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Petroleum geology of the Tucumcari Basin—overview and recent exploratory activity

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Introduction

The Tucumcari Basin is spread out over 5,000 mi^2 of east-central New Mexico (Fig. 1; Broadhead and King 1988; Broadhead et al. 2002). It stretches from San Ignacio, approximately 15 mi west of Santa Rosa, New Mexico, on the west to central Quay County, New Mexico, on the east and from Fort Sumner on the south to Trementina on the north. It is an Ancestral Rocky Mountain basin that developed structurally and existed as a depositional entity during the Pennsylvanian and Early Permian. The present-day topographic expression of the basin is deceptively simple, consisting of the high plains and rolling hills underlain by Triassic red beds, and mesas formed by erosional remnants of Jurassic and Cretaceous strata (Fig. 2). The subsurface geology of the region is extremely complex and consists of buried uplifts and mountain ranges that border the Tucumcari Basin as well as complex segmentation of the basin into deep elevator sub-basins and adjoining shelf areas (Fig. 3).

The Tucumcari Basin began to form during the Early to Middle Pennsylvanian Period when large basin-bounding faults began to move in a regional strike-slip setting. During this time, the Tucumcari Basin, its component elevator basins, and the bordering uplifts were formed primarily along regional shear zones activated during the Ouachita and Arbuckle orogenies (see Szabo and Wengerd 1975; Kluth and Coney 1981; Budnik 1986). As vertical offset along the basin-bounding faults increased, the Tucumcari Basin was divided into a number of discrete tectonic elements that influenced depositional facies from the Pennsylvanian into the Early Permian (Broadhead and King 1988; Broadhead et al. 2002). Chief among these tectonic elements are four elevator basins in the north and a wide shelf area to the south. The elevator basins were the sites of deposition of thick sections of organically rich shales that, when buried, were turned into thermally mature source rocks of oil and gas.

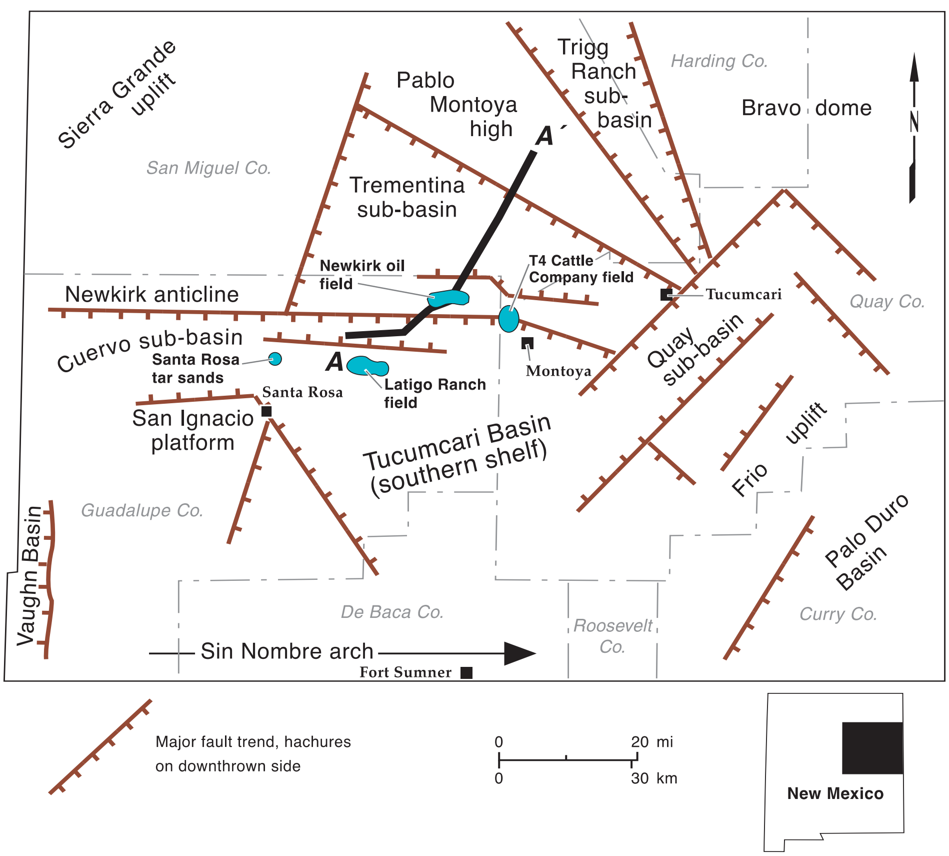

FIGURE 1—Map of the Tucumcari Basin showing the location of the four elevator basins, the southern shelf, and the bordering uplifts.

Elevator basins and petroleum source rocks

The Tucumcari Basin is bordered on the north by the Sierra Grande uplift and on the northeast by the Bravo Dome, which separates it from the Dalhart Basin. On the west the basin is bordered by the San Ignacio platform of Reynolds (1998) and Reynolds and Reynolds (2004 this issue), which separates it from the Vaughn Basin. On the east the Frio uplift separates the Tucumcari Basin from the Palo Duro Basin of the Texas panhandle. To the south, the Sin Nombre arch (Broadhead and Jones 2002) separates the Tucumcari Basin from the Permian Basin. The Tucumcari Basin and its adjoining uplifts and arches formed during the Pennsylvanian and Early Permian as tectonic elements of the Ancestral Rocky Mountains, primarily along regional shear zones activated during the Ouachita and Arbuckle orogenies (see Szabo and Wengerd 1975; Kluth and Coney 1981; Budnik 1986).

"Elevator basins" (Broadhead 1998; Broadhead and Chapin 1999; Broadhead 2001a,b) are defined as long, narrow, and structurally deep troughs bounded by high-angle faults. They are typically 20–50 mi long and 5–15 mi wide. Bounding faults have vertical offsets that can exceed 5,000 ft. The geometry of several elevator basins suggests that they were formed in a regional strike-slip setting and are generally similar to the pull-apart basins described by Dooley and McClay (1997). Although the bounding faults appear to have a significant strike-slip aspect, the amount of lateral displacement along the faults is not documented.

There are four elevator basins within the Tucumcari Basin: the Cuervo sub-basin, the Quay sub-basin, the Trementina sub-basin, and the Trigg Ranch sub-basin (Fig. 1). The Cuervo sub-basin (see Reynolds and Reynolds 2004 this issue) is elongated east-west and is parallel to the southern boundary of the Newkirk anticline and the Sierra Grande uplift. The Quay sub-basin is elongated northeast-southwest and is parallel to the southeastern margin of the Sierra Grande uplift. The Trementina sub-basin is elongated northwest-southeast and cuts into the southeastern flank of the Sierra Grande uplift. The Trigg Ranch sub-

FIGURE 2—View southeast across the Tucumcari Basin from Montoya. The thin alluvial sediments in the foreground are underlain by Triassic strata. The mesa along the skyline is formed by erosional remnants of Jurassic and Cretaceous strata.

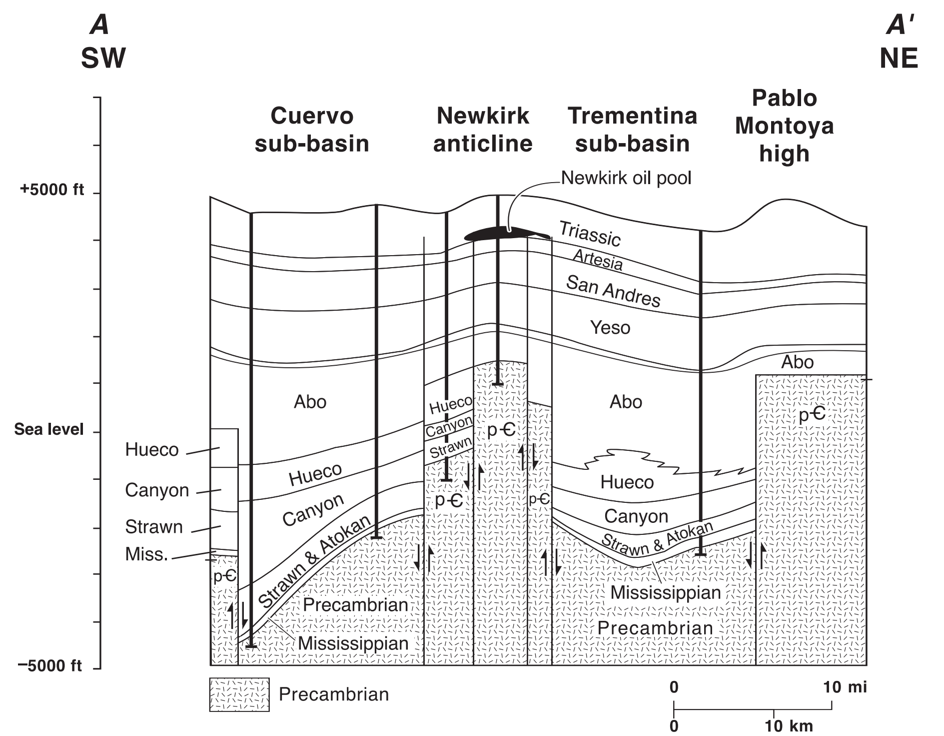

FIGURE 3—Structural cross section across the Cuervo and Trementina sub-basins and the intervening Newkirk anticline. See Figure 1 for location. After Broadhead (2001a).

basin also is elongated northwest-southeast, and it too cuts into the southeastern flank of the Sierra Grande uplift. The Pablo Montoya high, a southeastern projection of the Sierra Grande uplift, separates the Trigg Ranch sub-basin from the Trementina sub-basin. The Newkirk anticline separates the Cuervo sub-basin from the Trementina sub-basin. The Newkirk anticline is manifested at the surface as an anticline that folds Triassic strata along an east-west axis, but at depth it is a fault-bounded block that is elongated east-west.

Although the elevator basins are structurally deep, paleobathymetric relief of the basins during the Pennsylvanian and Early Permian was much less than final structural relief because as the elevator basins formed they were partially or wholly infilled by sediments derived from erosion of the adjoining uplifts. As a result, the Pennsylvanian and Lower Permian strata within the elevator basins are thicker than age-equivalent strata on adjoining shelves and uplifts. The Pennsylvanian section exceeds 4,000 ft in deeper parts of the elevator basins but is generally less than 1,500 ft thick on the broad shelf that occupies the southern part of the Tucumcari Basin. Where present on adjoining uplifts, Pennsylvanian strata are thinner than on the shelf, but they are mostly absent altogether.

Depositional facies patterns were controlled by the locations of the elevator basins and adjoining uplifts. During the Pennsylvanian and Early Permian, the uplifts that adjoin the Tucumcari Basin were emergent erosional highlands whose Precambrian cores were the sources of the clastic sediments deposited within the Tucumcari Basin. Clastic wedges were shed off of the Sierra Grande and Pedernal uplifts, the Bravo dome, and to a lesser extent the Frio uplift from Atokan through Wolfcampian time. These clastic wedges consist of interbedded alluvial, fluvial, deltaic, and possibly shoreline sandstones and shales, and they intertongue with marine carbonates and shales deposited on the shelf areas of the Tucumcari Basin.

The elevator basins are located adjacent to the uplifts that bound the northern part of the Tucumcari Basin. Elevator basins are either parallel to the flanks of the uplifts or cut into the flanks of the uplifts. Source rock and reservoir characteristics of strata within the elevator basins are strongly influenced by this orientation (Broadhead 2001b). During times when depositional accretion exceeded subsidence rates, the elevator basins became completely filled with sediments and had little or no bathymetric expression; sands were transported across the basins and onto distant shelf areas. During times when subsidence exceeded depositional accretion, the basins acted as traps for the coarse clastics shed off the adjacent uplifts. Furthermore, they became bathymetrically low areas with restricted marine circulation; anaerobic conditions prevailed at depth in the water column, and thick sections of black, organically rich shales were deposited (Fig. 4). Pennsylvanian shales within the elevator basins are not only thicker than on adjoining shelf areas but typically have total organic carbon (TOC) contents between 2% and 10% (Fig. 5). TOC contents of dark-gray to black shales on the shelf areas are typically 1–2%. In addition, because the strata in the lower parts of the elevator basins were buried more deeply than the strata on the shallower adjoining shelf areas, the Pennsylvanian shales in the elevator basins are thermally mature (Fig. 6) and are within the oil window, whereas Pennsylvanian shales on the shelf areas are mostly immature to only moderately mature. In the deeper parts of the elevator basins, the shales may be within the gas condensate window. Kerogens within the shales are mixtures of oil- and gas-prone amorphous types, gas-prone woody types,

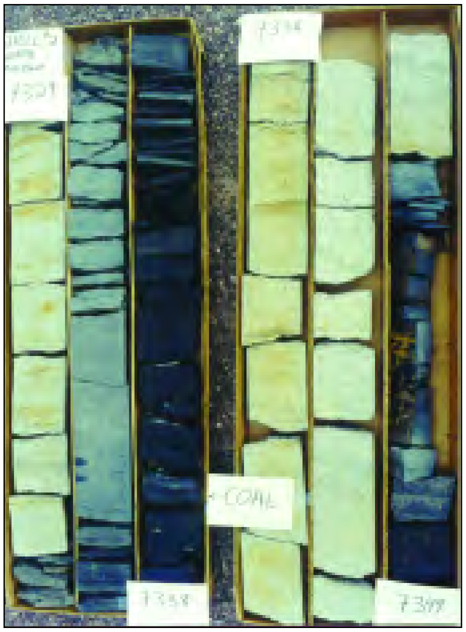

FIGURE 4—Core of Pennsylvanian sandstones, dark organic-rich shales, and a thin coal bed in the Shell No. 2 North Pueblo well in the central part of the Quay sub-basin. Core box is 3 ft long. From Broadhead et al. (2002).

and lesser amounts of inertinite. Thus, the primary areas of hydrocarbon generation are in the elevator basins, where the shales are thicker and more mature than on the adjacent shelf areas and contain enhanced levels of organic matter.

Shelf areas adjacent to the elevator basins were dominated by fine-grained sandstones, widespread shales, and limestones. During times when sands were trapped within the bathymetrically deep elevator basins, deposition of carbonates was widespread on the shelf areas. These carbonate beds are correlation markers. Some are high-energy, shallow-water deposits (Broadhead and King 1988). Areas of thick limestone deposition on the southern rim of the Cuervo sub-basin (Broadhead and King 1988) may be areas of reef development (Reynolds and Reynolds 1998, 2004 this issue; Broadhead 2001a). Regional lithofacies maps indicate some of the carbonates on the southern rim of the Cuervo sub-basin have been dolomitized (Broadhead and King 1988).

Productive analogs

There are a number of oil and gas fields that produce from geologic settings similar to those encountered in the Tucumcari Basin. Two analogs from the southwestern United States, in particular, are in strikingly similar geologic settings and produce from strata similar in age and lithology to potential reservoirs in the Tucumcari Basin.

Stephens and Gunn (1995) and Brister et al. (2002) document gas fields in Pennsylvanian sandstones in the Broken Bone graben, an elevator basin of Pennsylvanian age developed along the Matador arch in north-central Texas. The gas fields in the Broken Bone graben produce from Bend (Lower Pennsylvanian) conglomerates at depths of 6,000–11,000 ft.

Trentham et al. (1998) describe the Wolf Flat field, which is productive of oil and associated gas from a karsted Upper Pennsylvanian carbonate mound along the rimmed margin of the northeast shelf of the Palo Duro Basin. Its paleobathymetric position is similar to the southern margin of the Cuervo sub-basin, and the field is an analog for exploration targets along the southern margin of the Cuervo sub-basin (see Reynolds and Reynolds 2004 this issue).

Exploration history

The Tucumcari Basin has been the object of sporadic exploratory drilling since 1909. Early wells reached total depth in Triassic or Permian strata; however, during the 1950s and 1960s, several deep wells were drilled to Precambrian basement and thus penetrated the Pennsylvanian section. These deep wells revealed that the basin, although seemingly uncomplicated and structurally simple at the surface, was very complex in the subsurface. A number of wells drilled in what were subsequently revealed to be elevator basins encountered significant shows of hydrocarbons on mudlogs. Most of the shows were in Pennsylvanian sandstones, although gas shows in carbonates on the south rim of the Cuervo sub-basin were also encountered. Shows were generally not tested because the region was remote from gas pipeline infrastructure and the San Juan Basin was undergoing rapid development as a large supplier of gas, so there was little demand for gas particularly if it meant constructing a new pipeline system.

Two major accumulations of heavy oil and asphalt have been discovered in the shallow Santa Rosa Sandstone (Triassic): the Santa Rosa tar sands and the Newkirk oil field (Fig. 1). The Santa Rosa tar sands are a surface exposure of oil-impregnated sandstone with an estimated 90.0 million bbls of oil in place (Gorman and Robeck 1946; Budding 1979, 1980; Budding and Broadhead 1987). The oil is heavy with an API gravity of 11.9°. The Santa Rosa tar sands were mined during the 1930s and used as road-surfacing material. The Newkirk oil field of northeast Guadalupe County contains heavy oil at depths of 400–800 ft (Fig. 7; Martin 1983; McKallip 1984). Estimated resources are 62 million bbls of oil in place (Scott and Joy 1983). Attempts at commercial production have been unsuccessful because of the high viscosity of the oil, the limited permeability of the reservoir, and low reservoir pressures associated with shallow burial.

The basin saw a resurgence in exploration during the early 1980s. Deep exploratory wells drilled to Precambrian encountered two significant occurrences of gas in Pennsylvanian sandstones. These occurrences have been referred to as the T-4 Ranch field and the Latigo Ranch field

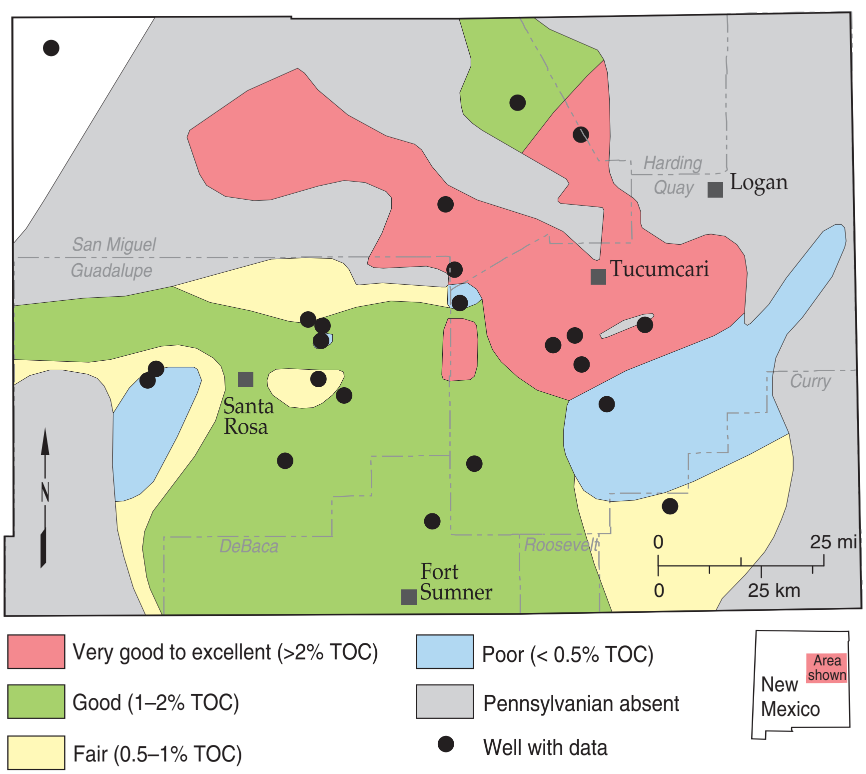

FIGURE 5—Maximum total organic carbon (TOC) in Pennsylvanian shales, Tucumcari Basin. From Broadhead et al. (2002).

(Broadhead and King 1988; Fig. 1). The T-4 Ranch field, located in what is now known as the Quay sub-basin in northwest Quay County, is an occurrence of gas and light oil in Strawn (Middle Pennsylvanian) sandstones at a depth of approximately 7,100 ft. A single well, the Yates Petroleum No. 1 T-4 Cattle Company, tested 1,100 thousand ft^3 gas per day and 48 bbls of oil per day. Oil gravity was 40° API. The gas had a heating value of 1,133 BTU/ft^3 despite a nitrogen content of 11.6%; the high heating value is partially due to a gas liquids content of 19.3%. Two offset wells were drilled to the north of the first well in an attempt to find the reservoir in an up-structure position; these two wells were drilled on the north side of a major basin-bounding fault, and the Pennsylvanian section was not present.

The Latigo Ranch field is located in the Cuervo sub-basin. Four wells encountered gas in Strawn sandstones between depths of 6,600 ft and 7,400 ft. Significant completion problems and enigmatic well tests resulted in poor well performance and field abandonment (Montgomery 1986).

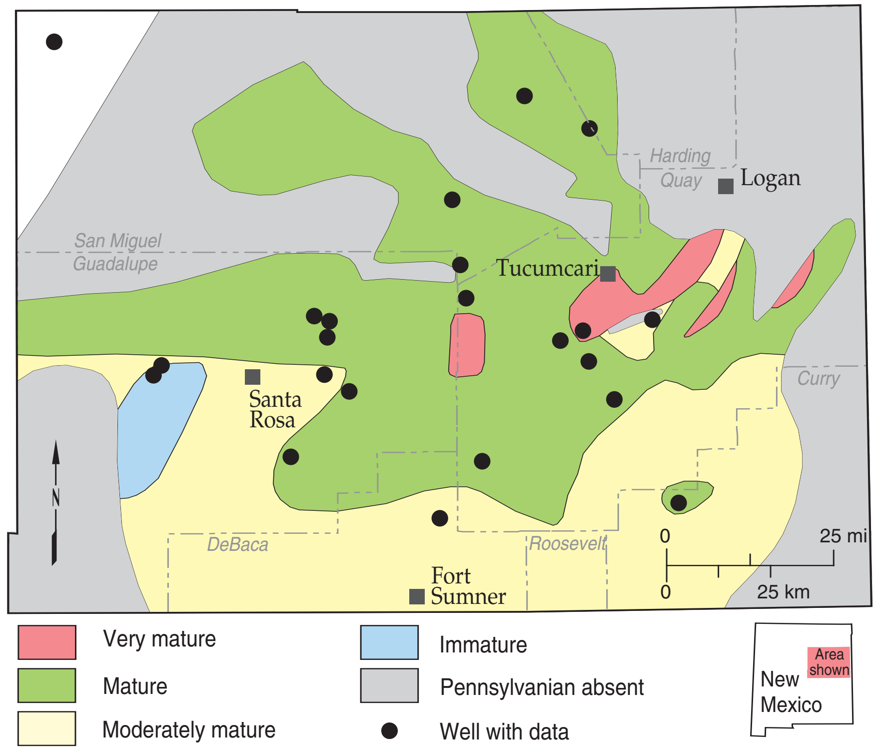

FIGURE 6—Maximum thermal maturity of Pennsylvanian strata, Tucumcari Basin. From Broadhead et al. (2002).

Recent exploration and drilling

As a result of improved understanding of the Tucumcari Basin, a significant exploration play has emerged within the past several years (Shirley 2004). A number of companies acquired lease positions in the basin, and exploratory drilling followed. The most currently active companies are Yates Petroleum, Coulthurst Management, and Ceja Corp. Other active parties include Ace Petroleum, Roy Barton, Blanco Corp., Caza, CKG Energy, David Petroleum, DMT Energy, Ben Donegan, Ibis Petroleum, Inter-American Corp., Pitch Energy, Charles Reynolds, SDX Resources, Craig Settle, Strata View, Gene Wilson, and Xeric Corp., as well as local ranchers and land holders.

Exploratory drilling has followed the leasing of oil and gas rights. CKG Energy drilled several wells and reported promising occurrences of gas and light petroleum liquids. The wells were drilled to approximately 7,000 ft in lower Canyon (Upper Pennsylvanian) or upper Strawn (Middle Pennsylvanian) strata near the juncture of the Quay and Cuervo sub-basins in northwest Quay County. Coulthurst Management, in conjunction with Gene Wilson, drilled two exploratory wells in northwest Quay County and reported good shows and recovery of gas. Yates Petroleum also drilled two wells in northwest Quay County, but results have not been released. The wells drilled during the latest round of exploration confirm the geologic model of the basin as presented in Broadhead (2001 a,b,c).

The encouraging aspect of this round of exploratory activity is the large number of operators who have taken a position in the basin. During this exploratory phase, success is not dependent on a single operator to develop prospects and drill wells. All of these companies are pursuing their own ideas concerning reservoirs and traps. This increases the possibility of seeing several wells drilled based on a variety of exploration concepts. The documentation of source rocks, regional basin structure, and basin-wide facies tracts are only three components of the petroleum system. Reservoirs, traps, and seals are three other components of the petroleum system, and ideas about these components are currently being tested by the drill bit.

FIGURE 7—Core of oil-saturated Triassic sandstones in the Newkirk field. Core box is 3 ft long.

References

Brister, B. S., Stephens, W. C., and Norman, G. A., 2002, Structure, stratigraphy, and hydrocarbon system of a Pennsylvanian pull-apart basin in north-central Texas: American Association of Petroleum Geologists, Bulletin, v. 86, pp. 1–20.

Broadhead, R. F., 1998, Petroleum source rocks in late Paleozoic elevator basins: the Tucumcari, Estancia, Vaughn, and Carrizozo Basins; *in* Proceedings volume for Frontier and underexplored basins of New Mexico: Petroleum Technology Transfer Council Southwest Regional Lead Organization and New Mexico Bureau of Mines and Mineral Resources, pages not consecutively numbered.

Broadhead, R. F., 2001a, New Mexico elevator basins—1. Petroleum systems studied in southern Ancestral Rocky Mountains: Oil and Gas

Journal, v. 99, no. 2, pp. 32–38.
Broadhead, R. F., 2001b, New Mexico elevator basins—3. Elevator basin models—implications for exploration in central New Mexico: Oil and Gas Journal, v. 99, no. 4, pp. 30–36.
Broadhead, R. F., 2001c, Tucumcari Basin potential borne out in new source rock studies: Oil and Gas Journal, v. 99, no. 38, pp. 34–37.
Broadhead, R. F., and Chapin, C. E., 1999, Petroleum systems in late Paleozoic elevator basins, southern Ancestral Rocky Mountains (abs.): American Association of Petroleum Geologists, 1999 annual convention, program, p. A16.
Broadhead, R. F., and Jones, G., 2002, Petroleum potential of the Sin Nombre area, De Baca, Roosevelt, Curry, Lincoln, Guadalupe, and Chaves Counties, New Mexico—a reconnaissance report: New Mexico Bureau of Geology and Mineral Resources, Open-file Report 467, 1 CD-ROM.
Broadhead, R. F., Frisch, K., and Jones, G., 2002, Geologic structure and petroleum source rocks of the Tucumcari Basin, east-central New Mexico: New Mexico Bureau of Geology and Mineral Resources, Open-file Report 460, 1 CD-ROM.
Broadhead, R. F., and King, W. E., 1988, Petroleum geology of Pennsylvanian and Lower Permian strata, Tucumcari Basin, east-central New Mexico: New Mexico Bureau of Mines and Mineral Resources, Bulletin 119, 75 pp.
Budding, A. J., 1979, Geology and oil characteristics of the Santa Rosa tar sands, Guadalupe County, New Mexico: New Mexico Energy Research and Development program, Report EMD 78-3316, 19 pp.
Budding, A. J., 1980, Geology and oil characteristics of tar sands near Santa Rosa, New Mexico: New Mexico Geology, v. 2, no. 1, pp. 4–5.
Budding, A. J., and Broadhead, R. F., 1987, Geology and geochemistry of Santa Rosa tar sands; *in* Meyer, R. F. (ed.), Exploration for heavy crude and natural bitumen: American Association of Petroleum Geologists, Studies in Geology 25, pp. 293–299.
Budnik, R. T., 1986, Left-lateral intraplate deformation along the Ancestral Rocky Mountains—implications for late Paleozoic plate reconstructions: Tectonophysics, v. 132, pp. 195–214.
Dooley, T., and McClay, K., 1997, Analog modeling of pull-apart basins: American Association of Petroleum Geologists, Bulletin, v. 81, pp. 1804–1826.
Gorman, J. M., and Robeck, R. C., 1946, Geology and asphalt deposits of north-central Guadalupe County, New Mexico: U.S. Geological Survey, Oil and Gas Investigations Preliminary Map PM-44, scale 1:63,360.
Kluth, C. F., and Coney, P. J., 1981, Plate tectonics of the Ancestral Rocky Mountains: Geology, v. 9, pp. 10–15.
Martin, F. D., 1983, Steamflood pilot in the O'Connell Ranch field: New Mexico Energy Research and Development Institute, Report NMERDI 2-69-3302, 70 pp.
McKallip, C., Jr., 1984, Newkirk field—the geology of a shallow steamflood project in Guadalupe County, New Mexico: Unpublished M.S. thesis, New Mexico Institute of Mining and Technology, 89 pp.
Montgomery, S. L., 1986, New Mexico's frontier on the verge: Petroleum Frontiers, v. 3, no. 2, 61 pp.
Reynolds, C. M., 1998, South margin of the Cuervo trough; *in* Proceedings volume for Frontier and underexplored basins of New Mexico: Petroleum Technology Transfer Council Southwest Regional Lead Organization and New Mexico Bureau of Mines and Mineral Resources, pages not consecutively numbered.
Reynolds, C. M., and Reynolds, I. B., 2004, Petroleum possibilities of the Cuervo trough, Tucumcari Basin, New Mexico: New Mexico Geology, v. 26, no. 3, pp. 83–89.
Scott, G. L., and Joy, C. C., 1983, Recovering heavy oil in the Santa Rosa Sandstone (abs.); *in* Abstracts of papers presented, Conference on Improved production of oil and gas in New Mexico: New Mexico Petroleum Recovery Research Center, pages not numbered.
Shirley, K., 2004, Elevator sub-basins draw interest: American Association of Petroleum Geologists, Explorer, v. 25, no. 6, pp. 16–17.
Stephens, W. C., Jr., and Gunn, R. D., 1995, Early Pennsylvanian wrenching along the Red River–Matador arch—formation of a pull-apart basin, depocenter for Atokan to lower Desmoinesian (Bend) clastics, Cottle County, Texas (abs.): American Association of Petroleum Geologists, Bulletin, v. 79, p. 912.
Szabo, E., and Wengerd, S. A., 1975, Stratigraphy and tectogenesis of the Paradox Basin; *in* Fassett, J. A., and Wengerd, S. A. (eds.), Canyonlands country: Four Corners Geological Society, Field Conference Guidebook 8, pp. 193–210.
Trentham, R. C., Lindsay, R. F., and Pack, D. D., 1998, Lower Cisco (Pennsylvanian Virgilian) paleokarst, Wolf Flat field, northwest shelf of Palo Duro Basin, Texas; *in* Winfree, K. (ed.), Cored reservoir examples from Upper Pennsylvanian and Lower Permian carbonate margins, slopes and basinal sandstones: West Texas Geological Society, Publication 98-103, pages not consecutively numbered.