per million cubic feet of gas; bngl/mmcfg, barrels of natural gas liquids per million cubic feet of gas; cfg/bo, cubic feet of gas per barrel of oil; m, meters; min. minimum; mmboe, million barrels of oil equivalent; ngl, natural gas liquids]—Continued

Assessment Unit (name, no.)
Vermejo Coalbed Gas, 50410182

SELECTED ANCILLARY DATA FOR UNTESTED CELLS

(values are inherently variable)

Oil assessment unit:	minimum	mode	maximum
API gravity of oil (degrees)			
Sulfur content of oil (%)			
Depth (m) of water (if applicable)			

Drilling depth (m)

minimum	F75	mode	F25	maximum

Gas assessment unit:	minimum	mode	maximum
Inert-gas content (%)			
CO_2 content (%)	0.00	0.50	2.00
Hydrogen sulfide content (%)	0.00	0.00	0.00
Heating value (BTU)	900	950	1000
Depth (m) of water (if applicable)			

Drilling depth (m)

minimum	F75	mode	F25	maximum
30	547	280	1009	1600

Success ratios:	calculated mean	minimum	mode	maximum
Future success ratio (%)	55	35	55	75

Historic success ratio, tested cells (%) 70.6

Completion practices:

1. Typical well-completion practices (conventional, open hole, open cavity, other) Conventional
2. Fraction of wells drilled that are typically stimulated ______
3. Predominant type of stimulation (none, frac, acid, other) Possible cavitation
4. Fraction of wells drilled that are horizontal 0

Appendix 6. Basic input data for the Vermejo Coalbed Gas Assessment Unit (50410182). SEVENTH APPROXIMATION DATA FORM (NOGA, Version 5, 6–30–01). [AU, assessment unit; bcfg, billion cubic feet of gas; bliq/mmcfg, barrels of liquid per million cubic feet of gas; bngl/mmcfg, barrels of natural gas liquids per million cubic feet of gas; cfg/bo, cubic feet of gas per barrel of oil; m, meters; min. minimum; mmboe, million barrels of oil equivalent; ngl, natural gas liquids]—Continued

Assessment Unit (name, no.)
Vermejo Coalbed Gas, 50410182

ALLOCATIONS OF POTENTIAL ADDITIONS TO RESERVES TO STATES
Surface Allocations (uncertainty of a fixed value)

1. Colorado represents 59.14 area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit: Volume % in entity			
Gas in gas assessment unit: Volume % in entity		40	

2. New Mexico represents 40.86 area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit: Volume % in entity			
Gas in gas assessment unit: Volume % in entity		60	

3. ______ represents ______ area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit: Volume % in entity			
Gas in gas assessment unit: Volume % in entity			

4. ______ represents ______ area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit: Volume % in entity			
Gas in gas assessment unit: Volume % in entity			

5. ______ represents ______ area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit: Volume % in entity			
Gas in gas assessment unit: Volume % in entity			

6. ______ represents ______ area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit: Volume % in entity			
Gas in gas assessment unit: Volume % in entity			

Appendix 6. Basic input data for the Vermejo Coalbed Gas Assessment Unit (50410182). SEVENTH APPROXIMATION DATA FORM (NOGA, Version 5, 6–30–01). [AU, assessment unit; bcfg, billion cubic feet of gas; bliq/mmcfg, barrels of liquid per million cubic feet of gas; bngl/mmcfg, barrels of natural gas liquids per million cubic feet of gas; cfg/bo, cubic feet of gas per barrel of oil; m, meters; min. minimum; mmboe, million barrels of oil equivalent; ngl, natural gas liquids]—Continued

Assessment Unit (name, no.)
Vermejo Coalbed Gas, 50410182

7. ______________________ represents ________ area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit:			
Volume % in entity	____	____	____
Gas in gas assessment unit:			
Volume % in entity	____	____	____

8. ______________________ represents ________ area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit:			
Volume % in entity	____	____	____
Gas in gas assessment unit:			
Volume % in entity	____	____	____

9. ______________________ represents ________ area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit:			
Volume % in entity	____	____	____
Gas in gas assessment unit:			
Volume % in entity	____	____	____

10. ______________________ represents ________ area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit:			
Volume % in entity	____	____	____
Gas in gas assessment unit:			
Volume % in entity	____	____	____

11. ______________________ represents ________ area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit:			
Volume % in entity	____	____	____
Gas in gas assessment unit:			
Volume % in entity	____	____	____

12. ______________________ represents ________ area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit:			
Volume % in entity	____	____	____
Gas in gas assessment unit:			
Volume % in entity	____	____	____

Appendix 6. Basic input data for the Vermejo Coalbed Gas Assessment Unit (50410182). SEVENTH APPROXIMATION DATA FORM (NOGA, Version 5, 6–30–01). [AU, assessment unit; bcfg, billion cubic feet of gas; bliq/mmcfg, barrels of liquid per million cubic feet of gas; bngl/mmcfg, barrels of natural gas liquids per million cubic feet of gas; cfg/bo, cubic feet of gas per barrel of oil; m, meters; min. minimum; mmboe, million barrels of oil equivalent; ngl, natural gas liquids]—Continued

Assessment Unit (name, no.)
Vermejo Coalbed Gas, 50410182

ALLOCATIONS OF POTENTIAL ADDITIONS TO RESERVES TO GENERAL LAND OWNERSHIPS
Surface Allocations (uncertainty of a fixed value)

1. Federal Lands represents 7.81 area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit: Volume % in entity			
Gas in gas assessment unit: Volume % in entity		5.4	

2. Private Lands represents 89.23 area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit: Volume % in entity			
Gas in gas assessment unit: Volume % in entity		90.4	

3. Tribal Lands represents ____ area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit: Volume % in entity			
Gas in gas assessment unit: Volume % in entity			

4. Other Lands represents ____ area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit: Volume % in entity			
Gas in gas assessment unit: Volume % in entity			

5. Colorado State Lands represents 2.54 area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit: Volume % in entity			
Gas in gas assessment unit: Volume % in entity		4	

6. New Mexico State Lands represents 0.41 area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit: Volume % in entity			
Gas in gas assessment unit: Volume % in entity		0.2	

Appendix 6. Basic input data for the Vermejo Coalbed Gas Assessment Unit (50410182). SEVENTH APPROXIMATION DATA FORM (NOGA, Version 5, 6–30–01). [AU, assessment unit; bcfg, billion cubic feet of gas; bliq/mmcfg, barrels of liquid per million cubic feet of gas; bngl/mmcfg, barrels of natural gas liquids per million cubic feet of gas; cfg/bo, cubic feet of gas per barrel of oil; m, meters; min. minimum; mmboe, million barrels of oil equivalent; ngl, natural gas liquids]—Continued

Assessment Unit (name, no.)
Vermejo Coalbed Gas, 50410182

7. ____________________ represents ________ area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit:			
Volume % in entity	________	________	________
Gas in gas assessment unit:			
Volume % in entity	________	________	________

8. ____________________ represents ________ area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit:			
Volume % in entity	________	________	________
Gas in gas assessment unit:			
Volume % in entity	________	________	________

9. ____________________ represents ________ area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit:			
Volume % in entity	________	________	________
Gas in gas assessment unit:			
Volume % in entity	________	________	________

10. ____________________ represents ________ area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit:			
Volume % in entity	________	________	________
Gas in gas assessment unit:			
Volume % in entity	________	________	________

11. ____________________ represents ________ area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit:			
Volume % in entity	________	________	________
Gas in gas assessment unit:			
Volume % in entity	________	________	________

12. ____________________ represents ________ area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit:			
Volume % in entity	________	________	________
Gas in gas assessment unit:			
Volume % in entity	________	________	________

Appendix 6. Basic input data for the Vermejo Coalbed Gas Assessment Unit (50410182). SEVENTH APPROXIMATION DATA FORM (NOGA, Version 5, 6–30–01). [AU, assessment unit; bcfg, billion cubic feet of gas; bliq/mmcfg, barrels of liquid per million cubic feet of gas; bngl/mmcfg, barrels of natural gas liquids per million cubic feet of gas; cfg/bo, cubic feet of gas per barrel of oil; m, meters; min. minimum; mmboe, million barrels of oil equivalent; ngl, natural gas liquids]—Continued

Assessment Unit (name, no.)
Vermejo Coalbed Gas, 50410182

ALLOCATIONS OF POTENTIAL ADDITIONS TO RESERVES TO FEDERAL LAND SUBDIVISIONS
Surface Allocations (uncertainty of a fixed value)

1. Bureau of Land Management (BLM) represents 1.75 area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit: Volume % in entity			
Gas in gas assessment unit: Volume % in entity		1.4	

2. BLM Wilderness Areas (BLMW) represents ____ area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit: Volume % in entity			
Gas in gas assessment unit: Volume % in entity			

3. BLM Roadless Areas (BLMR) represents ____ area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit: Volume % in entity			
Gas in gas assessment unit: Volume % in entity			

4. National Park Service (NPS) represents ____ area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit: Volume % in entity			
Gas in gas assessment unit: Volume % in entity			

5. NPS Wilderness Areas (NPSW) represents ____ area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit: Volume % in entity			
Gas in gas assessment unit: Volume % in entity			

6. NPS Protected Withdrawals (NPSP) represents ____ area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit: Volume % in entity			
Gas in gas assessment unit: Volume % in entity			

Appendix 6. Basic input data for the Vermejo Coalbed Gas Assessment Unit (50410182). SEVENTH APPROXIMATION DATA FORM (NOGA, Version 5, 6–30–01). [AU, assessment unit; bcfg, billion cubic feet of gas; bliq/mmcfg, barrels of liquid per million cubic feet of gas; bngl/mmcfg, barrels of natural gas liquids per million cubic feet of gas; cfg/bo, cubic feet of gas per barrel of oil; m, meters; min. minimum; mmboe, million barrels of oil equivalent; ngl, natural gas liquids]—Continued

Assessment Unit (name, no.)
Vermejo Coalbed Gas, 50410182

7. US Forest Service (FS) represents 6.06 area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit:			
Volume % in entity			
Gas in gas assessment unit:			
Volume % in entity		4	

8. USFS Wilderness Areas (FSW) represents ____ area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit:			
Volume % in entity			
Gas in gas assessment unit:			
Volume % in entity			

9. USFS Roadless Areas (FSR) represents ____ area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit:			
Volume % in entity			
Gas in gas assessment unit:			
Volume % in entity			

10. USFS Protected Withdrawals (FSP) represents ____ area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit:			
Volume % in entity			
Gas in gas assessment unit:			
Volume % in entity			

11. US Fish and Wildlife Service (FWS) represents ____ area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit:			
Volume % in entity			
Gas in gas assessment unit:			
Volume % in entity			

12. USFWS Wilderness Areas (FWSW) represents ____ area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit:			
Volume % in entity			
Gas in gas assessment unit:			
Volume % in entity			

Appendix 6. Basic input data for the Vermejo Coalbed Gas Assessment Unit (50410182). SEVENTH APPROXIMATION DATA FORM (NOGA, Version 5, 6–30–01). [AU, assessment unit; bcfg, billion cubic feet of gas; bliq/mmcfg, barrels of liquid per million cubic feet of gas; bngl/mmcfg, barrels of natural gas liquids per million cubic feet of gas; cfg/bo, cubic feet of gas per barrel of oil; m, meters; min. minimum; mmboe, million barrels of oil equivalent; ngl, natural gas liquids]—Continued

Assessment Unit (name, no.)
Vermejo Coalbed Gas, 50410182

13. USFWS Protected Withdrawals (FWSP) represents ______ area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit:			
Volume % in entity			
Gas in gas assessment unit:			
Volume % in entity			

14. Wilderness Study Areas (WS) represents ______ area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit:			
Volume % in entity			
Gas in gas assessment unit:			
Volume % in entity			

15. Department of Energy (DOE) represents ______ area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit:			
Volume % in entity			
Gas in gas assessment unit:			
Volume % in entity			

16. Department of Defense (DOD) represents ______ area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit:			
Volume % in entity			
Gas in gas assessment unit:			
Volume % in entity			

17. Bureau of Reclamation (BOR) represents ______ area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit:			
Volume % in entity			
Gas in gas assessment unit:			
Volume % in entity			

18. Tennessee Valley Authority (TVA) represents ______ area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit:			
Volume % in entity			
Gas in gas assessment unit:			
Volume % in entity			

Appendix 6. Basic input data for the Vermejo Coalbed Gas Assessment Unit (50410182). SEVENTH APPROXIMATION DATA FORM (NOGA, Version 5, 6–30–01). [AU, assessment unit; bcfg, billion cubic feet of gas; bliq/mmcfg, barrels of liquid per million cubic feet of gas; bngl/mmcfg, barrels of natural gas liquids per million cubic feet of gas; cfg/bo, cubic feet of gas per barrel of oil; m, meters; min. minimum; mmboe, million barrels of oil equivalent; ngl, natural gas liquids]—Continued

Assessment Unit (name, no.)
Vermejo Coalbed Gas, 50410182

19. Other Federal ______ represents ______ area % of the AU

Oil in oil assessment unit:	minimum	mode	maximum
Volume % in entity			
Gas in gas assessment unit:			
Volume % in entity			

20. ______ represents ______ area % of the AU

Oil in oil assessment unit:	minimum	mode	maximum
Volume % in entity			
Gas in gas assessment unit:			
Volume % in entity			

Appendix 6. Basic input data for the Vermejo Coalbed Gas Assessment Unit (50410182). SEVENTH APPROXIMATION DATA FORM (NOGA, Version 5, 6–30–01). [AU, assessment unit; bcfg, billion cubic feet of gas; bliq/mmcfg, barrels of liquid per million cubic feet of gas; bngl/mmcfg, barrels of natural gas liquids per million cubic feet of gas; cfg/bo, cubic feet of gas per barrel of oil; m, meters; min. minimum; mmboe, million barrels of oil equivalent; ngl, natural gas liquids]—Continued

Assessment Unit (name, no.)
Vermejo Coalbed Gas, 50410182

ALLOCATIONS OF POTENTIAL ADDITIONS TO RESERVES TO ECOSYSTEMS
Surface Allocations (uncertainty of a fixed value)

1. Arkansas Tablelands (ARTL) represents 6.03 area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit:			
Volume % in entity			
Gas in gas assessment unit:			
Volume % in entity		5	

2. Southern Parks and Ranges (SPRA) represents 93.97 area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit:			
Volume % in entity			
Gas in gas assessment unit:			
Volume % in entity		95	

3. ______ represents ______ area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit:			
Volume % in entity			
Gas in gas assessment unit:			
Volume % in entity			

4. ______ represents ______ area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit:			
Volume % in entity			
Gas in gas assessment unit:			
Volume % in entity			

5. ______ represents ______ area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit:			
Volume % in entity			
Gas in gas assessment unit:			
Volume % in entity			

6. ______ represents ______ area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit:			
Volume % in entity			
Gas in gas assessment unit:			
Volume % in entity			

Appendix 6. Basic input data for the Vermejo Coalbed Gas Assessment Unit (50410182). SEVENTH APPROXIMATION DATA FORM (NOGA, Version 5, 6–30–01). [AU, assessment unit; bcfg, billion cubic feet of gas; bliq/mmcfg, barrels of liquid per million cubic feet of gas; bngl/mmcfg, barrels of natural gas liquids per million cubic feet of gas; cfg/bo, cubic feet of gas per barrel of oil; m, meters; min. minimum; mmboe, million barrels of oil equivalent; ngl, natural gas liquids]—Continued

Assessment Unit (name, no.)
Vermejo Coalbed Gas, 50410182

7. __________ represents ______ area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit:			
Volume % in entity	____	____	____
Gas in gas assessment unit:			
Volume % in entity	____	____	____

8. __________ represents ______ area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit:			
Volume % in entity	____	____	____
Gas in gas assessment unit:			
Volume % in entity	____	____	____

9. __________ represents ______ area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit:			
Volume % in entity	____	____	____
Gas in gas assessment unit:			
Volume % in entity	____	____	____

10. __________ represents ______ area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit:			
Volume % in entity	____	____	____
Gas in gas assessment unit:			
Volume % in entity	____	____	____

11. __________ represents ______ area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit:			
Volume % in entity	____	____	____
Gas in gas assessment unit:			
Volume % in entity	____	____	____

12. __________ represents ______ area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit:			
Volume % in entity	____	____	____
Gas in gas assessment unit:			
Volume % in entity	____	____	____

Appendix 7. Basic input data for the Upper Cretaceous–Tertiary Sandstones Assessment Unit (50410101). SEVENTH APPROXIMATION DATA FORM (NOGA, Version 5, 6–30–01). [AU, assessment unit; bcfg, billion cubic feet of gas; bliq/mmcfg, barrels of liquid per million cubic feet of gas; bngl/mmcfg, barrels of natural gas liquids per million cubic feet of gas; cfg/bo, cubic feet of gas per barrel of oil; m, meters; min. minimum; mmboe, million barrels of oil equivalent; ngl, natural gas liquids]

FORSPAN ASSESSMENT MODEL FOR CONTINUOUS ACCUMULATIONS--BASIC INPUT DATA FORM (NOGA, Version 9, 2-10-03)

IDENTIFICATION INFORMATION

Assessment Geologist:	D.K. Higley-Feldman	Date:	9/14/2004
Region:	North America	Number:	5
Province:	Raton Basin-Sierra Grande Uplift	Number:	5041
Total Petroleum System:	Upper Cretaceous-Tertiary Coalbed Gas	Number:	504101
Assessment Unit:	Vermejo Coalbed Gas	Number:	50410182
Based on Data as of:	IHS Energy (PI/Dwights) 2004 (data current through 1 January 2004)		
Notes from Assessor:	Comingled Raton and Vermejo production not included.		

CHARACTERISTICS OF ASSESSMENT UNIT

Assessment-unit type: Oil (<20,000 cfg/bo) **or Gas** (≥20,000 cfg/bo), incl. disc. & pot. additions: Gas

What is the minimum total recovery per cell? 0.02 (mmbo for oil A.U.; bcfg for gas A.U.)

Number of tested cells: 1700

Number of tested cells with total recovery per cell ≥ minimum: 1200

Established (discovered cells): X Hypothetical (no cells): ____

Median total recovery per cell (for cells ≥ min.): (mmbo for oil A.U.; bcfg for gas A.U.)

1st 3rd discovered 0.81 2nd 3rd 0.35 3rd 3rd 0.2

Assessment-Unit Probabilities:

Attribute	Probability of occurrence (0-1.0)
1. **CHARGE:** Adequate petroleum charge for an untested cell with total recovery ≥ minimum.	1.0
2. **ROCKS:** Adequate reservoirs, traps, seals for an untested cell with total recovery ≥ minimum.	1.0
3. **TIMING:** Favorable geologic timing for an untested cell with total recovery ≥ minimum.	1.0

Assessment-Unit GEOLOGIC Probability (Product of 1, 2, and 3): 1.0

NO. OF UNTESTED CELLS WITH POTENTIAL FOR ADDITIONS TO RESERVES

1. Total assessment-unit area (acres): (uncertainty of a fixed value)

   calculated mean 1,312,000 minimum 1,246,000 mode 1,312,000 maximum 1,378,000

2. Area per cell of untested cells having potential for additions to reserves (acres): (values are inherently variable)

   calculated mean 147 minimum 80 mode 120 maximum 240

   uncertainty of mean: minimum 125 maximum 180

3. Percentage of total assessment-unit area that is untested (%): (uncertainty of a fixed value)

   calculated mean 80 minimum 75 mode 81 maximum 85

Appendix 7. Basic input data for the Upper Cretaceous–Tertiary Sandstones Assessment Unit (50410101). SEVENTH APPROXIMATION DATA FORM (NOGA, Version 5, 6–30–01). [AU, assessment unit; bcfg, billion cubic feet of gas; bliq/mmcfg, barrels of liquid per million cubic feet of gas; bngl/mmcfg, barrels of natural gas liquids per million cubic feet of gas; cfg/bo, cubic feet of gas per barrel of oil; m, meters; min. minimum; mmboe, million barrels of oil equivalent; ngl, natural gas liquids]—Continued

Assessment Unit (name, no.)
Upper Cretaceous-Tertiary Sandstones, 50410101

AVERAGE RATIOS FOR UNDISCOVERED ACCUMS., TO ASSESS COPRODUCTS
(uncertainty of fixed but unknown values)

Oil Accumulations:	minimum	mode	maximum
Gas/oil ratio (cfg/bo)			
NGL/gas ratio (bngl/mmcfg)			

Gas Accumulations:	minimum	mode	maximum
Liquids/gas ratio (bliq/mmcfg)	0	0	0
Oil/gas ratio (bo/mmcfg)			

SELECTED ANCILLARY DATA FOR UNDISCOVERED ACCUMULATIONS
(variations in the properties of undiscovered accumulations)

Oil Accumulations:	minimum	mode	maximum
API gravity (degrees)			
Sulfur content of oil (%)			
Depth (m) of water (if applicable)			

	minimum	F75	mode	F25	maximum
Drilling Depth (m)					

Gas Accumulations:	minimum	mode	maximum
Inert gas content (%)			
CO_2 content (%)	0.00	0.50	2.00
Hydrogen-sulfide content (%)	0.00	0.00	0.00
Depth (m) of water (if applicable)	900	950	1000

	minimum	F75	mode	F25	maximum
Drilling Depth (m)	90	280	360	900	1600

Appendix 7. Basic input data for the Upper Cretaceous–Tertiary Sandstones Assessment Unit (50410101). SEVENTH APPROXIMATION DATA FORM (NOGA, Version 5, 6–30–01). [AU, assessment unit; bcfg, billion cubic feet of gas; bliq/mmcfg, barrels of liquid per million cubic feet of gas; bngl/mmcfg, barrels of natural gas liquids per million cubic feet of gas; cfg/bo, cubic feet of gas per barrel of oil; m, meters; min. minimum; mmboe, million barrels of oil equivalent; ngl, natural gas liquids]—Continued

Assessment Unit (name, no.)
Upper Cretaceous-Tertiary Sandstones, 50410101

ALLOCATIONS OF POTENTIAL ADDITIONS TO RESERVES TO STATES
Surface Allocations (uncertainty of a fixed value)

1. Colorado represents 59.14 area % of the AU

	minimum	mode	maximum
Oil in Oil Accumulations: Volume % in entity			
Gas in Gas Accumulations: Volume % in entity		30	

2. New Mexico represents 40.86 area % of the AU

	minimum	mode	maximum
Oil in Oil Accumulations: Volume % in entity			
Gas in Gas Accumulations: Volume % in entity		70	

3. ______ represents ______ area % of the AU

	minimum	mode	maximum
Oil in Oil Accumulations: Volume % in entity			
Gas in Gas Accumulations: Volume % in entity			

4. ______ represents ______ area % of the AU

	minimum	mode	maximum
Oil in Oil Accumulations: Volume % in entity			
Gas in Gas Accumulations: Volume % in entity			

5. ______ represents ______ area % of the AU

	minimum	mode	maximum
Oil in Oil Accumulations: Volume % in entity			
Gas in Gas Accumulations: Volume % in entity			

6. ______ represents ______ area % of the AU

	minimum	mode	maximum
Oil in Oil Accumulations: Volume % in entity			
Gas in Gas Accumulations: Volume % in entity			

Appendix 7. Basic input data for the Upper Cretaceous–Tertiary Sandstones Assessment Unit (50410101). SEVENTH APPROXIMATION DATA FORM (NOGA, Version 5, 6–30–01). [AU, assessment unit; bcfg, billion cubic feet of gas; bliq/mmcfg, barrels of liquid per million cubic feet of gas; bngl/mmcfg, barrels of natural gas liquids per million cubic feet of gas; cfg/bo, cubic feet of gas per barrel of oil; m, meters; min. minimum; mmboe, million barrels of oil equivalent; ngl, natural gas liquids]—Continued

Assessment Unit (name, no.)
Upper Cretaceous-Tertiary Sandstones, 50410101

7. ____________ represents ______ area % of the AU

Oil in Oil Accumulations:	minimum	mode	maximum
Volume % in entity			
Gas in Gas Accumulations:			
Volume % in entity			

8. ____________ represents ______ area % of the AU

Oil in Oil Accumulations:	minimum	mode	maximum
Volume % in entity			
Gas in Gas Accumulations:			
Volume % in entity			

9. ____________ represents ______ area % of the AU

Oil in Oil Accumulations:	minimum	mode	maximum
Volume % in entity			
Gas in Gas Accumulations:			
Volume % in entity			

10. ____________ represents ______ area % of the AU

Oil in Oil Accumulations:	minimum	mode	maximum
Volume % in entity			
Gas in Gas Accumulations:			
Volume % in entity			

11. ____________ represents ______ area % of the AU

Oil in Oil Accumulations:	minimum	mode	maximum
Volume % in entity			
Gas in Gas Accumulations:			
Volume % in entity			

12. ____________ represents ______ area % of the AU

Oil in Oil Accumulations:	minimum	mode	maximum
Volume % in entity			
Gas in Gas Accumulations:			
Volume % in entity			

Appendix 7. Basic input data for the Upper Cretaceous–Tertiary Sandstones Assessment Unit (50410101). SEVENTH APPROXIMATION DATA FORM (NOGA, Version 5, 6–30–01). [AU, assessment unit; bcfg, billion cubic feet of gas; bliq/mmcfg, barrels of liquid per million cubic feet of gas; bngl/mmcfg, barrels of natural gas liquids per million cubic feet of gas; cfg/bo, cubic feet of gas per barrel of oil; m, meters; min. minimum; mmboe, million barrels of oil equivalent; ngl, natural gas liquids]—Continued

Assessment Unit (name, no.)
Upper Cretaceous-Tertiary Sandstones, 50410101

ALLOCATIONS OF POTENTIAL ADDITIONS TO RESERVES TO LAND ENTITIES
Surface Allocations (uncertainty of a fixed value)

1. Federal Lands represents 7.81 area % of the AU

	minimum	mode	maximum
Oil in Oil Accumulations: Volume % in entity			
Gas in Gas Accumulations: Volume % in entity		2.4	

2. Private Lands represents 89.23 area % of the AU

	minimum	mode	maximum
Oil in Oil Accumulations: Volume % in entity			
Gas in Gas Accumulations: Volume % in entity		94.5	

3. Tribal Lands represents ____ area % of the AU

	minimum	mode	maximum
Oil in Oil Accumulations: Volume % in entity			
Gas in Gas Accumulations: Volume % in entity			

4. Other Lands represents ____ area % of the AU

	minimum	mode	maximum
Oil in Oil Accumulations: Volume % in entity			
Gas in Gas Accumulations: Volume % in entity			

5. Colorado State Lands represents 2.54 area % of the AU

	minimum	mode	maximum
Oil in Oil Accumulations: Volume % in entity			
Gas in Gas Accumulations: Volume % in entity		3	

6. New Mexico State Lands represents 0.41 area % of the AU

	minimum	mode	maximum
Oil in Oil Accumulations: Volume % in entity			
Gas in Gas Accumulations: Volume % in entity		0.1	

Appendix 7. Basic input data for the Upper Cretaceous–Tertiary Sandstones Assessment Unit (50410101). SEVENTH APPROXIMATION DATA FORM (NOGA, Version 5, 6–30–01). [AU, assessment unit; bcfg, billion cubic feet of gas; bliq/mmcfg, barrels of liquid per million cubic feet of gas; bngl/mmcfg, barrels of natural gas liquids per million cubic feet of gas; cfg/bo, cubic feet of gas per barrel of oil; m, meters; min. minimum; mmboe, million barrels of oil equivalent; ngl, natural gas liquids]—Continued

Assessment Unit (name, no.)
Upper Cretaceous-Tertiary Sandstones, 50410101

7. ______ represents ______ area % of the AU

Oil in Oil Accumulations:	minimum	mode	maximum
Volume % in entity			
Gas in Gas Accumulations:			
Volume % in entity			

8. ______ represents ______ area % of the AU

Oil in Oil Accumulations:	minimum	mode	maximum
Volume % in entity			
Gas in Gas Accumulations:			
Volume % in entity			

9. ______ represents ______ area % of the AU

Oil in Oil Accumulations:	minimum	mode	maximum
Volume % in entity			
Gas in Gas Accumulations:			
Volume % in entity			

10. ______ represents ______ area % of the AU

Oil in Oil Accumulations:	minimum	mode	maximum
Volume % in entity			
Gas in Gas Accumulations:			
Volume % in entity			

11. ______ represents ______ area % of the AU

Oil in Oil Accumulations:	minimum	mode	maximum
Volume % in entity			
Gas in Gas Accumulations:			
Volume % in entity			

12. ______ represents ______ area % of the AU

Oil in Oil Accumulations:	minimum	mode	maximum
Volume % in entity			
Gas in Gas Accumulations:			
Volume % in entity			

Appendix 7. Basic input data for the Upper Cretaceous–Tertiary Sandstones Assessment Unit (50410101). SEVENTH APPROXIMATION DATA FORM (NOGA, Version 5, 6–30–01). [AU, assessment unit; bcfg, billion cubic feet of gas; bliq/mmcfg, barrels of liquid per million cubic feet of gas; bngl/mmcfg, barrels of natural gas liquids per million cubic feet of gas; cfg/bo, cubic feet of gas per barrel of oil; m, meters; min. minimum; mmboe, million barrels of oil equivalent; ngl, natural gas liquids]—Continued

Assessment Unit (name, no.)
Upper Cretaceous-Tertiary Sandstones, 50410101

ALLOCATIONS OF POTENTIAL ADDITIONS TO RESERVES TO FEDERAL LAND SUBDIVISIONS
Surface Allocations (uncertainty of a fixed value)

1. Bureau of Land Management (BLM) represents 1.75 area % of the AU

	minimum	mode	maximum
Oil in Oil Accumulations: Volume % in entity			
Gas in Gas Accumulations: Volume % in entity		0.4	

2. BLM Wilderness Areas (BLMW) represents ____ area % of the AU

	minimum	mode	maximum
Oil in Oil Accumulations: Volume % in entity			
Gas in Gas Accumulations: Volume % in entity			

3. BLM Roadless Areas (BLMR) represents ____ area % of the AU

	minimum	mode	maximum
Oil in Oil Accumulations: Volume % in entity			
Gas in Gas Accumulations: Volume % in entity			

4. National Park Service (NPS) represents ____ area % of the AU

	minimum	mode	maximum
Oil in Oil Accumulations: Volume % in entity			
Gas in Gas Accumulations: Volume % in entity			

5. NPS Wilderness Areas (NPSW) represents ____ area % of the AU

	minimum	mode	maximum
Oil in Oil Accumulations: Volume % in entity			
Gas in Gas Accumulations: Volume % in entity			

6. NPS Protected Withdrawals (NPSP) represents ____ area % of the AU

	minimum	mode	maximum
Oil in Oil Accumulations: Volume % in entity			
Gas in Gas Accumulations: Volume % in entity			

Appendix 7. Basic input data for the Upper Cretaceous–Tertiary Sandstones Assessment Unit (50410101). SEVENTH APPROXIMATION DATA FORM (NOGA, Version 5, 6–30–01). [AU, assessment unit; bcfg, billion cubic feet of gas; bliq/mmcfg, barrels of liquid per million cubic feet of gas; bngl/mmcfg, barrels of natural gas liquids per million cubic feet of gas; cfg/bo, cubic feet of gas per barrel of oil; m, meters; min. minimum; mmboe, million barrels of oil equivalent; ngl, natural gas liquids]—Continued

Assessment Unit (name, no.)
Upper Cretaceous-Tertiary Sandstones, 50410101

7. US Forest Service (FS) represents 6.06 area % of the AU

	minimum	mode	maximum
Oil in Oil Accumulations: Volume % in entity			
Gas in Gas Accumulations: Volume % in entity		2	

8. USFS Wilderness Areas (FSW) represents ______ area % of the AU

	minimum	mode	maximum
Oil in Oil Accumulations: Volume % in entity			
Gas in Gas Accumulations: Volume % in entity			

9. USFS Roadless Areas (FSR) represents ______ area % of the AU

	minimum	mode	maximum
Oil in Oil Accumulations: Volume % in entity			
Gas in Gas Accumulations: Volume % in entity			

10. USFS Protected Withdrawals (FSP) represents ______ area % of the AU

	minimum	mode	maximum
Oil in Oil Accumulations: Volume % in entity			
Gas in Gas Accumulations: Volume % in entity			

11. US Fish and Wildlife Service (FWS) represents ______ area % of the AU

	minimum	mode	maximum
Oil in Oil Accumulations: Volume % in entity			
Gas in Gas Accumulations: Volume % in entity			

12. USFWS Wilderness Areas (FWSW) represents ______ area % of the AU

	minimum	mode	maximum
Oil in Oil Accumulations: Volume % in entity			
Gas in Gas Accumulations: Volume % in entity			

Appendix 7. Basic input data for the Upper Cretaceous–Tertiary Sandstones Assessment Unit (50410101). SEVENTH APPROXIMATION DATA FORM (NOGA, Version 5, 6–30–01). [AU, assessment unit; bcfg, billion cubic feet of gas; bliq/mmcfg, barrels of liquid per million cubic feet of gas; bngl/mmcfg, barrels of natural gas liquids per million cubic feet of gas; cfg/bo, cubic feet of gas per barrel of oil; m, meters; min. minimum; mmboe, million barrels of oil equivalent; ngl, natural gas liquids]—Continued

Assessment Unit (name, no.)
Upper Cretaceous-Tertiary Sandstones, 50410101

13. USFWS Protected Withdrawals (FWSP) represents ____ area % of the AU

Oil in Oil Accumulations:	minimum	mode	maximum
Volume % in entity			
Gas in Gas Accumulations:			
Volume % in entity			

14. Wilderness Study Areas (WS) represents ____ area % of the AU

Oil in Oil Accumulations:	minimum	mode	maximum
Volume % in entity			
Gas in Gas Accumulations:			
Volume % in entity			

15. Department of Energy (DOE) represents ____ area % of the AU

Oil in Oil Accumulations:	minimum	mode	maximum
Volume % in entity			
Gas in Gas Accumulations:			
Volume % in entity			

16. Department of Defense (DOD) represents ____ area % of the AU

Oil in Oil Accumulations:	minimum	mode	maximum
Volume % in entity			
Gas in Gas Accumulations:			
Volume % in entity			

17. Bureau of Reclamation (BOR) represents ____ area % of the AU

Oil in Oil Accumulations:	minimum	mode	maximum
Volume % in entity			
Gas in Gas Accumulations:			
Volume % in entity			

18. Tennessee Valley Authority (TVA) represents ____ area % of the AU

Oil in Oil Accumulations:	minimum	mode	maximum
Volume % in entity			
Gas in Gas Accumulations:			
Volume % in entity			

Appendix 7. Basic input data for the Upper Cretaceous–Tertiary Sandstones Assessment Unit (50410101). SEVENTH APPROXIMATION DATA FORM (NOGA, Version 5, 6–30–01). [AU, assessment unit; bcfg, billion cubic feet of gas; bliq/mmcfg, barrels of liquid per million cubic feet of gas; bngl/mmcfg, barrels of natural gas liquids per million cubic feet of gas; cfg/bo, cubic feet of gas per barrel of oil; m, meters; min. minimum; mmboe, million barrels of oil equivalent; ngl, natural gas liquids]—Continued

Assessment Unit (name, no.)
Upper Cretaceous-Tertiary Sandstones, 50410101

19. Other Federal ______ represents ______ area % of the AU

Oil in Oil Accumulations:	minimum	mode	maximum
Volume % in entity			
Gas in Gas Accumulations:			
Volume % in entity			

20. ______ represents ______ area % of the AU

Oil in Oil Accumulations:	minimum	mode	maximum
Volume % in entity			
Gas in Gas Accumulations:			
Volume % in entity			

Appendix 7. Basic input data for the Upper Cretaceous–Tertiary Sandstones Assessment Unit (50410101). SEVENTH APPROXIMATION DATA FORM (NOGA, Version 5, 6–30–01). [AU, assessment unit; bcfg, billion cubic feet of gas; bliq/mmcfg, barrels of liquid per million cubic feet of gas; bngl/mmcfg, barrels of natural gas liquids per million cubic feet of gas; cfg/bo, cubic feet of gas per barrel of oil; m, meters; min. minimum; mmboe, million barrels of oil equivalent; ngl, natural gas liquids]—Continued

Assessment Unit (name, no.)
Upper Cretaceous-Tertiary Sandstones, 50410101

ALLOCATIONS OF POTENTIAL ADDITIONS TO RESERVES TO ECOSYSTEMS
Surface Allocations (uncertainty of a fixed value)

1. Arkansas Tablelands (ARTL) represents 6.03 area % of the AU

	minimum	mode	maximum
Oil in Oil Accumulations: Volume % in entity			
Gas in Gas Accumulations: Volume % in entity		4	

2. Southern Parks and Ranges (SPRA) represents 93.97 area % of the AU

	minimum	mode	maximum
Oil in Oil Accumulations: Volume % in entity			
Gas in Gas Accumulations: Volume % in entity		96	

3. ______ represents ______ area % of the AU

	minimum	mode	maximum
Oil in Oil Accumulations: Volume % in entity			
Gas in Gas Accumulations: Volume % in entity			

4. ______ represents ______ area % of the AU

	minimum	mode	maximum
Oil in Oil Accumulations: Volume % in entity			
Gas in Gas Accumulations: Volume % in entity			

5. ______ represents ______ area % of the AU

	minimum	mode	maximum
Oil in Oil Accumulations: Volume % in entity			
Gas in Gas Accumulations: Volume % in entity			

6. ______ represents ______ area % of the AU

	minimum	mode	maximum
Oil in Oil Accumulations: Volume % in entity			
Gas in Gas Accumulations: Volume % in entity			

Appendix 7. Basic input data for the Upper Cretaceous–Tertiary Sandstones Assessment Unit (50410101). SEVENTH APPROXIMATION DATA FORM (NOGA, Version 5, 6–30–01). [AU, assessment unit; bcfg, billion cubic feet of gas; bliq/mmcfg, barrels of liquid per million cubic feet of gas; bngl/mmcfg, barrels of natural gas liquids per million cubic feet of gas; cfg/bo, cubic feet of gas per barrel of oil; m, meters; min. minimum; mmboe, million barrels of oil equivalent; ngl, natural gas liquids]—Continued

Assessment Unit (name, no.)
Upper Cretaceous-Tertiary Sandstones, 50410101

7. ________________ represents ________ area % of the AU

Oil in Oil Accumulations:	minimum	mode	maximum
Volume % in entity	____	____	____
Gas in Gas Accumulations:			
Volume % in entity	____	____	____

8. ________________ represents ________ area % of the AU

Oil in Oil Accumulations:	minimum	mode	maximum
Volume % in entity	____	____	____
Gas in Gas Accumulations:			
Volume % in entity	____	____	____

9. ________________ represents ________ area % of the AU

Oil in Oil Accumulations:	minimum	mode	maximum
Volume % in entity	____	____	____
Gas in Gas Accumulations:			
Volume % in entity	____	____	____

10. ________________ represents ________ area % of the AU

Oil in Oil Accumulations:	minimum	mode	maximum
Volume % in entity	____	____	____
Gas in Gas Accumulations:			
Volume % in entity	____	____	____

11. ________________ represents ________ area % of the AU

Oil in Oil Accumulations:	minimum	mode	maximum
Volume % in entity	____	____	____
Gas in Gas Accumulations:			
Volume % in entity	____	____	____

12. ________________ represents ________ area % of the AU

Oil in Oil Accumulations:	minimum	mode	maximum
Volume % in entity	____	____	____
Gas in Gas Accumulations:			
Volume % in entity	____	____	____

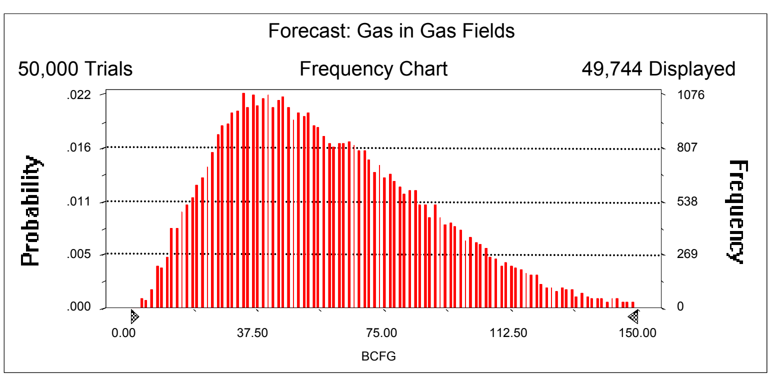
Appendix 8. Monte Carlo Assessment Output—Upper Cretaceous–Tertiary Sandstones Assessment Unit (50410101). Contained in this appendix are detailed descriptions of the probability distributions of the results of the assessment of the Upper Cretaceous–Tertiary Sandstones AU (50410101). These details may be of use to those conducting further analysis of the results. All distributions in this appendix are fully risked. They include the probability that there are no gas or NGL fields of minimum size or larger. Each distribution is documented by two pages. The first page contains distribution parameters, most importantly the mean, as well as a graph of the probability density function. The second page lists the percentiles (fractiles) of the distribution at 5-percent intervals.Also included are the descriptions of probability distributions of the input based on the input parameters documented in appendix 7. Each of the distributions used in calculating the results is documented by its parameters and a graph of the probability density function. Note that, for the distribution of size of undiscovered oil fields and for the distribution of size of undiscovered gas fields, the parameters of both the shifted and unshifted lognormal distributions are given. Each accompanying graph is that of the unshifted distribution.

50410101
Upper Cretaceous-Tertiary Sandstones
Monte Carlo Results

Forecast: Gas in Gas Fields

Summary:
Display range is from 0.00 to 150.00 BCFG
Entire range is from 3.12 to 247.97 BCFG
After 50,000 trials, the standard error of the mean is 0.13

Statistics:	Value
Trials	50000
Mean	58.53
Median	54.00
Mode	---
Standard Deviation	29.76
Variance	885.95
Skewness	0.70
Kurtosis	3.30
Coefficient of Variability	0.51
Range Minimum	3.12
Range Maximum	247.97
Range Width	244.84
Mean Standard Error	0.13



Appendix 8. Monte Carlo Assessment Output—Upper Cretaceous–Tertiary Sandstones Assessment Unit (50410101). Contained in this appendix are detailed descriptions of the probability distributions of the results of the assessment of the Upper Cretaceous–Tertiary Sandstones AU (50410101). These details may be of use to those conducting further analysis of the results. All distributions in this appendix are fully risked. They include the probability that there are no gas or NGL fields of minimum size or larger. Each distribution is documented by two pages. The first page contains distribution parameters, most importantly the mean, as well as a graph of the probability density function. The second page lists the percentiles (fractiles) of the distribution at 5-percent intervals.Also included are the descriptions of probability distributions of the input based on the input parameters documented in appendix 7. Each of the distributions used in calculating the results is documented by its parameters and a graph of the probability density function. Note that, for the distribution of size of undiscovered oil fields and for the distribution of size of undiscovered gas fields, the parameters of both the shifted and unshifted lognormal distributions are given. Each accompanying graph is that of the unshifted distribution.—Continued

50410101
Upper Cretaceous-Tertiary Sandstones
Monte Carlo Results

Forecast: Gas in Gas Fields (cont'd)

Percentiles:

Percentile	BCFG
100%	3.12
95%	17.52
90%	23.57
85%	28.05
80%	31.99
75%	35.61
70%	39.19
65%	42.81
60%	46.35
55%	50.15
50%	54.00
45%	58.19
40%	62.74
35%	67.25
30%	72.07
25%	77.55
20%	83.73
15%	90.86
10%	99.80
5%	113.12
0%	247.97

End of Forecast

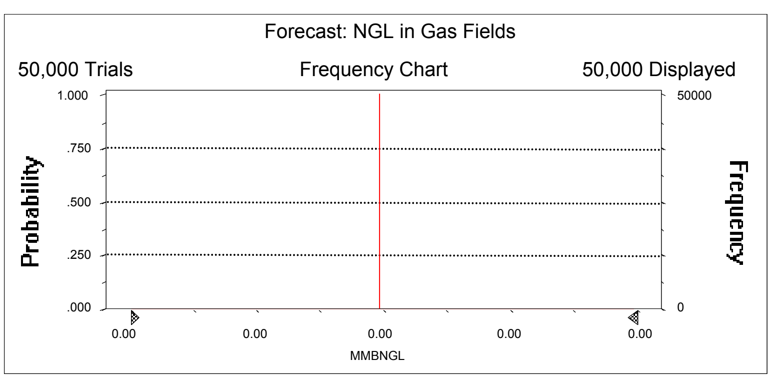
Appendix 8. Monte Carlo Assessment Output—Upper Cretaceous–Tertiary Sandstones Assessment Unit (50410101). Contained in this appendix are detailed descriptions of the probability distributions of the results of the assessment of the Upper Cretaceous–Tertiary Sandstones AU (50410101). These details may be of use to those conducting further analysis of the results. All distributions in this appendix are fully risked. They include the probability that there are no gas or NGL fields of minimum size or larger. Each distribution is documented by two pages. The first page contains distribution parameters, most importantly the mean, as well as a graph of the probability density function. The second page lists the percentiles (fractiles) of the distribution at 5-percent intervals.Also included are the descriptions of probability distributions of the input based on the input parameters documented in appendix 7. Each of the distributions used in calculating the results is documented by its parameters and a graph of the probability density function. Note that, for the distribution of size of undiscovered oil fields and for the distribution of size of undiscovered gas fields, the parameters of both the shifted and unshifted lognormal distributions are given. Each accompanying graph is that of the unshifted distribution.—Continued

50410101
Upper Cretaceous-Tertiary Sandstones
Monte Carlo Results

Forecast: NGL in Gas Fields

Summary:
Display range is from 0.00 to 0.00 MMBNGL
Entire range is from 0.00 to 0.00 MMBNGL
After 50,000 trials, the standard error of the mean is 0.00

Statistics:	Value
Trials	50000
Mean	0.00
Median	0.00
Mode	0.00
Standard Deviation	0.00
Variance	0.00
Skewness	0.00
Kurtosis	+Infinity
Coefficient of Variability	+Infinity
Range Minimum	0.00
Range Maximum	0.00
Range Width	0.00
Mean Standard Error	0.00



Appendix 8. Monte Carlo Assessment Output—Upper Cretaceous–Tertiary Sandstones Assessment Unit (50410101). Contained in this appendix are detailed descriptions of the probability distributions of the results of the assessment of the Upper Cretaceous–Tertiary Sandstones AU (50410101). These details may be of use to those conducting further analysis of the results. All distributions in this appendix are fully risked. They include the probability that there are no gas or NGL fields of minimum size or larger. Each distribution is documented by two pages. The first page contains distribution parameters, most importantly the mean, as well as a graph of the probability density function. The second page lists the percentiles (fractiles) of the distribution at 5-percent intervals.Also included are the descriptions of probability distributions of the input based on the input parameters documented in appendix 7. Each of the distributions used in calculating the results is documented by its parameters and a graph of the probability density function. Note that, for the distribution of size of undiscovered oil fields and for the distribution of size of undiscovered gas fields, the parameters of both the shifted and unshifted lognormal distributions are given. Each accompanying graph is that of the unshifted distribution.—Continued

50410101
Upper Cretaceous-Tertiary Sandstones
Monte Carlo Results

Forecast: NGL in Gas Fields (cont'd)

Percentiles:

Percentile	MMBNGL
100%	0.00
95%	0.00
90%	0.00
85%	0.00
80%	0.00
75%	0.00
70%	0.00
65%	0.00
60%	0.00
55%	0.00
50%	0.00
45%	0.00
40%	0.00
35%	0.00
30%	0.00
25%	0.00
20%	0.00
15%	0.00
10%	0.00
5%	0.00
0%	0.00

End of Forecast

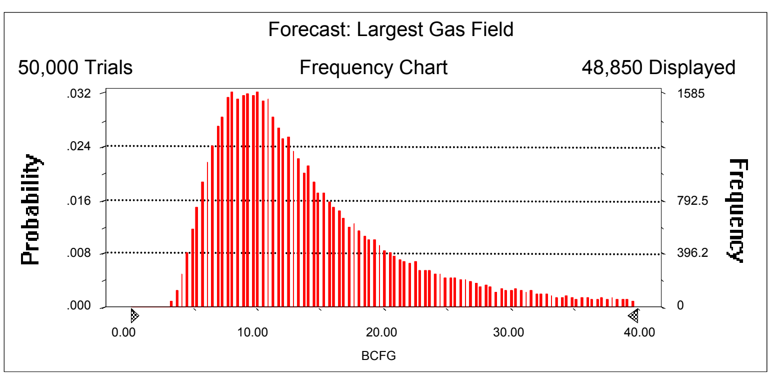
Appendix 8. Monte Carlo Assessment Output—Upper Cretaceous–Tertiary Sandstones Assessment Unit (50410101). Contained in this appendix are detailed descriptions of the probability distributions of the results of the assessment of the Upper Cretaceous–Tertiary Sandstones AU (50410101). These details may be of use to those conducting further analysis of the results. All distributions in this appendix are fully risked. They include the probability that there are no gas or NGL fields of minimum size or larger. Each distribution is documented by two pages. The first page contains distribution parameters, most importantly the mean, as well as a graph of the probability density function. The second page lists the percentiles (fractiles) of the distribution at 5-percent intervals.Also included are the descriptions of probability distributions of the input based on the input parameters documented in appendix 7. Each of the distributions used in calculating the results is documented by its parameters and a graph of the probability density function. Note that, for the distribution of size of undiscovered oil fields and for the distribution of size of undiscovered gas fields, the parameters of both the shifted and unshifted lognormal distributions are given. Each accompanying graph is that of the unshifted distribution.—Continued

50410101
Upper Cretaceous-Tertiary Sandstones
Monte Carlo Results

Forecast: Largest Gas Field

Summary:
Display range is from 0.00 to 40.00 BCFG
Entire range is from 3.12 to 59.95 BCFG
After 50,000 trials, the standard error of the mean is 0.04

Statistics:	Value
Trials	50000
Mean	14.50
Median	12.05
Mode	---
Standard Deviation	8.60
Variance	73.98
Skewness	1.90
Kurtosis	7.57
Coefficient of Variability	0.59
Range Minimum	3.12
Range Maximum	59.95
Range Width	56.83
Mean Standard Error	0.04



Appendix 8. Monte Carlo Assessment Output—Upper Cretaceous–Tertiary Sandstones Assessment Unit (50410101). Contained in this appendix are detailed descriptions of the probability distributions of the results of the assessment of the Upper Cretaceous–Tertiary Sandstones AU (50410101). These details may be of use to those conducting further analysis of the results. All distributions in this appendix are fully risked. They include the probability that there are no gas or NGL fields of minimum size or larger. Each distribution is documented by two pages. The first page contains distribution parameters, most importantly the mean, as well as a graph of the probability density function. The second page lists the percentiles (fractiles) of the distribution at 5-percent intervals.Also included are the descriptions of probability distributions of the input based on the input parameters documented in appendix 7. Each of the distributions used in calculating the results is documented by its parameters and a graph of the probability density function. Note that, for the distribution of size of undiscovered oil fields and for the distribution of size of undiscovered gas fields, the parameters of both the shifted and unshifted lognormal distributions are given. Each accompanying graph is that of the unshifted distribution.—Continued

50410101
Upper Cretaceous-Tertiary Sandstones
Monte Carlo Results

Forecast: Largest Gas Field (cont'd)

Percentiles:

Percentile	BCFG
100%	3.12
95%	5.77
90%	6.70
85%	7.44
80%	8.10
75%	8.74
70%	9.38
65%	10.01
60%	10.65
55%	11.33
50%	12.05
45%	12.85
40%	13.77
35%	14.79
30%	16.00
25%	17.47
20%	19.30
15%	21.76
10%	25.42
5%	31.98
0%	59.95

End of Forecast

Appendix 8. Monte Carlo Assessment Output—Upper Cretaceous–Tertiary Sandstones Assessment Unit (50410101). Contained in this appendix are detailed descriptions of the probability distributions of the results of the assessment of the Upper Cretaceous–Tertiary Sandstones AU (50410101). These details may be of use to those conducting further analysis of the results. All distributions in this appendix are fully risked. They include the probability that there are no gas or NGL fields of minimum size or larger. Each distribution is documented by two pages. The first page contains distribution parameters, most importantly the mean, as well as a graph of the probability density function. The second page lists the percentiles (fractiles) of the distribution at 5-percent intervals.Also included are the descriptions of probability distributions of the input based on the input parameters documented in appendix 7. Each of the distributions used in calculating the results is documented by its parameters and a graph of the probability density function. Note that, for the distribution of size of undiscovered oil fields and for the distribution of size of undiscovered gas fields, the parameters of both the shifted and unshifted lognormal distributions are given. Each accompanying graph is that of the unshifted distribution.—Continued

50410101
Upper Cretaceous-Tertiary Sandstones
Monte Carlo Results

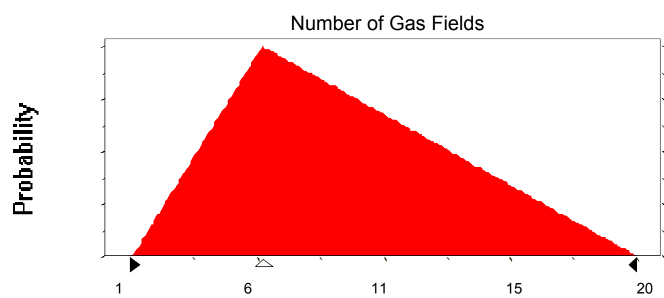
Assumptions

Assumption: Number of Gas Fields

Triangular distribution with parameters:

Minimum	1
Likeliest	6
Maximum	20

Selected range is from 1 to 20



Assumption: Sizes of Gas Fields

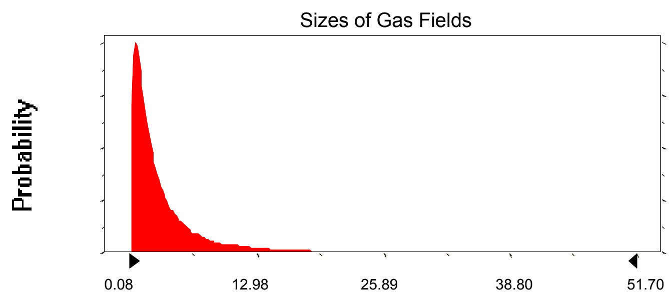
Lognormal distribution with parameters:		Shifted parameters
Mean	3.60	6.60
Standard Deviation	5.39	5.39

Selected range is from 0.00 to 57.00 3.00 to 60.00

Appendix 8. Monte Carlo Assessment Output—Upper Cretaceous–Tertiary Sandstones Assessment Unit (50410101). Contained in this appendix are detailed descriptions of the probability distributions of the results of the assessment of the Upper Cretaceous–Tertiary Sandstones AU (50410101). These details may be of use to those conducting further analysis of the results. All distributions in this appendix are fully risked. They include the probability that there are no gas or NGL fields of minimum size or larger. Each distribution is documented by two pages. The first page contains distribution parameters, most importantly the mean, as well as a graph of the probability density function. The second page lists the percentiles (fractiles) of the distribution at 5-percent intervals.Also included are the descriptions of probability distributions of the input based on the input parameters documented in appendix 7. Each of the distributions used in calculating the results is documented by its parameters and a graph of the probability density function. Note that, for the distribution of size of undiscovered oil fields and for the distribution of size of undiscovered gas fields, the parameters of both the shifted and unshifted lognormal distributions are given. Each accompanying graph is that of the unshifted distribution.—Continued

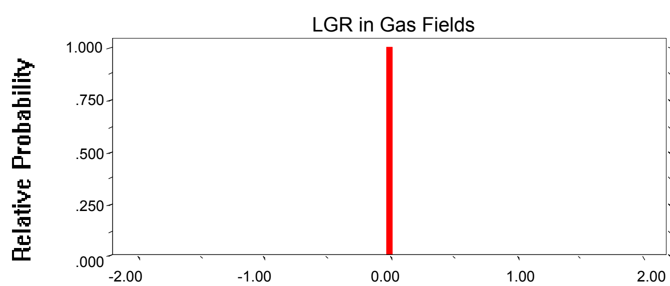
50410101
Upper Cretaceous-Tertiary Sandstones
Monte Carlo Results

Assumption: Sizes of Gas Fields (cont'd)



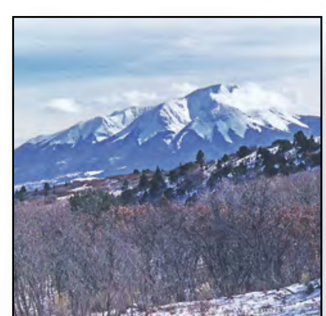
Assumption: LGR in Gas Fields

		Relative Prob.
Custom distribution with parameters:		
Single point	0.00	1.000000
Total Relative Probability		1.000000



End of Assumptions

Simulation started on 9/17/04 at 16:12:51
Simulation stopped on 9/17/04 at 16:14:07



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