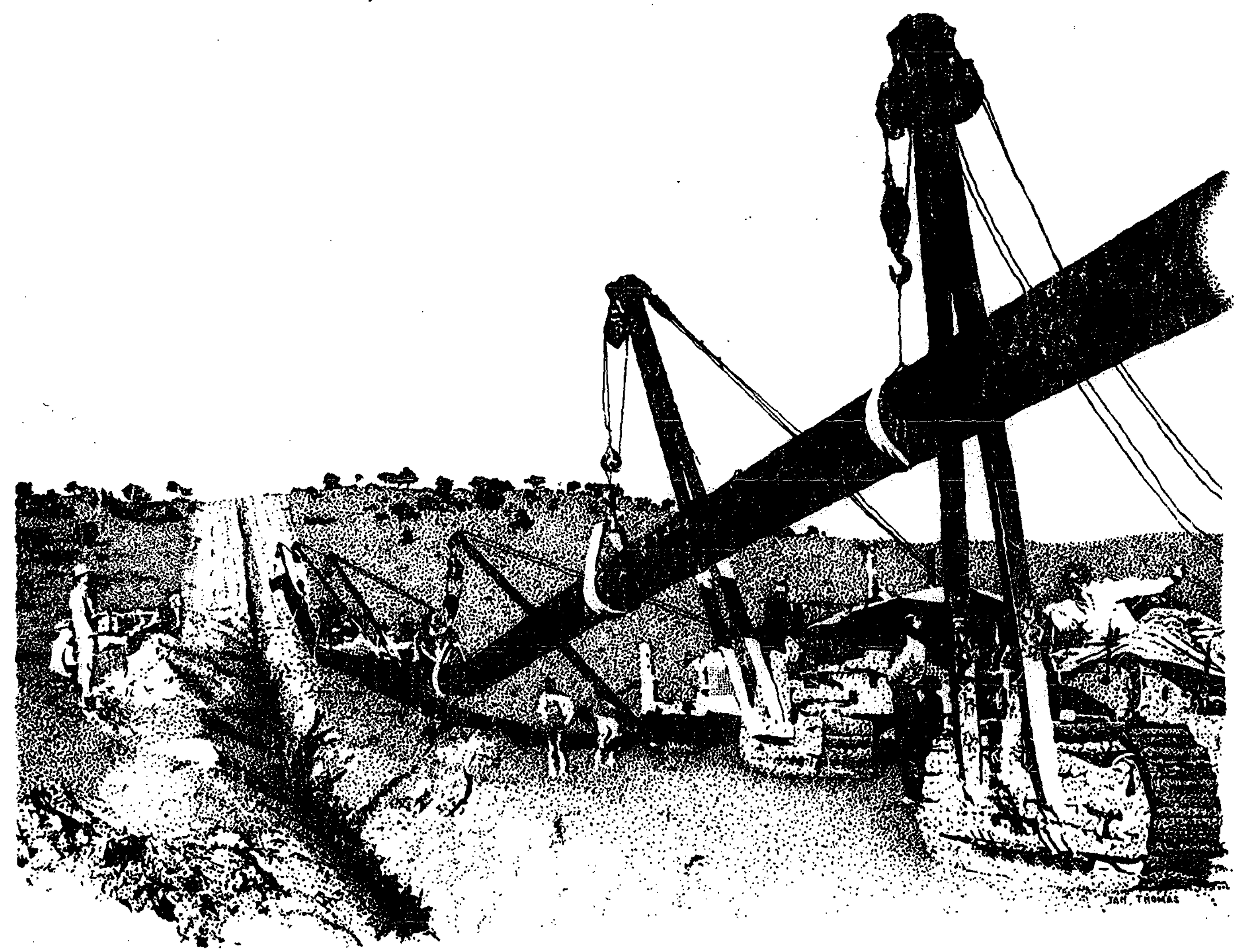
ATLAS OF MAJOR ROCKY MOUNTAIN GAS RESERVOIRS

New Mexico Bureau of Mines & Mineral Resources
C. E. Chapin, Director and State Geologist
New Mexico Institute of Mining and Technology
Socorro, New Mexico 87801

Geological Survey of Wyoming
G. B. Glass, Director and State Geologist
Laramie, Wyoming 82071

Colorado Geological Survey
J. W. Rold, Director and State Geologist
Department of Natural Resources
Denver, Colorado 80203

Utah Geological Survey
M. L. Allison, Director and State Geologist
Department of Natural Resources
Salt Lake City, Utah 84109-1491



Samson Exhibit 18
NMOCD Case Nos. 13492/13493
Submitted 8/10/06

Gas Research Institute
S. D. Ban, President
Chicago, Illinois 60631

Department of Energy
H. R. O'Leary, Secretary
Washington, D.C. 20585

New Mexico Bureau of Mines and Mineral Resources 1993

PERMIAN BASIN PERMIAN [PB] PLAYS—OVERVIEW

Ronald F. Broadhead

The Permian System in southeast New Mexico (Fig. PB.1) has been divided into 10 plays on the basis of stratigraphy, lithology, and depositional setting of the reservoirs. The 107 reservoirs in these plays with production greater than 5 BCF have produced 11.195 TCF gas and 2.84 billion bbls oil (Fig. PB.2, Table PB.1). Production has been obtained from 18,629 active wells and 8,322 now-abandoned wells (Fig. PB.2). Additional production has been obtained from several hundred reservoirs, each of which has produced less than 5 BCF gas.

Permian strata dip southeast from the Northwest shelf into the Delaware Basin (Figs. PB.1, PB.3). The shelf margin is constructional and marked successively by the Abo, Getaway, Goat Seep, and Capitan bank and barrier reef complexes (Figs. PB.4, PB.5). The Central Basin platform, a late-Paleozoic fault-bounded uplift, bisects the deep Permian Basin into the Delaware Basin on the west and the Midland Basin on the east (Fig. PB.1).

Restricted shelf sediments of the Upper Guadalupian Platform, San Andres and Grayburg Platform, and Yeso Platform plays (PB-1, PB-3, PB-6) dominate production (Fig. PB.2, Table PB.1). These three plays produce oil and associated gas from backreef sediments. Significant hydrocarbons are produced from shelf-margin barrier reefs only in the Wolfcamp Carbonate and Abo Platform Carbonate plays (PB-9, PB-7). The Getaway, Goat Seep, and Capitan barrier complexes are essentially devoid of production. Overall, shelf sediments have produced 97% of the Permian gas and 95% of the Permian oil. In the deep Delaware Basin, allochthonous sandstones and carbonates of the Delaware Mountain and Bone Spring plays (PB-2, PB-5) have produced oil and associated gas from relatively small oil reservoirs.

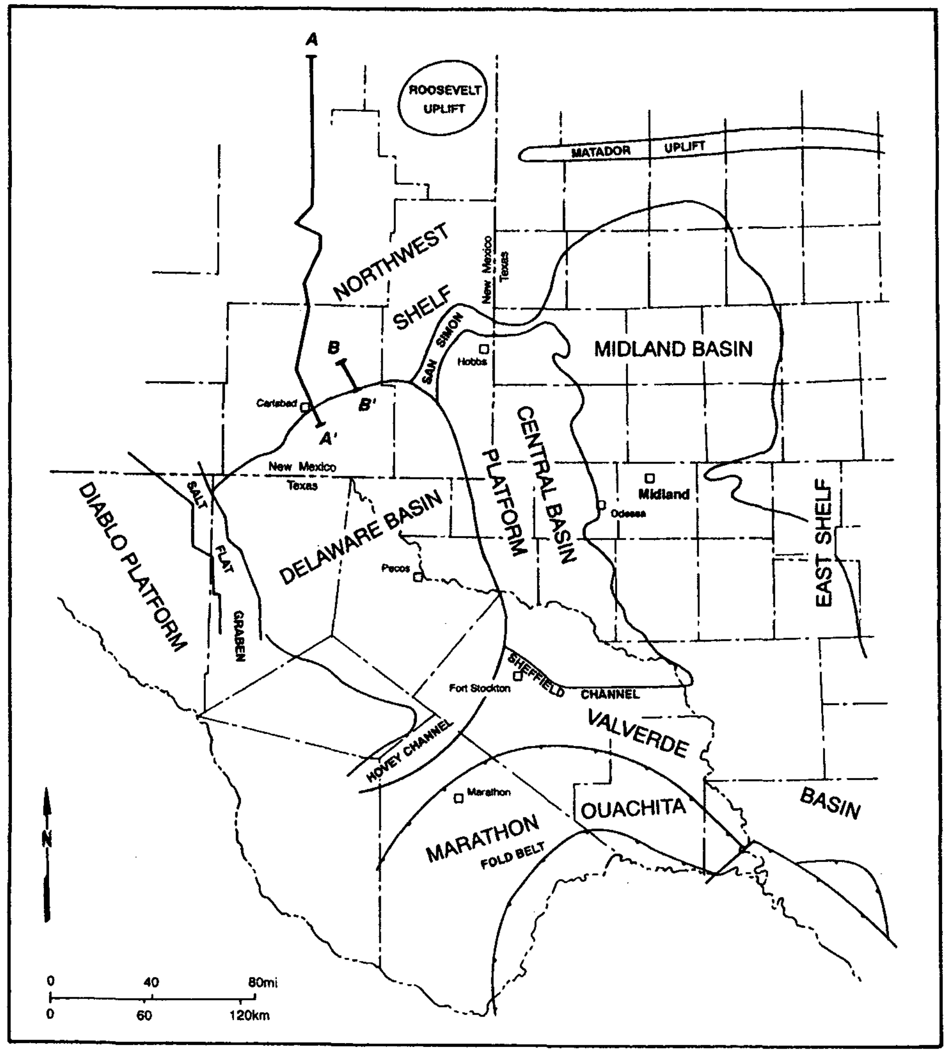


FIGURE PB.1—Major Permian bathymetric elements in the Permian Basin, southeast New Mexico and west Texas. Modified from Hills, 1984. Cross sections are in Figs. PB.4, PB.5.

TABLE PB.1—Permian plays in the Permian Basin. *Cumulative production from major (≥5 BCF) reservoirs.

	Play	Permian Series	Principal productive stratigraphic units	Depositional setting	Main reservoir lithology	Main trap types	Cumulative production* gas, TCF	Cumulative production* oil, MMBO
PB-1	Upper Guadalupian Platform	Guadalupian	Yates, Queen	restricted shelf	sandstone	stratigraphic, anticlines	4.924	471
PB-2	Delaware Mountain Basinal Sandstone	Guadalupian	Delaware	deep basin	sandstone	stratigraphic	0.043	28
PB-3	San Andres and Grayburg Platform	Guadalupian	Grayburg, San Andres	restricted shelf	dolostone, sandstone	stratigraphic, combination	1.723	1,455
PB-4	Glorieta and Upper Yeso Shelf	Leonardian	Glorieta, Paddock, Yeso	restricted shelf	dolostone	anticlines	0.326	122
PB-5	Bone Spring Basinal Sediments	Leonardian	Bone Spring	deep basin	dolostone	stratigraphic	0.046	29
PB-6	Yeso Platform	Leonardian	Blinebry, Tubb, Drinkard	restricted shelf	dolostone, sandstone	anticlines	2.928	237
PB-7	Abo Platform Carbonate	Leonardian	Abo	shelf-margin reef, restricted shelf	dolostone	stratigraphic	0.683	409
PB-8	Abo Fluvial/Deltaic Sandstone	Leonardian	Abo	fluvial-deltaic	red-bed sandstones	stratigraphic	0.273	<1
PB-9	Wolfcamp Carbonate	Wolfcampian	Wolfcamp	shelf, shelf margin, basin	limestone	stratigraphic	0.217	81
PB-10	Granite Wash	Wolfcampian	Granite wash	alluvial fan	sandstone, conglomerate, granite?	combination	0.032	7

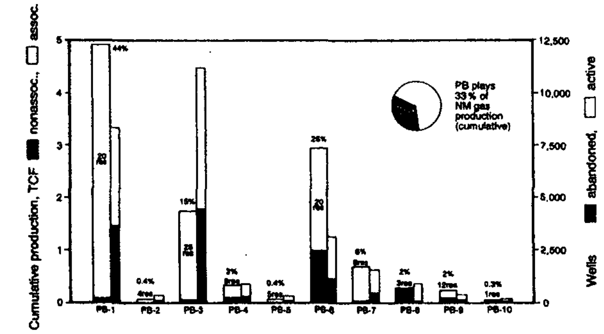


FIGURE PB.2—Gas production and productive wells, Permian plays, southeast New Mexico, based on reservoirs with production greater than 5 BCF. Plays are described in Table PB.1.

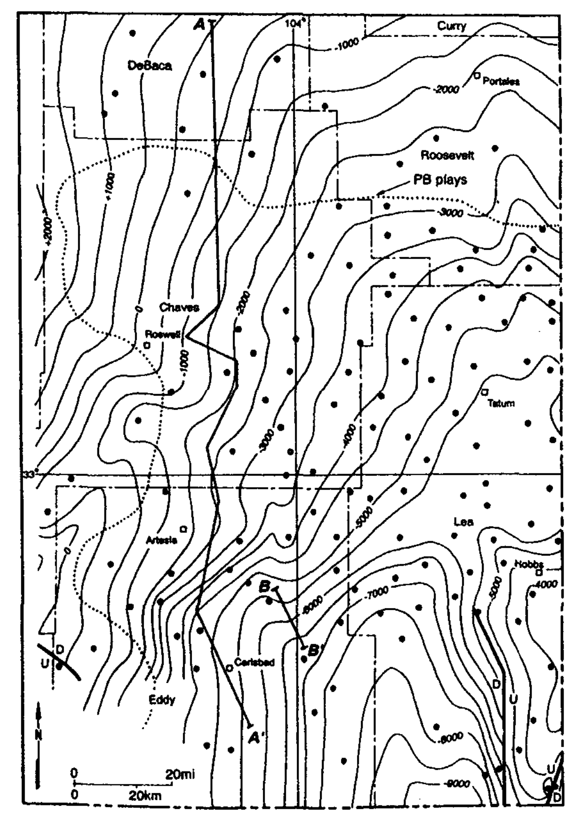


FIGURE PB.3—Structure on top of Wolfcampian strata, southeast New Mexico. After Meyer, 1966. Cross sections are in Figs. PB.4, PB.5.

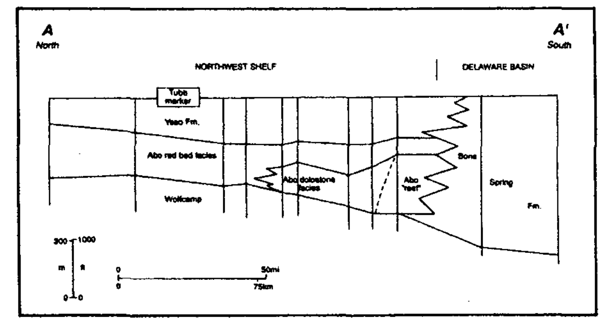


FIGURE PB.4—North-south stratigraphic cross section through Abo and lower Yeso strata. Line of section is in Figs. PB.1, PB.3. After Broadhead, 1984.

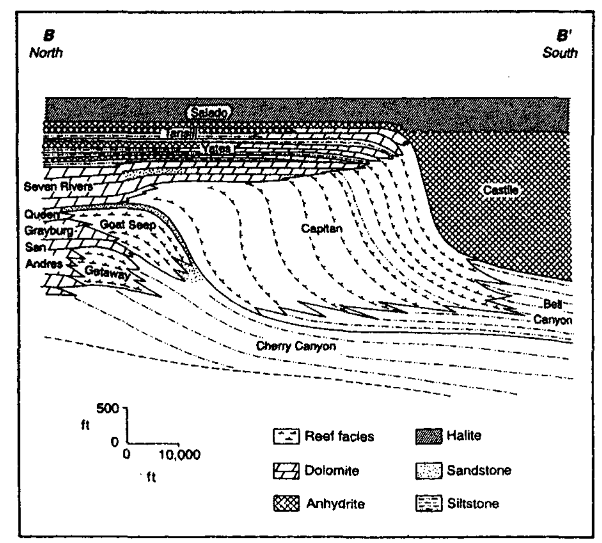


FIGURE PB.5—North-south cross section through Guadalupian and Ochoan strata, showing Getaway, Goat Seep, and Capitan shelf-margin barrier complexes. Line of section is in Figs. PB.1, PB.3. After Garber et al., 1989.

PB-1. UPPER GUADALUPIAN PLATFORM

Ronald F. Broadhead

Reservoirs in the Upper Guadalupian Platform play are present on the Northwest shelf of the Permian Basin and on the Central Basin platform (Fig. PB-1.1). The Upper Guadalupian Platform play is equivalent to the Upper Guadalupian Platform Sandstone play of the *Atlas of Major Texas Gas Reservoirs* (Texas Atlas play code PM-6; Bebout and Garrett, 1989). The 20 reservoirs with cumulative production greater than 5 BCF have produced a total of 4.924 TCF gas since the Rhodes reservoir was discovered in 1927. The largest reservoirs were discovered in the 1920s and 1930s, but new discoveries have been made through the 1980s. Production has been dominated by the Eumont (1.953 TCF) and Jalmat (1.943 TCF) reservoirs (Table PB-1.1). Monthly gas production from reservoirs in this play declined during the 1970s but has been fairly stable since 1982 (Fig. PB-1.2).

Production is obtained from all five formations in the Artesia Group (Fig. PB-1.3; Tait et al., 1962). In most cases, reservoirs that produce from the Grayburg Formation have been assigned to the San Andres and Grayburg Platform play (*see* sec. PB-3) but are included in this play where the Grayburg represents a relatively minor amount of production that has been commingled with production from the Queen and Seven Rivers Formations. Most reservoirs produce associated gas; only four reservoirs in the Queen Formation (Arkansas Junction, Byers, Maljamar, Vandagriff–Keyes) produce nonassociated gas. The associated reservoirs generally produce by solution gas drive, or combination solution gas and water drive. Depths to production range from 1,400 ft at Vandagriff–Keyes to 4,830 ft at Pearl. For the most part, reservoir boundaries on the western Central Basin platform are industrial and not geological (Ward et al., 1986). Production in the Queen, Seven Rivers, and Yates is essentially continuous along the 90 miles from the Eumont reservoir in Lea County to the Shipley reservoir in Ward County, Texas.

Upper Guadalupian sediments were deposited on a restricted shelf north and east of the shelf edge defined by the Capitan reef complex (Fig. PB-1.1; *see* Fig. PB.5). Reservoirs occur principally in sandstones of the Queen and Yates Formations. Dolostones in the Queen, Seven Rivers, Yates, and Tansill Formations are secondary and generally minor reservoirs. Most reservoir sandstones and other clastics were deposited during eustatic sea-level lowstands, and the interbedded carbonates were deposited during eustatic sea-level highstands (Mazzullo et al., 1991; Borer and Harris, 1991a).

Reservoirs producing solely from the Queen occur along and north of a trend from Hobbs to Artesia (Fig. PB-1.1). Most production is from desert coastal-plain sandstones and siltstones in the Shattuck Member, but the Penrose sand (Fig. PB-1.3) is productive in some smaller reservoirs like Arkansas Junction. The sandstones are fine to medium grained, and average reservoir porosities generally range from 17 to 22%. Traps are largely stratigraphic with porosity plugged in an updip direction by evaporites (Figs. PB-1.4, PB-1.5; Ward et al., 1986; Malicse and Mazzullo, 1990).

Productive Yates sands (Fig. PB-1.6) are poorly consolidated, silty, very fine to fine grained, well sorted, and arkosic with porosities of 15–28% (Borer and Harris, 1991a,b). Both vertical and horizontal heterogeneities are high. These reservoir sandstones are interbedded with argillaceous sandstones (poor reservoirs) and are found in a clastic-rich belt 2–4 mi wide on the middle shelf. This clastic-rich belt separates the evaporitic inner shelf from the carbonate-rich outer shelf (Fig. SC-3.12). Depositional processes that formed the reservoir sandstones are poorly understood (Borer and Harris, 1991a). Traps are largely stratigraphic, formed in an updip direction (Fig. PB-1.7) by the impermeable evaporitic facies of the inner shelf. Dolostones of the middle and outer shelves are generally dense and do not form reservoirs.

The cyclical, eustatic origin of sandstones in the Yates has resulted in vertical stacking of reservoirs (Borer and Harris, 1991a). In conjunction with varying topographic profiles and subsidence histories of the shelf, this eustatically driven cyclicity has resulted in different stacking geometries. The paleotopographic profile of the Central Basin platform was relatively steep, so reservoirs are vertically stacked (Fig. PB-1.8) and production is confined to a relatively narrow north-south-trending belt. In comparison, the Northwest shelf had a relatively flat paleotopographic profile; the productive belt is wider than on the Central Basin platform and reservoirs are generally thinner. Individual wells produce from fewer and thinner sandstones, resulting in less-prolific oil and gas accumulations on the Northwest shelf. Additionally, the steeper profile of the Central Basin platform led to enhanced reworking of sands during deposition, generally resulting in higher permeabilities and porosities (Borer and Harris, 1991a). Heterogeneities in reservoirs resulted partly from small-scale (0.1 m.y.) eustatic sea-level fluctuations (Borer and Harris, 1991a, b; *see* sec. SC-3).

INTERA BERGESON—Gas production is controlled in part by reservoir type. Associated gas production from waterflooded oil reservoirs (e.g. Double L) is controlled by oil rate and trends of gas-oil ratios in the reservoir. Nonassociated gas production (e.g. Chaves Gas Area) is controlled by deliverability together with gas prorationing as mandated by the New Mexico Oil Conservation Division. Gas production from the giant Eumont and Jalmat reservoirs is affected by prorationing of both oil and gas.

Associated gas production from oil wells is limited by the oil allowable multiplied by a 2,000 SCF/barrel gas-oil ratio. This sets the maximum volume of gas that can be produced. Wells with producing gas-oil ratios in excess of 30,000 SFC/barrel are classified as gas wells and assigned to a gas proration unit. Monthly total field gas allowables are set by the New Mexico Oil Commission Division and distributed to the individual gas prorationing units (which may contain multiple wells) on the basis of the proration unit acreage. This process first excludes gas allowables assigned to gas proration units classified as marginal.

TABLE PB-1.1—Geologic, engineering, and production data for the Upper Guadalupian Platform play. Heads explained on last page.

St	County	Reservoir	Ty	Disc	Wells	Aban	Spa	Acres	Depth	Trap	Dri	Lith	DeEn	PostD	Por	Perm	Temp	PrGr	CumBCF	PDR
NM	Lea	Arkansas Junction (Queen)	N	1960	4	11	160	3200	4450	Ant	PD	Sand	Shun				102	0.400	6.158	
NM	Lea	Byers (Queen)	N	1958	2	6	160	2720	3680	Ant		Sand	Shun					0.435	11.376	
NM	Chaves, Lea	Caprock (Queen)	K	1940	322	621	40	42440	3030	Iso	CO	Sand	Eoun	Indi	0.18	250.000		0.380	6.668	
NM	Chaves	Chaves Gas Area SE (Queen)	A	1965	48	1	40	1960	2890	Sa	CO	Sand	Eoun	Indi	0.17	25.000	99	0.334	8.448	
NM	Chaves	Double L (Queen)	A	1969	83	31	40	8320	1980	Lpp	CO	Sand	Eoun	Indi	0.22	121.000	84	0.391	8.974	
NM	Lea	Eumont (Ytes Svrv Quen)	A	1929	1040	375	40	115840	2950	Ant	CO	Sand	Ssre		0.12	30.000	109	0.407	1952.512	
NM	Lea	Eunice S (Svrv Quen)	A	1930	307	153	40	20640	3610	Cou	WD	Sand	Ssre	Dolo	0.10		103		193.520	
NM	Eddy	Fren (Seven Rivers)	K	1943	155	57	40	13040	2100	Spm	SG	Dolo	Ssre	Dolo	0.15		90		5.486	
NM	Lea	Jalmat (Tnsl Ytes Svrv)	A	1928	975	478	40	115760	3100	Sa	CO	Sand	Ssre	Dolo	0.18	1.800	100	0.465	1943.370	
NM	Lea	Langlie Mattix (Artesia)	A	1935	1532	820	40	95400	3410	Cou	SG	Sand	Shun		0.15		115	0.478	448.627	
NM	Lea	Maljamar (Queen)	N	1939	2	2	160	640	3100	Ant		Sand	Eoun	Indi	0.11	15.800			5.404	0.3
NM	Eddy, Lea	Mesa (Queen)	K	1962	28	22	40	4320	3350	Sa	SG	Sand	Eoun	Indi	0.21	100.000	90	0.326	19.241	
NM	Lea	Pearl (Queen)	K	1955	202	117	40	11760	4830	Sa	SG	Sand	Shun		0.10	5.880	101	0.362	10.621	
NM	Lea	Rhodes (Yates Seven Rivers)	G	1927	67	35	40	4920	3040	Iso	CO	Sand	Ssre	Dolo			100	0.461	224.197	
NM	Lea	San Simon N (Yates)	A	1983	24	4	40	1560	3760			Sand					98		7.229	0.2
NM	Lea	Scarborough (Ytes Svrv)	A	1929	70	36	40	5640	3050	Cou	WD	Dolo	Ssre	Dolo	0.14	4.600			28.258	
NM	Eddy, Lea	Shugart (Artesia)	K	1937	362	121	40	23200	2560	Spm	CO	Sand	Ssre	Dolo			90		12.162	
NM	Lea	Skaggs (Queen Grayburg)	K	1937	73	43	40	6080	3780	Spm	SG	Sand	Ssre	Dolo	0.03	7.000		0.408	16.486	
NM	Eddy	Vandagriff Keyes (Queen)	N	1953	19	9	160	4160	1400		SG	Sand			0.15				8.804	
NM	Chaves	Vest Ranch (Queen)	A	1970	20	9	40	5160	2140	Lpp		Sand	Eoun	Indi				0.389	6.722	0.1

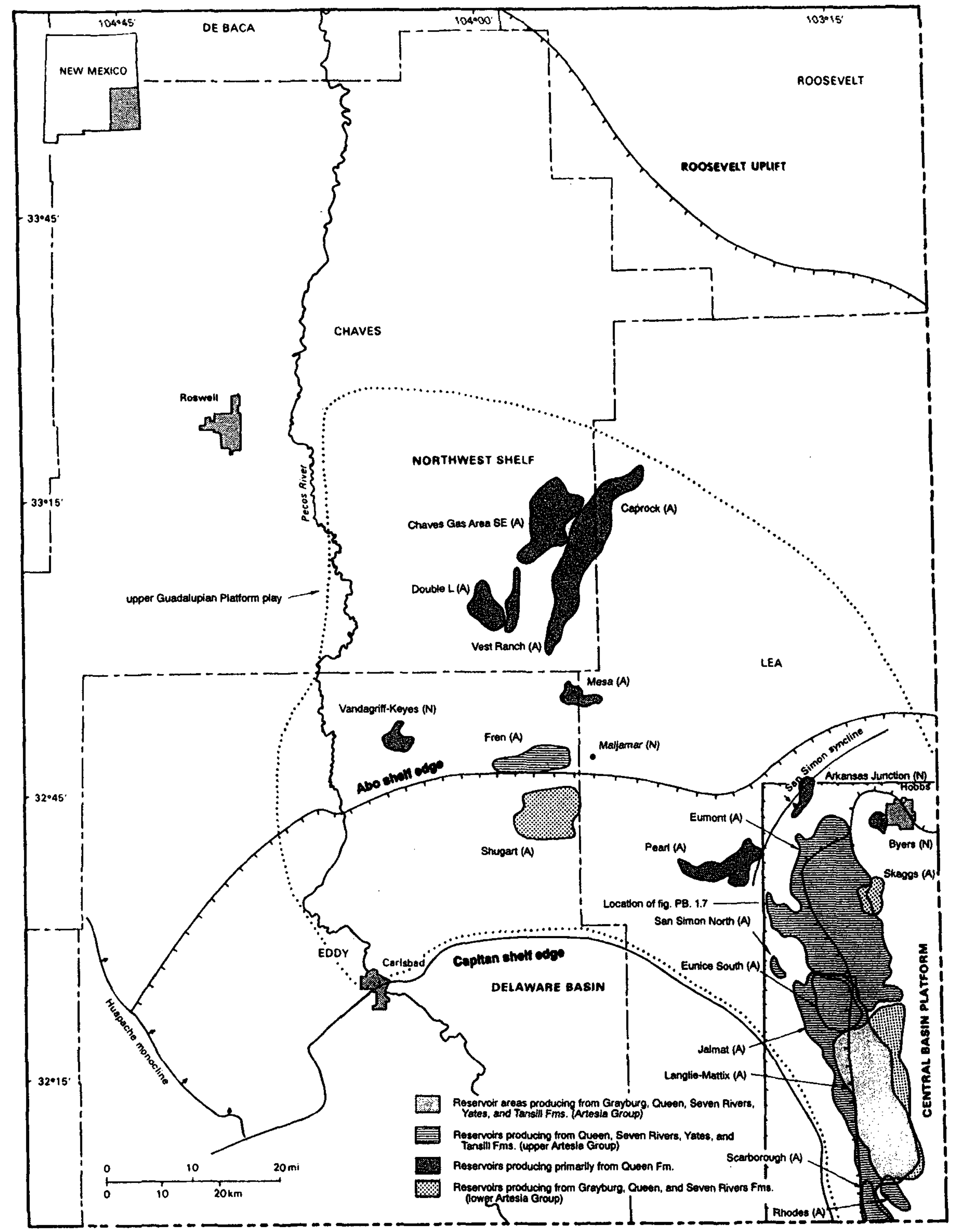


FIGURE PB-1.1—Reservoirs in the Upper Guadalupian Platform play.

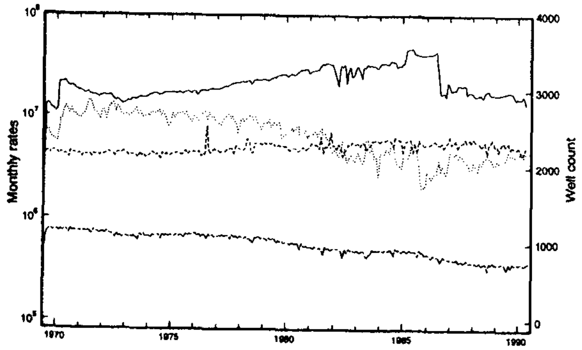


FIGURE PB-1.2—Historical production from the Upper Guadalupian Platform play. ···, gas (MCF); — - —, oil (BBLS); —, water (BBLS); —, wells. From INTERA Bergeson; data source, Dwight's Energydata, Inc.

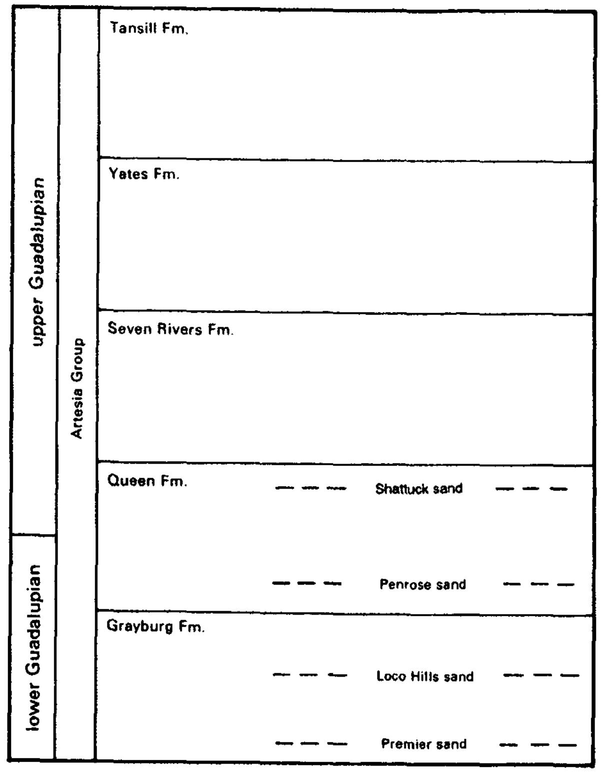


FIGURE PB-1.3—Stratigraphy of Guadalupian Artesia Group, Central Basin platform and Northwest shelf.

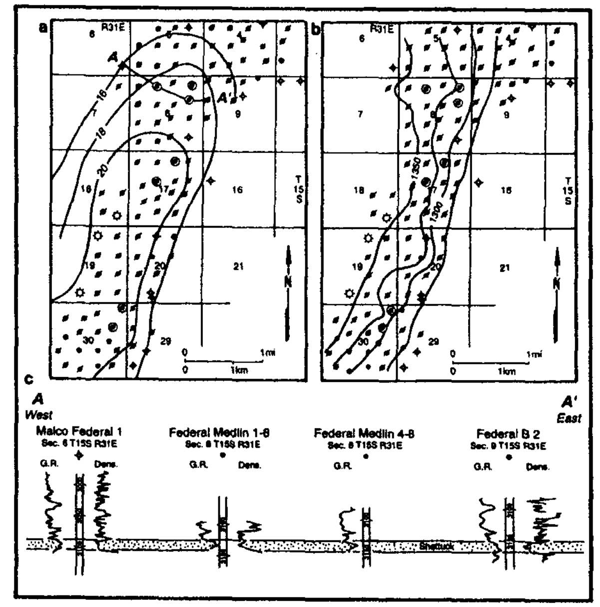


FIGURE PB-1.5—Caprock (Queen) reservoir. A, Isopach and B, structure of Shattuck Sandstone; C, west-east cross section through Shattuck; line of section shown in A. After Malicse and Mazzullo, 1990, with permission.

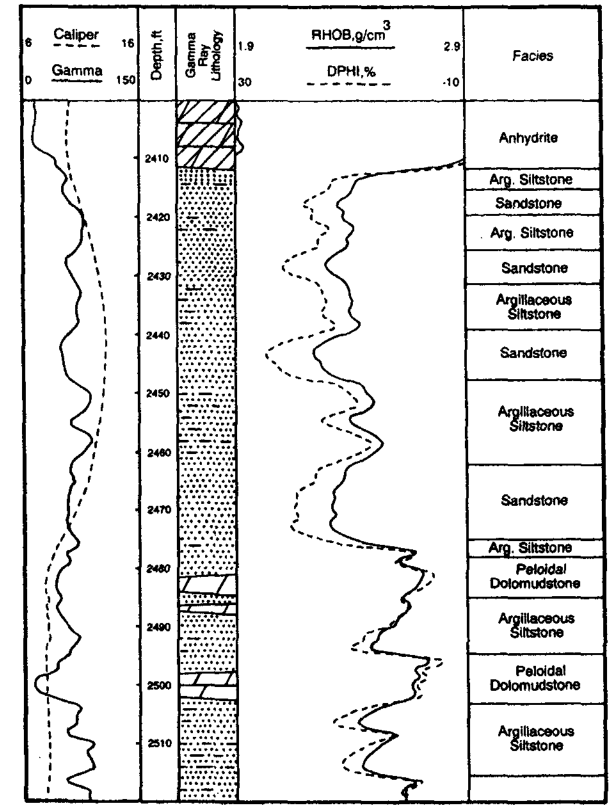


FIGURE PB-1.6—Typical log of reservoir sandstones in Yates Formation, Central Basin platform. Well HSA 1257, North Ward Estes reservoir, Ward Co., Texas. After Borer and Harris, 1991b.

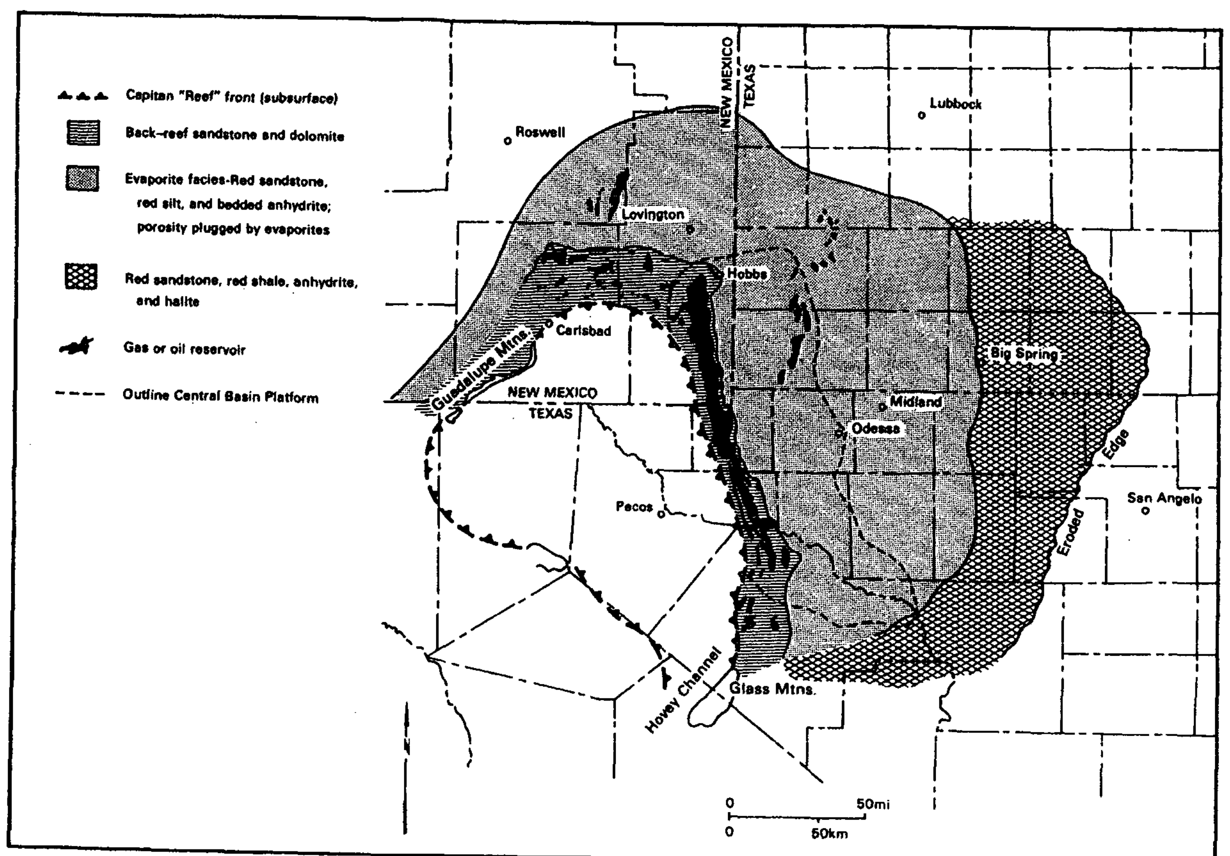


FIGURE PB-1.4—Simplified lithofacies map of Queen, Seven Rivers, and Yates Formations, Permian Basin of southeast New Mexico and west Texas. After Ward et al., 1986.

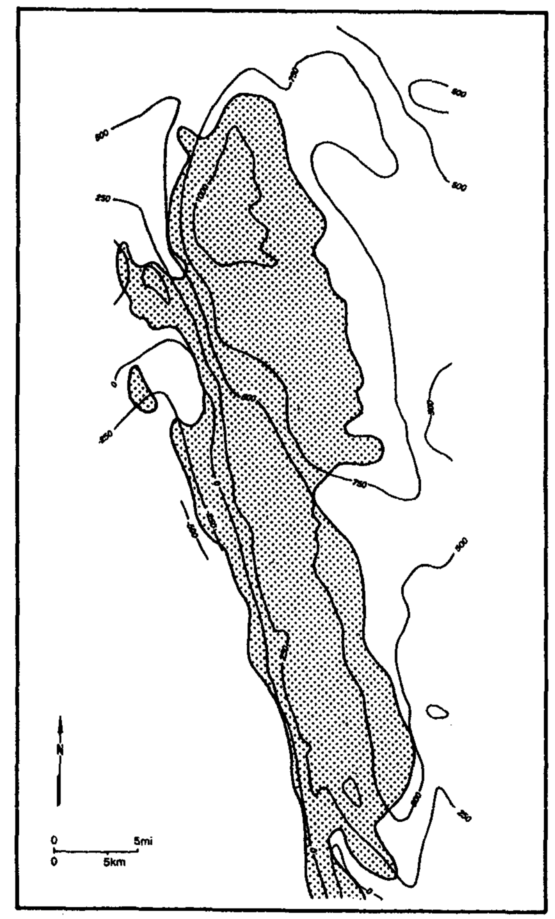


FIGURE PB-1.7—Structure on top of Yates Formation and productive area of major Yates reservoirs, Central Basin platform, New Mexico. See Fig. PB-1.1 for location. Structure contours after Stipp and Haigler, 1957.

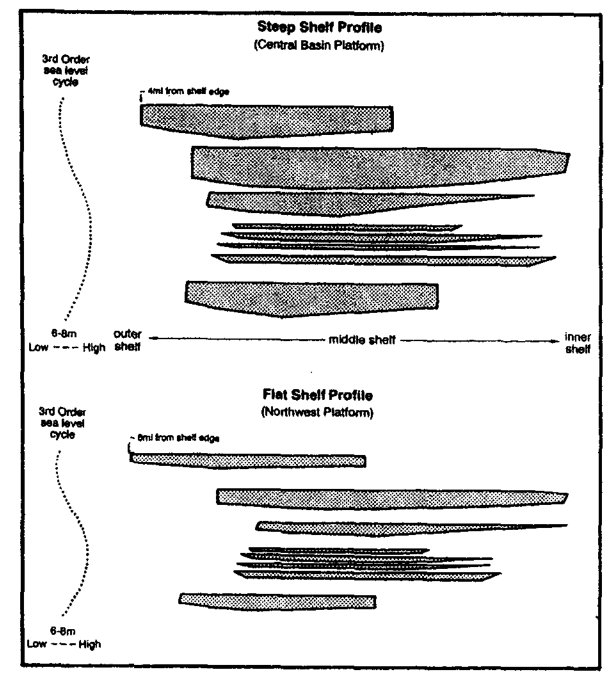


FIGURE PB-1.8—Schematic cross sections of distribution of sandstone bodies in middle-shelf clastic belt of Yates Formation on Central Basin platform and on Northwest shelf. After Borer and Harris, 1991a.

PB-2. DELAWARE MOUNTAIN BASINAL SANDSTONE

Ronald F. Broadhead

Reservoirs of the Delaware Mountain Basinal Sandstone play lie in the southern part of the Delaware Basin (Fig. PB-2.1). The Delaware Mountain Basinal Sandstone play is equivalent to the Delaware Sandstone play of the *Atlas of Major Texas Gas Reservoirs* (Texas atlas play code PM-5; Bebout and Garrett, 1989). Production is obtained from the Bell Canyon, Cherry Canyon, and Brushy Canyon Formations (Fig. PB-2.2). The four reservoirs in this play with production exceeding 5 BCF have produced a total of 43 BCF gas since the Mason North reservoir was discovered in 1954. Monthly gas production increased from 19 MMCF in early 1983 to 122 MMCF in 1986 following extensive drilling and development (Fig. PB-2.3). All four reservoirs produce associated gas by solution gas drive. Depth to production ranges from 3,000 ft for Bell Canyon pay zones to more than 8,000 ft for Brushy Canyon pay zones in the structurally deeper, central part of the basin.

The Delaware Mountain Group was deposited basinward of the Getaway, Goat Seep, and Capitan shelf-margin reef and carbonate complexes (*see* Fig. PB.5). The Delaware consists of sandstone, siltstone, and minor (<5%) limestone, dolostone, and conglomerate (Harms and Williamson, 1988). Siltstones were deposited by suspension settling and blanket the basin. Straight to slightly sinuous channels were eroded by density currents into the siltstones. These channels are filled by shelf-derived sandstones also deposited by density currents (Fig. PB-2.4; Bozanich, 1979; Jacka, 1979; Harms and Williamson, 1988).

The channel sandstones form the oil and gas reservoirs. Most are silty, very fine grained subarkoses (Harms and Williamson, 1988). Porosities are typically 15–25%, and permeabilities range from 0.1 to 200 md but typically average 7–25 md. Porosity is mostly secondary and was formed by dissolution of early-stage calcite, sulfate, and halite cements; subsequently this porosity was partially occluded by late-stage authigenic chlorite (Hays and Tieh, 1992; Walling et al., 1992). Some workers (Meissner, 1972; Jacka, 1979) believe the Delaware Mountain clastics were derived from shelf sands deposited on the shelf during sea-level lowstands; therefore, they are roughly correlative with shelf clastics but not with shelf carbonates deposited during sea-level highstands (Borer and Harris, 1991; *see* sec. SC-3).

Traps in Delaware Mountain sandstones are stratigraphic or combination stratigraphic-structural. At Paduca (Figs. PB-2.5, PB-2.6), the major component of the trapping mechanism is the geometry of the channel-shaped sandstone body; a structural nose has localized the hydrocarbon accumulation. The channel-form trapping mechanism is typical of reservoirs in the Delaware Mountain Group. Most Delaware Mountain hydrocarbons have been produced from the upper part of the Bell Canyon. El Mar, Mason North, and Paduca produce from the Bell Canyon. Brushy Draw produces mostly from the Cherry Canyon.

This play has not yet reached the mature stage. In addition to the four reservoirs in Table PB-2.1, there are 140 within the play outline with individual cumulative gas production less than 5 BCF. All but 11 are oil reservoirs. Many of these reservoirs are relatively young and have not been fully developed; many will produce 1–3 MMB oil but few will produce 5 BCF gas (John Worrall, pers. comm.). Potential for new discoveries remains high, especially in the Brushy Canyon and Cherry Canyon Formations.

Most wells completed in the Delaware sandstones are artificially fractured. Because the authigenic chlorites can retrogress to expansive forms if pore-fluid pH is altered (Walling et al., 1992), fracture treatments must be carefully designed.

INTERA BERGESON—The four major reservoirs in the Delaware Mountain Basinal Sandstone play are classified as oil reservoirs with associated natural gas. All are in the late stage of depletion after having been waterflooded. Current water cuts range from 60 to 80% while current per well oil rates range from an average 3.6 BOPD with a gas-oil ratio of 2,000 SCF/STB at Mason North to 12.6 BOPD at El Mar with a gas-oil ratio of 500 SCF/STB.

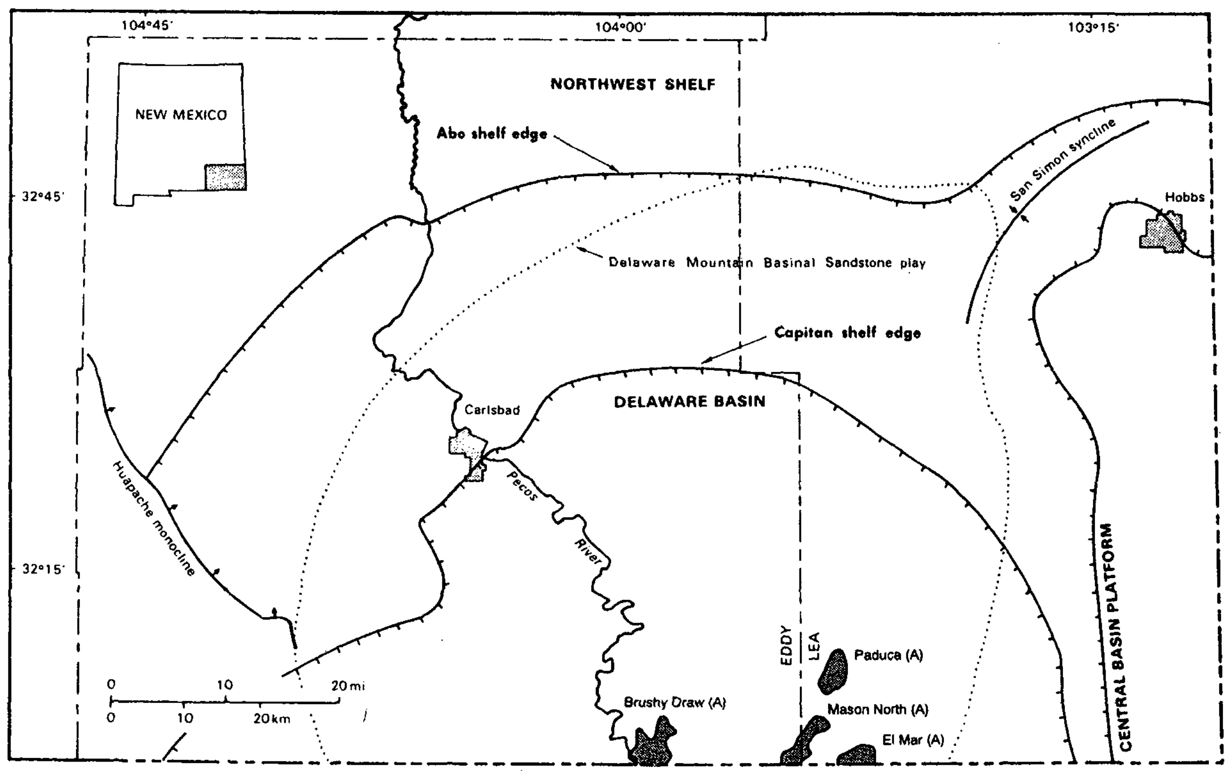


FIGURE PB-2.1—Reservoirs in the Delaware Mountain Basinal Sandstone play.

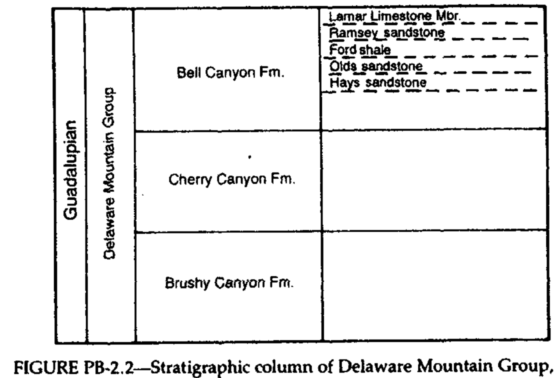


FIGURE PB-2.2—Stratigraphic column of Delaware Mountain Group, Delaware Basin. Compiled from Payne, 1976; Grauten, 1979; and Harms and Williamson, 1988.

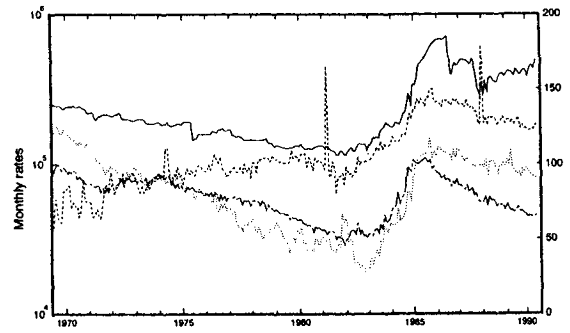


FIGURE PB-2.3—Historical production from the Delaware Mountain Basinal Sandstone play. ···, gas (MCF); — · —, oil (BBLS); ---, water (BBLS); —, wells. From INTERA Bergeson; data source, Dwight's Energydata, Inc.

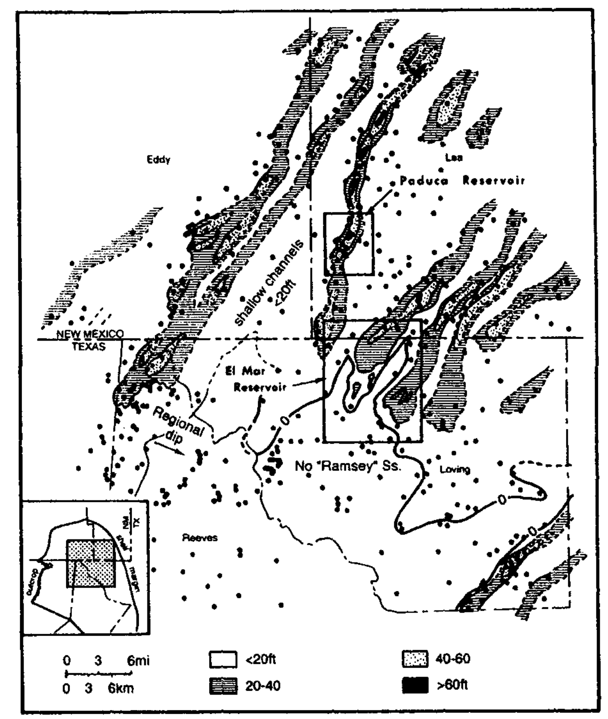


FIGURE PB-2.4—Regional sandstone isolith map of Ramsey sandstone, upper Bell Canyon Formation. After Harms and Williamson, 1988.

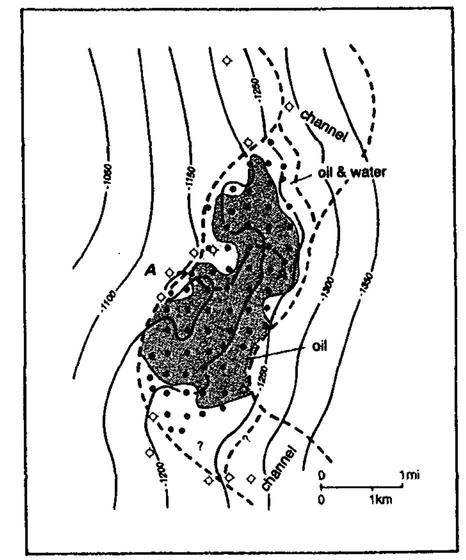


FIGURE PB-2.5—Bell Canyon structure and outline of sandstone channel, Paduca reservoir. See Fig. PB-2.6 for cross section *A-A'*. After Berg, 1975.

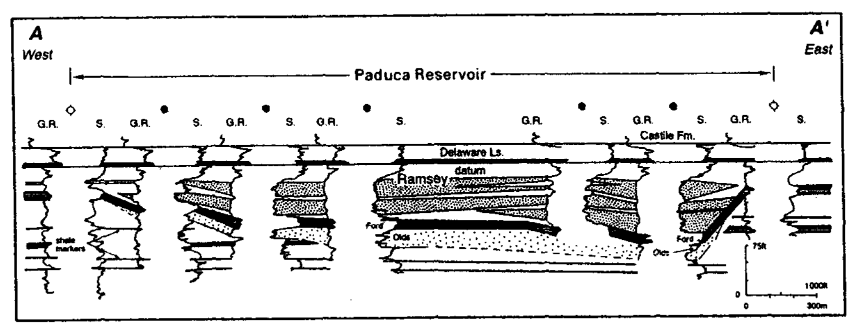


FIGURE PB-2.6—West-east stratigraphic cross section, upper Bell Canyon Formation, Paduca reservoir. See Fig. PB-2.5 for location. After Harms and Williamson, 1988 and Berg, 1979.

TABLE PB-2.1—Geologic, engineering, and production data for the Delaware Mountain Basinal Sandstone play. Heads explained on last page.

St	County	Reservoir	Ty	Disc	Wells	Aban	Spa	Acres	Depth	Trap	Dri	Lith	DeEn	PostD	Por	Perm	Temp	PrGr	CumBCF	PDR
NM	Eddy	Brushy Draw (Delaware)	A	1958	105	8	40	7200	5010	Sa	SG	Sand	Sbun	Aucl	0.23				6.419	
NM	Lea	El Mar (Delaware)	A	1959	62	33	40	2720	4550	Sa	SG	Sand	Sbun	Aucl	0.22	7.700		0.481	13.577	
NM	Eddy, Lea	Mason N (Delaware)	A	1954	61	9	40	4320	4220	Sa	SG	Sand	Sbun	Aucl	0.25	24.000			7.812	
NM	Lea	Paduca (Delaware)	A	1960	61	25	40	4000	4660	Spm	SG	Sand	Sbun	Aucl	0.23	15.500	100	0.439	15.589	

PB-3. SAN ANDRES AND GRAYBURG PLATFORM

Ronald F. Broadhead

Reservoirs in the San Andres and Grayburg Platform play are present on the Northwest shelf of the Permian Basin and on the Central Basin platform (Fig. PB-3.1). They have produced a total of 1.723 TCF gas (Table PB-3.1). In addition to these 25 reservoirs, there are approximately 175 reservoirs with cumulative gas production less than 5 BCF per reservoir; subplay outlines (Fig. PB-3.1) reflect their presence. The San Andres and Grayburg Platform play is equivalent to the San Andres and Grayburg Platform Carbonate play of the *Atlas of Major Texas Gas Reservoirs* (Texas Atlas play code PM-4; Bebout and Garrett, 1989). Although monthly production has declined from 5.7 BCF in 1970 to 2.2 BCF in 1990 (Fig. PB-3.2), this play still produces a substantial amount of gas; the decline curve indicates that established reservoirs in the play will supply significant volumes of gas for years to come. Based on stratigraphic position of reservoirs in the San Andres–Grayburg section (Fig. PB-3.3), this play has been subdivided into the Lower San Andres–Slaughter Zone subplay and the Upper San Andres–Grayburg subplay. Each subplay lies along distinct geologic and geographic trends.

The Lower San Andres–Slaughter Zone subplay produces from nine reservoirs in the Slaughter zone of the lower part of the San Andres Formation (Figs. PB-3.3, PB-3.4). This subplay has produced 0.161 TCF gas since the Sawyer reservoir was discovered in 1947. Six of the reservoirs were discovered in the 1960s; development continues in others. Except for Sawyer, all reservoirs produce associated gas, and solution gas drive is the dominant production mechanism. Depths to production generally vary from 4,000 to 5,000 ft depending on structural elevation of the San Andres.

Reservoirs occur in four porosity zones in the lower San Andres (Figs. PB-3.3, PB-3.4; Gratton and LeMay, 1969; Elliott and Warren, 1989). Each zone consists of one or more upward-shallowing progradational carbonate sequences; each sequence consists ideally of: 1) basal open-marine limestones overlain by 2) restricted-marine subtidal limestones or dolostones (reservoir facies) overlain by 3) intertidal and supratidal carbonates overlain by 4) salina and sabkha anhydrites (Elliott and Warren, 1989). The reservoirs in the subtidal facies have moldic and intercrystalline-dolomite porosity.

Traps in the Lower San Andres–Slaughter Zone subplay are stratigraphic or combination structural-stratigraphic (Gratton and LeMay, 1969; Yedlosky and McNeal, 1969; Cowan and Harris, 1986; Ward et al., 1986; Keller, 1992). Porosity zones in the lower San Andres pinch out regionally updip to the north and northwest where porosity is occluded by anhydrite cement. Traps at Cato, Chaveroo, and Milnesand are formed by geometric arrangement of zero-porosity lines and structural noses (Fig. PB-3.5) off the south flank of the Roosevelt uplift. Cyclic deposition of regressive sequences has led to vertical stacking of porosity zones and nearly coincident zero-porosity lines; the result is that a single reservoir may produce from two or more hydraulically isolated porosity zones.

Traps at Mescalero, Todd, Bluitt, Sawyer, and Sawyer West may be combination structural-diagenetic (Keller, 1992). Oil trapped in pre-Tertiary anticlines was sealed from below by evaporite cementation beneath the oil-water contact; structures were tilted eastward in the Tertiary and the evaporite cements kept oil from spilling out of them, resulting in east-tilted oil-water contacts. These diagenetic seals explain the underpressuring of lower San Andres Reservoirs (pressure gradients range from 0.240 psi/ft at Milnesand to 0.363 psi/ft at Atoka).

The Upper San Andres–Grayburg subplay produces from 16 reservoirs in the upper part of the San Andres Formation and in the Grayburg Formation (Figs. PB-3.1, PB-3.3). This subplay has produced 1.562 TCF gas since the Artesia reservoir was discovered in 1923. Most gas produced has been solution gas, and solution gas drive is the dominant production mechanism; however, water drive is thought to be dominant or significant in some reservoirs (Eunice Monument, Hobbs, Vacuum). The largest reservoirs in this mature subplay (Eunice Monument, Grayburg Jackson, Hobbs, Maljamar, Penrose Skelly, Vacuum) were discovered in the 1920s and 1930s. Most of the reservoirs are presently under waterflood. Depths to production generally vary from 1,700 to 4,100 ft depending on: 1) stratigraphic position of the reservoir within the San Andres–Grayburg section and 2) structural elevation of the reservoir.

Reservoirs are present in both the upper part of the San Andres and in the Grayburg (Fig. PB-3.3). Porous zones occur in dolostones and dolomitic sandstones in a back-reef environment north of the Goat Seep reef (Ward et al., 1986; Purves, 1986; Lindsay, 1991). In most of the reservoirs, production is primarily from the Grayburg Formation; the main exception is the Hobbs reservoir with major production from both the San Andres and the Grayburg.

On the Central Basin platform, traps are generally formed by north-trending anticlines (Fig. PB-3.6). In the Eunice Monument reservoir, the trap is structural to the west, north, and south (Fig. PB-3.6) but is stratigraphic to the east; porous dolograinstones of a high-energy shoal complex and subtidal dolomitic sandstones are sealed updip by impermeable dolomitic sandstones, dolostones, and evaporites (Penrose facies) of a low-energy back-shoal environment (*see* Fig. SC-3.14; Lindsay, 1991). The vertical seal is formed by the Penrose facies in the overlying Queen Formation and uppermost part of the Grayburg Formation.

On the Northwest shelf, San Andres and Grayburg reservoirs lie along the Artesia–Vacuum arch, a shallow structural reflection of the deeper Abo shelf-edge reef trend and Bone Spring flexure (Fig. PB-3.1). Reservoirs are in back-reef dolowackestones, dolopackstones, and dolograinstones with intercrystalline and moldic porosity (Ward et al., 1986). The carbonate reservoir facies grade northward into a lagoonal evaporite facies (Fig. PB-3.7). Traps are mainly stratigraphic and are formed by evaporitic plugging of porous carbonates in an updip direction to the north (Ward et al., 1986).

The Upper San Andres–Grayburg subplay is mature and located in a densely drilled area. Prospects of discovering major new gas reserves are low within producing trends. However, the Slaughter Zone subplay holds more promise. Porosity zones with updip pinchouts have been mapped in the lowermost San Andres north and west of the known productive trend (Pitt and Scott, 1981) where exploratory drilling has been relatively sparse.

INTERA BERGESON—The San Andres and Grayburg reservoirs tend to be discontinuous, heterogeneous reservoirs; high permeability is associated with vugular porosity zones. The wells are commonly completed in several zones. This presents problems in zone isolation during both primary and secondary recovery operations. Wells are generally stimulated by artificial fracturing with small acid or sand loads.

Various methods of improving oil recovery have been undertaken in these reservoirs. Gas injection has been used successfully in early production stages. Waterflooding has been the secondary recovery technique and has been quite successful despite the heterogeneous, discontinuous nature of the reservoirs. Incorrect handling and treating of injection water has caused dissolution of reservoirs near injector wells with subsequent deposition of scale in producing wells. Problems have also arisen with early water breakthrough in highly permeable zones. These zones may be identified with parasequence analysis (Lindsay et al., 1992). Recent improvements in logging, such as the use of borehole televiewers, are also playing an important role in identifying highly permeable zones, resulting in selective completions that improve oil recovery and reduce water production. Polymers and CO_2 are being used in tertiary recovery projects to recover additional oil left behind by the waterfloods. Polymer is also being used at the initiation of waterfloods to enhance their efficiency. For example, primary recoveries in the Vacuum field were 25% of original oil-in-place, with waterflooding projected to provide an additional 16%, and polymer flooding yet another 1%.

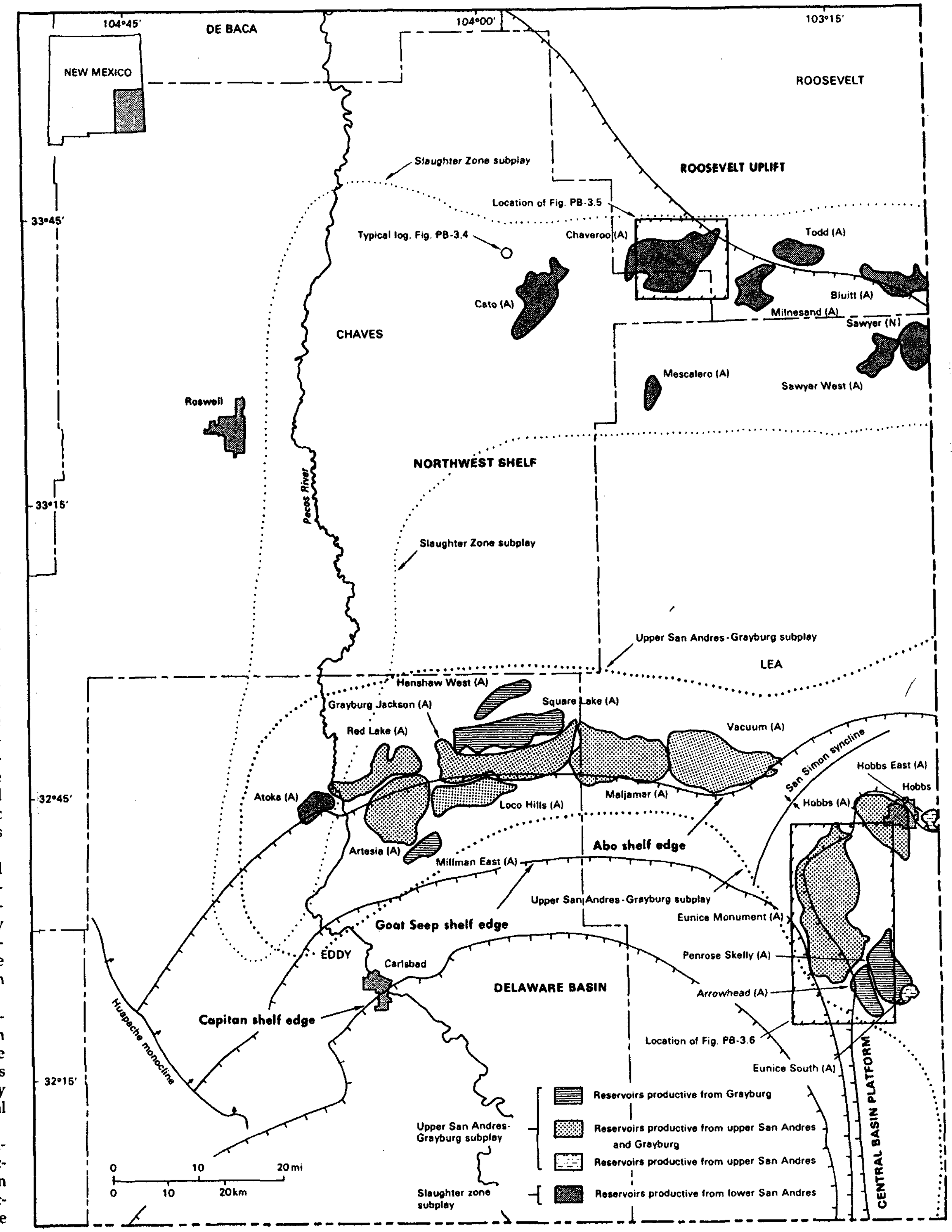


FIGURE PB-3.1—Reservoirs in the San Andres and Grayburg Platform play and in its two subplays.

TABLE PB-3.1—Geologic, engineering, and production data for the San Andres and Grayburg Platform play. Heads explained on last page.

St	County	Reservoir	Ty	Disc	Wells	Aban	Spa	Acres	Depth	Trap	Dri	Lith	DeEn	PostD	Por	Perm	Temp	PrGr	CumBCF	PDR
NM	Lea	Arrowhead (Grayburg)	A	1938	60	70	40	6900	3710	Ant	SG	Dolo	Ssre	Dolo	0.08		90	0.389	39.881	
NM	Eddy	Artesia (Quen Grbg Sadr)	K	1923	599	293	40	34560	2190	Sa	SG	Sand	Shun	Dolo	0.21	90.000	96	0.457	10.564	
NM	Eddy	Atoka (San Andres)	K	1956	123	42	40	6240	1680	Sa	SG	Dolo	Ssre	Dolo	0.09	1.400		0.363	8.737	
NM	Roosevelt	Bluitt (San Andres)	K	1963	55	22	80	9600	4580	Bdp	SG	Dolo	Ssre	Dolo	0.08	5.000	105	0.332	12.222	
NM	Chaves	Cato (San Andres)	K	1966	224	69	40	16400	3500	Bdp	SG	Dolo	Ssre	Dolo	0.08	21.700	125	0.318	30.571	
NM	Chaves & Roosevelt	Chaveroo (San Andres)	K	1965	420	183	40	29760	4220	Bdp	SG	Dolo	Ssre	Doev	0.06	0.700	120	0.314	34.788	
NM	Lea	Eunice Monument (Grbg Sadr)	A	1929	878	344	40	62400	3730	Cou	CO	Dolo	Ssre	Madi	0.08		90	0.380	628.896	
NM	Lea	Eunice S (San Andres)	A	1969	15	6	80	1520	3910				Ssre						7.517	
NM	Eddy, Lea	Grayburg Jackson (Artesia)	K	1929	1280	417	40	46400	2770	Cou	SG	Dolo	Ssre	Dolo				0.469	89.709	
NM	Eddy	Henshaw W (Grayburg)	A	1956	75	52	40	6700	2870	Bdp	SG	Sand	Shun	Dolo					5.449	
NM	Lea	Hobbs (Grbg Sadr)	A	1928	537	252	40	19120	4120	Ant	WD	Lsun	Ssre		0.15	50.000		0.377	302.068	
NM	Lea	Hobbs E (San Andres)	K	1951	17	8	40	1600	4430	Ant	WD	Dolo	Ssre	Dolo	0.25	500.00		0.364	11.956	
NM	Eddy	Loco Hills (Quen Grbg Sadr)	K	1939	349	221	40	19240	2590	Sa	SG	Sand	Ssre	Dolo	0.20	49.900		0.386	5.088	
NM	Eddy, Lea	Maljamar (Grbg Sadr)	K	1926	827	437	40	39040	4043	Cou	SG	Dolo	Ssre	Dolo	0.12	47.000		0.334	117.888	
NM	Lea	Mescalero (San Andres)	K	1962	47	6	40	3040	4140	Cou	SG	Dolo	Ssre	Dolo	0.11		105	0.324	6.767	
NM	Eddy	Millman E (Quen Grbg Sadr)	A	1959	83	36	40	5160	1750	Cou	SG	Dolo	Ssre	Dolo				0.347	7.994	
NM	Roosevelt	Milnesand (San Andres)	K	1958	147	68	40	9200	4590	Spm	SG	Dolo	Ssre	Doev	0.08	0.010	90	0.240	14.616	
NM	Lea	Penrose Skelly (Quen Grbg)	A	1936	195	147	40	19680	3640	Ant	GC	Lsun	Ssre		0.06			0.390	108.693	
NM	Eddy	Red Lake (Quen Grbg Sadr)	A	1934	245	88	40	17500	1870	Sa	SG		Ssre	Dolo	0.10	2.000			10.986	
NM	Lea	Sawyer (San Andres)	N	1947	53	27	40	10080	4900	Bdp	GC	Dolo	Ssre	Doev	0.07	5.900	103		39.070	
NM	Lea	Sawyer W (San Andres)	K	1969	71	11	80	6160	4950	Bdp	SG	Dolo	Ssre	Doev	0.08	.890	115	0.315	8.301	
NM	Eddy	Square Lake (Grbg Sadr)	A	1941	360	248	40	23920	3040	Sa	SG	Sand	Ssre	Dolo	0.21	110.00		0.313	10.208	
NM	Roosevelt	Todd (Lower San Andres)	A	1965	54	35	80	3360	4250	Spm	SG	Dolo	Ssre	Doev	0.04		102	0.318	6.002	
NM	Roosevelt	Todd (Upper San Andres)	N	1963	3	9	320	4480	4180	Ant	PD	Dolo	Ssre	Doev	0.05		102	0.334	9.332	0.1
NM	Lea	Vacuum (Grbg Sadr)	K	1929	880	429	40	44960	4530	Bdp	CO	Dolo	Ssre	Doev	0.09	28.600	101	0.366	195.375	

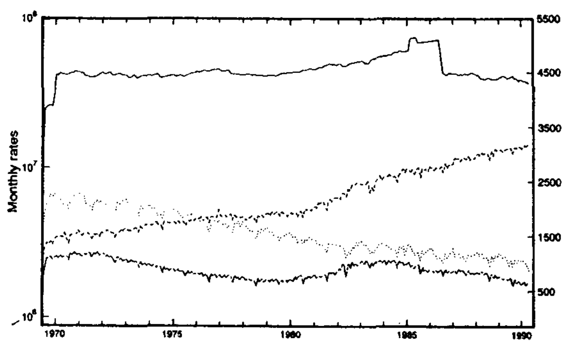


FIGURE PB-3.2—Historical production from the San Andres and Grayburg Platform play. ···, gas (MCF); — - —, oil (BBLS); ---, water (BBLS); —, wells. From INTERA Bergeson; data source, Dwight's Energydata, Inc.

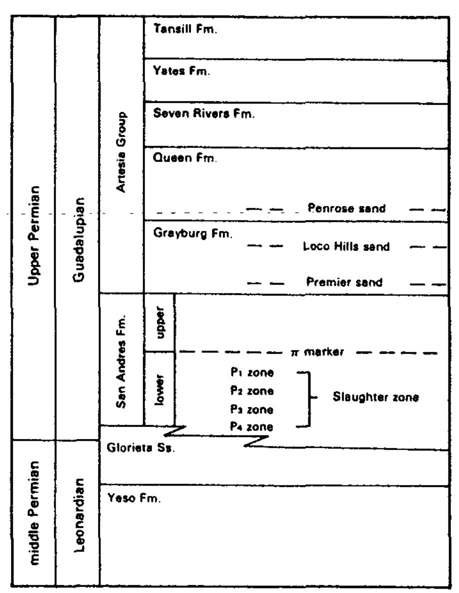


FIGURE PB-3.3—Stratigraphic column of upper Leonardian and Guadalupian strata, Northwest shelf of Permian Basin and Central Basin platform. A regionally mappable radioactive siltstone, π marker, defines the top of the lower San Andres; P_1, P_2, P_3, and P_4 are porosity zones.

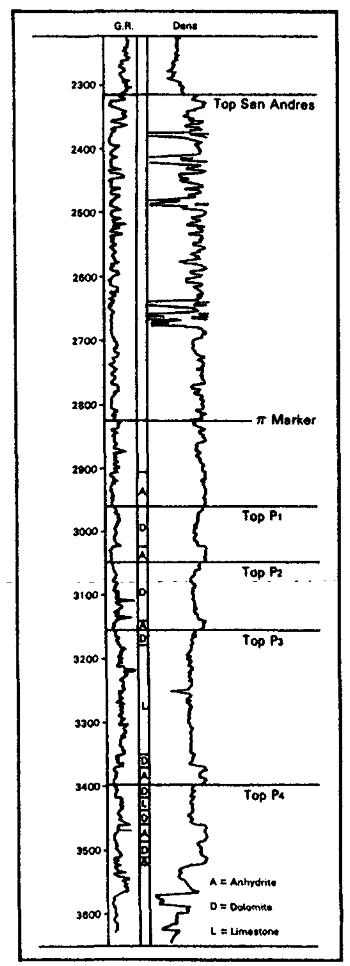


FIGURE PB-3.4—Typical log through San Andres Formation on Northwest shelf showing π marker and four porosity zones in the lower San Andres (P_1, P_2, P_3, P_4). Cities Service No. 1 Government K well, sec. 24 T7S R29E, Chaves County. See Fig PB-3.1 for location. After Gratton and LeMay, 1969.

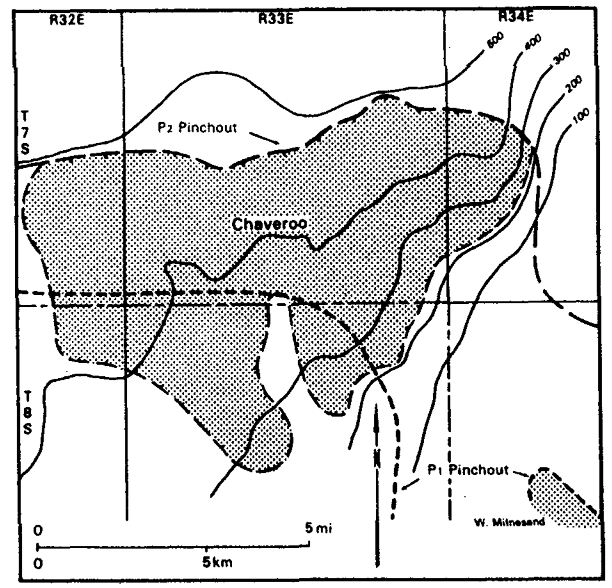


FIGURE PB-3.5—Structure contours on π marker and pinchouts of P_1 and P_2 porosity zones, Chaveroo reservoir. Datum is sea level. See Fig. PB-3.1 for location. After Gratton and LeMay, 1969.

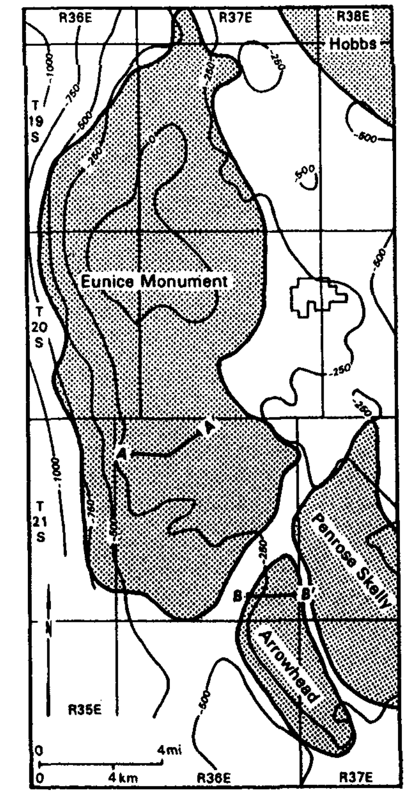


FIGURE PB-3.6—Structure contours on top of Grayburg Formation, northwest part of Central Basin platform, and location of San Andres–Grayburg reservoirs. See Fig. PB-3.1 for location, Fig. SC-3.14 for cross section A–A'. Modified from Lindsay, 1991.

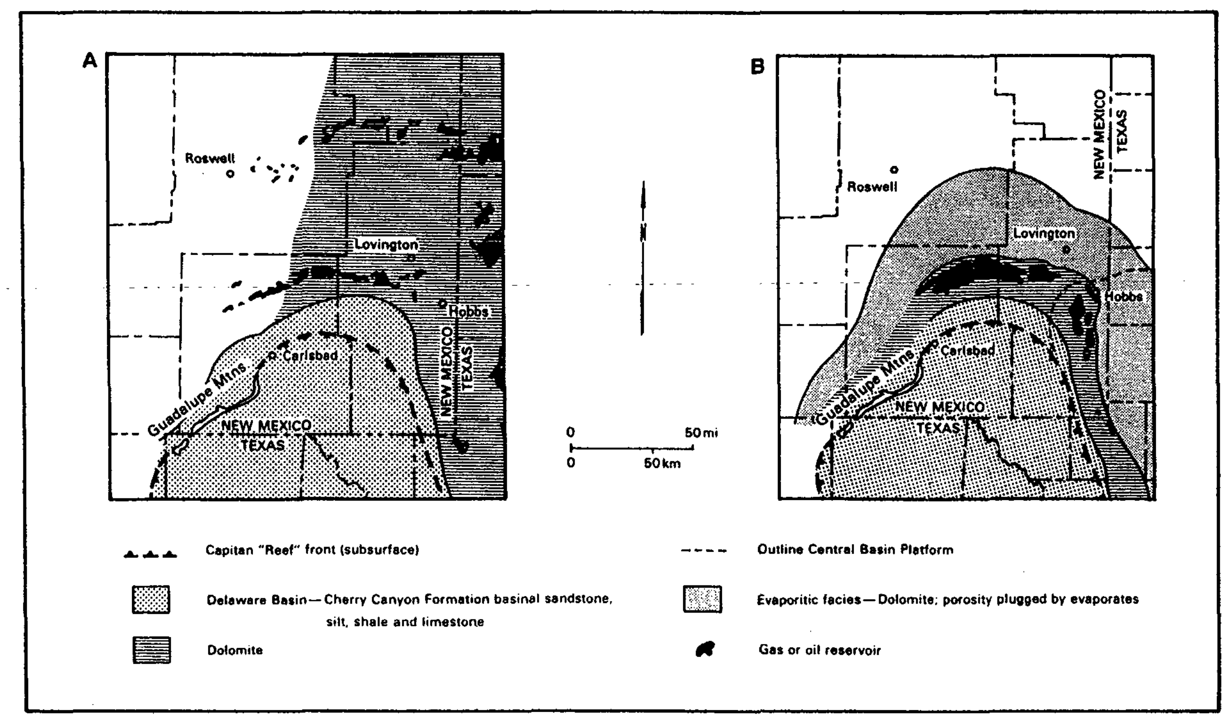


FIGURE PB-3.7—Simplified lithofacies map of A, San Andres Formation and B, Grayburg Formation, Permian Basin of southeast New Mexico, showing principal oil and gas reservoirs in San Andres and Grayburg Formations respectively. After Ward et al., 1986.

PB-4. GLORIETA AND UPPER YESO SHELF

Ronald F. Broadhead

Reservoirs of the Glorieta and Upper Yeso Shelf play lie along the west part of the Central Basin platform and the south edge of the Northwest shelf (Fig. PB-4.1). The nine reservoirs in the play (Table PB-4.1) with cumulative production greater than 5 BCF have yielded 326 BCF since the Justis reservoir was discovered in 1944. Monthly production from the play has decreased from 1.263 BCF during 1972 to 0.453 BCF during 1990 and has been steady since 1988 (Fig. PB-4.2). Most reservoirs produce associated gas by solution gas drive or water drive; in some reservoirs, these two mechanisms act in combination with each other. At Fowler and Paddock, nonassociated gas is produced by pressure depletion drive. Sour oil and gas are produced from many of the reservoirs in this play. Depths to reservoirs range from 2,660 ft at Atoka to 6,160 ft at Lovington on the structurally deeper, east part of the Northwest shelf. In addition to the nine reservoirs listed in Table PB-4.1, 25 reservoirs that have produced less than 5 BCF each are in the play outline.

Reservoirs in this play are primarily tan to brown, sucrosic to finely crystalline dolostones of the Paddock zone and the Glorieta (Figs. PB-4.3, PB-4.4). Most production comes from the Paddock dolostones. The term Paddock is used for a loosely defined package of dolostones on the Northwest shelf and Central Basin platform; although some workers include it in the Glorieta, the more common usage puts it in the upper Yeso. The relationship of the Paddock to the Glorieta is poorly understood, but the two units appear to intertongue (Grant and Foster, 1989). In the play area, the Glorieta is generally less than 100 ft thick and consists mostly of dolostone and minor, interbedded, gray to white, fine- to coarse-grained quartzose sandstones. Percentage of sandstone increases to the west and northwest to the point where, in the Atoka reservoir, sandstones contribute a significant amount to production. Farther to the northwest in Lincoln County (*see* Sheet 6), the Glorieta thickens to more than 100 ft and consists mostly of sandstone (Milner, 1978). The Glorieta and Paddock dolostones are vertically fractured, but it is uncertain to what extent the fractures connect the isolated, lenticular porous zones present in each reservoir. Average porosity of the dolostones ranges from 2% at Fowler to 12% at Justis. Matrix permeability is fairly low, ranging from 2 md at Paddock to 9 md at Justis.

The Glorieta and Paddock were deposited on a shallow marine shelf. Milner (1978) concluded that most Glorieta sandstones in east New Mexico were deposited as southeast-prograding barrier-island complexes. Glorieta and Paddock dolostones were deposited offshore in upward-shoaling sequences (Milner, 1978; Presley and McGillis, 1982).

Most traps in the Glorieta and Upper Yeso Shelf play are formed by anticlines. On the Central Basin platform, those anticlines are roughly parallel to the platform margin and form traps in deeper zones (*see* secs. PB-6, PB-7, PP-6, PP-7). On the Northwest shelf, the anticlines are coincident with the Abo shelf edge and are formed by drape over the Abo reef (*see* sec. PB-7); the Atoka reservoir is formed by porosity pinchout in strata draped over the south flank of the Abo reef (Fig. PB-4.5).

In most Glorieta and Paddock wells, porous zones are selectively perforated and acidized. Artificial fracturing with a small to medium sand load may be employed.

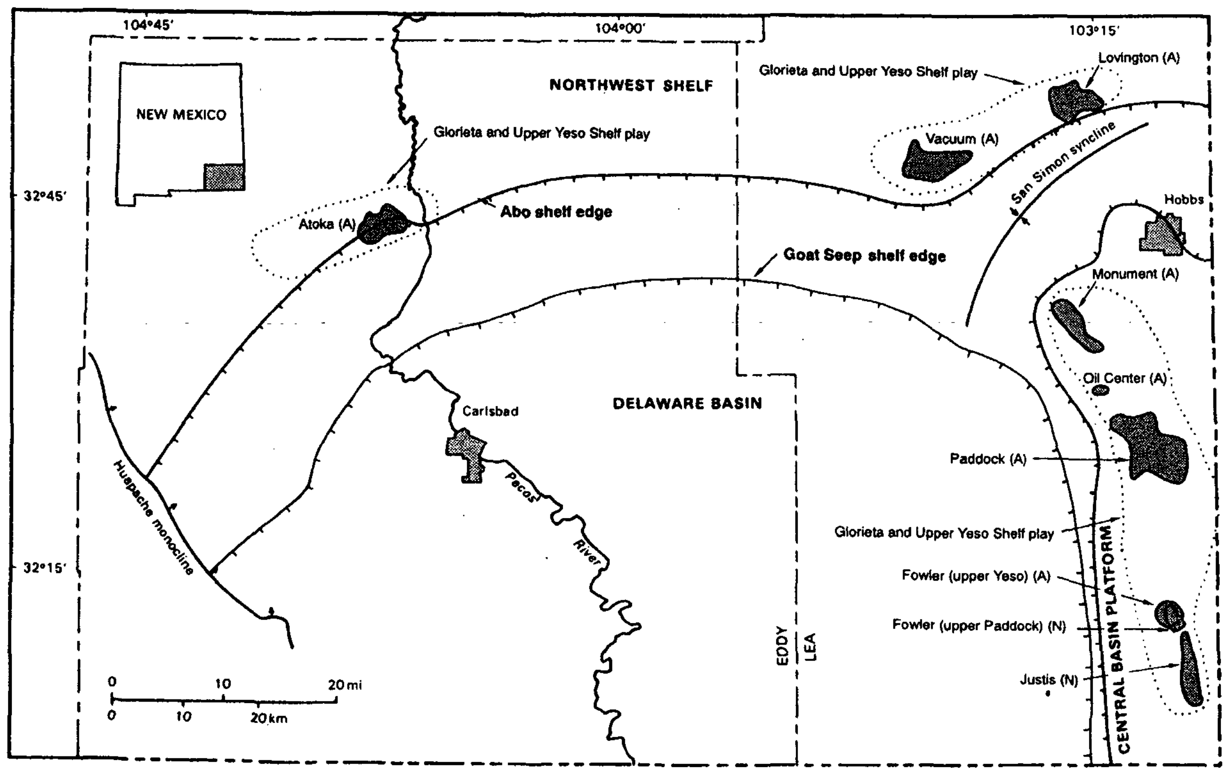


FIGURE PB-4.1—Reservoirs in the Glorieta and Upper Yeso Shelf play.

TABLE PB-4.1—Geologic, engineering, and production data for the Glorieta and Upper Yeso Shelf play. Heads explained on last page.

St	County	Reservoir	Ty	Disc	Wells	Aban	Spa	Acres	Depth	Trap	Dri	Lith	DeEn	PostD	Por	Perm	Temp	PrGr	CumBCF	PDR
NM	Eddy	Atoka (Glorieta Yeso)	A	1977	91	3	40	5200	2660	Lpp	CO	Sand	Shsr	Dolo			104		5.768	
NM	Lea	Fowler (Upper Paddock)	N	1959	7	1	320	1600	4880	Sa	PD	Dolo	Ssre	Dolo					21.971	2.7
NM	Lea	Fowler (Upper Yeso)	K	1950	40	9	80	2400	5700	Ant	SG	Dolo	Ssre	Doev	0.02	5.000			48.201	
NM	Lea	Justis (Glorieta)	N	1944	15	6	320	4480	4740	Ant	PD	Dolo	Ssre	Dolo	0.12	9.000			76.835	
NM	Lea	Lovington (Paddock)	K	1952	119	48	40	8320	6160	Ant	WD	Dolo	Ssre	Dolo	0.08				11.357	
NM	Lea	Monument (Paddock)	K	1948	33	25	40	5280	5190	Ant	SG	Dolo	Ssre	Dolo	0.08			0.382	8.890	
NM	Lea	Oil Center (Glorieta)	A	1979	7	1	40	960	5210				Ssre						6.895	
NM	Lea	Paddock (Paddock)	K	1945	113	110	40	18080	5170	Lpp	CO	Dolo	Ssre	Dolo	0.11	2.000		0.410	68.564	
NM	Lea	Vacuum (Glorieta)	A	1963	170	27	40	8320	6100	Ant		Dolo	Ssre	Dolo					77.272	

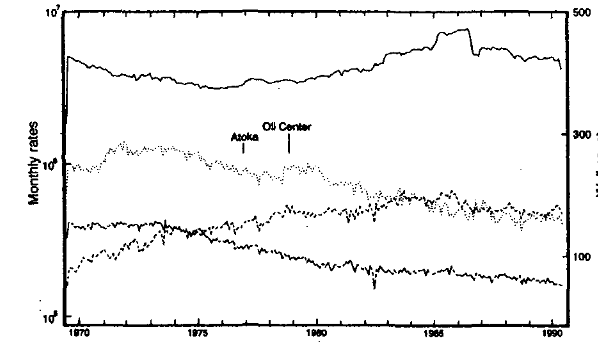


FIGURE PB-4.2—Historical production from the Glorieta and Upper Yeso Shelf play. ···, gas (MCF); — - —, oil (BBLS); —, water (BBLS); — wells. From INTERA Bergeson; data source, Dwight's Energydata, Inc.

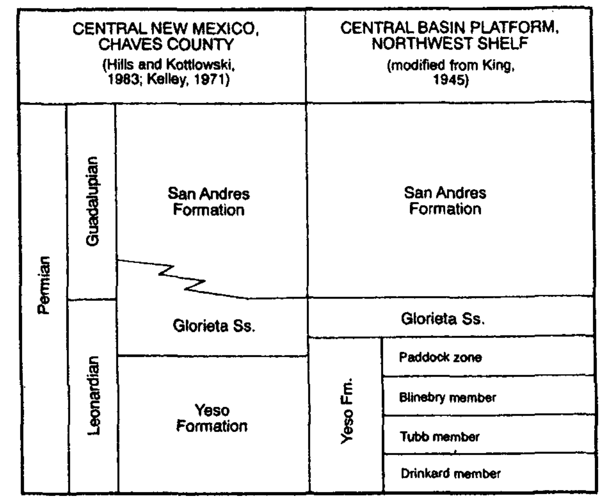


FIGURE PB-4.3—Stratigraphic nomenclature of upper Leonardian and lower Guadalupian strata in the shelf areas of Lea and Eddy Counties and in central New Mexico. Hachured units produce in play PB-4.

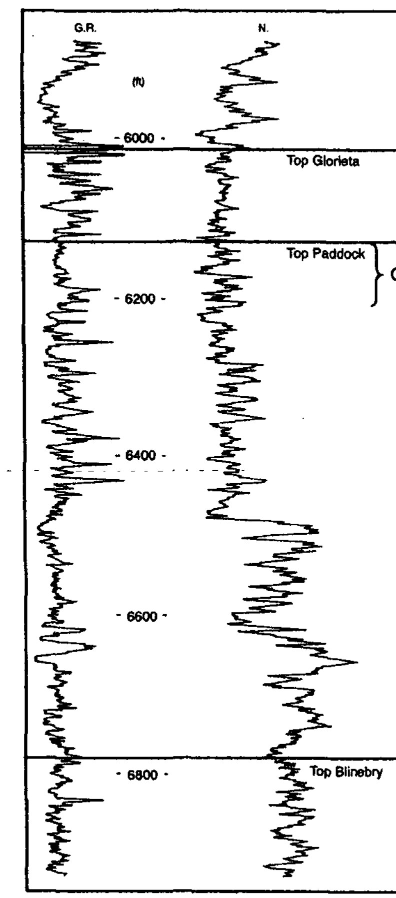


FIGURE PB-4.4—Typical log through Glorieta and Paddock, Vacuum reservoir. Shell Oil Co. No. 1 State M well, sec. 29 T17S R35E, Lea County.

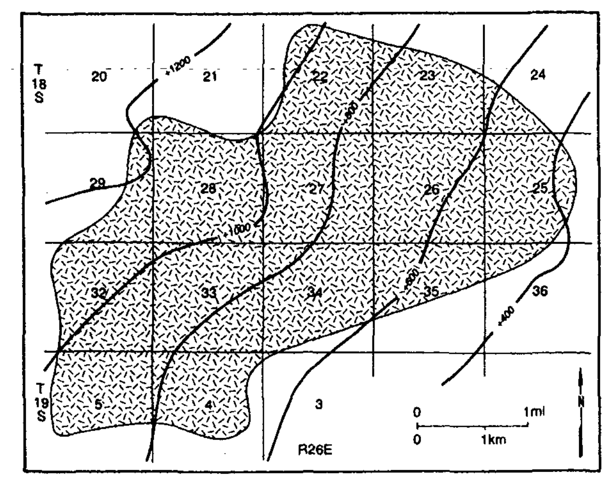


FIGURE PB-4.5—Atoka (Glorieta Yeso) reservoir and relation to Glorieta structure. Trap formed by updip porosity pinchout. Structural contours from Park, 1988.

PB-5. BONE SPRING BASINAL SEDIMENTS

Ronald F. Broadhead

Reservoirs of the Bone Spring Basinal Sediments play lie in the northern part of the Delaware Basin (Fig. PB-5.1). The five reservoirs in the play with cumulative gas production greater than 5 BCF have produced 46 BCF of associated gas since discovery of the Scharb and Lea reservoirs in the early 1960s (Table PB-5.1). Production from the play has increased from approximately 17 MMCF/mo during 1979 to approximately 405 MMCF/mo during 1990 (Fig. PB-5.2). This increase in production rate was caused by discovery of the Young North reservoir in 1980 and discovery of the Avalon East and Mescalero Escarpe reservoirs in 1984. Monthly gas production has been relatively constant since 1984. Depths to the Bone Spring reservoirs range from 5,480 ft at Avalon East to 9,720 ft at Scharb in the structurally deeper eastern part of the basin.

Bone Spring reservoirs are carbonate debris flows and siliciclastic turbidites deposited downslope of the Abo shelf edge (Wiggins and Harris, 1985; Gawloski, 1987; Mazzullo and Reid, 1987; Saller et al., 1989). These reservoirs are interbedded with and sealed by impermeable dark basinal shales and micritic carbonates. Carbonate debris-flow deposits in the second and third Bone Spring carbonates (Fig. PB-5.3) are the primary reservoirs; they consist of dolomitized conglomerate breccias and dolomitized bioclast-peloid packstones. Porosity is mostly secondary; vugular, moldic, intergranular, and intercrystalline pores are dominant. In the Mescalero Escarpe reservoir (Saller et al., 1989), open fractures in dolopackstones have enhanced permeability.

Siliciclastic turbidites have widespread distribution in the first, second, and third Bone Spring sands. They consist of fine-grained sandstones cemented by dolomite and authigenic clays (Gawloski, 1987; Saller et al., 1989). They appear to have been deposited within a channel and fan system at the base of slope and on the basin plain.

Traps in the Bone Spring are stratigraphic or combination stratigraphic/structural. Porous debris-flow or turbidite reservoirs were deposited in channels perpendicular to the shelf margin (Gawloski, 1987; Mazzullo and Reid, 1987; Saller et al., 1989). The porous reservoirs pinch out depositionally updip as they rise onto the submarine slope (Fig. PB-5.4). In the Lea reservoir, a combination trap is formed by depositional pinch-out of the reservoir across a structural nose.

In most Bone Spring wells, the pay zone is acidized before completion, and artificial fracturing may be employed. In the Avalon East and Lea reservoirs, carbon dioxide and nitrogen have been used in the fracture process in order to minimize formation damage.

This play has not yet reached full maturity. Approximately 120 oil reservoirs with less than 5 BCF gas production have been discovered within the play area (Fig. PB-5.1). Existing reservoirs are currently being developed and there is significant potential for additional discoveries in the Delaware Basin.

INTERA Bergeson—Bone Spring sandstone reservoirs are tight and on average are one-third as productive as the carbonate zones. The carbonate zones of these fields are waterflooded to enhance oil recovery through reservoir-pressure maintenance. Water for the floods is a combination of produced Bone Spring water and additional water from the Ogallala Formation (Tertiary). These fields as a rule have been successful and have performed as projected by early evaluations.

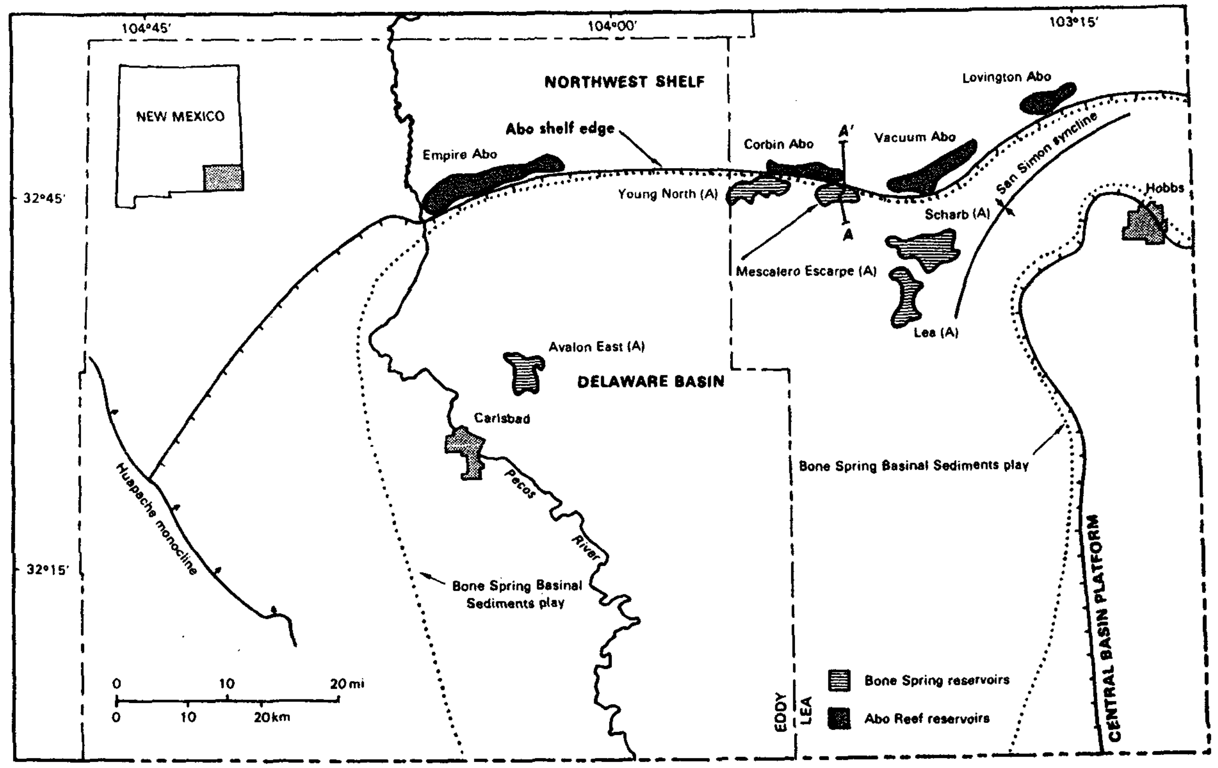


FIGURE PB-5.1—Reservoirs in the Bone Spring Basinal Sediments play and the Abo Reef subplay (PB-7).

TABLE PB-5.1—Geologic, engineering, and production data for the Bone Spring Basinal Sediments play. Heads explained on last page.

St	County	Reservoir	Ty	Disc	Wells	Aban	Spa	Acres	Depth	Trap	Dri	Lith	DeEn	PostD	Por	Perm	Temp	PrGr	CumBCF	PDR
NM	Lea	Lea (Bone Spring)	K	1960	14	13	80	4160	9700	Spm	SG	Dolo	Sbdf	Dolo			140	0.423	5.855	
NM	Lea	Young N (Bone Spring)	K	1980	75	7	40	5760	8470	Sa	SG	Dolo	Sbdf	Dolo			128	0.343	7.600	
NM	Eddy	Avalon E (Bone Spring)	A	1984	28	5	40	4680	5480				Sbun						15.159	
NM	Lea	Mescalero Escarpe (Bspg)	K	1984	46	2	40	3200	8660	Lpp		Dolo	Sbdf	Dolo			143	0.393	5.297	
NM	Lea	Scharb (Bone Spring)	K	1962	52	29	80	7840	9720	Sa	SG	Dolo	Sbdf	Dolo			180	0.428	12.368	

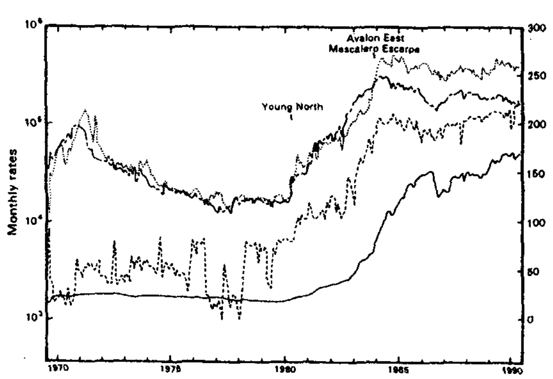


FIGURE PB-5.2—Historical production from the Bone Spring Basinal Sediments play. Note effect of reservoir discoveries (Young North, Avalon East, Mescalero Escarpe) on production. ···, gas (MCF); — - —, oil (BBLS); ---, water (BBLS); —, wells. From INTERA Bergeson; data source, Dwight's Energydata, Inc.

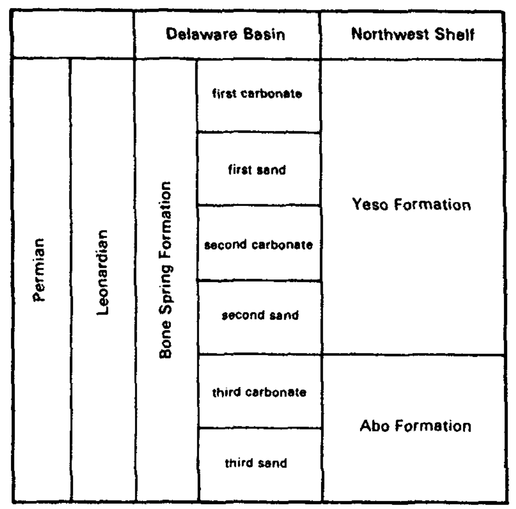


FIGURE PB-5.3—Stratigraphic column of the Bone Spring Formation in the Delaware Basin showing informal stratigraphic subdivisions and correlation with stratigraphic units on the Northwest shelf. Modified from Gawloski, 1987 and Saller et al., 1989.

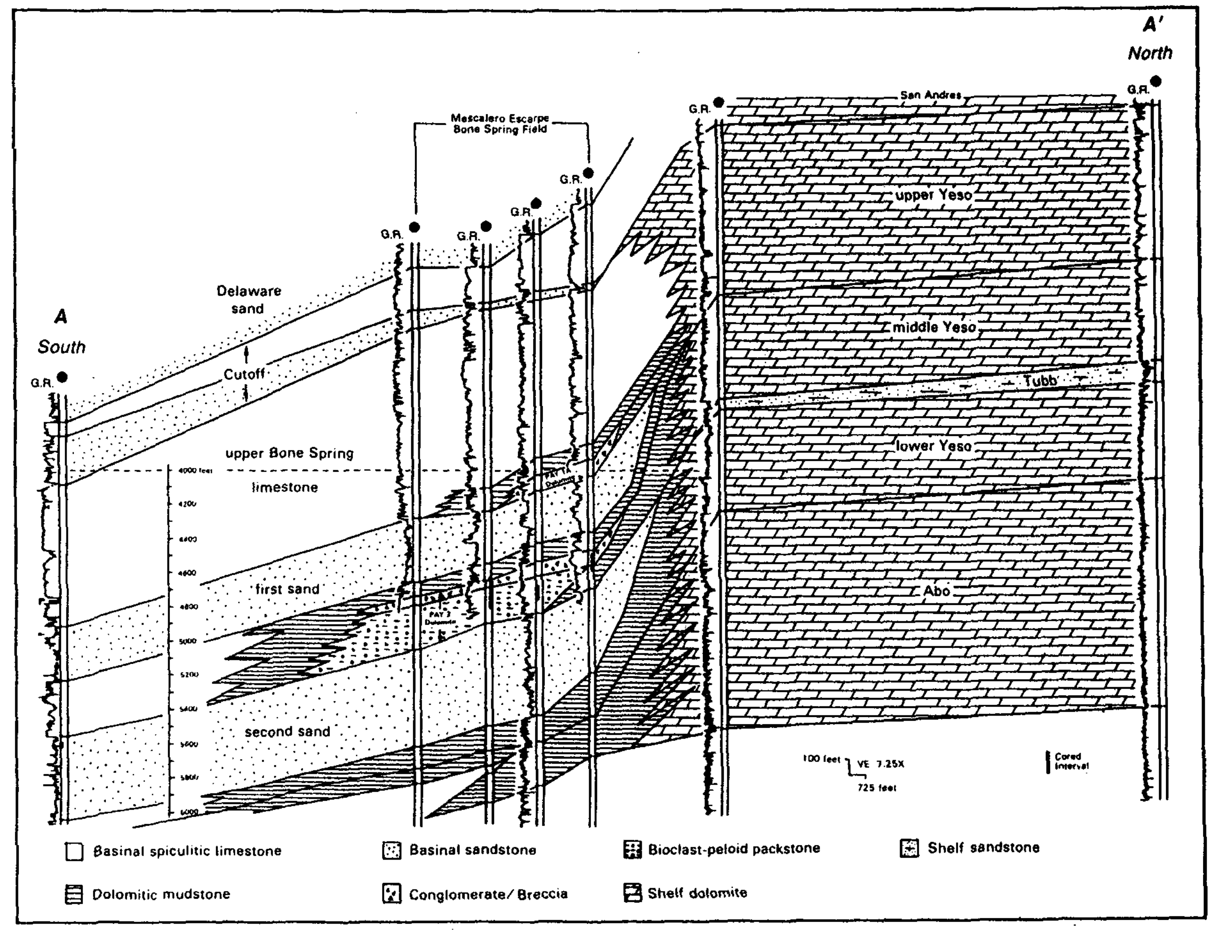


FIGURE PB-5.4—North-south structural cross section through Mescalero Escarpe reservoir showing southward depositional dip and transition from shelf facies in north to basinal facies in south. See Fig. PB-5.1 for location. After Saller et al., 1989.

PB-6. YESO PLATFORM

Ronald F. Broadhead

Reservoirs of the Yeso Platform play (Figs. PB-6.1–PB-6.3) lie on the Central Basin platform. The play consists of reservoirs in the Drinkard, Tubb, and Blinebry members of the Yeso Formation (Fig. PB-6.4, Table PB-6.1). The Yeso Platform play is roughly equivalent to the Clear Fork Platform play of the *Atlas of Major Texas Gas Reservoirs* (Texas Atlas play code PM-3; Bebout and Garrett, 1989). In Texas, most production is obtained from the Tubb and lower Clear Fork, but reservoirs are evenly distributed throughout the Yeso section in New Mexico.

The twenty reservoirs in the play with more than 5 BCF gas production have produced a cumulative 2,928 BCF of associated gas. All reservoirs produce oil as well as gas, and many have been partially under waterflood since the 1960s. Production may be commingled from two, or even three, of the Yeso members, but generally one member dominates production within a field. The main exception is the Eunice North reservoir that produces from the Blinebry, Tubb, and Drinkard members; Eunice North was established in 1987 because it was determined that wellbores with commingled production had effectively provided intercommunication among fluids in the three members. In the Yeso Platform play, Drinkard reservoirs have produced a cumulative total of 722 BCF gas, Tubb reservoirs have produced 569 BCF gas, and Blinebry reservoirs have produced 1,244 BCF gas. Fields with extensive commingled production from both the Drinkard and Tubb have produced 75 BCF gas, and the Eunice North reservoir has produced 319 BCF gas. Production from the play has decreased from approximately 9 BCF/mo during 1970 to approximately 4 BCF/mo during 1990 (Fig. PB-6.5); this decrease has not been dependent on the total number of productive wells within the play but instead appears to be caused by a decrease in the productive capability of many of the reservoirs.

Depths to reservoirs vary because of both structural elevation and topography. Depths to productive Drinkard reservoirs range from 5,900 ft at the Justis reservoir to 6,880 ft at the Hobbs reservoir (Fig. PB-6.1). Depths to Tubb reservoirs range from 5,720 ft at the Justis reservoir to 6,500 ft at the Dollarhide reservoir and the Warren reservoir (Fig. PB-6.2). Depths to productive Blinebry reservoirs range from 5,000 ft at the Justis reservoir to 5,900 ft at the Oil Center reservoir at the western edge of the platform, to 5,870 ft at the Hobbs reservoir (Fig. PB-6.3).

The Drinkard consists of limestone and dolostone with minor interbedded sandstone. The reservoir rocks are limestones and dolostones; porosity may be interparticle, intercrystalline-sucrosic, moldic, or minor intraparticle. Temporally equivalent lower Clear Fork strata in west Texas are peritidal dolostones and dolomitic limestones that are not associated with evaporites (Mazzullo, 1989). In the Eunice North reservoir, reservoir rocks are mostly skeletal grainstones. Nonreservoir rocks and seals are mud-supported dolostones and lime wackestones and mudstones. These lithologies form a series of thin regressive cycles consisting of subtidal carbonates that grade upward into intertidal and supratidal carbonates; the marine subtidal carbonates generally form the best reservoirs. There are five reservoir zones within the Drinkard member at Eunice North (Fig. PB-6.6); all five zones produce oil and associated gas.

The Tubb member consists of fine-grained silty sandstones and interbedded finely sucrosic sandy dolostones. In the Tubb reservoir, sandstones form most of the reservoir rocks. Variations in porosity and permeability within the reservoir have resulted in the formation of local fluid barriers that have affected production and gas-oil ratios from adjacent wells. Gas-oil ratios of individual wells show unique histories, increasing with time in some wells and decreasing with time in other wells. In the Eunice North reservoir, reservoir-quality sandstones and dolostones form discontinuous lenses within the Tubb (Fig. PB-6.6), each of which differs in its original gas and oil contents. In both Eunice North and Tubb, pockets of gas may lie at structurally lower levels than reservoir lenses that contain oil.

The Blinebry member consists of dolostones and very thin beds of shale, limestone, and anhydrite. Reservoir rocks consist of pelletal dolopackstones with interparticle, intercrystalline-sucrosic, and moldic porosity. Seals and other nonreservoir rocks are mud-supported dolostones and limestones. In the Eunice North reservoir, the Blinebry is similar to the Drinkard, consisting of thin regressive cycles of subtidal carbonates that grade upward into intertidal and supratidal carbonates; the best reservoirs generally occur in the subtidal carbonates. At Eunice North, the Blinebry consists of five reservoir zones separated by seals (Figs. PB-6.6, PB-6.7); the upper two zones produce nonassociated gas and the lower three zones produce oil and associated gas. Temporally equivalent upper Clear Fork strata on the Central Basin platform in west Texas consist of interbedded marine carbonates and supratidal dolostones (Lucia, 1972).

Traps are generally formed by low-relief anticlines (Figs. PB-6.8–PB-6.10). Stratigraphic variations can create porosity pinch-outs on anticlinal noses (Fig. PB-6.11), as well as unevenness in reservoir quality across a structure. Most of the trap-forming anticlines are elongated north-south and are roughly parallel to the western border of the Central Basin platform. *A single structure will generally form traps in all three members.*

The Yeso Platform play is mature and Leonardian reservoirs have been densely drilled throughout the Central Basin platform. In addition to the reservoirs listed in Table PB-6.1, 39 oil and gas reservoirs with less than 5 BCF production have been discovered and have produced in this play. The Yeso has been drilled and evaluated on all but the smallest anticlinal structures. Prospects of discovering major new gas reserves are low within the defined play area (Figs. PB-6.1–6.3).

INTERA BERGESON—Production from the Drinkard, Tubb, and Blinebry reservoirs can vary from oil and associated gas, with GORs in excess of 10,000 scf/bbl, to dry gas depending on structural position. The reservoirs tend to be low permeability (2–5 md), and porosities average 8%. The reservoir drive mechanism is solution gas drive with many of the fields having primary gas caps. Wells in the Drinkard and Tubb are gel-acid fractured, while those in the Blinebry are fractured with cross-linked gels and 100,00–150,000 lbs of sand. The Blinebry and Tubb are waterflooded on 80-acre 5 spots with both producers and injectors refractured prior to flood initiation. The Drinkard is a discontinuous reservoir in most areas that does not lend itself to waterflooding.

TABLE PB-6.1—Geologic, engineering, and production data for the Yeso Platform play. Heads explained on last page.

St	County	Reservoir	Ty	Disc	Wells	Aban	Spa	Acres	Depth	Trap	Dri	Lith	DeEn	PostD	Por	Perm	Temp	PrGr	CumBCF	PDR
NM	Lea	Nadine W (Drinkard)	K	1981	7	9	40	1840	6490	Sa	SG	Dolo	Peun	Dolo			115		5.595	
NM	Lea	Blinebry O & G (Blinebry)	A	1945	604	153	40	40720	5600	Ant	SG	Dolo	Peun	Dolo	0.08	4.500		0.403	973.971	
NM	Lea	Dollarhide (Tubb Drinkard)	K	1951	96	48	40	4560	6600	Ant	SG	Dolo	Peun	Dolo	0.08	10.000		0.419	27.938	
NM	Lea	Drinkard (Drinkard)	A	1944	522	320	40	36160	6500	Ant	GC	Dolo	Peun	Dolo	0.12	5.600		0.409	641.762	
NM	Lea	Eunice N (Blin Tubb Drkd)	A	1944	152	34	40	4960	5700	Ant	SG	Dolo	Peun	Dolo	0.09	2.030			318.656	
NM	Lea	Hobbs (Blinebry)	K	1968	23	12	40	3040	5870	Ant		Dolo	Peun	Dolo	0.13	16.500	107		5.884	
NM	Lea	Hobbs (Drinkard)	A	1952	21	12	80	2880	6880	Ant	SG	Lsun	Peun				118	0.377	25.859	
NM	Lea	House (Drinkard)	K	1949	10	7	40	2880	7030	Spm	SG	Dolo	Peun	Dolo				0.263	6.998	
NM	Lea	Justis (Blinebry)	K	1958	189	50	40	10960	5000	Ant	SG	Dolo	Peun	Dolo	0.05	3.000		0.495	185.406	
NM	Lea	Justis (Tubb Drinkard)	A	1957	94	64	40	8720	5720	Ant	SG	Dolo	Peun	Dolo				0.453	47.055	
NM	Lea	Monument (Blinebry)	A	1948	25	23	40	4000	5660	Ant	SG	Dolo	Peun	Dolo	0.08			0.402	11.979	
NM	Lea	Monument (Tubb)	A	1959	36	25	80	5920	6400	Ant	SG	Dolo	Peun	Dolo	0.06				54.549	
NM	Lea	Oil Center (Blinebry)	K	1959	37	6	80	4040	5910	Spm	SG	Dolo	Peun	Dolo		1.800	105	0.323	28.455	
NM	Lea	Skaggs (Drinkard)	A	1953	43	10	40	3680	6850	Spm		Dolo	Peun	Dolo				0.402	34.646	
NM	Lea	Teague (Blinebry)	A	1967	52	17	40	4160	5400	Ant		Dolo	Peun	Dolo			105		22.847	
NM	Lea	Tubb O & G (Tubb)	A	1946	189	102	40	36880	6000	Ant		Sand			0.19	5.000	122	0.313	478.921	
NM	Lea	Warren (Tubb)	A	1957	46	3	40	2080	6500										35.023	
NM	Lea	Weir (Blinebry)	A	1961	13	7	40	1920	5700										5.563	
NM	Lea	Weir (Drinkard)	A	1946	7	9	40	2240	6760		SG	Dolo	Peun	Dolo					7.032	
NM	Lea	Weir E (Blinebry)	A	1962	12	4	40	1280	5800						0.08	1.800			9.506	

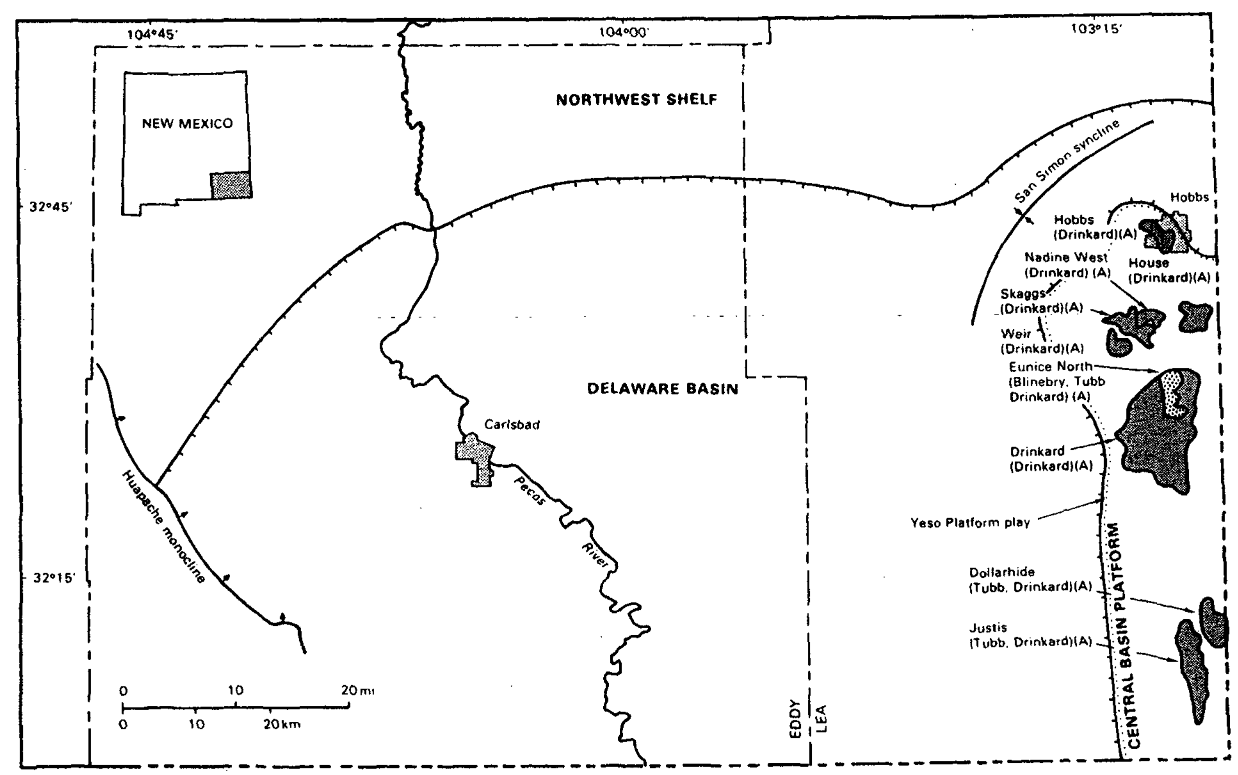


FIGURE PB-6.1—Reservoirs that produce from the Drinkard member of the Yeso Formation in the Yeso Platform play.

PB-9. WOLFCAMP CARBONATE

Ronald F. Broadhead

Reservoirs of the Wolfcamp Carbonate play lie on the Northwest shelf and in the Delaware Basin (Fig. PB-9.1). The play is equivalent to the Wolfcamp Carbonate play of the *Atlas of Major Texas Gas Reservoirs* (Texas atlas play code PM-1; Bebout and Garrett, 1989). Production is obtained mostly from the lower Wolfcamp (Fig. PB-9.2). The term "Wolfcamp" is variously ranked as a group, formation, or member (of Hueco Formation) in southeast New Mexico and is the most commonly used industry term for strata below the Abo Formation and above the Pennsylvanian. The 12 reservoirs in this play with more than 5 BCF production have produced 217 BCF gas (Table PB-9.1, Fig. PB-9.3). In addition, there are 205 reservoirs in the play that have produced less than 5 BCF. Reservoirs on the shelf produce mostly associated gas by solution gas drive. Reservoirs in the basin produce nonassociated gas by pressure depletion drive. Depth to production ranges from 8,020 ft at the Bluitt reservoir on the shelf to 13,250 ft at the Red Hills reservoir in the basin.

Wolfcamp reservoirs were deposited in different depositional environments (Fig. PB-9.1, Table PB-9.1). Kemnitz was deposited as a shelf-margin barrier reef (Figs. PB-9.1, PB-9.4; Malek-Aslani, 1970). Productive zones at Kemnitz include hydrozoan boundstones of the reef wall, backreef skeletal grainstones, and forereef talus deposits. The trap is formed by a combination of a south-plunging structural nose and porosity development in the reef facies.

Reservoirs north of the barrier reef (Malek-Aslani, 1985; Cys, 1986) were deposited on a shallow shelf. Most reservoirs are in phylloid-algal patch reefs developed on pre-existing structures (Fig. PB-9.1, inset). Carbonate grainstones cap some patch reefs and also form important reservoirs. Traps are stratigraphic and are formed by porosity zones restricted to these environments. Because of the relationship of Wolfcamp reservoirs to pre-existing structures, Wolfcamp traps are typically stacked over structural traps in deeper pre-Wolfcamp zones.

Reservoirs south of the barrier reef were deposited in a basinal setting. Production is obtained mostly from small algal carbonate mounds interbedded with dark basinal shales and also from scattered, thin basinal sands (Anderson, 1977). Traps are mostly stratigraphic. In the Texas part of the basin, reservoirs are found in carbonate debris-flow deposits adjacent to the Central Basin platform (Hobson et al., 1985). Debris flows are present near the shelf edge in New Mexico (Loucks et al., 1985) and may form the reservoirs at Vacuum and Vacuum North. Reservoirs in the deep basin (Big Sinks, Burton Flat North, Carlsbad East, Red Hills) are overpressured.

Wells in the Wolfcamp Carbonate play are generally drilled through the pay zone, perforated through casing, and acidized with loads of 500 to 2,000 gallons. Artificial fracturing is not generally needed to obtain economic production, at least in the larger reservoirs.

INTERA Bergeson—Because of the diversity of reservoir types ranging from oil (Anderson Ranch, Anderson Ranch North, Denton, Kemnitz, Henshaw, Vacuum and Vacuum North) to rich condensate (Burton Flat North and Carlsbad East) to lean gas (Big Sinks, Bluitt and Red Hills), it is difficult to characterize typical performance for this play. Variations also exist in well spacing (Table PB-9.1) and drive mechanism. The nonassociated gas reservoirs produce by pressure depletion, whereas the oil reservoirs produce by solution gas drive and partial water drive. Water production varies from essentially no water for the nonassociated gas reservoirs to a maximum of 237 BWPD per well in the Denton Field. Current water production ranges from 0 to 75 BWPD per well for the remaining oil reservoirs with oil rates varying from 6 to 32 BOPD per well.

Sec. PB-10 follows sec. PP-5.

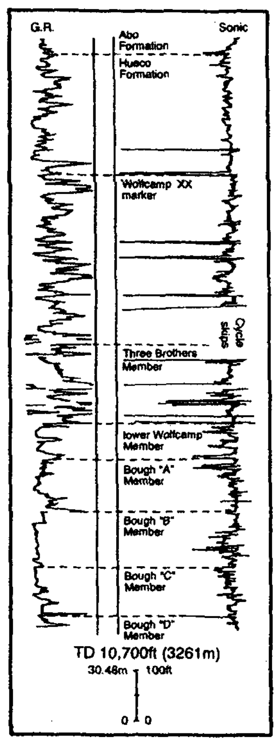


FIGURE PB-9.2—Typical log through Wolfcamp strata on Northwest shelf, Union of California No. 1 State 7 well, sec. 7 T15S R35E, Morton reservoir (<5 BCF production). Bough D is top of Pennsylvanian. See Fig. PB-9.1 for location. After Cys, 1986.

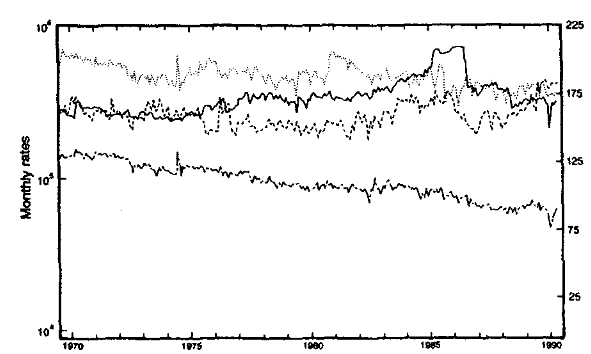


FIGURE PB-9.3—Historical production from the Wolfcamp Carbonate play. ···, gas (MCF); — - —, oil (BBLS); ---, water (BBLS); —, wells. From INTERA Bergeson; data source, Dwight's Energydata, Inc.

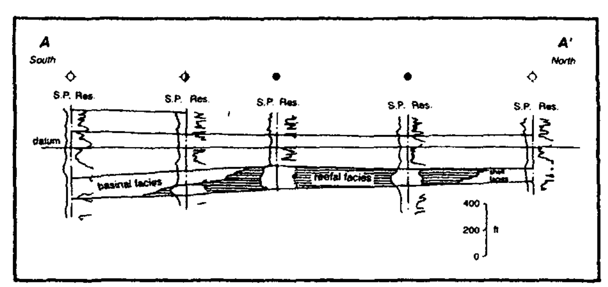


FIGURE PB-9.4—Cross section through barrier reef of Kemnitz reservoir. See Fig. PB-9.1 for location. After Malek-Aslani, 1970.

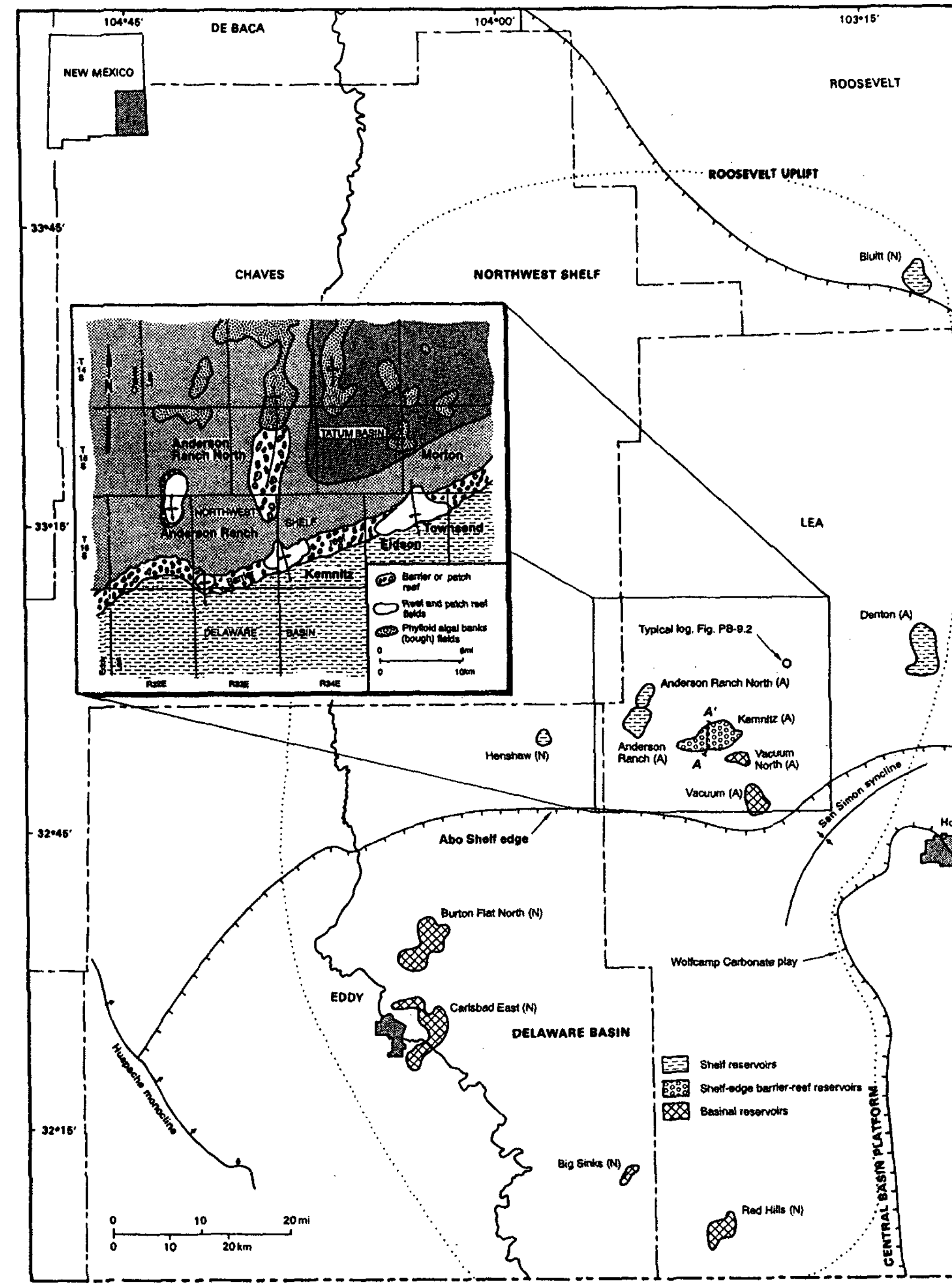


FIGURE PB-9.1—Reservoirs in the Wolfcamp Carbonate play and (inset) relationship of reservoirs to depositional environments and paleostructures, Anderson Ranch–Kemnitz area. Inset after Malek-Aslani, 1985, with permission.

TABLE PB-9.1—Geologic, engineering, and production data for the Wolfcamp Carbonate play. Heads explained on last page.

St	County	Reservoir	Ty	Disc	Wells	Aban	Spa	Acres	Depth	Trap	Dri	Lith	DeEn	PostD	Por	Perm	Temp	PrGr	CumBCF	PDR
NM	Eddy	Big Sinks (Wolfcamp)	N	1982	2	0	320	640	12530		PD	Lsun	Bade				193	0.585	5.384	6.3
NM	Roosevelt	Bluitt (Wolfcamp)	N	1959	13	1	320	4480	8020		PD	Dolo	Ssun	Dolo			149	0.362	26.754	10.0
NM	Lea	Anderson Ranch (Wolfcamp)	K	1953	21	14	40	4240	9760	Lpp	CO	Lsun	Reeb	Madi	0.10	79.000		0.374	5.407	
NM	Lea	Anderson Ranch N (Wolfcamp)	K	1960	10	17	80	2320	9870	Lpp	SG	Lsun	Reeb	Madi	0.10	124.00		0.364	11.980	
NM	Eddy	Burton Flat N (Wolfcamp)	N	1975	17	10	320	10240	9160	Iso	PD	Lsun	Bade				150	0.505	15.648	5.4
NM	Eddy	Carlsbad E (Wolfcamp)	N	1975	22	6	320	9040	9540	Iso	PD	Lsun	Bade		0.05		150	0.645	11.721	
NM	Lea	Denton (Wolfcamp)	K	1950	98	38	40	8960	9240	Ant	SG	Lsun	Ssun	Dolo	0.07	13.000		0.413	9.439	
NM	Eddy	Henshaw (Wolfcamp)	K	1960	9	5	80	1320	8760	Lpp	CO	Lsun	Ssun		0.09	78.000	129	0.387	9.690	0.3
NM	Lea	Kemnitz (Lower Wolfcamp)	K	1956	50	10	80	9600	10690	Lpp	SG	Lsun	Smri	Coce	0.09	8.800		0.354	68.319	
NM	Lea	Red Hills (Wolfcamp)	N	1965	5	0	640	3200	13250	Spm	PD	Lsun	Bade		0.05	1.040	190	0.843	31.079	
NM	Lea	Vacuum (Wolfcamp)	K	1962	23	13	80	3840	9950	Iso	SG	Lsun	Sbun		0.09	3.200	130	0.387	15.476	
NM	Lea	Vacuum N (Lower Wolfcamp)	K	1967	4	8	80	1600	10690	Iso	SG	Lsun	Sbun		0.10		154	0.387	5.759	0.2

PERMIAN BASIN PRE-PERMIAN [PP] PLAYS—OVERVIEW

Stephen W. Speer

Pre-Permian plays range in age from the Late Pennsylvanian to the Early Ordovician and are found in the New Mexico portion of the Permian Basin on or in 1) the Northwest shelf, 2) the Central Basin platform, or 3) the Delaware Basin (Fig. PP.1). Seven major plays are recognized based on a combination of age, lithology, and/or depositional setting (Table PP.1).

A total of 173 reservoirs (composed of 4,431 wells) in the Pre-Permian play suite have produced more than 5 BCF each for a total of 6.173 TCF (Fig. PP.2). This figure represents more than 92% of the gas produced from the 800+ pre-Permian reservoirs found in southeast New Mexico and constitutes more than 18% of the gas produced in New Mexico through 1990. Eighty-six percent, or 5.322 TCF, of this total is nonassociated gas found primarily in stratigraphic and combination traps of Pennsylvanian age.

Ordovician, Siluro-Devonian, and Mississippian reservoirs in southeast New Mexico produce primarily from shelf carbonates deposited in the shallow seaways characteristic of this area during the early Paleozoic. Strandline sandstones of the Simpson Group (Ordovician) also contribute to production totals where they are found on the Central Basin platform. In contrast, roughly two-thirds of the Pennsylvanian reservoirs are composed of sandstones. These were deposited in a variety of depositional environments (Table PP.1) primarily during the early Pennsylvanian (Morrow and Atoka) in response to incipient tectonism in and around the basin. Relatively quiescent conditions during the later Pennsylvanian permitted carbonate deposition to predominate in shelf settings. Tectonic activity renewed itself at the end of the Pennsylvanian and culminated during the early Permian, wherein Wolfcampian erosion of exposed highlands and the subsequent deposition of as much as 10,000 ft of Permian sediments resulted in the structural/stratigraphic relationships observed today (Fig. PP.3).

Traps of all manner are found in pre-Permian rocks in southeast New Mexico. Stratigraphic trapping figures significantly in the Pennsylvanian reservoirs, whereas structural and/or combination traps dominate most of the Siluro-Devonian and Ordovician reservoirs. Subcrop traps developed by Wolfcampian erosion constitute a significant trap type in the Siluro-Devonian and Ordovician sections and have been exploited with great success where they occur, especially around the Central Basin platform (Fig. PP.4).

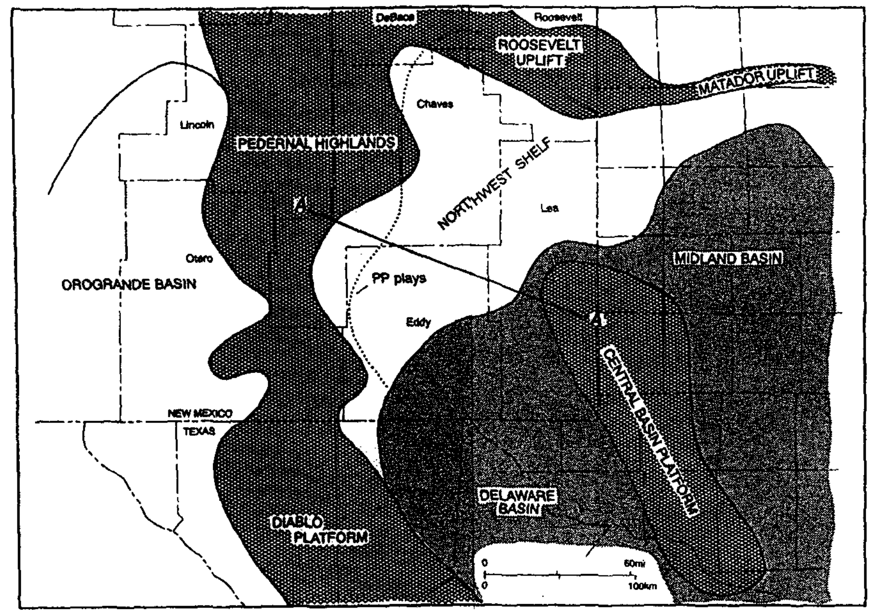


FIGURE PP.1—Principal structural provinces in southeast New Mexico. Modified from Kumar, 1985.

TABLE PP.1—Pre-Permian plays in the Permian Basin. Numbers apply to major (>5 BCF) reservoirs.

	Play	Number of reservoirs	Age (Period)	Principal productive stratigraphic units	Depositional setting	Main reservoir lithology	Main trap types	Cumulative production Gas, TCF Nonasso.	Asso.	Oil, MMBO
PP-1	Upper Pennsylvanian	26	Pennsylvanian	Cisco, Canyon	Shallow open shelf & shelf margin	Limestone & dolomite	Stratigraphic & combination	1.295	0.551	274
								Total = 1.846		
PP-2	Strawn	13	Pennsylvanian	Strawn	Shallow open shelf ramp	Limestone	Stratigraphic & combination	0.131	0.125	43
								Total = 0.256		
PP-3	Atoka	23	Pennsylvanian	Atoka	Fluvial, strandplain, shelf, & shelf margin	Sandstone & limestone	Stratigraphic & combination	0.561	0.000	5
								Total = 0.561		
PP-4	Morrow	85	Pennsylvanian	Morrow	Fluvial, deltaic, strandplain & submarine fan	Sandstone	Stratigraphic & combination	2.929	0.000	21
								Total = 2.929		
PP-5	Mississippian	1	Mississippian	Mississippian	Shallow open shelf	Limestone	Stratigraphic	0.011	0.000	0
								Total = 0.011		
PP-6	Siluro-Devonian	15	Devonian, Silurian	Thirtyone, Fusselman	Shallow restricted shelf	Dolomite	Anticlines, faulted anticlines, subcrop, stratigraphic (?)	0.272	0.087	126
								Total = 0.359		
PP-7	Ordovician	10	Ordovician	Montoya, Simpson, Ellenburger	Shallow restricted shelf	Dolomite & sandstone	Anticlines, faulted anticlines, subcrop	0.123	0.088	95
								Total = 0.211		
Total:	7 Plays	173						5.322	0.851	564
								Total = 6.173		

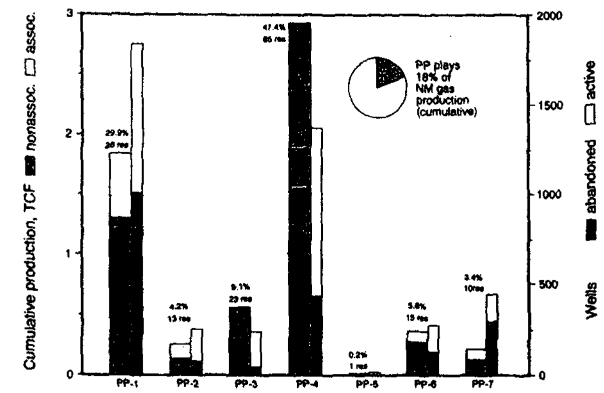


FIGURE PP.2—Gas production and well status for all Pre-Permian plays, based on *reservoirs with production more than 5 BCF. Plays are described* in Table PP.1.

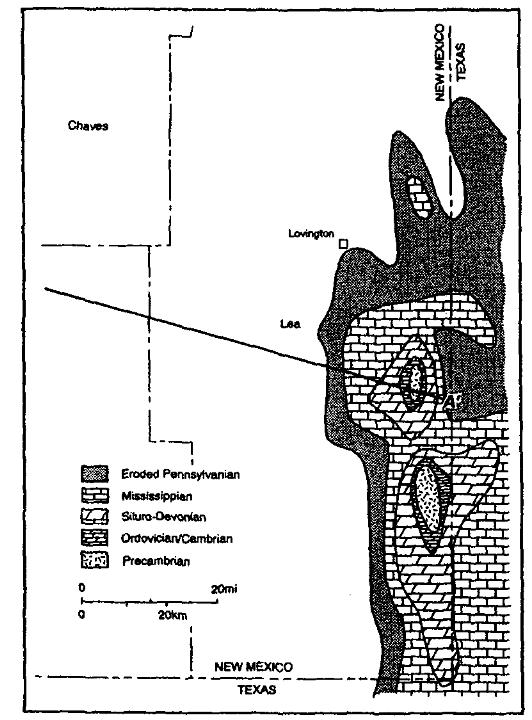


FIGURE PP.4—Pre-Permian subcrop patterns developed by Wolfcampian erosion of the Central Basin platform. Cross section *A–A'* is in Fig. PP.3. Modified from Grant and Foster, 1989; from Oriel et al., 1967.

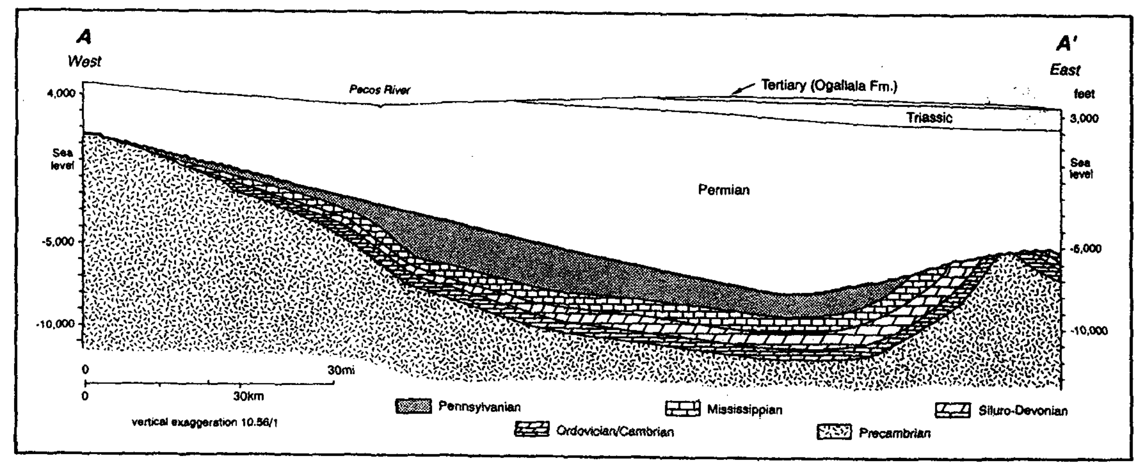


FIGURE PP.3—Simplified structural-stratigraphic cross section across the Northwest shelf/Delaware Basin from the Pedernal highlands on the west to the Central Basin platform on the east. Line of section is in Fig. PP.1. Modified from Grant and Foster, 1989.

PP-1. UPPER PENNSYLVANIAN

Stephen W. Speer

The Upper Pennsylvanian (Cisco/Canyon) section has contributed significantly to gas production in southeast New Mexico since its initial development in the 1950s and 60s, and indications are that it will continue to do so for many more years. Through 1990, more than 1.846 TCF of gas had been produced from the 26 designated reservoirs in the play with production greater than 5 BCF (Fig. PP-1.1; Table PP-1.1). Although only one-third of the 1,800+ original producing wells were still active at the end of 1990 (Fig. PP-1.2), a swell of development activity was underway in the Dagger Draw Upper Penn reservoir complex of west Eddy County (Fig. PP-1.1) that now indicates much more oil and gas remains to be produced from this play.

Two basic areas of Upper Pennsylvanian reservoir development are in southeast New Mexico: one in north Lea, east Chaves, and south Roosevelt Counties, and one in west Eddy County (Fig. PP-1.1). These two geographic areas have distinct reservoir qualities; the northeast region characteristically produces large quantities of oil, associated gas, and water from a system of relatively thin (10–35 ft) but laterally extensive shelf limestones ranging from 5,900 to 11,500 ft deep (Fig. PP-1.3). These units are collectively referred to as the Lower Wolfcampian and/or the Bough A, B, C, and D intervals in industry (Cys, 1986), and although there is some uncertainty and hence controversy about exact age, in this play they are all considered Upper Pennsylvanian (Cisco/Canyon). Reservoirs in these units are most often found in stratigraphically trapped grainstones, bioclastic wackestones, and phylloid algal bafflestones with 6–13% porosity (Cys, 1986). Production is often localized and developed on older, deeper-seated structures, so there is frequently a strong structural component to the trapping mechanism (Fig. PP-1.4).

Conversely, the Upper Pennsylvanian play of Eddy County produces large quantities of lighter condensate, water, and both nonassociated and associated gas primarily from high-relief (to 750+ ft; David, 1976), shelf-margin dolomite banks found at depths ranging from 6,600 to 9,600 ft and exemplified by the large and extremely prolific Indian Basin/Dagger Draw reservoir complex (Table PP-1.1; Fig. PP-1.5). These dolomites generally are stratigraphically bounded by tight shelf limestones and shales but again are commonly situated over older, deeper-seated structural features that not only appear to have influenced Upper Pennsylvanian carbonate deposition, but also influence the present day productive behavior of the reservoir (Figs. PP-1.5, PP-1.6). Trapping at the Indian Basin/Dagger Draw complex seems to be further influenced by a strong hydrodynamic water drive that is apparently induced from the Huapache monocline (Fig. PP-1.1). This drive has tilted and spread the gas/oil/water contacts along the long axis of the dolomite bank and thus complicated the fluid relationships in structurally lower parts of the reservoir (Frenzel, 1988; W. Hardie and D. Fly, pers. comm. 1993). Log porosities of most Upper Pennsylvanian dolomites are commonly quite low (< 7%), but their productive capabilities indicate excellent permeability (Figs. PP-1.6, PP-1.7). This has been commonly thought the result of well-developed reservoir fracturing and brecciation, but new information obtained from borehole imaging tools indicates that much porosity is present as large, interconnected secondary vugs not recognized earlier either by coring or other porosity measurements (W. Hardie and D. Jackson, pers. comm. 1993). Updip back-reef shelf limestones, primarily northwest of the dolomite trend (e.g. Penasco Draw and Eagle Creek Permo–Penn reservoirs), are also productive but are generally less permeable than the dolomite facies and produce primarily dry gas. As a result of the low porosities in both the dolomites and limestones, as well as the tight nature of the limestones, much of this part of Eddy County has been designated as a tight formation by the FERC (Fig. PP-1.1).

TABLE PP-1.1—Geologic, engineering, and production data for the Upper Pennsylvanian play. Heads explained on last page.

St	County	Reservoir	Ty	Disc	Wells	Aban	Spa	Acres	Depth	Trap	Dri	Lith	DeEn	PostD	Por	Per	Temp	PrGr	CumBCF	PDR
NM	Lea, Rsvlt	Allison (Penn)	A	1954	147	110	80	15040	9650	Lpp	CO	Lsun	Reeb	Gren	0.07	200.000	154	0.35	16.580	0.5
NM	Lea	Bagley North (Permo Penn)	A	1957	232	71	80	19800	9600	Spm	CO	Lsun	Reeb	Gren	0.08		162	0.38	149.340	15.8
NM	Lea	Baum (Upper Penn)	A	1955	101	37	160	13120	9900	Lpp	CO	Lsun	Reeb	Gren	0.11		150	0.32	22.740	1.4
NM	Lea	Bough (Permo Penn)	A	1949	32	25	40	2560	9625	Ant	CO	Lsun	Reeb	Gren	0.13	76.000	145	0.37	8.370	
NM	Eddy	Dagger Draw North (U Penn)	A	1974	72	14	160	10560	7550	Cou	CO	Dolo	Smra	Dolo	0.05	2.800	130	0.40	24.200	
NM	Eddy	Dagger Draw South (U Penn)	A	1973	18	0	160	4160	7500	Cou	CO	Dolo	Smra	Dolo	0.05	2.800	130	0.40	8.540	
NM	Lea	Dean (Permo Penn)	A	1955	31	26	80	2640	11500	Spm	CO	Lsun	Reeb	Gren	0.06	2.150	160	0.36	5.720	0.2
NM	Eddy	Eagle Creek (Permo Penn)	N	1977	32	0	320	13440	6600	Lpp	PD	Lsun	Ssop	Gren	0.04		140	0.35	12.080	13.2
NM	Eddy	Hackberry Hills (Canyon)	N	1967	2	0	320	640	9600	Spm	PD	Lsun	Smra	Gren	0.07		156	0.43	5.560	0.2
NM	Chaves	Haystack (Cisco)	N	1970	7	5	320	3520	5900	Spm	CO	Lsun	Reeb	Gren	0.07	13.000	112	0.41	5.460	1.6
NM	Lea	Hightower (Permo Penn)	A	1950	6	4	40	2560	8600	Spm	CO	Lsun	Reeb	Gren	0.07		132	0.36	5.970	0.2
NM	Lea	Inbe (Permo Penn)	A	1962	145	132	80	13600	9650	Spm	CO	Lsun	Reeb	Gren	0.06	104.000	143	0.36	37.000	0.8
NM	Eddy	Indian Basin (Upper Penn)	N	1963	70	18	640	37600	7400	Cou	CO	Dolo	Smra	Dolo	0.04		146	0.40	1218.350	477.2
NM	Lea	Lazy J (Penn)	A	1952	78	54	40	5360	9650	Spm	CO	Lsun	Reeb	Gren	0.06	8.100	146	0.37	7.000	0.4
NM	Eddy	McKittrick Hills (U Penn)	N	1976	2	1	320	320	7850	Spm	PD	Dolo	Smra	Dolo	0.04		128	0.22	9.350	5.0
NM	Eddy	McMillan (Upper Penn)	N	1982	7	3	320	2880	7825	Lpp	PD	Dolo	Smra	Dolo	0.05		130	0.40	13.390	3.5
NM	Eddy	Peñasco Draw (Permo Penn)	N	1979	17	0	320	8960	8800	Lpp	PD	Lsun	Ssop	Gren	0.04		148	0.35	7.720	4.1
NM	Roosevelt	Peterson (Penn)	A	1973	8	3	160	1440	7650	Spm	CO	Lsun	Reeb	Gren	0.08		140		5.000	0.6
NM	Roosevelt	Peterson South (Penn)	A	1973	25	6	40	5160	7650	Spm	CO	Lsun	Reeb	Gren	0.08		137	0.34	10.650	4.7
NM	Lea	Ranger Lake (Penn)	A	1956	34	30	80	3120	10300	Spm	CO	Dolo	Ssop	Dolo	0.10	28.000	144	0.35	6.240	0.2
NM	Lea	Saunders (Permo Penn)	A	1950	215	69	40	12560	9800	Spm	CO	Lsun	Reeb	Gren	0.10	1.000	146	0.36	49.140	3.4
NM	Eddy	Springs (Upper Penn)	N	1966	7	5	320	10280	8000	Spm	CO	Dolo	Smra	Dolo	0.10		131	0.42	23.330	1.6
NM	Chaves	Tobac (Penn)	A	1964	44	26	80	6080	9060	Lpp	CO	Lsun	Reeb	Gren	0.07	100.000	138	0.34	12.280	0.5
NM	Lea	Townsend (Permo Penn)	A	1952	141	76	40	11320	10550	Spm	CO	Lsun	Reeb	Gren	0.08	38.000	160	0.37	37.300	4.3
NM	Lea	Vacuum (Upper Penn)	A	1964	21	8	80	2400	10000	Spm	CO	Lsun	Reeb	Gren	0.13		163	0.32	10.470	0.5
NM	Lea, Rsvlt	Vada (Penn)	A	1956	345	284	160	60240	9800	Lpp	CO	Lsun	Reeb	Gren	0.08	150.000	145	0.28	134.740	1.9

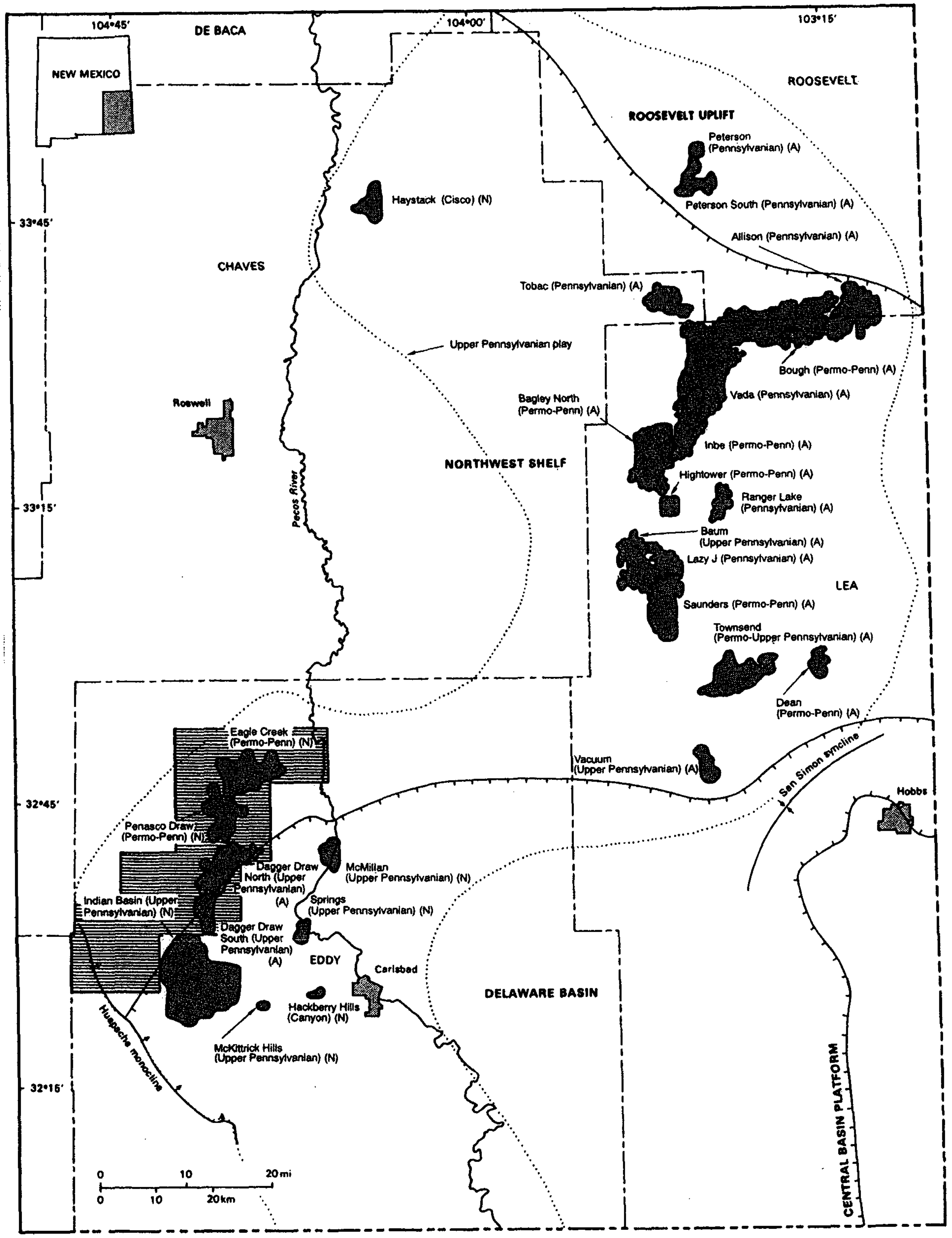


FIGURE PP-1.1—Reservoirs in the Upper Pennsylvanian play and designated Permo–Penn tight formation areas (designation includes the Cisco Formation).

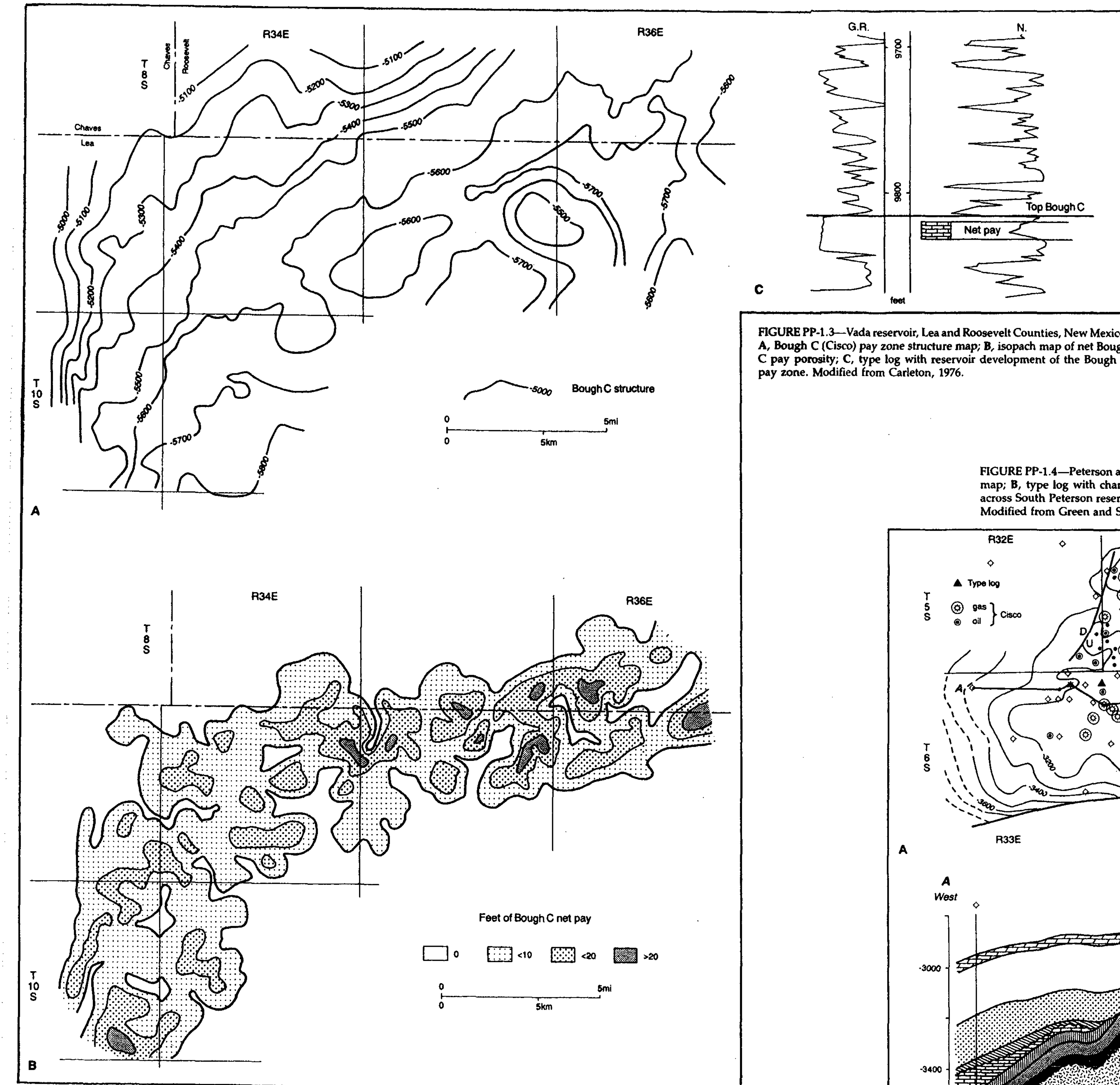


FIGURE PP-1.3—Vada reservoir, Lea and Roosevelt Counties, New Mexico. A, Bough C (Cisco) pay zone structure map; B, isopach map of net Bough C pay porosity; C, type log with reservoir development of the Bough C pay zone. Modified from Carleton, 1976.

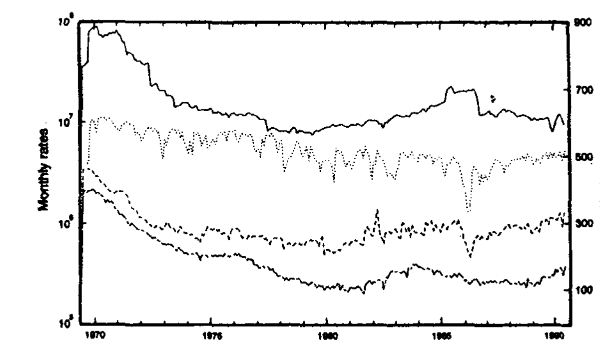
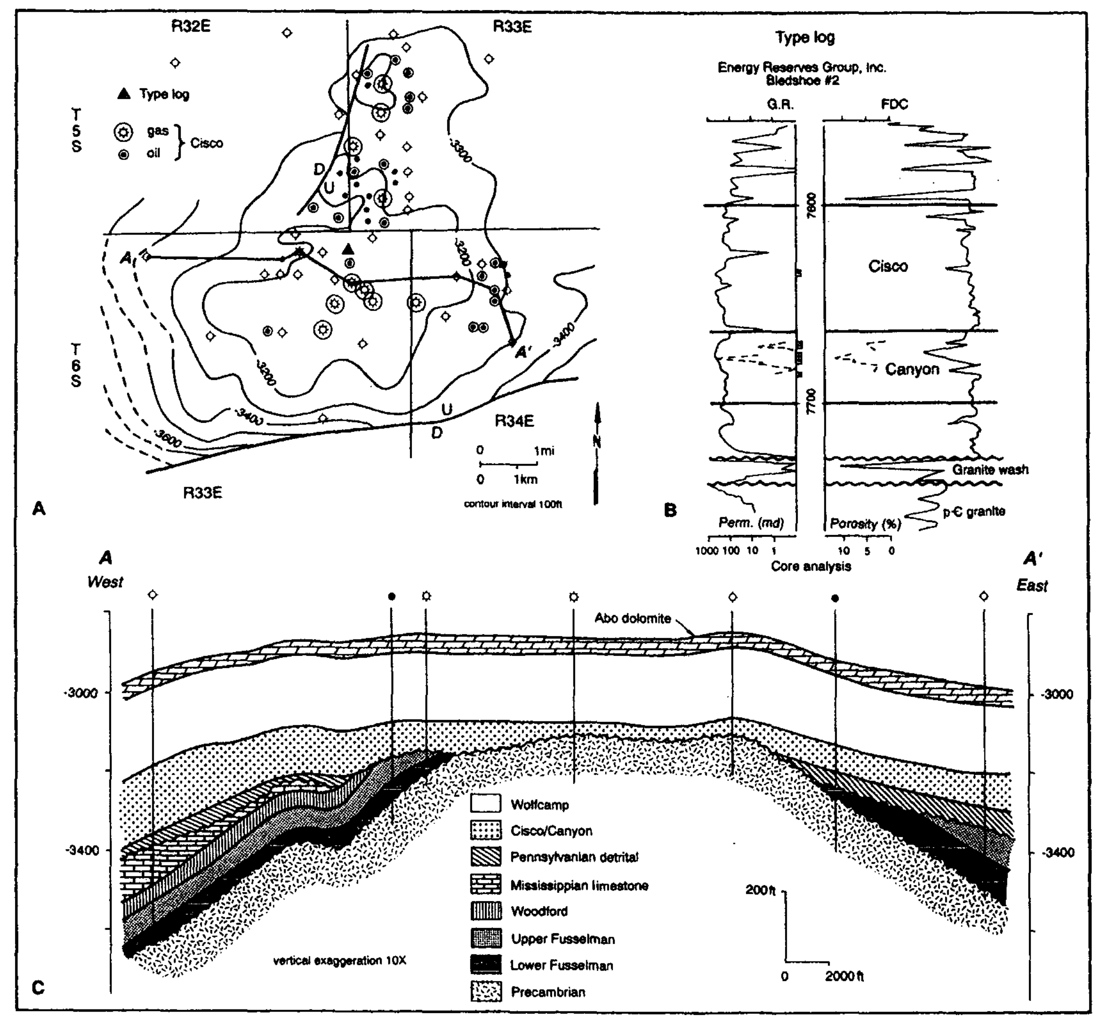


FIGURE PP-1.2—Historical production from the Upper Pennsylvanian play. ···, gas (MCF); — · —, oil (BBLS); ---, water (BBLS); —, wells. From INTERA Bergeson; data source, Dwight's Energydata, Inc.

FIGURE PP-1.4—Peterson and South Peterson reservoirs, Roosevelt County, New Mexico. A, Cisco Formation structure map; B, type log with character and reservoir properties of the Cisco/Canyon pay zones; C, structural cross section across South Peterson reservoir complex. Lower Paleozoic reservoirs also produce here in a subcrop pinch-out setting. Modified from Green and Schlueter, 1988.



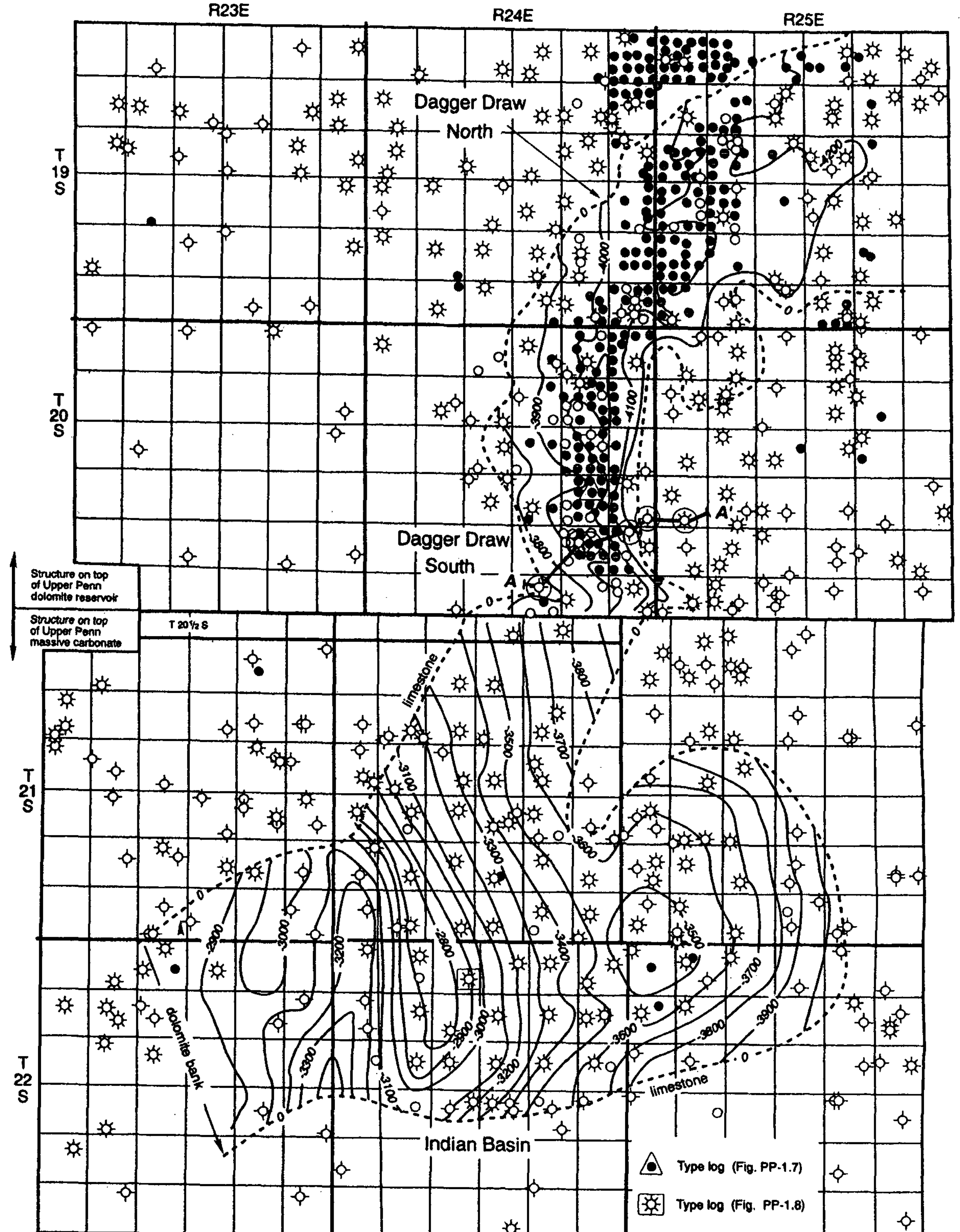


FIGURE PP-1.5—Composite structure/lithofacies map of Indian Basin and Dagger Draw Upper Pennsylvanian (Cisco/Canyon) reservoirs, Eddy County, New Mexico. *Well data is current to February 1993. Note that the structural mapping* horizon changes from the top of the dolomite reservoir north of T20½S to the top of the massive carbonate south of T20½S. See Figs. PP-1.6—PP-1.8 for the relationship of these two horizons. Cross section is in Fig. PP-1.7. Modified from Frenzel, 1988; Yates Petroleum Company, 1991.

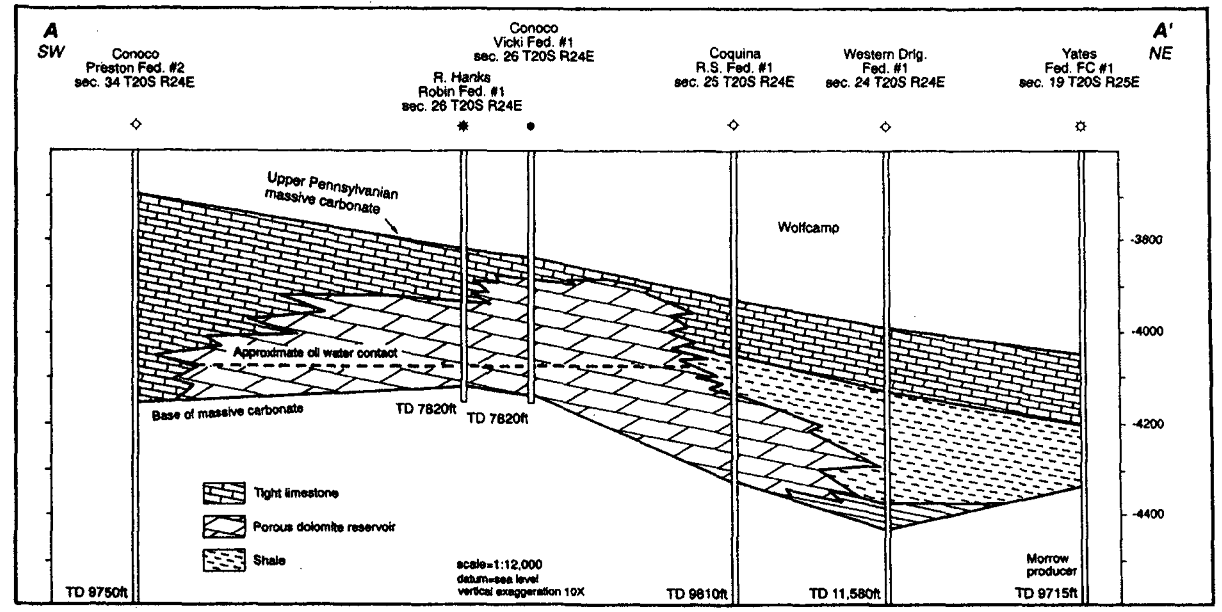


FIGURE PP-1.6—Structural cross section across Dagger Draw South reservoir. Line of section is in Fig. PP-1.5. Modified from McKay Oil Corporation, 1991.

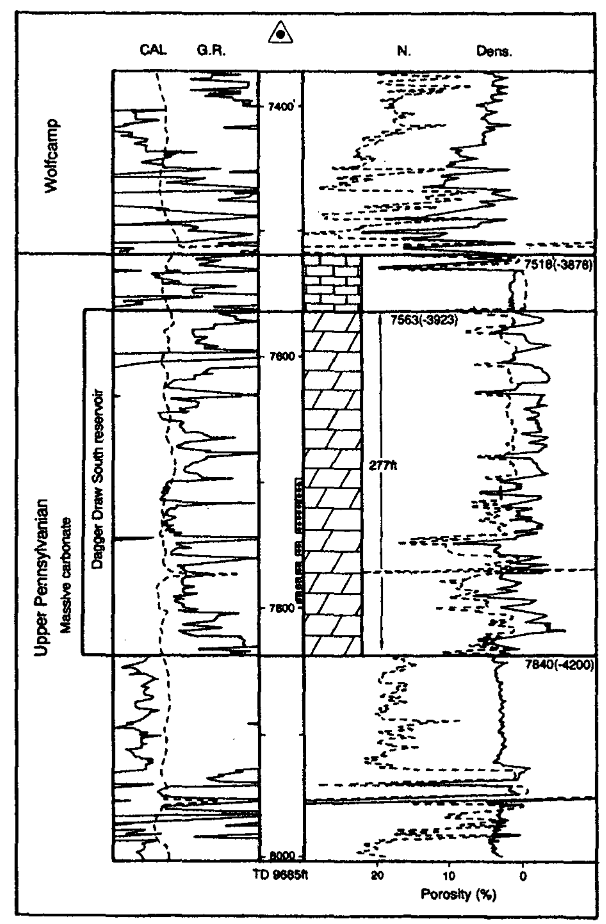


FIGURE PP-1.7—GR/neutron-density log from the Conoco Penny Fed Com #2 well in Dagger Draw South Upper Penn reservoir. Well was completed in 1982 for a pumping initial potential of 163 BOPD and 841 BWPD in SW¼ NE¼ sec. 23 T20S R24E (Fig. PP-1.5). It is now operated by Yates Petroleum Corp. as the Hillview AHE #2 and had cumulative production through 1990 of 485.5 MMCFG, 91,514 BO, and 1,461,841 BW.

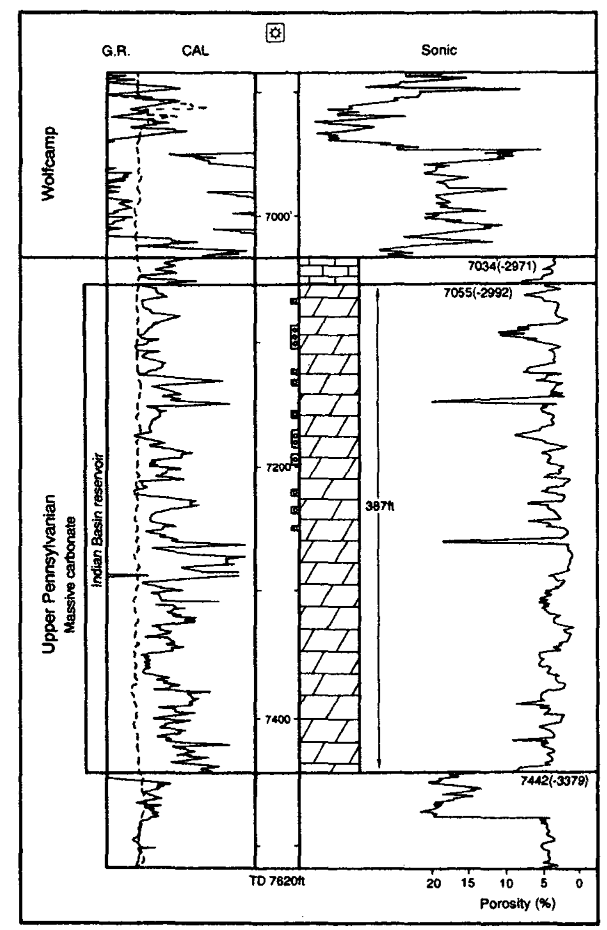


FIGURE PP-1.8—GR/sonic log from the Standard Oil Co. of Texas Fed. 33 #1 well in Indian Basin Upper Penn reservoir. Well was completed in 1965 for a calculated absolute open flow potential of 92,000,000 CFD in NW¼ SE¼ sec. 33 T21S R23E (Fig. PP-1.5). Cumulative production through 1990 for this well was 32.834 BCFG, 185,830 BC, and 6,300 BW.

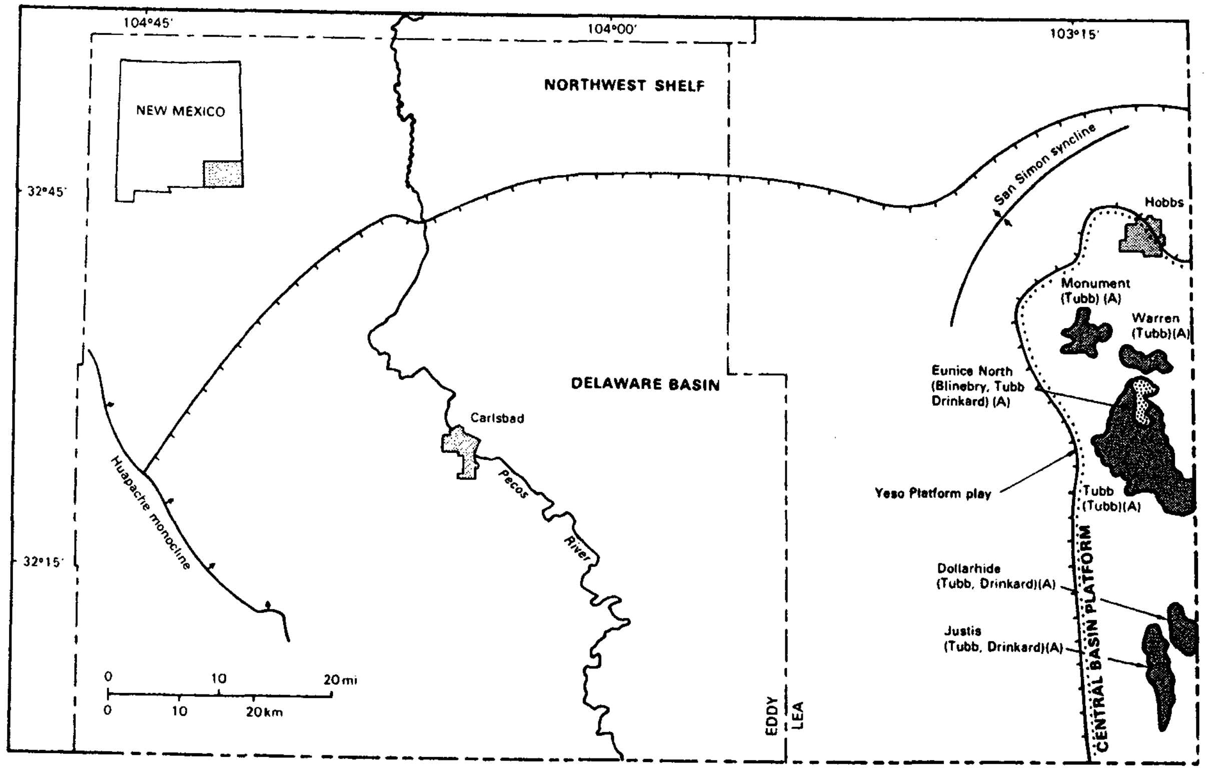


FIGURE PB-6.2—Reservoirs that produce from the Tubb member of the Yeso Formation in the Yeso Platform play.

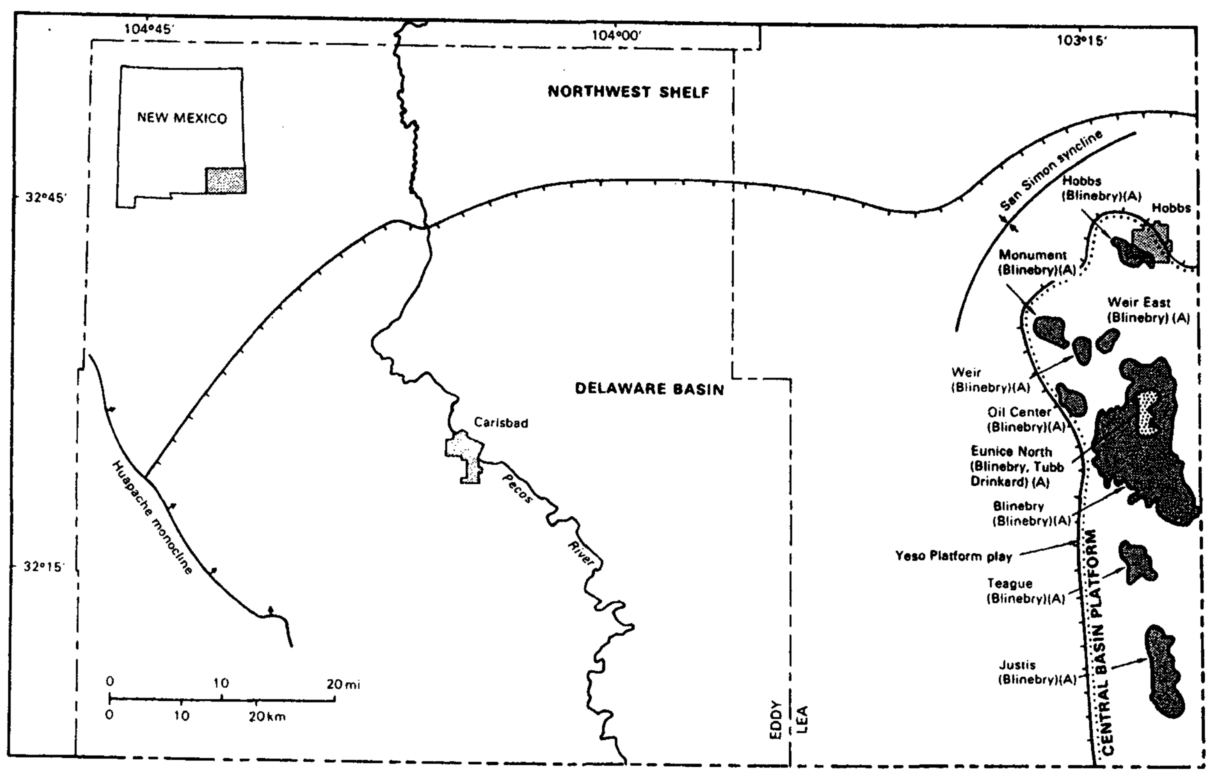


FIGURE PB-6.3—Reservoirs that produce from the Blinebry member of the Yeso Formation in the Yeso Platform play.

			NEW MEXICO	WEST TEXAS
Permian	Leonardian		San Andres Formation	San Andres Formation
		Yeso Formation	Blinebry member	upper Clearfork Formation
			Tubb member	Tubb sandstone
			Drinkard member	lower Clearfork Formation
			Abo Formation	Wichita Group

FIGURE PB-6.4—Stratigraphic column of the Yeso Formation showing relationship of the Drinkard, Tubb, and Blinebry members on the Central Basin platform and lithostratigraphic equivalence to west Texas rock units.

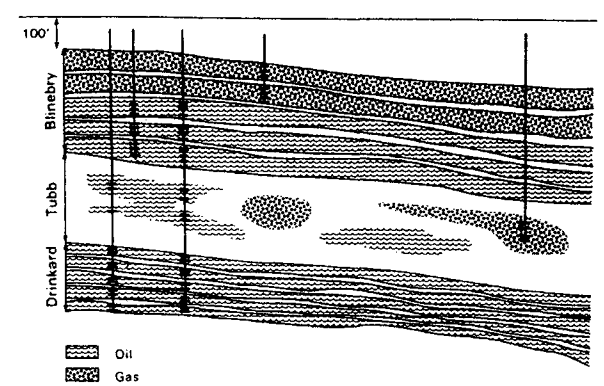


FIGURE PB-6.6—Schematic cross section of Drinkard, Tubb, and Blinebry members in Eunice North reservoir. From New Mexico Oil Conservation Division Case Files 9,230, 9,231, and 9,232.

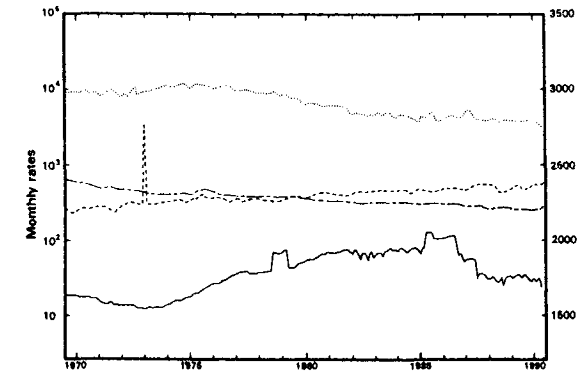


FIGURE PB-6.5—Historical production from the Yeso Platform play. ···, gas (MMCF); — - —, oil (MBO); —, water (MBW); —, wells. From INTERA Bergeson; data source, Dwight's Energydata, Inc.

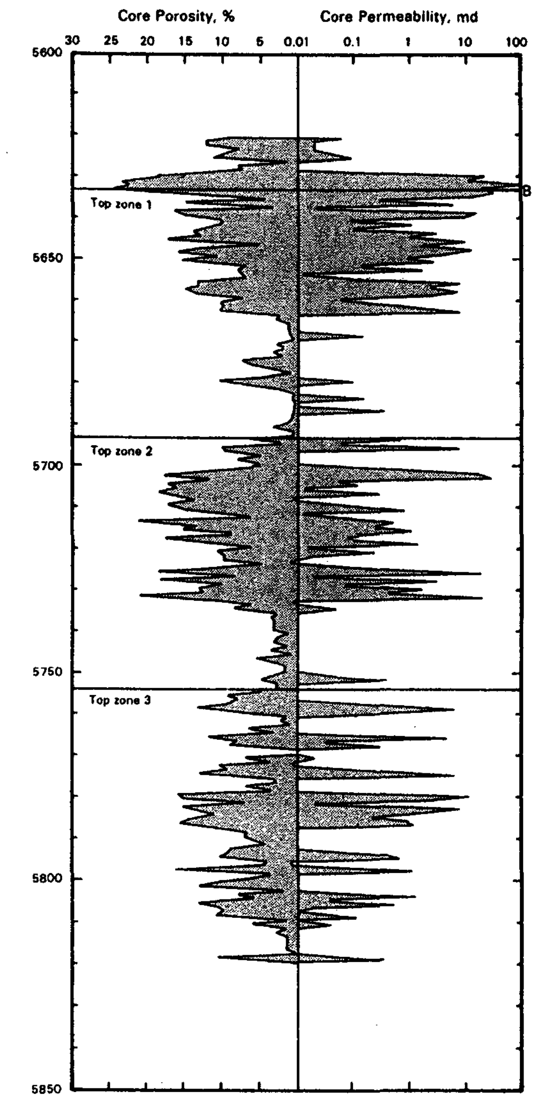


FIGURE PB-6.7—Core porosity and permeability measurements in upper three zones of Blinebry in the Exxon No. 1 Blinebry–Tubb Gas Com., sec. 10 T21S R37E, Eunice North Blinebry Tubb Drinkard reservoir. From New Mexico Oil Conservation Division Case Files 9,230, 9,231, and 9,232.

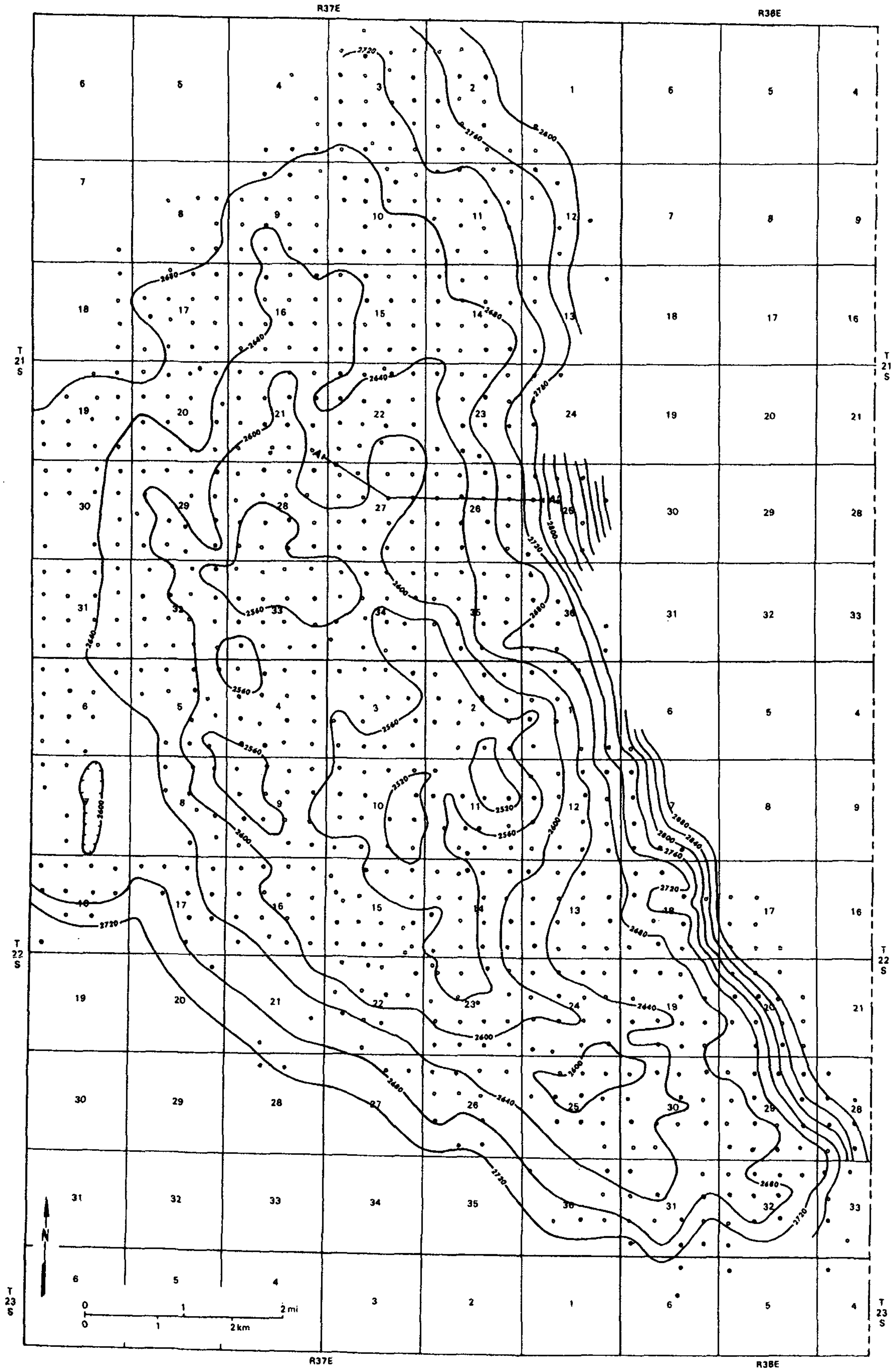


FIGURE PB-6.8—*Structure contour map* of the Tubb marker, Tubb Oil and Gas reservoir. Contours in feet below sea level; contour interval is 40 ft. Simplified from New Mexico Oil Conservation Division Case File 6,525.

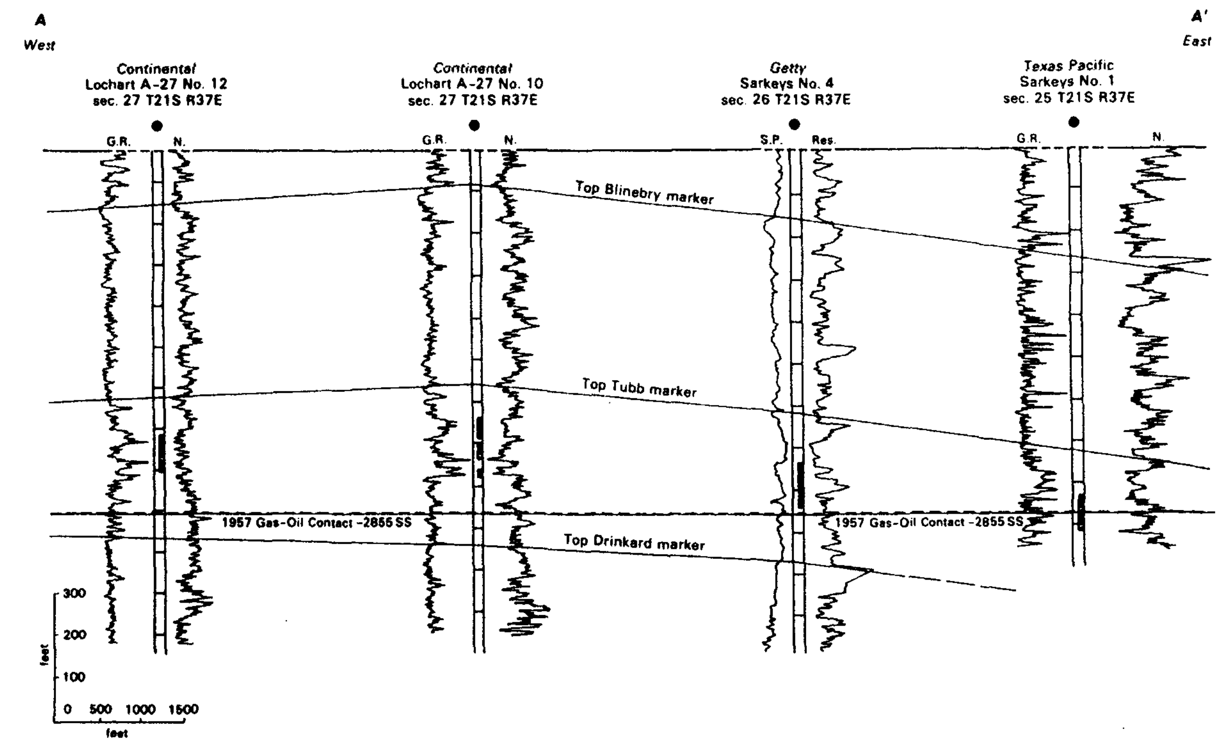


FIGURE PB-6.9—East-west cross section through Tubb Oil and Gas reservoir. See Fig. PB-6.8 for location. From New Mexico Oil Conservation Division Case File 6,525.

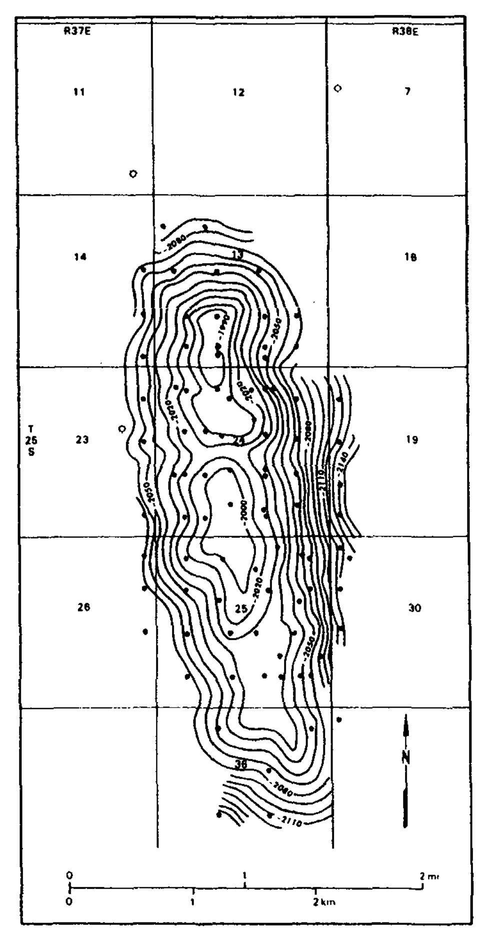


FIGURE PB-6.10—Structure contour map on top of the Blinebry member of the Yeso Formation, Justis Blinebry reservoir. Datum is sea level. After Marshall and Foltz, 1960.

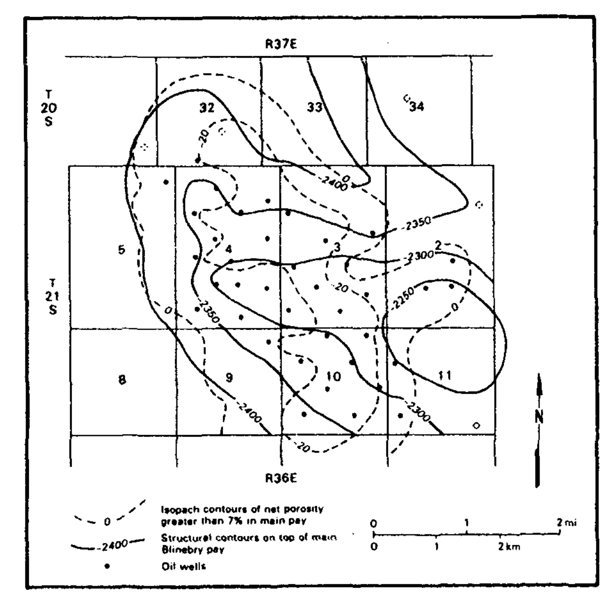


FIGURE PB-6.11—Structure contour map on top of the main Blinebry pay and isopach map of porosity greater than 7% in main Blinebry pay, Oil Center Blinebry reservoir. Datum is sea level. *After Kincheloe and David, 1977.*

PB-7. ABO PLATFORM CARBONATE

Ronald F. Broadhead

Reservoirs of the Abo Platform Carbonate play (Fig. PB-7.1) lie along the southern edge of the Northwest shelf and on the Central Basin platform. The Abo Platform Carbonate play is roughly equivalent to the Wichita–Albany (Abo) reservoirs in the Clear Fork Platform play of the *Atlas of Major Texas Gas Reservoirs* (Texas Atlas play code PM-3; Bebout and Garrett, 1989). Four reservoirs (Corbin, Empire, Lovington, Vacuum) constitute the Abo Reef subplay and four reservoirs (Brunson South, Skaggs, Vacuum North, Wantz) constitute the Abo Carbonate Shelf subplay.

The eight reservoirs in the play with more than 5 BCF production have produced a cumulative 683 BCF gas (Table PB-7.1). With the exception of Skaggs, all reservoirs produce oil and associated gas; nonassociated gas and minor condensate are produced from Skaggs. Partial waterflooding of many of these reservoirs commenced during the 1960s, 1970s, and 1980s. Reservoirs in the Abo Reef subplay have produced 456 BCF gas; production has been dominated by Empire Abo, which has yielded 294 BCF or 64% of the gas produced by the subplay. Reservoirs in the Abo Carbonate Shelf subplay have produced 227 BCF gas and have been dominated by the 129 BCF gas produced by Brunson South. Monthly gas production in the Abo Reef subplay has declined from approximately 1.7 BCF in 1970 to approximately 0.5 BCF in 1990 (Fig. PB-7.2); the decline roughly parallels a decline in oil production from this play. In contrast, monthly gas production in the Abo Carbonate Shelf subplay has increased during the same period (Fig. PB-7.3) from 0.4 BCF/mo during 1970 to 0.6 BCF/mo during 1990, but is down from a maximum production of 1.2 BCF/mo during 1977; the increase in gas production has resulted from extensive infill and extension drilling during the past two decades that resulted in an increase in the number of producing wells from approximately 200 during 1970 to approximately 450 during 1990.

Traps in the Abo Reef subplay are located along the southern edge of the Northwest shelf (Fig. PB-7.1). Depths to productive Abo range from approximately 6,000 ft at the Empire reservoir to approximately 8,650 ft at the structurally deeper Vacuum reservoir. Traps are predominantly stratigraphic and are located in porous reefal masses 5 to 13 mi long and 1 to 5 mi wide. These have been interpreted as classic fringing barrier reefs (LeMay, 1960). The reef trend is thought to have been localized by growth along the pre-existing Bone Spring flexure (Snyder, 1962), which apparently formed a hingeline that marked the boundary between the Northwest shelf and the Delaware Basin during the Early Permian. The reef trend is reflected as draping of overlying sediments (Artesia–Vacuum arch; Kelley, 1971).

The reef reservoirs are clean, white to light-tan to light-gray, finely to coarsely crystalline dolostones (LeMay, 1960, 1972; Snyder, 1962; Wilson, 1960). Depositional sedimentary structures and textures have been obliterated by pervasive dolomitization. Pay thickness exceeds 700 ft in parts of the Empire Abo reservoir but is less than 100 ft in most of the reservoirs. Porosity is secondary, consisting of vugular solution cavities and vertical to near-vertical fractures as well as intercrystalline pores, and distribution is irregular, ranging from 1.5 to 18.3% in the Empire Abo reservoir.

Permeability is also variable, ranging from 0.1 to 1,970 md in the Empire Abo reservoir. The irregular distribution of permeability has resulted in poor fluid communication within the reservoirs (LeMay, 1960, 1972). As a result, small gas pockets can be found within structurally low areas of a reservoir. Anhydrite cement fills or partially fills vugs and fractures in parts of the reservoirs.

The dominant trapping mechanism in the Abo Reef subplay is stratigraphic. The vertical seal is provided by green siliciclastic shales and interbedded, finely crystalline, impermeable dolostones. On the north, the seal is formed by a facies change into backreef shelf sediments (Figs. PB-7.1, PB-7.4; LeMay, 1960, 1972; Snyder, 1962). The backreef facies is formed by interbedded green shales and impermeable dolostones. Variations in morphology of the reef result in slightly different trapping geometries in the different reservoirs (LeMay, 1960, 1972). East–west limits of the reservoirs are defined by gentle structural or morphologic plunge of the reef top under the oil–water contact (LeMay, 1960) or by occlusion of porosity by anhydrite cement, as is the case with the western boundary of the Empire Abo reservoir (LeMay, 1972). The southern limits of the Abo reef reservoirs are delineated by transition to the nonporous, black, argillaceous limestones and fine-grained sandstones of the basinal Bone Spring Formation. In places, the Bone Spring overlaps Abo reservoirs (Fig. PB-7.4). In each of the four Abo reef reservoirs, the top of the porous Abo dips underneath the oil–water contact in a basinward direction.

Reservoirs in the Abo Carbonate Shelf subplay are dolostones. Depths to production range from 6,750 ft at Brunson South on the Central Basin platform to 8,500 ft at Vacuum North. Traps are formed by broad, low-relief anticlines. On the Central Basin platform, traps are formed by the same structures that form traps in the Yeso Platform play, but the Abo does not produce from structures on the southern part of the platform where Abo reservoirs are not well developed. The Vacuum North Abo reservoir produces from porous shelf dolostones north of the Abo reef trend where porosity and permeability are unevenly distributed. Production at Vacuum North is obtained from a section approximately 100 ft thick in the upper part of the Abo; net pay is approximately 18 ft. Porous zones within defined reservoirs appear to have relatively good continuity. Available data indicate average porosity ranges from 11.3% at Vacuum North to 14% at Wantz.

An additional 55 reservoirs with less than 5 BCF production are present in the Abo Platform Carbonate play. The densely drilled Abo appears mostly played out along all but the western part of the reef trend and on the Northwest shelf where considerable potential remains.

Intera Bergeson—The primary producing mechanisms for reservoirs in the Abo Reef subplay are primary gas-cap expansion supplemented by secondary gas-cap growth resulting from release of solution gas with pressure decline. Some water-drive support is present in parts of these reservoirs. Reservoir voidage rates are restricted in order to maximize the benefits of gravity drainage. In the past, selective production from lower gas-oil ratio producers and reinjection of residue gas have been used to minimize reservoir voidage and maintain pressure. Drilling density is on the order of 20 acres to adequately drain these fractured, vugular dolomites, although some areas have been drilled to densities of 10 acres/well. See LeMay (1960, 1972), Christianson (1977), Killough and Foster (1979).

TABLE PB-7.1—Geologic, engineering, and production data for the Abo Platform Carbonate play. Heads explained on last page.

St	County	Reservoir	Ty	Disc	Wells	Aban	Spa	Acres	Depth	Trap	Dri	Lith	DeEn	PostD	Por	Perm	Temp	PrGr	CumBCF	PDR
NM	Lea	Brunson S (Abo Drinkard)	A	1975	165	12	40	12320	6750			Dolo	Ssun	Dolo					129.085	44.5
NM	Lea	Corbin (Abo)	K	1959	33	10	40	3360	8580	Lpp	CO	Dolo	Smri	Dolo	0.06	25.000	128	0.375	20.254	2.6
NM	Eddy	Empire (Abo)	K	1957	391	47	40	12320	6020	Lpp	CO	Dolo	Smri	Dolo			109	0.398	293.551	48.0
NM	Lea	Lovington (Abo)	K	1951	26	43	40	4000	8340	Lpp	WD	Dolo	Smri	Dolo				0.389	12.989	
NM	Lea	Skaggs (Abo)	N	1953	6	2	40	2080	7050				Ssun				140	0.286	7.028	2.8
NM	Lea	Vacuum (Abo)	K	1960	134	45	40	9160	8650	Lpp	CO	Dolo	Smri	Dolo	0.05	13.900	136	0.369	129.165	4.0
NM	Lea	Vacuum N (Abo)	A	1962	284	115	80	17440	8500			Dolo	Ssre	Dolo	0.11	1.500	131	0.422	40.769	
NM	Lea	Wantz (Abo)	K	1950	144	112	40	22320	6800	Ant	SG	Dolo	Ssun	Dolo	0.14			0.430	50.486	

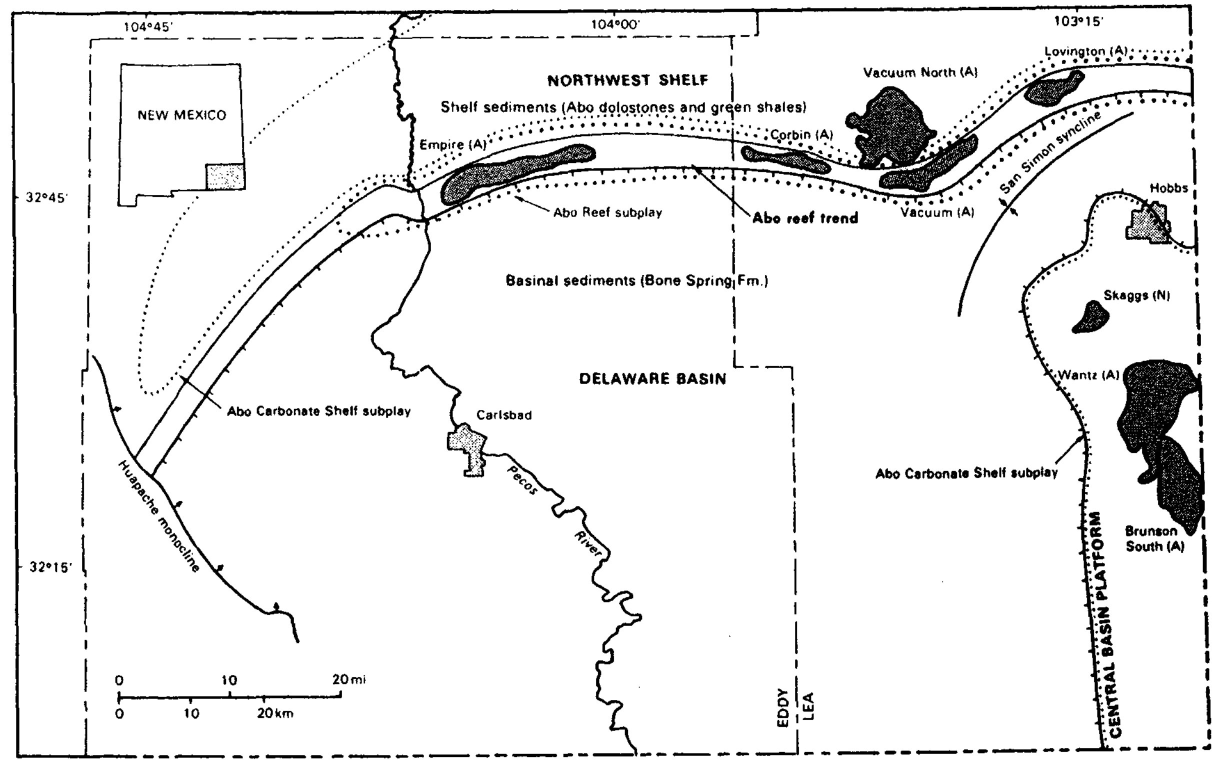


FIGURE PB-7.1—Reservoirs and subplays in the Abo Platform Carbonate play.

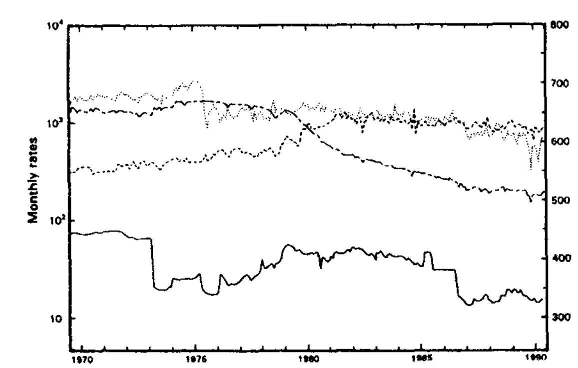


FIGURE PB-7.2—Historical production from the Abo Reef subplay. ···, gas (MMCF); — - —, oil (MBO); ---, water (MBW); —, wells. From INTERA Bergeson; data source, Dwight's Energydata, Inc.

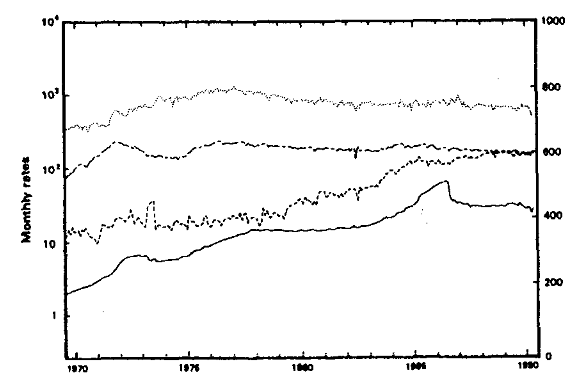


FIGURE PB-7.3—Historical production from the Abo Carbonate Shelf subplay. ···, gas (MMCF); — - —, oil (MBO); ---, water (MBW); —, wells. From INTERA Bergeson; data source, Dwight's Energydata, Inc.

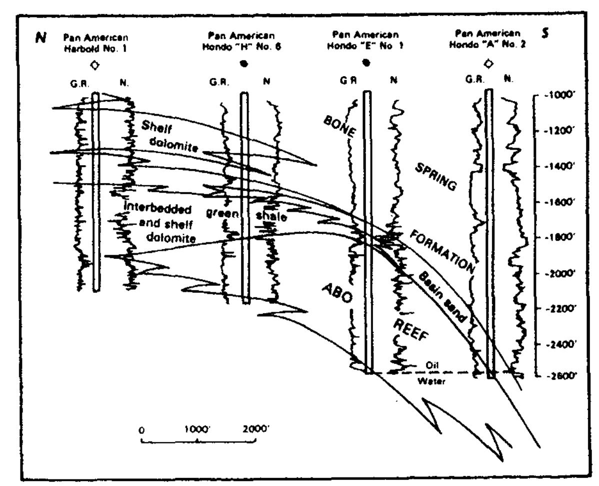


FIGURE PB-7.4—North–south structural cross section through Empire Abo reservoir showing relationship of porous Abo reef to Abo backreef facies and basinal Bone Spring Formation. After LeMay, 1960.

PB-8. ABO FLUVIAL/DELTAIC SANDSTONE

Ronald F. Broadhead

Reservoirs in the Abo Fluvial/Deltaic Sandstone play are present on the Northwest shelf of the Permian Basin (Fig. PB-8.1). The three reservoirs in the play with cumulative production greater than 5 BCF have produced 273 BCF since the Pecos Slope South reservoir was discovered in 1977 (Fig. PB-8.2). Production has been dominated by the Pecos Slope reservoir (231 BCF; Table PB-8.1). The boundary between the Pecos Slope and Pecos Slope South reservoirs is industrial and not geological. In addition to these three major reservoirs, there are three reservoirs in the play with production less than 5 BCF.

Following discovery of Pecos Slope South, development was minimal until 1981 when FERC designated the Abo a tight formation under 1,536,000 acres in Chaves and south De Baca Counties (Fig. PB-8.1). The tight sand designation increased the regulated ceiling price of Abo gas from \$2.81/MCF to \$4.92/MCF. With higher prices obtainable for Abo gas, development surged, and drilling activity reached a peak level in 1982 when almost 350 Abo wells were drilled. In 1983, 5,775,360 additional acres in San Miguel, Torrance, Guadalupe, De Baca, Lincoln, and Chaves Counties were designated tight, but this acreage remains largely undrilled and Abo production has not been established outside of Chaves County. Currently, there are 880 active gas wells in the three reservoirs (Table PB-8.1).

During 1990, average monthly gas production was approximately 1.5 BCF. Produced fluids are nonassociated gas, minor condensate, and minor water. A pressure depletion/gas expansion mechanism provides the reservoir energy.

Before discovery in 1977, fewer than 12 wells had penetrated the Abo in the 600-mi² west part of the Northwest shelf (Bentz, 1988). The wells that had penetrated the Abo were mostly unsuccessful lower Paleozoic tests. The Pecos Slope South discovery well (Fig. PB-8.3) was one such well. It was re-entered by Yates Petroleum Corp. After the lower Paleozoic was tested unsuccessfully, the Abo was tested to verify gas detected by crossover of neutron-porosity and density-porosity logs. After acidization and artificial fracturing, an 18-ft sandstone bed yielded a stabilized flow of 2,550 MCFGPD.

The Abo of the Pecos Slope area consists of interbedded lenticular red sandstones and red siliciclastic shales. Gross thickness of the Abo varies from 650 ft at Pecos Slope to 400 ft at Pecos Slope West. In the producing area, the Abo overlies the Wolfcamp (or Hueco) Formation and is overlain by the Yeso Formation; the Abo dips east at approximately 20 ft/mi on the Pecos Slope (Fig. PB-8.4). South and east of the producing area, the Abo siliciclastics grade into finely crystalline dolostones (Fig. PB-4). To the west, the Abo consists of a shale facies that onlaps and locally pinches out against the Pedernal uplift (Fig. PB-8.5).

Production is obtained from lenticular sandstones in the upper two-thirds of the Abo. Average net pay is 30 ft; pay ranges from 10 ft to more than 80 ft (Bentz, 1988, 1992). The sandstones are typically red, very fine to fine-grained, silty arkosic arenites (Broadhead, 1984). Many have been fractured naturally. The red color is imparted by a matrix of finely crystalline clays intermixed with finely crystalline hematite. This clay-hematite matrix generally clogs pore throats and occludes most primary porosity. Early-stage anhydrite cement and late-stage carbonate cements are also present.

Abo sandstone reservoirs are tight. Average in situ permeability is 0.0067 md (New Mexico Oil Conservation Division, Case file 7093). Permeability is limited by the fine grain size, compaction, clay-hematite matrix, and cements (Broadhead, 1984).

Average porosity of productive sandstones is 12–14%. Minimum porosity necessary for economic production is 9%, and porosities more than 20% have been measured (Bentz, 1988). Although some large-scale primary pores are present, most porosity appears as a micropore system in the clay-hematite matrix; this micropore system contributes to a high irreducible water saturation (Broadhead, 1984). The average water saturation of Abo sandstones is 38.5% (Bentz, 1988, 1992).

Abo sands were deposited in and near meandering channels at the distal end of a fluvial system (Scott et al., 1983; Broadhead, 1984; Bentz, 1992). This fluvial system flowed south into a shallow-marine lagoon whose deposits are characterized by microcrystalline dolostones (*see* Fig. PB.4). Farther to the south, a barrier-reef complex developed at the shelf margin and prolific oil reservoirs were formed in reef dolostones (sec. PB-7). In the Pecos Slope South area, the productive Abo section contains thinly interbedded dolostones and anhydrites, indicating marine influences were present; the fluvial Pecos Slope reservoirs were probably deposited in a proximal to distal deltaic setting, although the exact nature of the delta has not been ascertained.

The trapping mechanism at Pecos Slope, Pecos Slope South, and Pecos Slope West is poorly understood. The distribution of reservoir sandstones (Fig. PB-8.6) indicates stratigraphy plays a partial role in trapping; production is confined to the sandy distal lobes of the fluvial system. Structure (Fig. PB-8.4) does not appear to play a significant role in trapping. The Abo reservoirs are underpressured (Table PB-8.1). Pressures are essentially uniform across all three reservoirs, despite the large structural relief, and average 1,125 psi (Bentz, 1988, 1992); this suggests the reservoirs may have a common component of trapping that may not be entirely stratigraphic.

The north limits of production at Pecos Slope and Pecos Slope West are not defined by discrete structural or lithologic breaks. Instead, there seems to be a transition from gas-productive sandstones in the reservoirs to water-productive sandstones to the north. The water-producing areas have greater bulk volume water (Bentz, 1988), and the Abo north of Pecos Slope is characterized by somewhat coarser-grained sandstones and a higher percentage of sandstones (Broadhead, 1984). Sand bodies lie along channel-like trends in the Pecos Slope reservoirs, but these channels coalesce to form a widespread area of sand deposition to the north (Fig. PB-8.6). It is possible that the north margin of the Abo traps is formed by a capillary pressure barrier related to increased grain size, or it could be related to loss of internal shale seals in the more proximal fluvial system.

Wells in the Abo play are generally drilled into the lowermost Abo or into the underlying Wolfcamp carbonate section. Casing is set and individual sandstone beds are selectively perforated and acidized. Generally, all perforated zones are fractured simultaneously with loads of approximately 40,000 gallons gelled water and 80,000 lbs sand (Boneau et al., 1982). Carbon dioxide may be added to aid cleanup of wells that have poor production.

Most Abo wells do not produce gas before stimulation; after artificial fracturing, initial production is typically 600 MCFGPD (Boneau et al., 1982; Bentz, 1992). Typical wells are expected to produce economically for 15 years with an average ultimate recovery of 600 MMCF; the best wells may eventually recover 2 BCF and the poorest wells may only recover 100 MMCF (Bentz, 1992).

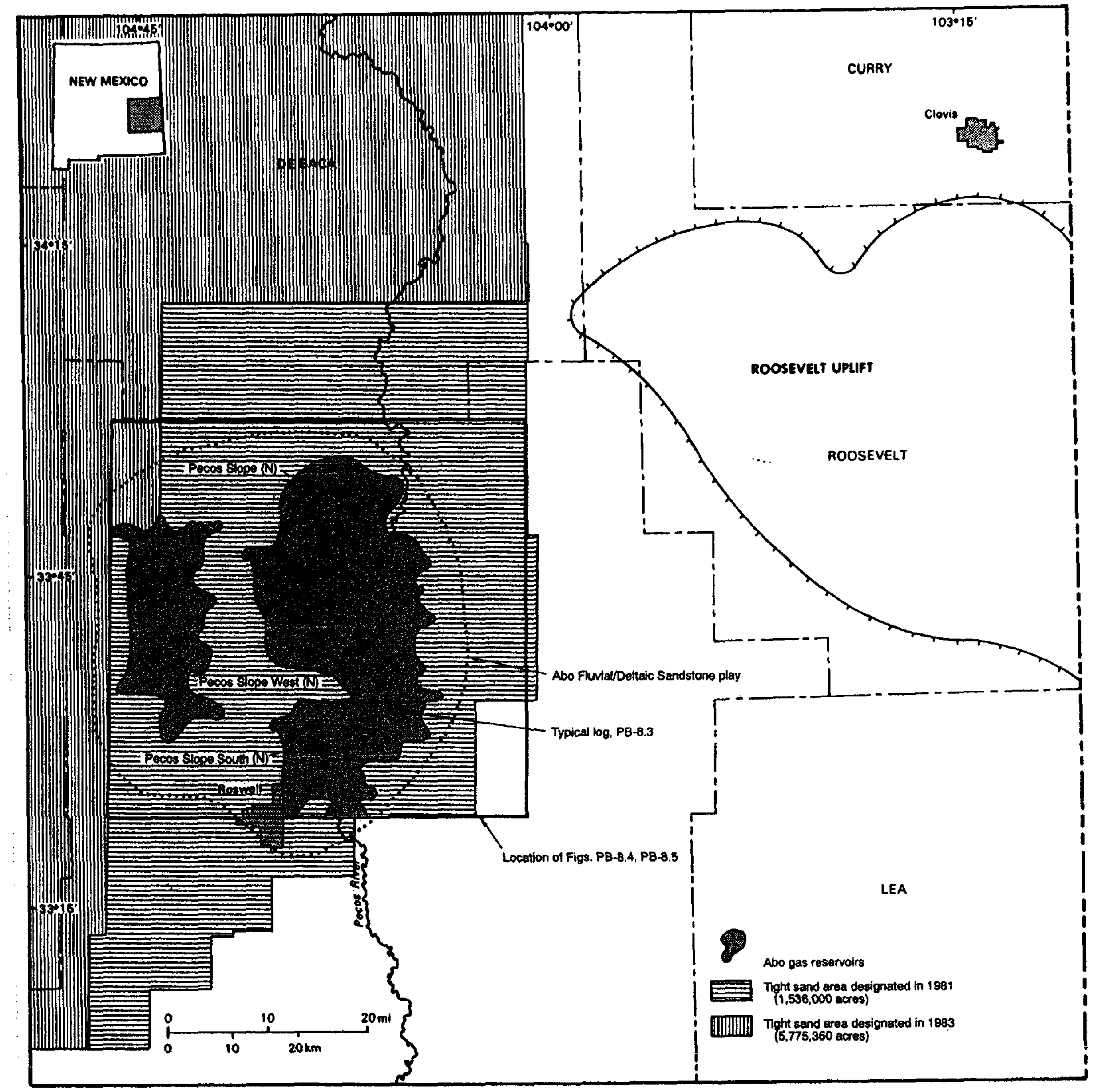


FIGURE PB-8.1—Reservoirs in the Abo Fluvial/Deltaic Sandstone play.

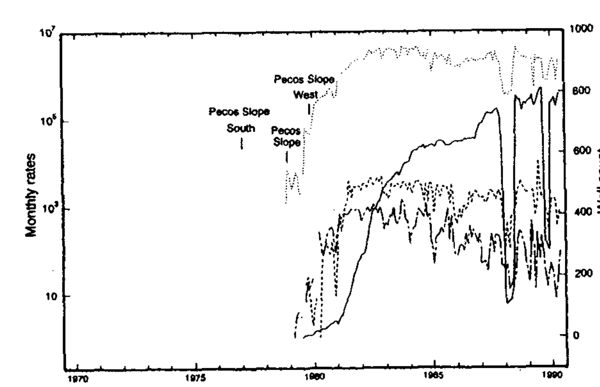


FIGURE PB-8.2—Historical production from the Abo Fluvial/Deltaic Sandstone play. ···, gas (MCF); — · —, oil (BBLS); ---, water (BBLS); —, wells. From INTERA Bergeson; data source, Dwight's Energydata, Inc.

TABLE PB-8.1—Geologic, engineering, and production data for the Abo Fluvial/Deltaic Sandstone play. Heads explained on last page.

St	County	Reservoir	Ty	Disc	Wells	Aban	Spa	Acres	Depth	Trap	Dri	Lith	DeEn	PostD	Por	Perm	Temp	PrGr	CumBCF	PDR
NM	Chaves	Pecos Slope W (Abo)	N	1980	170	18	160	88160	2830	Sa	PD	Sand	Defd	Aucl	0.13	0.007	101	0.367	21.391	29.6
NM	Chaves	Pecos Slope S (Abo)	N	1977	107	4	320	77440	4180	Sa	PD	Sand	Defd	Aucl	0.13	0.007	111	0.387	20.460	43.7
NM	Chaves	Pecos Slope (Abo)	N	1979	603	11	160	198560	3820	Sa	PD	Sand	Defd	Aucl	0.13	0.007	104	0.295	230.768	132.8

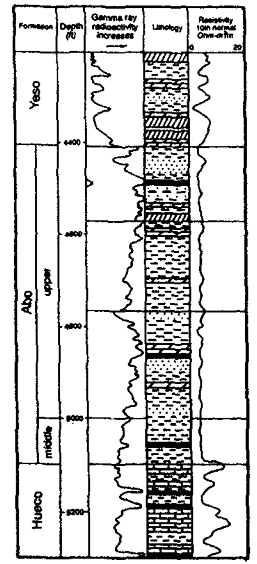


FIGURE PB-8.3—Typical log, Honolulu Oil Corp. No. 1 McConkey Estate, sec. 10 T9S R26E. Re-entered by Yates Petroleum Corp. to become Pecos Slope Abo discovery well. See Fig. PB-8.1 for location. After Broadhead, 1984.

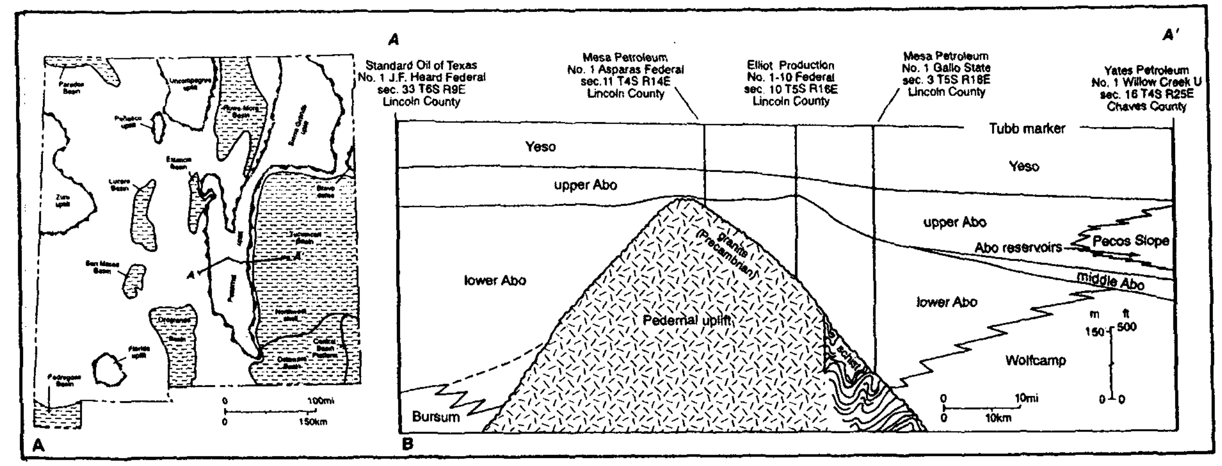


FIGURE PB-8.5—A, Major late Paleozoic basins and uplifts in New Mexico; B, west-east stratigraphic cross section across Pedernal uplift with Abo fluvial/deltaic sandstone reservoirs in easternmost well. Line of section is in A. Datum is top of Tubb sandstone member of Yeso Formation. After Broadhead, 1984.

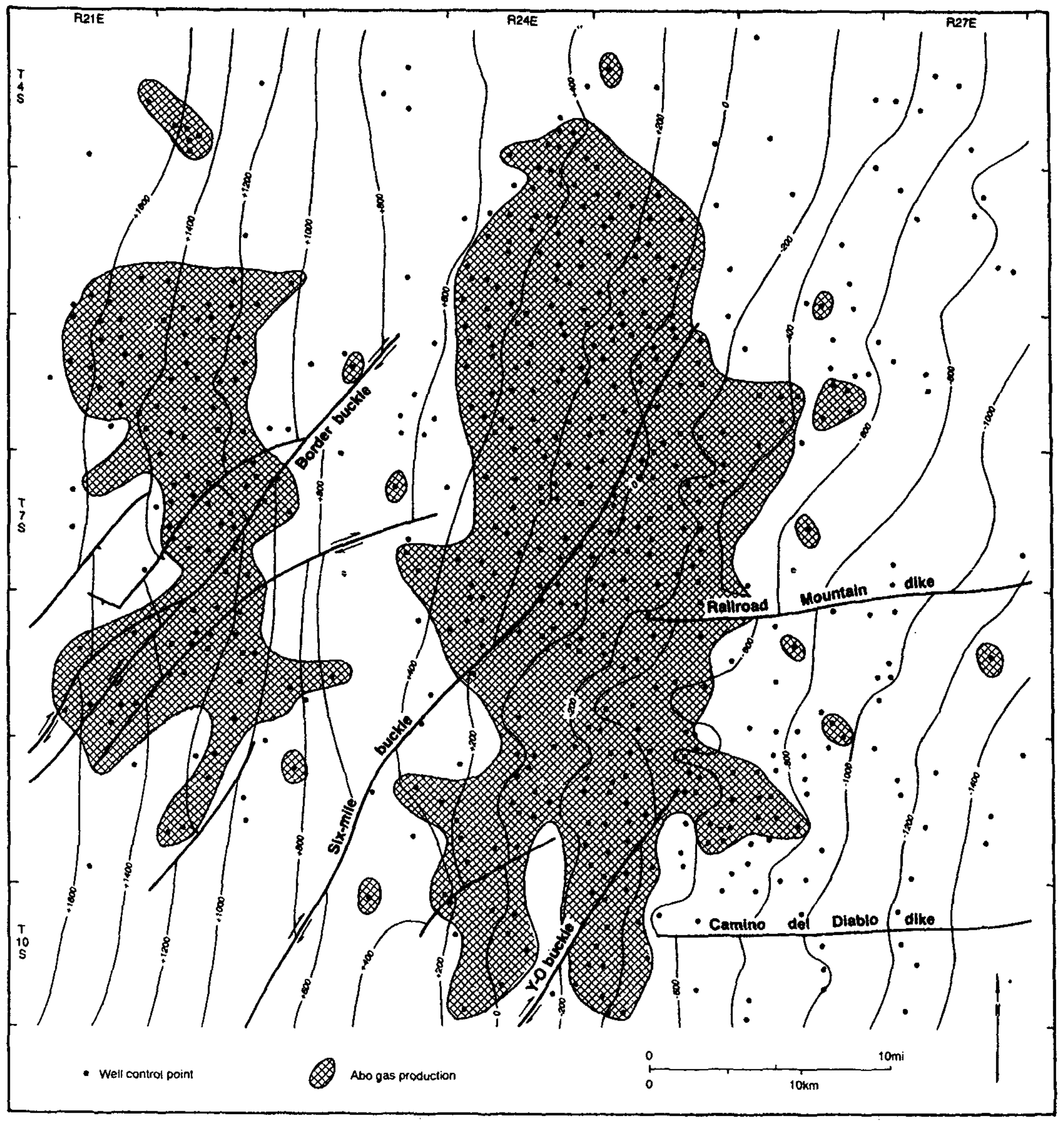


FIGURE PB-8.4—Structure on top of Abo Formation, Pecos Slope area. Modified from Kelley, 1971; Scott et al., 1983; Broadhead, 1984; and Bentz, 1988. See Fig. PB-8.1 for location.

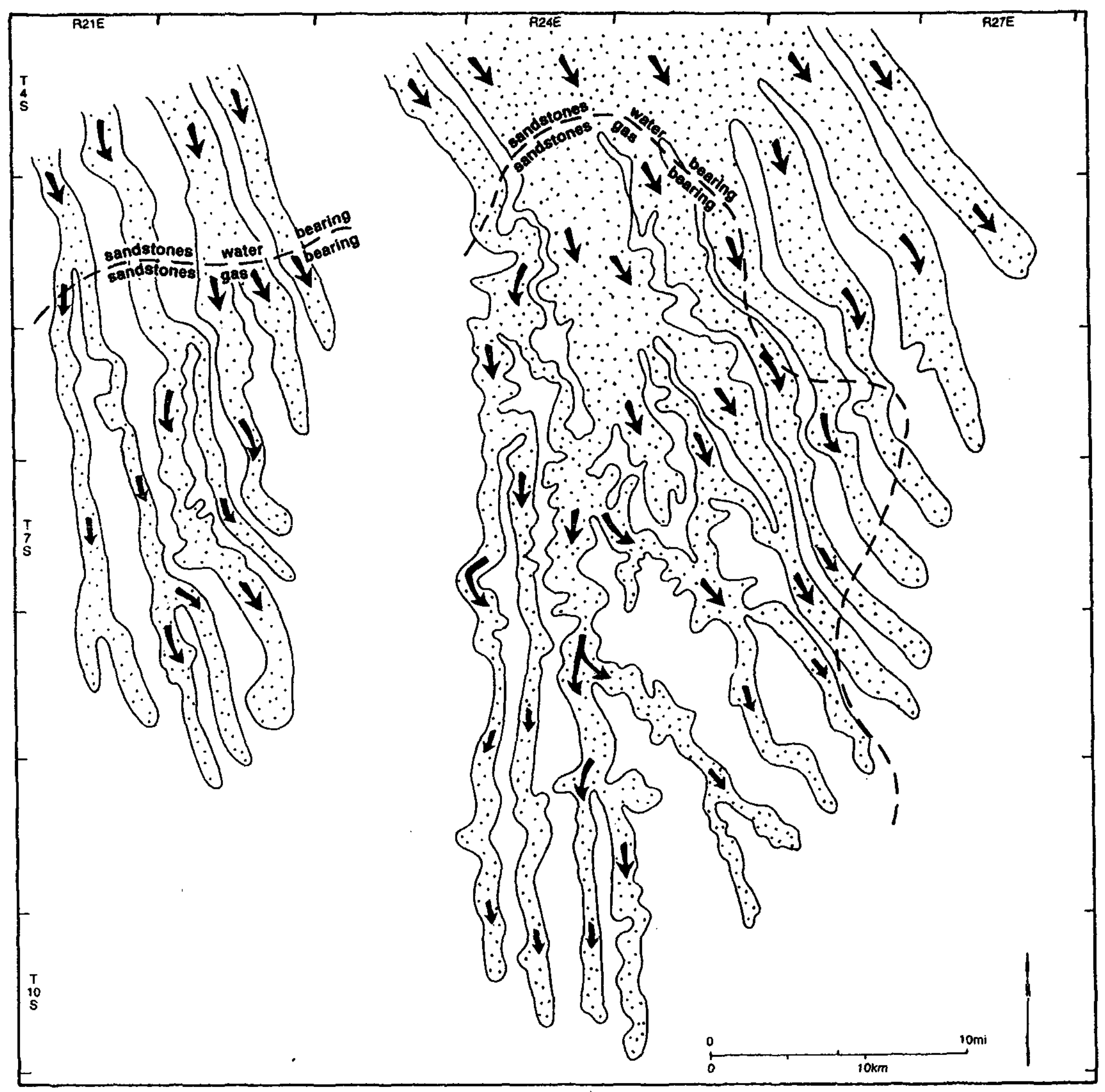


FIGURE PB-8.6—Major Abo sandstone channels with paleoflow direction and areal boundaries of gas-bearing and water-bearing sandstone, Pecos Slope area. Simplified from Bentz, 1988. See Fig. PB-8.1 for location.

PP-2. STRAWN

Stephen W. Speer

Ninety-four designated Strawn reservoirs of Desmoinesian age, producing from both carbonate and clastic rock types, can be found scattered throughout southeast New Mexico. However, of the 13 major reservoirs that have produced more than 5 BCF each (for a combined total of 256+ BCF, or approximately 58% of the designated Strawn production), 11 are uniformly found in localized, lenticular, biohermal shelf limestones in a distinct northeasterly trending ramp of shelf carbonates in central Eddy and Lea Counties (Table PP-2.1; Fig. PP-2.1). The two reservoirs with production exceeding 5 BCF not found in this trend (Antelope Ridge and Jal West) produce from similar limestones associated with large, deep anticlinal structures. A Strawn paleogeographic map shows that this carbonate ramp fringed both the Delaware and Tatum Basins, oriented roughly parallel to adjacent positive features in the Pedernal highlands on the northwest and the Central Basin platform on the east (Fig. PP-2.2).

Strawn reservoirs produce both associated and nonassociated gas from a gross carbonate interval as much as several hundred feet thick ranging from 8,000 to 12,100 ft deep. Many reservoirs are overpressured, with pressures reaching as high as 6,955 psi at a 0.59 lbs/ft pressure gradient. Occasionally, vertical stacking of individual bioherms can give net pay thicknesses greater than 220 ft, but more commonly net pay ranges from 10 to 50 ft thick with effective average porosity ranging from 2 to 9% (Fig. PP-2.3). Although these porosity values seemingly are quite low, Strawn reservoirs are generally very prolific because of permeabilities that reach as high as 100 md. It appears that most of the excellent permeability characteristics can be attributed to well-developed fracture systems found in individual bioherms (Thornton and Gaston, 1967; Harris, 1990). Because of these generally excellent reservoir characteristics, standard Strawn completion practices commonly only require perforating followed by small to moderately sized acid stimulations.

Trapping for most Strawn reservoirs is primarily stratigraphic, although several exhibit structural enhancement. Analysis shows that pre-existing structures were apparently present under some reservoirs during Strawn deposition that appeared to have localized mounding and that affected local facies stratigraphy and architecture (Thornton and Gaston, 1967; Harris, 1990). Most reservoirs are commonly composed of stacked sequences of individual bioherms made up primarily of coralgal-foraminiferal lime wacke/packstones (Harris, 1990). In the best reservoirs, phylloid algae, combined with encrusting foraminifera and bryozoa, appear to have formed bafflestones in individual bioherms. Both primary (intergranular and shelter) and secondary (moldic, vugular, and fracture) porosity types are found in Strawn reservoirs, with much of the fracture porosity apparently resulting from in situ mound collapse and brecciation (Harris, 1990).

As can be seen in the production/well plot in Fig. PP-2.4, the number of Strawn completions has risen steadily since the middle 1970s. This is due primarily to: 1) increased ability of modern seismic techniques to recognize and resolve the subtle stratigraphy and porosity development found in isolated Strawn mounds (Caughey, 1988), and 2) good productive characteristics, and hence economics, of successful Strawn completions. As seismic and geological understanding of these reservoirs continues to improve, the Strawn play will probably continue steady growth in both its size and scope.

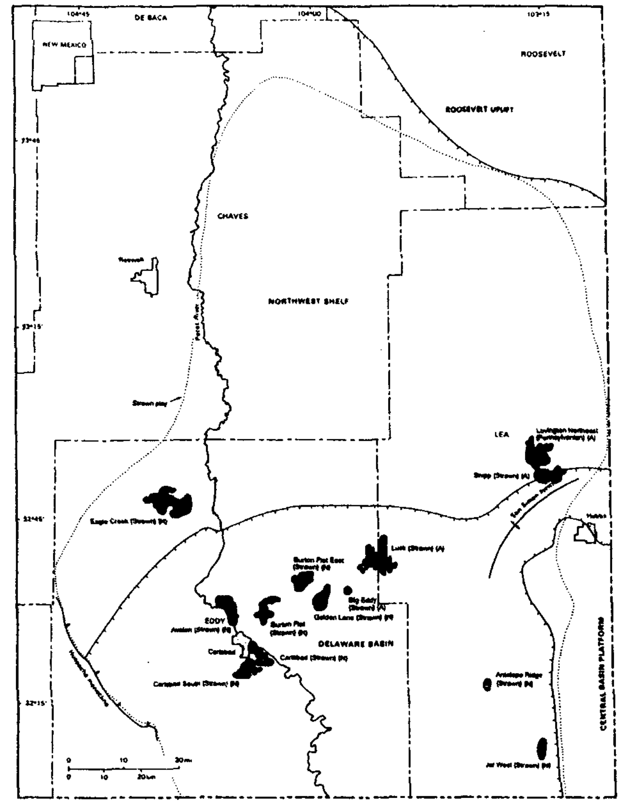


FIGURE PP-2.1—Reservoirs in the Strawn play.

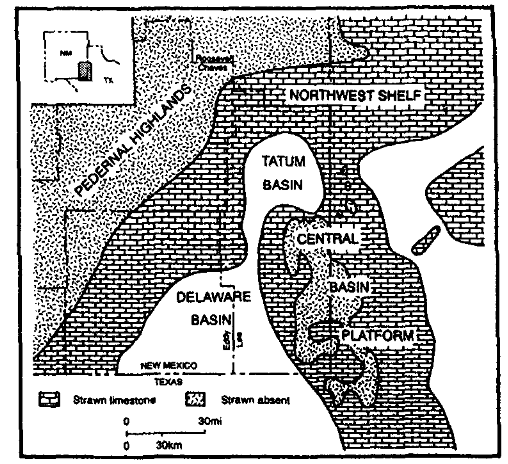


FIGURE PP-2.2—Schematic paleogeography in southeast New Mexico during the Middle Pennsylvanian with areas of Strawn carbonate deposition. Modified from Harris, 1990.

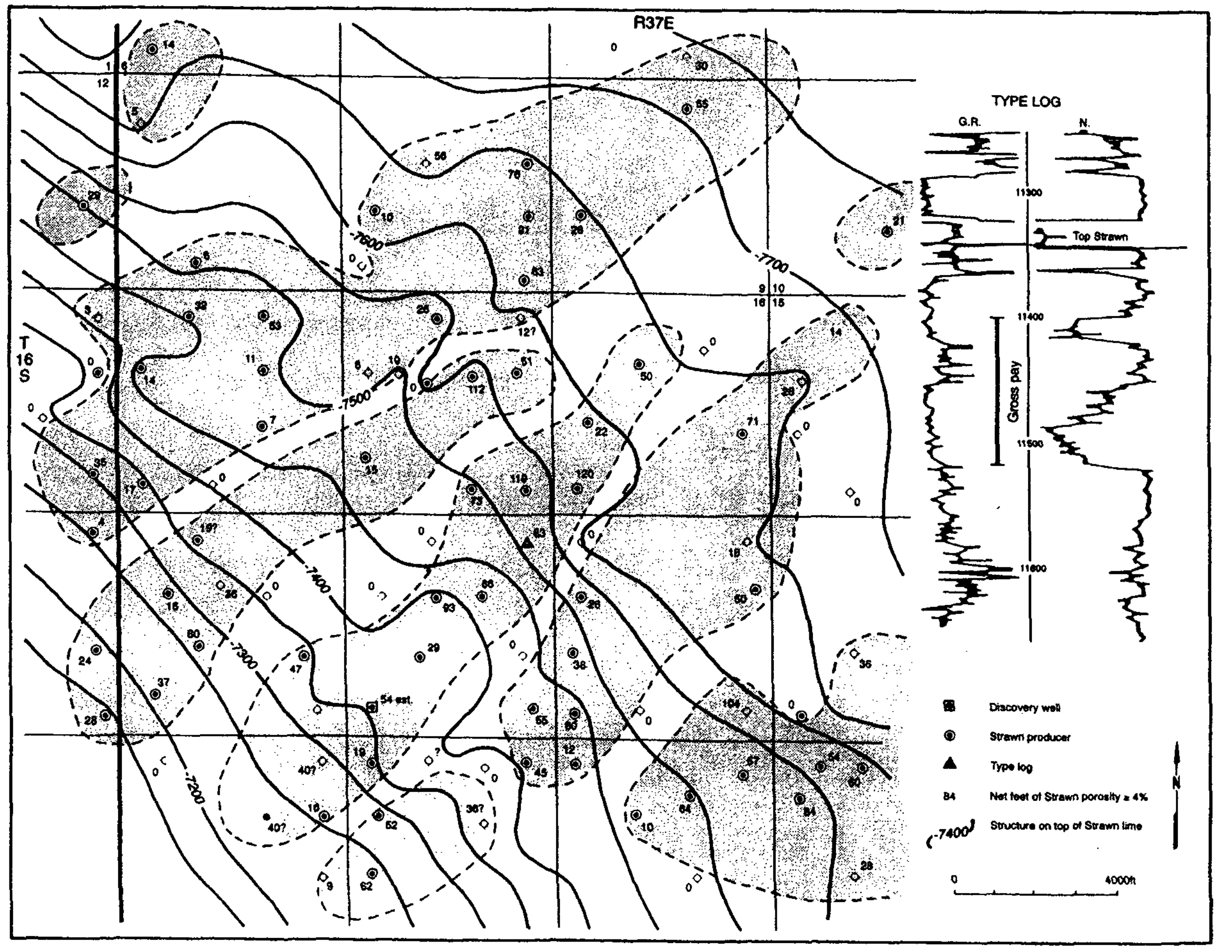


FIGURE PP-2.3—Strawn reservoir map at the Lovington Northeast reservoir. Strawn limestone structure is shown on a 50-ft contour interval with shaded regions where net values of Strawn porosity are greater than or equal to 4%. Note the lenticular and generally linear nature of these biohermal features and their highly variable and erratic net porosity values. Shallow wells are not shown. Modified from Caughey, 1988, and updated through June 1992.

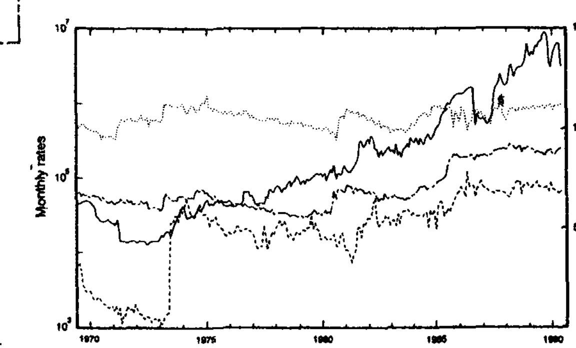


FIGURE PP-2.4—Historical production from the Strawn play. Note the steady increase in number of producing wells since 1976. ···, gas (MCF); — · —, oil (BBLS); ---, water (BBLS); —, wells. From INTERA Bergeson; data source, Dwight's Energydata, Inc.

TABLE PP-2.1—Geologic, engineering, and production data for the Strawn play. Heads explained on last page.

St	County	Reservoir	Ty	Disc	Wells	Aban	Spa	Acres	Depth	Trap	Dri	Lith	DeEn	PostD	Por	Perm	Temp	PrGr	CumBCF	PDR
NM	Lea	Antelope Ridge (Strawn)	N	1981	3	1	320	960	12100	Ant	PD	Lsun	Reeb	Gren	0.07		174	0.390	13.980	1.7
NM	Eddy	Avalon (Strawn)	N	1974	7	1	320	4960	9600	Lpp	PD	Lsun	Reeb	Gren	0.07	0.500	174	0.430	5.070	0.2
NM	Eddy	Big Eddy (Strawn)	K	1966	2	2	160	640	11350	Lpp	SG	Lsun	Reeb	Gren	0.08	100.000	170	0.520	8.140	0.0
NM	Eddy	Burton Flat (Strawn)	N	1973	8	4	320	4480	10225	Lpp	PD	Lsun	Reeb	Gren	0.04		145	0.500	10.970	1.5
NM	Eddy	Burton Flat East (Strawn)	N	1976	14	1	320	3840	10600	Lpp	PD	Lsun	Reeb	Gren	0.05		155	0.450	9.340	
NM	Eddy	Carlsbad (Strawn)	N	1976	6	3	320	4480	10400	Lpp	PD	Lsun	Reeb	Gren	0.04		150	0.560	20.190	4.3
NM	Eddy	Carlsbad South (Strawn)	N	1970	10	1	320	4480	10400	Lpp	PD	Lsun	Reeb	Gren	0.04		165	0.510	31.770	8.1
NM	Eddy	Eagle Creek (Strawn)	N	1977	18	0	320	12240	8050	Lpp	PD	Lsun	Ssun	Gren	0.02		123	0.380	5.180	1.6
NM	Eddy	Golden Lane (Strawn)	N	1967	8	3	320	3840	11200	Lpp	PD	Lsun	Reeb	Gren	0.07		150	0.540	25.360	4.1
NM	Lea	Jal West (Strawn)	N	1963	0	2	640	1920	11600	Lpp	PD	Lsun	Reeb	Gren	0.05		158	0.590	9.300	0.0
NM	Lea	Lovington NE (Penn)	K	1969	53	13	80	8320	11300	Lpp	PD	Lsun	Reeb	Gren	0.09	75.000	180	0.360	19.890	11.7
NM	Eddy, Lea	Lusk (Strawn)	K	1961	23	41	160	10560	11300	Lpp	SG	Lsun	Reeb	Gren	0.05	22.000	160	0.510	88.460	7.2
NM	Lea	Shipp (Strawn)	K	1985	29	1	80	5120	11100	Lpp	PD	Lsun	Reeb	Gren	0.09	55.000	191	0.310	8.840	

PP-3. ATOKA

Stephen W. Speer

Of the 130+ designated reservoirs that produce gas from Atokan age rocks, 23 have produced at least 5 BCF (Table PP-3.1). Cumulative production from these major reservoirs totaled 560.5 BCF through 1990 from 236 wells, 194 of which were still active. All produce nonassociated gas with varying amounts of condensate and are either in the Delaware Basin or near its margin on the Northwest shelf (Fig. PP-3.1). The number of Atoka producers increased dramatically around 1979 (Fig. PP-3.2) when gas demand was high and markets were favorable, although, interestingly, production did not seem to increase in a similar manner. This relationship can most likely be traced to a disproportionately high number of marginal recompletions or development attempts in Atokan zones of limited extent. Reservoirs with limited reserves are common in the Atoka and give a bimodal distribution to its production wherein wells are generally either marginal or extremely prolific in nature. An example of this can be seen at Los Medaños (Atoka) reservoir where, of the five wells now producing, one has accounted for 73%, or 25.60 BCF, of the 34.98 BCF produced thus far.

The majority of Atoka reservoirs are developed in both fluvial-deltaic and prograding strandline (beach and barrier bar) sandstones derived from the Pedernal highlands to the northwest, although a bank of carbonate mounds in south Lea and Eddy counties also contributes significantly to production (Fig. PP-3.3; James, 1985). Trapping is most commonly structural/stratigraphic with reservoirs found at depths ranging from 8,500 ft on the Northwest shelf, to more than 14,000 ft in the Delaware Basin. Many of the deeper reservoirs are significantly overpressured (up to 10,571 psi at a 0.76 pressure gradient), and thereby require additional casing strings and high mud weights to ensure successful drilling operations. Clastic reservoirs commonly consist of multiple, fine- to coarse-grained quartzose sands with net pay thicknesses ranging from 5 to more than 40 ft (Fig. PP-3.4). Although average porosities in these reservoirs range from 2% to as much as 16%, they more commonly average 10% with permeabilities running in the tens of millidarcies. Conversely, the carbonate reservoirs exhibit log porosities averaging only 1 to 7% but are generally described as fine crystalline, fossiliferous limestone exhibiting good vuggular and cavernous porosity (Harvard, 1967). Fracturing most likely contributes significantly to the productivity of these carbonates.

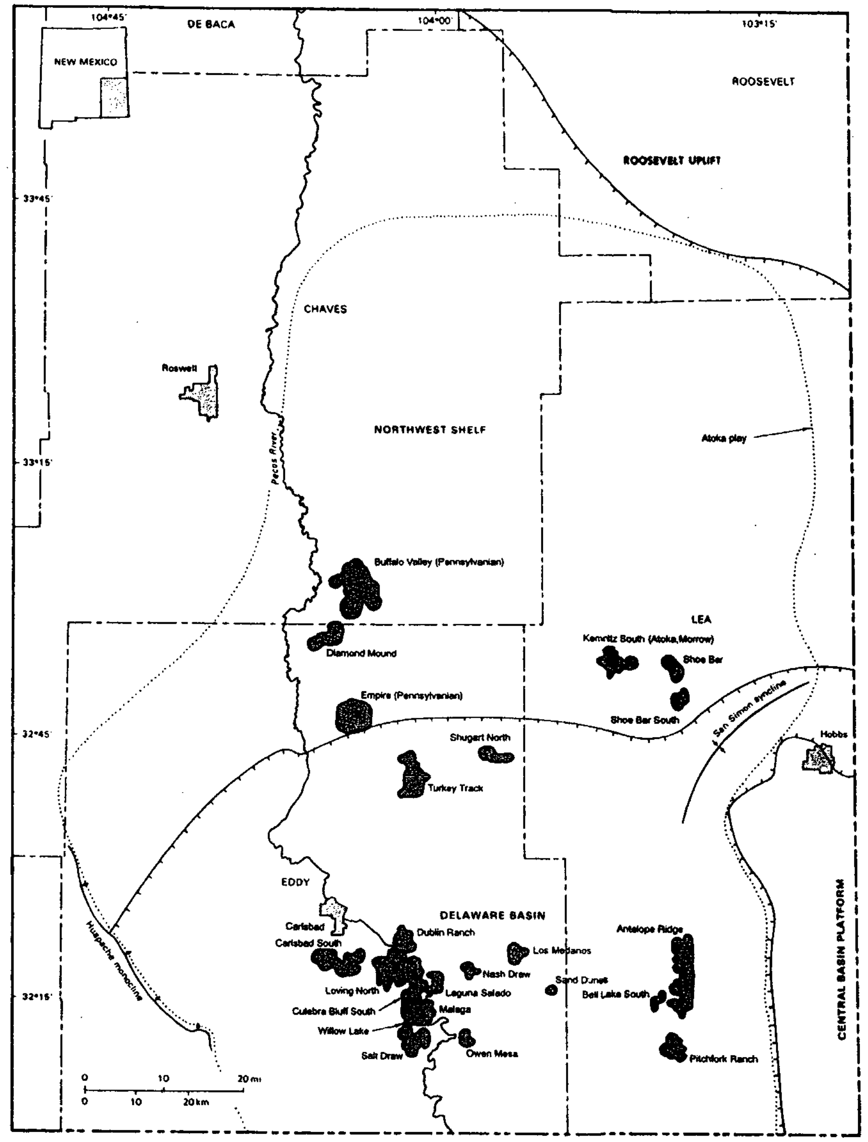


FIGURE PP-3.1—Reservoirs in the Atoka play.

TABLE PP-3.1—Geologic, engineering, and production data for the Atoka play. Heads explained on last page.

St	County	Reservoir	Ty	Disc	Wells	Aban	Spa	Acres	Depth	Trap	Dri	Lith	DeEn	PostD	Por	Perm	Temp	PrGr	CumBCF	PDR
NM	Lea	Antelope Ridge (Atoka)	N	1966	23	5	320	9600	12240	Spm	PD	Lsun	Sbmo	Gren	0.05	22.000	174	0.480	72.180	20.4
NM	Lea	Bell Lake South (Atoka)	N	1974	1	2	320	960	12475	Spm	PD	Lsun	Sbmo	Madi	0.06		178	0.500	13.150	0.0
NM	Chaves	Buffalo Valley (Penn)	N	1962	36	9	320	14400	8500	Lpp	PD	Sand	Defd	Coce	0.12		135	0.400	104.970	38.8
NM	Eddy	Carlsbad South (Atoka)	N	1969	9	3	320	5760	10900	Spm	PD	Sand	Spun	Coce	0.05		158	0.460	9.650	0.6
NM	Eddy	Culebra Bluff South (Atoka)	N	1979	14	5	320	6720	11550	Spm	PD	Sand	Spun	Coce	0.15		216	0.680	48.760	8.8
NM	Eddy	Diamond Mound (Atoka)	N	1977	2	2	320	3700	8500	Spm	PD	Sand	Defd	Coce	0.13		129	0.370	5.360	1.2
NM	Eddy	Dublin Ranch (Atoka)	N	1979	10	0	320	3520	11500	Spm	PD	Sand	Spun	Coce	0.08		198	0.510	16.130	0.6
NM	Eddy	Empire (Penn)	N	1953	5	1	320	8000	10200	Lpp	PD	Sand	Spun	Coce	0.09		161	0.300	33.180	0.0
NM	Lea	Kemnitz S (Atoka Morrow)	N	1979	10	0	320	4320	12560	Spm	PD	Sand	Spun	Coce	0.10	10.000	172	0.520	43.020	7.2
NM	Eddy	Laguna Salado (Atoka)	N	1979	4	0	320	2240	12050	Lpp	PD	Lsun	Sbmo	Gren	0.01		208	0.440	6.940	4.7
NM	Eddy	Los Medanos (Atoka)	N	1959	5	0	320	1600	12920	Spm	PD	Sand	Spun	Coce	0.02		176		34.980	3.9
NM	Eddy	Loving North (Atoka)	N	1982	11	3	320	7680	11450	Spm	PD	Sand	Spun	Coce	0.09		198	0.670	22.020	2.4
NM	Eddy	Malaga (Atoka)	N	1979	14	3	320	6560	11510	Lpp	PD	Sand	Spun	Coce	0.09		195	0.680	29.440	
NM	Eddy	Nash Draw (Atoka)	N	1976	2	0	320	960	12400	Lpp	PD	Lsun	Sbmo	Gren	0.03		180	0.510	5.980	1.0
NM	Eddy	Owen Mesa (Atoka)	N	1983	3	0	320	1120	12725	Spm	PD	Sand	Spun	Coce	0.06		190	0.580	8.060	8.6
NM	Lea	Pitchfork Ranch (Atoka)	N	1983	9	1	320	3360	13925	Spm	PD	Sand	Spun	Coce	0.16		176	0.760	21.790	24.4
NM	Eddy	Salt Draw (Atoka)	N	1983	6	1	320	3840	12050	Spm	PD	Sand	Spun	Coce	0.10		187	0.750	5.820	5.0
NM	Eddy	Sand Dunes (Atoka)	N	1970	2	1	640	640	13670	Spm	PD	Lsun	Sbmo	Gren	0.07		181	0.710	17.890	8.2
NM	Lea	Shoe Bar (Atoka)	N	1955	4	1	320	1760	12475	Spm	PD	Sand	Spun	Coce	0.10		187	0.500	14.790	3.3
NM	Lea	Shoe Bar South (Atoka)	N	1984	6	0	320	1440	12000	Spm	PD	Sand	Spun	Coce	0.10		158	0.450	8.550	0.7
NM	Eddy	Shugart North (Atoka)	N	1977	6	0	320	1920	11100	Spm	PD	Sand	Spun	Coce	0.12		164	0.430	9.670	0.4
NM	Eddy	Turkey Track (Atoka)	N	1980	10	5	320	6400	10800	Lpp	PD	Sand	Spun	Coce	0.09		160	0.470	18.010	
NM	Eddy	Willow Lake (Atoka)	N	1976	2	0	320	320	11725	Spm	PD	Sand	Spun	Coce	0.12		185	0.620	10.210	6.8

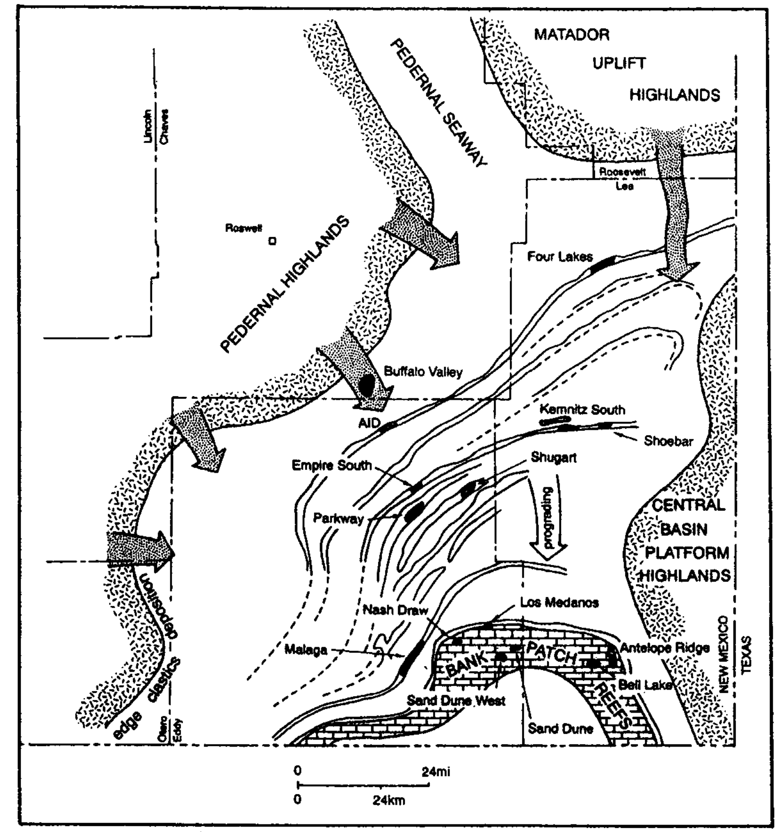


FIGURE PP-3.3—Schematic paleogeographic map of southeast New Mexico during Atokan time with various interpreted progradational strandlines and their resultant sand trends. Several significant gas reservoirs are superimposed. Modified from James, 1985.

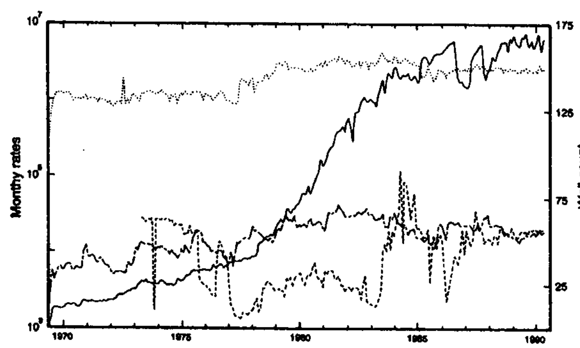


FIGURE PP-3.2—Historical production from the Atoka play. ···, gas (MCF); — - —, oil (BBLS); ---, water (BBLS); —, wells. From INTERA Bergeson; data source, Dwight's Energydata, Inc.

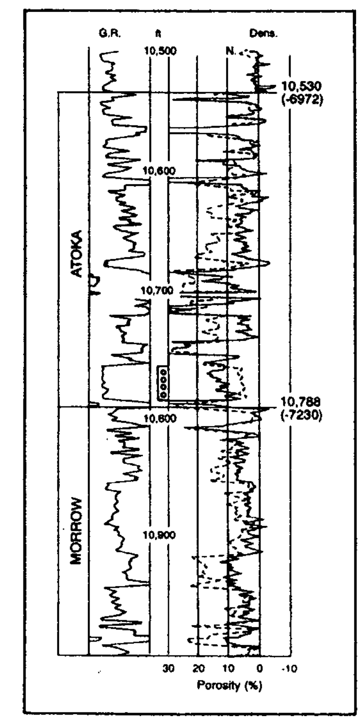


FIGURE PP-3.4—Neutron-density log of Atoka/Morrow section in the Southland Royalty #1 Empire "A" well in the NW¼ sec. 27 T18S R29E, Turkey Track Atoka reservoir, Eddy County, New Mexico. A 30-ft Atoka sand was perforated from 10,752 ft to 10,778 ft and completed for 2.51 MMCFD. Cumulative production for this well through December 1990 is 3.31 BCFG, 31,000 BC, and 891 BW. Modified from James, 1985.

PP-4. MORROW

Stephen W. Speer

The Morrow Formation has produced more than 3 TCF of nonassociated gas from 1,700+ wells in more than 220 designated reservoirs in southeast New Mexico. Of this total, 2.929 TCF comes from the 85 reservoirs (containing 1,374 wells) that have produced at least 5 BCF of gas (Table PP-4.1; Fig. PP-4.1). Field development has consolidated many reservoirs into several large contiguous areas of development. More than 20 MMB of 45° to 60°+ condensate have also been produced from this play even though the Morrow is generally considered a dry gas play having BTU values generally less than 1100 and gas-oil ratios ranging into the hundreds of thousands. The quality and abundance of this large gas reserve base led many operators to actively explore and exploit it during the boom times of the 1970s and early 1980s when peak production reached more than 15 BCF/month (Fig. PP-4.2). However, because of the inherent high risk and high costs of developing this deep play (typically from 8,500 to more than 15,000 ft deep), the dramatic decrease in oil and gas prices that befell the industry in 1986 significantly curtailed continued play development.

Stratigraphically, the Morrow Formation in southeast New Mexico unconformably overlies Mississippian limestones and can be subdivided into three distinct intervals commonly designated as either the lower, middle, and upper Morrow, or the "A," "B," and "C" Morrow zones (Fig. PP-4.3). The lower and middle Morrow intervals are primarily clastic in composition and are by far the dominant Morrow producing horizons, whereas the upper Morrow is principally composed of transgressive, oolitic limestones interbedded with thin shales and minor sandstones (Anderson, 1976; James, 1985; Mazzullo and Mazzullo, 1984). The composite thickness of the lower and middle Morrow intervals reaches as much as 1,700 ft in deeper parts of the basin and reflects the maximum progradational episode of Pennsylvanian clastic input into the basin from the surrounding Pedernal highlands to the north and west and the Central Basin highlands to the east (Figs. PP-4.4, PP-4.5). Subsequent upper Morrow sediments record a major marine inundation of this clastic wedge prior to Atokan time (James, 1985; Mazzullo and Mazzullo,1985) wherein areas on or immediately adjacent to the source areas received little to no Morrow sedimentation. Depositionally, the lower and middle Morrow intervals represent a diachronous, cyclically interbedded, fluvial-deltaic to basinal marine facies tract (Figs. PP-4.4, 4.5; Anderson, 1976; James, 1985; Mazzullo and Mazzullo, 1984). Production is found in depositional environments ranging from proximal distributary channel and point bar deposits to mid-tract channel mouth bar, beach, and delta front shelf sands (Fig. PP-4.6), on out to distal submarine fan deposits found off the edge of the delta platform in prodelta slope settings (Martin et al, 1986).

Productive lower Morrow reservoirs are typically characterized as straight and elongate, very coarse to medium-grained, angular to subangular quartzose sands oriented perpendicular to Morrow sediment source areas (Figs. PP-4.5, PP-4.7, PP-4.8, PP-4.9). They can be as much as 60 to 80+ ft thick with porosity ranging from 8 to 14% and are broadly interpreted as distributary channels that were the source of fluvially dominated lower Morrow deltas. These channel sands, together with their associated point bar and channel mouth bar deposits, can be extremely prolific and many times produce upwards of 10 to 20 BCF/well. Trapping is generally achieved through a combination of depositional, structural, and/or diagenetic factors, with cementation by either silica, carbonate, or clay commonly playing a significant role by occluding all porosity in these otherwise continuous, elongate sands (Anderson, 1976; James, 1985; Mazzullo and Mazzullo, 1985; Lambert and Berg, 1986). Authigenic and detrital clay (primarily kaolinite, chlorite, and lesser amounts of illite) are present in both lower and middle Morrow sands and can pose serious problems regarding well productivity if not addressed during drilling and completion programs (Mazzullo and Mazzullo, 1985).

As a whole, middle Morrow sands are individually thinner and more numerous than those found in the lower Morrow and map out not only as occasional dip-elongate distributary channels, but more often as broadly lobate delta front and strike-elongate beach accumulations (Figs. PP-4.8, PP-4.9). This pattern of deposition suggests multiple alternating periods of middle Morrow transgression and regression (Mazzullo and Mazzullo, 1984) and possibly a more wave-dominated delta setting affecting the sand distribution and deposition. Although porosity also ranges from 8 to 14% in these reservoirs, they are commonly finer grained and more glauconitic than those in the lower Morrow (James, 1985). Trapping, and hence gas production, is primarily controlled by a combination of both depositional and cementation patterns, with structure not playing nearly as significant a role as it does in the lower Morrow (Anderson, 1976; James, 1985).

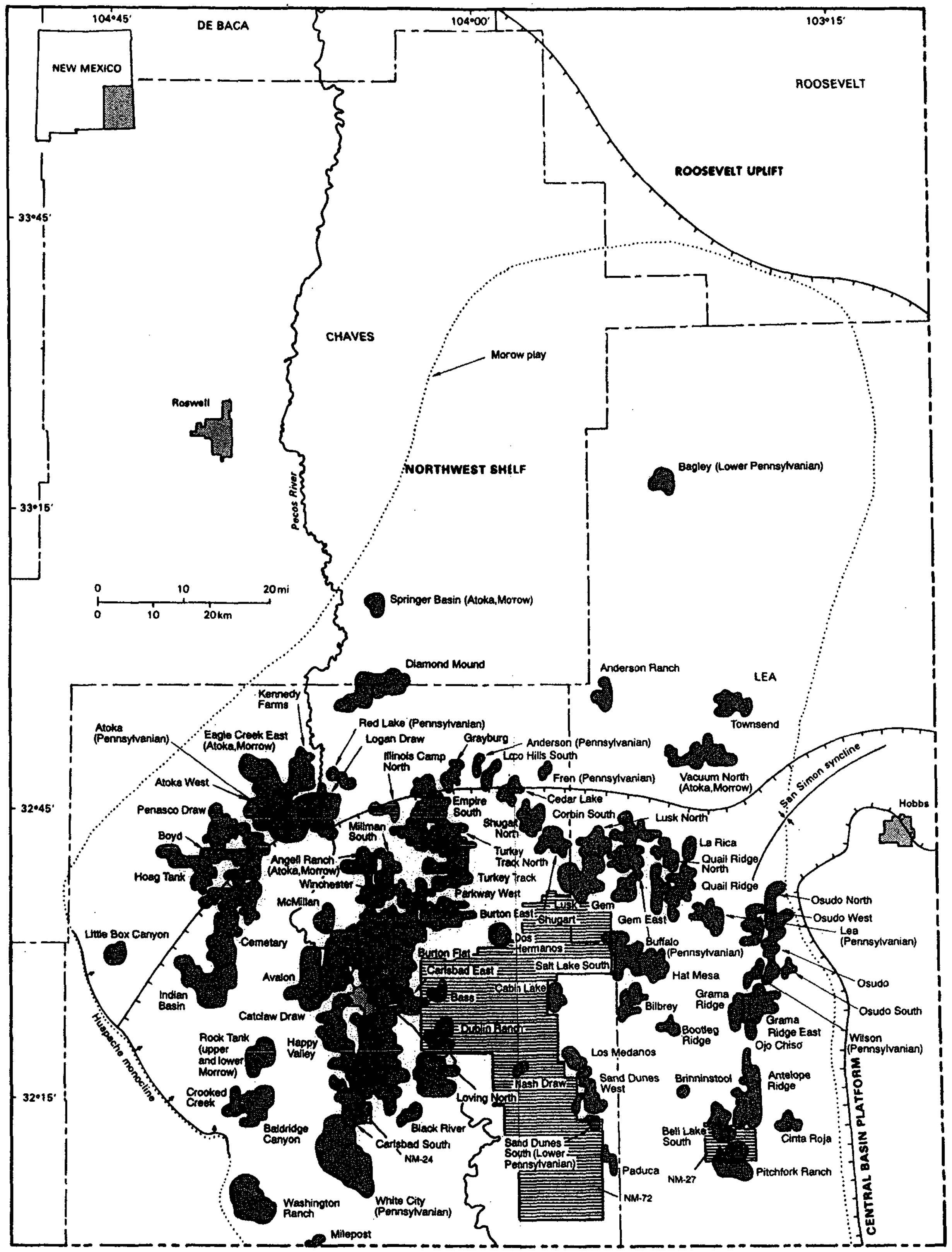


FIGURE PP-4.1—Reservoirs in the Morrow play and FERC-designated tight formation areas. All reservoirs produce from the Morrow only unless otherwise indicated.

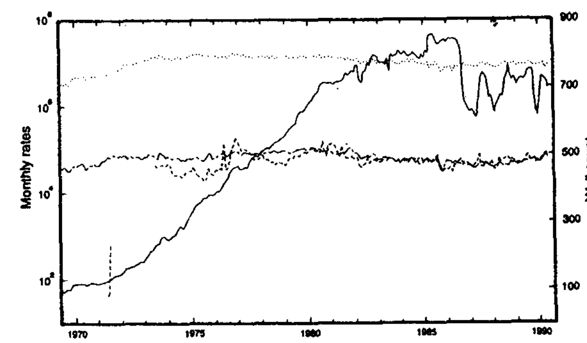


FIGURE PP-4.2—Historical production from the Morrow play. ···, gas (MCF); — · —, oil (BBLS); ---, water (BBLS); —, wells. From INTERA Bergeson; data source, Dwight's Energydata, Inc.

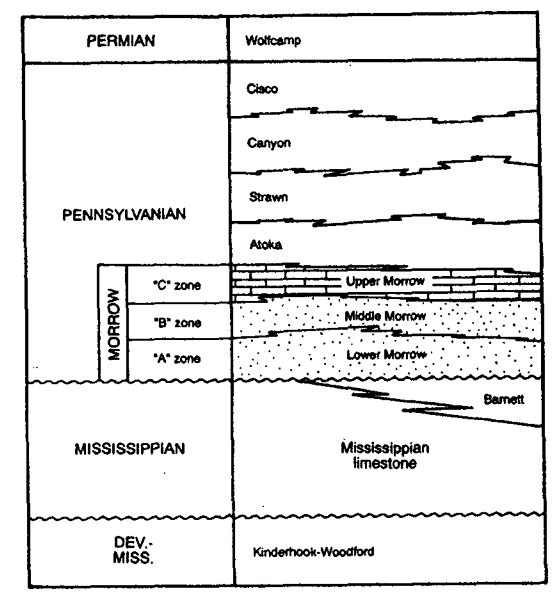


FIGURE PP-4.3—Generalized stratigraphic column of southeast New Mexico with commonly recognized Morrow subdivisions and nomenclature. Modified from Mazzullo and Mazzullo, 1985.

Several areas in southeast New Mexico have been delineated by the FERC as tight formation for Morrow production (Fig. PP-4.1). This designation qualifies affected Morrow gas for economic incentives and is due to the formation's combination of extreme depth and relatively low average reservoir permeability (and hence deliverability). Although standard Morrow completions generally require only a small acid cleanup job, many wells need additional fracture stimulation treatments to achieve acceptable economic production rates. Consequently, it is imperative for prudent operators to give serious and realistic consideration to economic factors when developing Morrow gas reserves. Although prices and demand have been relatively weak and/or unstable as of late, it is certain that when they become firmer, more Morrow gas will be developed.

TABLE PP-4.1—Geologic, engineering, and production data for the Morrow play. Heads explained on last page.

St	County	Reservoir	Ty	Disc	Wells	Aban	Spa	Acres	Depth	Trap	Dri	Lith	DeEn	PostD	Por	Perm	Temp	PrGr	CumBCF	PDR
NM	Eddy	Anderson (Penn)	N	1954	3	0	160	800	11050	Lpp	PD	Sand	Deun	Coce	0.09		142	0.45	18.410	
NM	Lea	Anderson Ranch (Morrow)	N	1968	2	2	160	2640	12200	Spm	PD	Sand	Defd	Coce			169	0.48	9.100	
NM	Eddy	Angell Ranch (Atoka Morrow)	N	1976	12	7	320	4160	10900	Spm	PD	Sand	Defd	Coce	0.12		165	0.31	11.740	
NM	Lea	Antelope Ridge (Morrow)	N	1963	16	8	320	9120	12900	Spm	PD	Sand	Deun	Coce	0.11	40.000	170	0.35	94.000	11.6
NM	Eddy	Atoka (Penn)	N	1957	21	14	320	11120	9100	Spm	PD	Sand	Deun	Coce	0.11	35.000	158	0.42	148.470	5.0
NM	Eddy	Atoka West (Morrow)	N	1970	15	5	320	8640	8800	Spm	PD	Sand	Defd	Coce	0.12		133	0.42	53.640	
NM	Eddy	Avalon (Morrow)	N	1974	18	10	320	7680	10550	Spm	PD	Sand	Deun	Coce	0.06	0.130	180	0.44	41.770	
NM	Lea	Bagley (Lower Penn)	N	1955	2	4	320	2280	9775	Spm	PD	Sand	Defd	Coce			149	0.32	11.320	0.1
NM	Eddy	Baldridge Canyon (Morrow)	N	1978	10	7	320	7040	11000	Cou	PD	Sand	Deun	Coce	0.08		172	0.39	24.970	
NM	Eddy	Bass (Morrow)	N	1975	2	2	320	1600	11750	Spm	PD	Sand	Deun	Coce	0.12		170	0.44	8.880	2.0
NM	Lea	Bell Lake South (Morrow)	N	1958	5	6	320	4160	14400	Spm	PD	Sand	Deun	Coce	0.05		187	0.62	71.450	
NM	Lea	Bilbrey (Morrow)	N	1981	4	0	320	3520	14250	Lpp	PD	Sand	Deun	Coce	0.09		183	0.47	6.190	
NM	Eddy	Black River (Morrow)	N	1981	4	1	320	1920	12250	Spm	PD	Sand	Deun	Coce	0.08		191	0.44	12.780	7.8
NM	Lea	Bootleg Ridge (Morrow)	N	1981	5	0	320	1440	14700	Lpp	PD	Sand	Deun	Coce	0.12		204	0.53	5.760	4.7
NM	Eddy	Boyd (Morrow)	N	1969	28	6	320	11200	9050	Spm	PD	Sand	Defd	Coce	0.07		151	0.41	35.240	3.3
NM	Lea	Brininstool (Morrow)	N	1975	2	1	320	640	15600	Spm	PD	Sand	Deun	Coce	0.04		208	0.58	5.620	
NM	Lea	Buffalo (Penn)	N	1958	5	13	320	5120	13200	Lpp	PD	Sand	Deun	Coce	0.08		175	0.48	15.620	1.0
NM	Eddy	Burton Flat (Morrow)	N	1973	78	32	320	40960	11000	Spm	PD	Sand	Defd	Coce	0.08	2.030	189	0.43	199.980	32.4
NM	Eddy	Burton Flat East (Morrow)	N	1974	12	13	320	8320	11400	Spm	PD	Sand	Defd	Coce	0.08		190	0.42	22.270	
NM	Eddy	Cabin Lake (Morrow)	N	1973	1	3	320	2240	13000	Spm	PD	Sand	Defd	Coce	0.11		190	0.46	5.550	
NM	Eddy	Carlsbad East (Morrow)	N	1974	7	3	320	2880	11500	Spm	PD	Sand	Deun	Coce	0.08		155	0.33	6.620	1.5
NM	Eddy	Carlsbad South (Morrow)	N	1969	64	41	320	39360	11200	Spm	PD	Sand	Deun	Coce	0.11		183	0.45	231.920	12.9
NM	Eddy	Catclaw Draw (Morrow)	N	1971	20	9	640	16320	10200	Spm	PD	Sand	Deun	Coce	0.13		178	0.43	83.810	4.7
NM	Eddy	Cedar Lake (Morrow)	N	1962	2	3	320	2880	11400	Spm	PD	Sand	Deun	Coce	0.10		171	0.32	7.510	
NM	Eddy	Cemetary (Morrow)	N	1964	38	12	320	20160	9350	Spm	PD	Sand	Deun	Coce	0.13	35.000	208	0.41	83.060	
NM	Lea	Cinta Roja (Morrow)	N	1964	4	0	640	2080	14000	Spm	PD	Sand	Defd	Coce	0.09		180	0.57	18.630	
NM	Lea	Corbin South (Morrow)	N	1965	4	8	320	4640	13200	Spm	PD	Sand	Deun	Coce	0.10	2.700	190	0.36	26.640	1.1
NM	Eddy	Crooked Creek (Morrow)	N	1974	8	2	320	2560	9900	Spm	PD	Sand	Defd	Coce	0.07		162	0.44	13.700	
NM	Eddy, Chaves	Diamond Mound (Morrow)	N	1979	25	4	320	10880	9000	Spm	PD	Sand	Defd	Coce	0.10		142	0.28	39.860	12.4
NM	Eddy	Dos Hermanos (Morrow)	N	1965	1	3	640	2560	12300	Spm	PD	Sand	Deun	Coce	0.09		168	0.40	12.730	
NM	Eddy	Dublin Ranch (Morrow)	N	1978	7	4	320	4480	12300	Spm	PD	Sand	Defd	Coce	0.14		190	0.35	11.360	2.9
NM	Eddy	Eagle Creek E (Atoka Mrrw)	N	1975	17	5	320	7680	8250	Spm	PD	Sand	Deun	Coce	0.11		130	0.34	25.130	4.0
NM	Eddy	Empire South (Morrow)	N	1971	31	8	320	12800	10750	Spm	PD	Sand	Defd	Coce	0.12		163	0.38	122.110	15.2
NM	Eddy	Fren (Penn)	N	1954	1	2	160	640	11150	Lpp	PD	Sand	Deun	Coce	0.08		147	0.44	6.470	
NM	Lea	Gem (Morrow)	N	1979	9	2	320	3680	13375	Spm	PD	Sand	Deun	Coce	0.14		165	0.31	9.530	12.9
NM	Lea	Gem East (Morrow)	N	1979	7	2	320	3840	13375	Spm	PD	Sand	Deun	Coce	0.11		158	0.35	6.100	
NM	Lea	Grama Ridge (Morrow)	N	1965	8	0	320	2880	12825	Spm	PD	Sand	Defd	Coce	0.13		158	0.60	23.840	
NM	Lea	Grama Ridge East (Morrow)	N	1979	20	2	320	6400	12750	Spm	PD	Sand	Defd	Coce	0.15		174	0.57	62.070	26.0
NM	Eddy	Grayburg (Morrow)	N	1957	3	5	320	3040	10700	Spm	PD	Sand	Deun	Coce	0.08		162	0.43	33.770	
NM	Eddy	Happy Valley (Morrow)	N	1973	13	5	320	7680	11150	Spm	PD	Sand	Deun	Coce	0.15		180	0.44	18.720	13.2
NM	Lea	Hat Mesa (Morrow)	N	1968	12	2	320	5120	13800	Spm	PD	Sand	Deun	Coce	0.08		184	0.52	30.150	2.9
NM	Eddy	Hoag Tank (Morrow)	N	1975	10	3	320	7680	8850	Spm	PD	Sand	Defd	Coce	0.09		159	0.38	6.620	
NM	Eddy	Illinois Camp N (Morrow)	N	1980	6	0	320	1920	10150	Spm	PD	Sand	Deun	Coce	0.08		155	0.43	7.180	
NM	Eddy	Indian Basin (Morrow)	N	1963	15	2	640	11840	9400	Spm	PD	Sand	Deun	Coce	0.07		137	0.41	35.180	
NM	Eddy	Kennedy Farms (Morrow)	N	1974	12	5	320	6720	8500	Spm	PD	Sand	Deun	Coce	0.08		126	0.41	14.810	1.9
NM	Lea	La Rica (Morrow)	N	1970	2	0	640	1280	13400	Spm	PD	Sand	Deun	Coce	0.10		209	0.49	26.220	1.3
NM	Lea	Lea (Penn)	N	1961	11	17	160	4320	13100	Spm	PD	Sand	Deun	Coce	0.12		168	0.55	46.430	3.4
NM	Eddy	Little Box Canyon (Morrow)	N	1975	3	3	320	2400	8050	Spm	PD	Sand	Deun	Coce	0.11		136	0.38	8.610	1.9
NM	Eddy	Loco Hills South (Morrow)	N	1973	3	0	320	1920	11150	Spm	PD	Sand	Deun	Coce	0.08		175	0.39	7.850	1.1
NM	Eddy	Logan Draw (Morrow)	N	1969	6	1	320	1920	9050	Spm	PD	Sand	Deun	Coce	0.07		150	0.32	17.790	
NM	Eddy	Los Medanos (Morrow)	N	1972	4	1	320	2240	14000	Spm	PD	Sand	Deun	Coce	0.08		215	0.35	13.440	
NM	Eddy	Loving North (Morrow)	N	1979	15	7	320	10560	12100	Spm	PD	Sand	Defd	Coce	0.08		192	0.46	19.820	4.2
NM	Eddy, Lea	Lusk (Morrow)	N	1961	9	11	640	10240	12400	Spm	PD	Sand	Defd	Coce	0.09		150	0.42	28.110	1.7
NM	Lea	Lusk North (Morrow)	N	1976	4	10	320	4800	12600	Spm	PD	Sand	Defd	Coce	0.10		164	0.45	13.260	
NM	Eddy	McMillan (Morrow)	N	1964	2	4	640	3200	10300	Spm	PD	Sand	Deun	Coce	0.09		160	0.32	11.700	0.1
NM	Eddy	Milepost (Morrow)	N	1980	1	1	320	640	10200	Spm	PD	Sand	Deun	Coce	0.05		180	0.37	6.990	
NM	Eddy	Millman South (Morrow)	N	1977	11	1	320	4480	10900	Spm	PD	Sand	Deun	Coce	0.09		159	0.41	9.700	
NM	Eddy	Nash Draw (Morrow)	N	1975	1	2	320	960	13500	Spm	PD	Sand	Deun	Coce	0.10		188	0.43	6.240	
NM	Lea	Ojo Chiso (Morrow)	N	1974	5	2	320	1280	12750	Spm	PD	Sand	Deun	Coce	0.12		172	0.45	9.670	
NM	Lea	Osudo (Morrow)	N	1965	3	4	320	4480	11350	Spm	PD	Sand	Deun	Coce	0.08		165	0.61	34.550	4.4
NM	Lea	Osudo North (Morrow)	N	1965	7	8	640	4800	11400	Spm	PD	Sand	Defd	Coce	0.12		165	0.58	40.290	3.6
NM	Lea	Osudo South (Morrow)	N	1967	2	1	320	960	12000	Spm	PD	Sand	Deun	Coce	0.08		182	0.61	7.340	0.2
NM	Lea	Osudo West (Morrow)	N	1969	9	4	320	3520	13000	Spm	PD	Sand	Deun	Coce	0.08		172	0.50	11.630	4.0
NM	Eddy	Paduca (Morrow)	N	1967	1	2	320	1280	14800	Spm	PD	Sand	Deun	Coce	0.10		180	0.57	38.230	3.9
NM	Eddy	Parkway West (Morrow)	N	1974	7	0	320	2560	11150	Spm	PD	Sand	Deun	Coce	0.09		183	0.30	9.650	2.3
NM	Eddy	Penasco Draw (Morrow)	N	1976	11	4	320	6080	8600	Lpp	PD	Sand	Defd	Coce	0.11		149	0.09	21.390	2.8
NM	Lea	Pitchfork Ranch (Morrow)	N	1982	27	2	320	7840	14900	Spm	PD	Sand	Defd	Coce	0.08		196	0.62	128.540	
NM	Lea	Quail Ridge (Morrow)	N	1962	14	3	320	4800	13300	Spm	PD	Sand	Deun	Coce	0.08		161	0.49	30.230	
NM	Lea	Quail Ridge North (Morrow)	N	1962	7	1	320	3040	13400	Spm	PD	Sand	Deun	Coce	0.07		161	0.51	5.180	
NM	Eddy	Red Lake (Penn)	N	1956	5	10	320	5600	9600	Lpp	PD	Sand	Deun	Coce	0.12		149	0.30	54.660	1.1
NM	Eddy	Rock Tank (Lower Morrow)	N	1968	3	5	640	5760	9800	Cou	PD	Sand	Deun	Coce	0.08	324.000	170	0.42	48.030	1.5
NM	Eddy	Rock Tank (Upper Morrow)	N	1968	3	3	640	5760	9600	Cou	PD	Sand	Deun	Coce	0.08	324.000	170	0.42	10.040	0.6
NM	Lea	Salt Lake South (Morrow)	N	1958	13	8	320	7200	13300	Spm	PD	Sand	Deun	Coce	0.07		178	0.49	47.610	8.8
NM	Eddy	Sand Dunes S (Lower Penn)	N	1972	4	1	320	3200	15000	Spm	PD	Sand	Deun	Coce	0.07		195	0.43	8.110	
NM	Eddy	Sand Dunes West (Morrow)	N	1973	6	1	320	3200	14400	Spm	PD	Sand	Deun	Coce	0.08		215	0.50	10.710	
NM	Eddy	Shugart (Morrow)	N	1958	6	6	160	4160	10950	Spm	PD	Sand	Defd	Coce	0.08		157	0.44	19.190	
NM	Eddy	Shugart North (Morrow)	N	1977	6	5	320	4160	11600	Spm	PD	Sand	Defd	Coce	0.10		165	0.43	10.150	
NM	Chaves	Springer Basin (Atoka Mrrw)	N	1979	7	0	320	1600	8050	Spm	PD	Sand	Defd	Coce	0.13		145	0.38	5.510	6.4
NM	Lea	Townsend (Morrow)	N	1969	6	4	320	4160	11800	Spm	PD	Sand	Deun	Coce	0.12		174	0.53	32.660	6.1
NM	Eddy	Turkey Track (Morrow)	N	1974	18	7	320	7360	11200	Lpp	PD	Sand	Defd	Coce	0.08		165	0.40	28.870	
NM	Eddy	Turkey Track North (Morrow)	N	1976	24	9	320	12800	11000	Spm	PD	Sand	Deun	Coce	0.10		160	0.41	38.610	
NM	Lea	Vacuum North (Atoka Mrrw)	N	1966	13	2	320	7360	12000	Spm	PD	Sand	Deun	Coce	0.12		181	0.48	105.060	
NM	Eddy	Washington Ranch (Morrow)	N	1971	26	3	320	12640	6800	Spm	PD	Sand	Deun	Coce	0.10		148	0.44	56.160	
NM	Eddy	White City (Penn)	N	1960	41	1	640	17280	10500	Spm	PD	Sand	Deun	Coce	0.12		183	0.34	137.800	22.5
NM	Lea	Wilson (Penn)	N	1963	0	2	320	1280	12150	Spm	PD	Sand	Deun	Coce	0.11	4.000	158	0.58	5.700	
NM	Eddy	Winchester (Morrow)	N	1972	8	9	320	6400	11200	Spm	PD	Sand	Deun	Coce	0.08		195	0.45	17.300	1.0

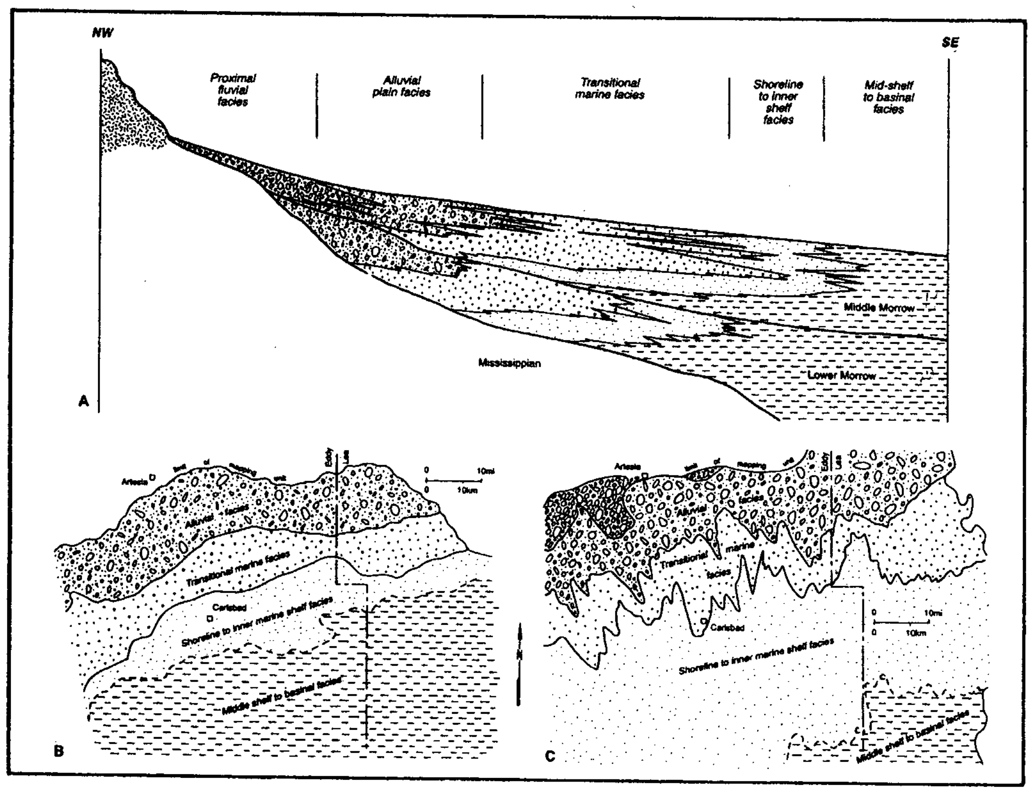


FIGURE PP-4.4—A, Schematic regional cross section in Eddy and west Lea Counties showing cyclic progradational/transgressive clastic facies tracts and patterns in both the lower and middle Morrow intervals. These facies tracts are mapped in B for the lower Morrow and in C for the middle Morrow. Modified from Mazzullo and Mazzullo, 1985.

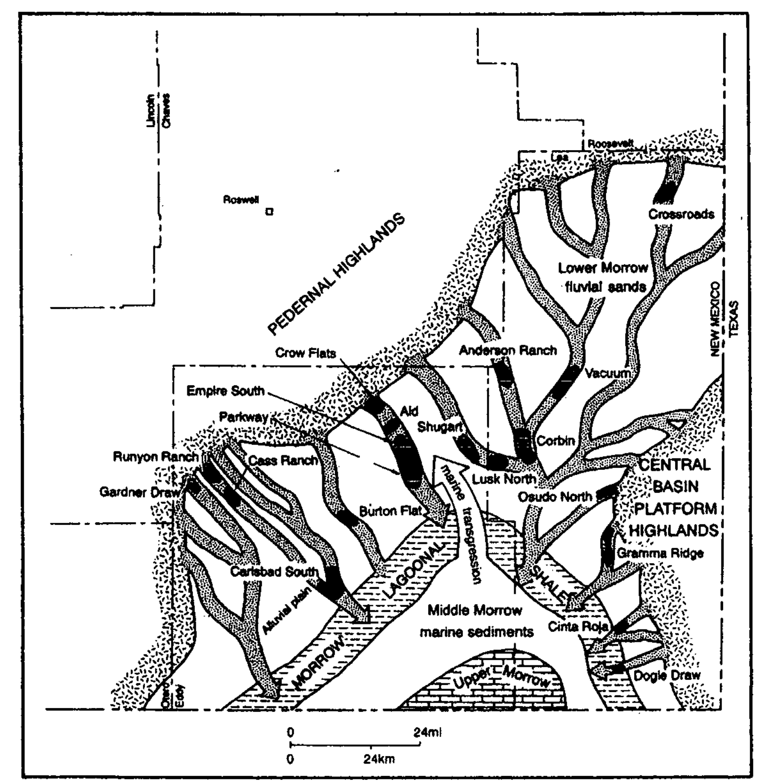


FIGURE PP-4.5—Schematic paleogeographic map of southeast New Mexico with interpreted clastic depositional axes and related facies patterns during early Morrowan time. Several Morrow reservoirs have been superimposed. Modified from James, 1985.

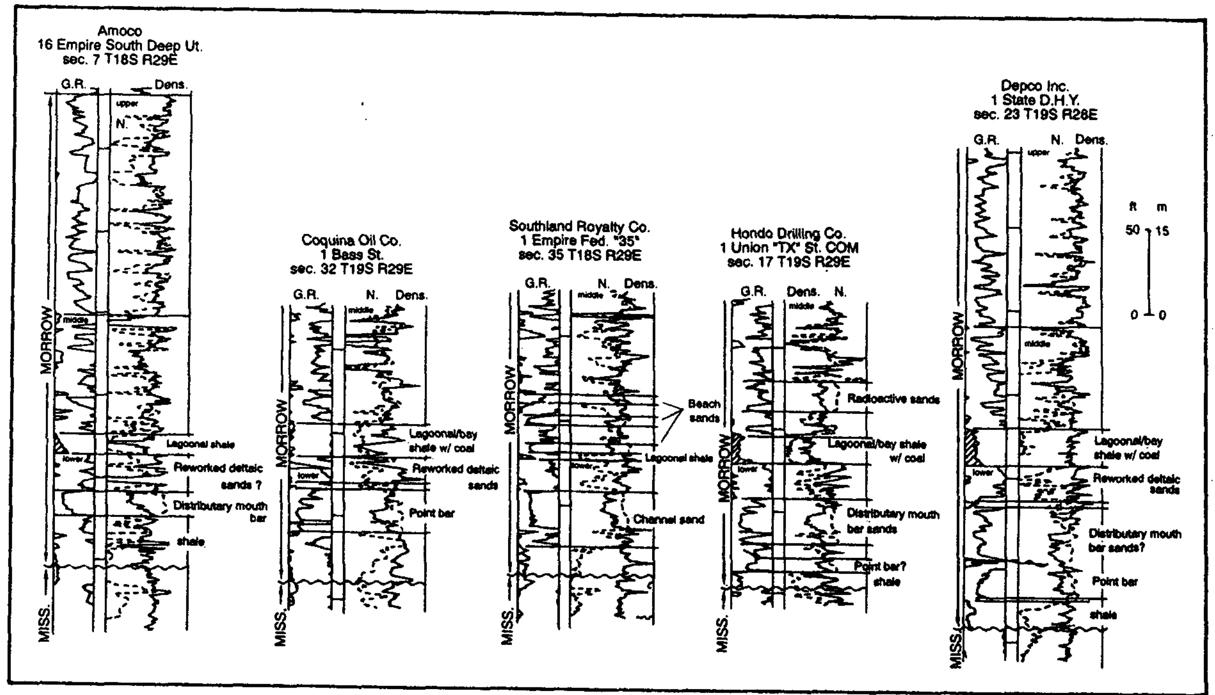


FIGURE PP-4.6—Various neutron-density porosity log sections from the Parkway–Empire South area with common sandstone log responses and their interpreted environments of deposition. Modified from James, 1985.

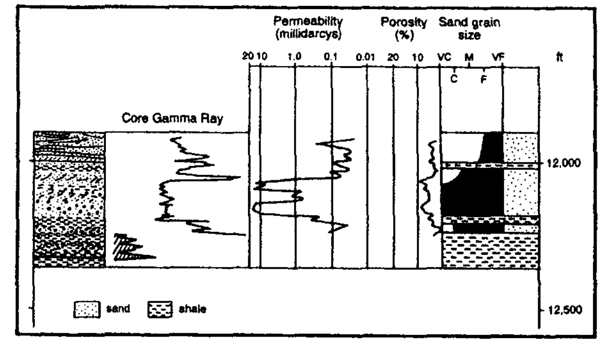


FIGURE PP-4.7—Core and log data from the Southland Royalty #1 Empire Federal 22 well in the SW¼ sec. 22 T18S R29E, Turkey Track North reservoir area, Eddy County, New Mexico. Modified from James, 1985.

FIGURE PP-4.9—Carlsbad South reservoir area. A, Structure on top of the lower Morrow; B, lower Morrow net sandstone isopach; and C, middle Morrow net sandstone isopach. Well data is current only through 1976. Modified from Anderson, 1976.

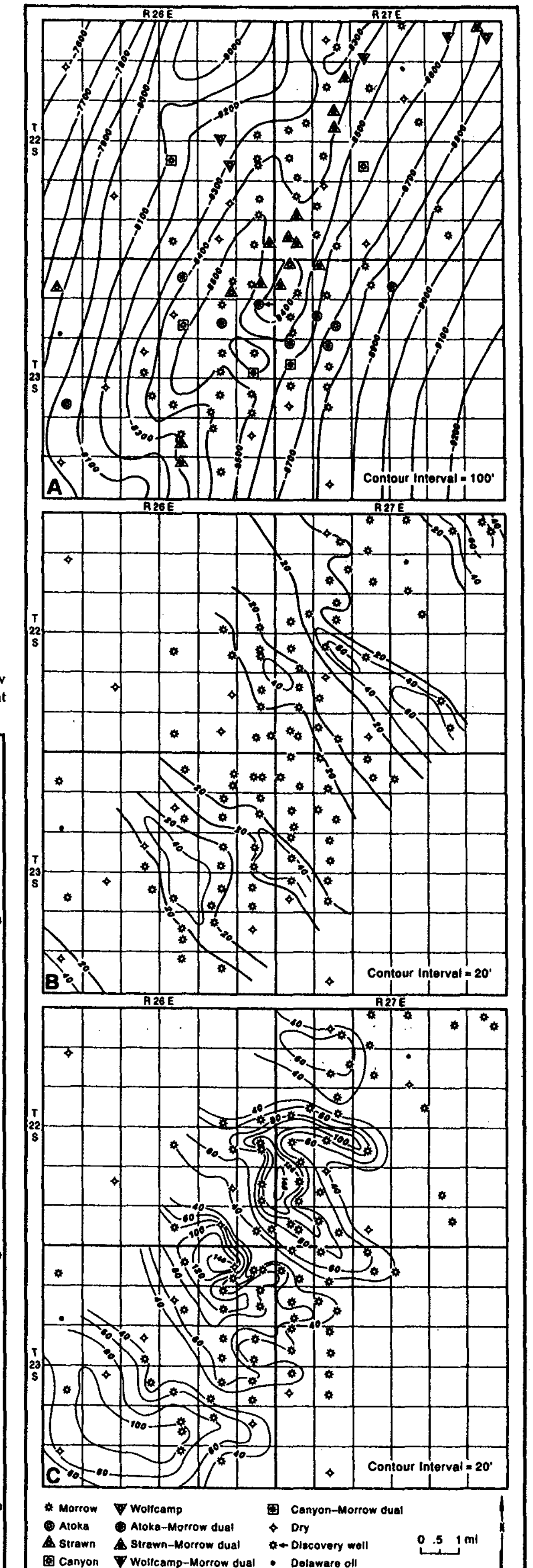
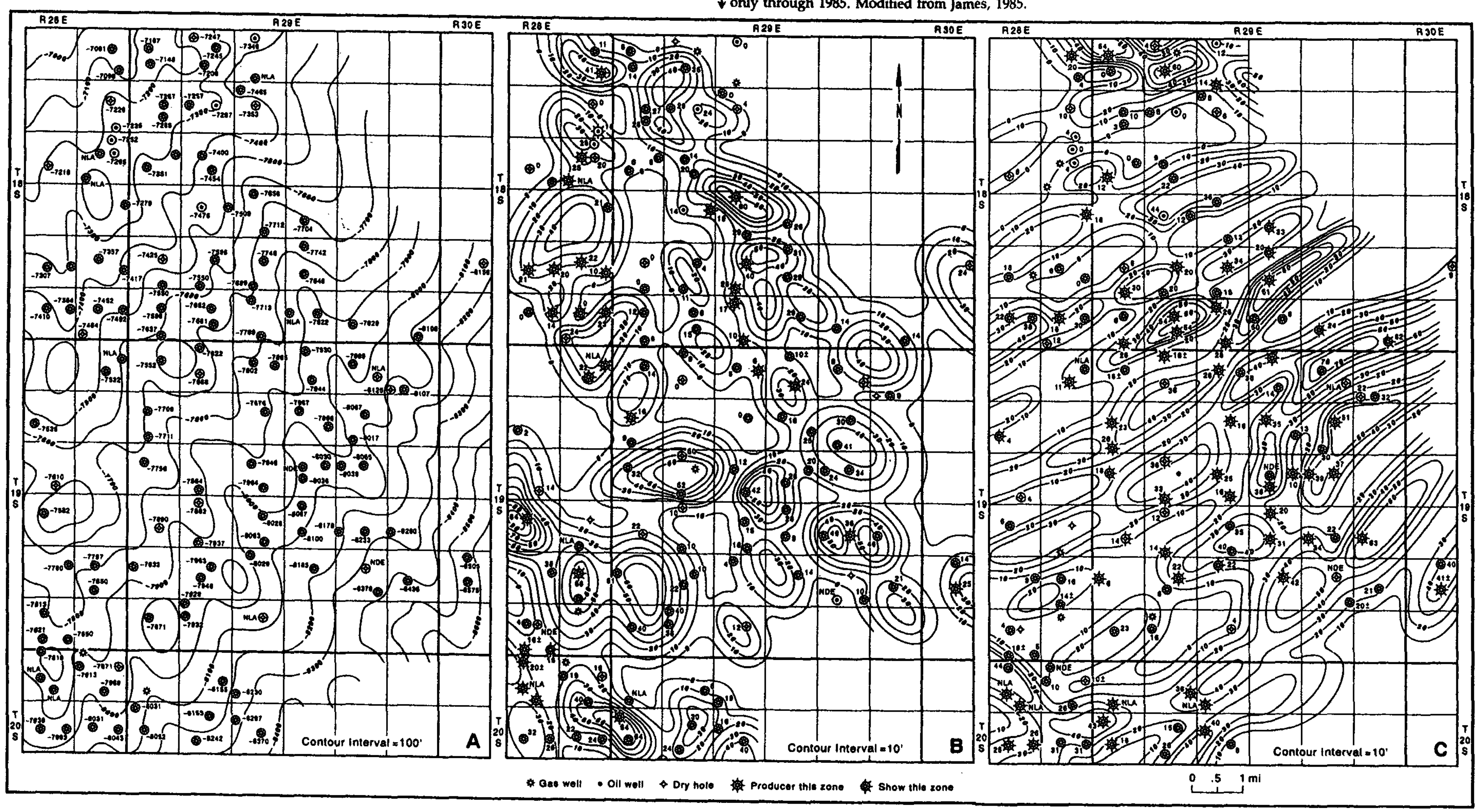


FIGURE PP-4.8—Parkway–Empire South reservoir area. A, Structure on top of the lower Morrow; B, lower Morrow net sandstone isopach; and C, middle Morrow net sandstone isopach. Only deep wells are shown and data is current only through 1985. Modified from James, 1985.



PP-5. MISSISSIPPIAN

Stephen W. Speer

Reservoirs found in Mississippian rocks are of relatively minor importance in southeast New Mexico. Of the 23 reservoirs only one thus far discovered, Austin Mississippian (Fig. PP-5.1, Table PB-10.1), has cumulative gas production exceeding 5 BCF. Although Mississippian rocks are present over much of the Permian Basin, it has yet to be demonstrated that significant-enough reservoirs are present that could trap and produce large quantities of hydrocarbons.

In southeast New Mexico the Mississippian section is as much as 1,500 ft thick and is composed primarily of dense, shallow-shelf limestone (Fig. PP-5.2) that is locally fossiliferous, crinoidal, and/or oolitic. In Eddy County, the limestone shelf facies grades southward into Texas into a basinal black shale facies, the Barnett shale (Wright, 1979; Grant and Foster, 1989). Post-depositional erosion of the entire Mississippian section has occurred over most of the Central Basin platform.

The Austin Mississippian reservoir in the limestone shelf facies in northern Lea County (Figs. PP-5.1, PP-5.2) produces dry gas and condensate from a localized crinoidal, oolite grainstone shoal of Chesterian age. Discovered in 1957, Austin has produced more than 10.6 BCF gas and 152 MBBLS of 49–56° API condensate from 10 wells, with approximately 40% of the production coming from the discovery well (Fig. PP-5.3). Net pay averages approximately 26 ft of 6% porosity with 60–70% hydrocarbon saturation at roughly 13,300 ft (Fig. PP-5.4). The reservoir is normally pressured, and although successful openhole completions have been performed in several of the wells, the majority are completed either naturally or with acid through perforations in production pipe. Inherently low reservoir permeabilities, in combination with the extreme depth, have qualified the reservoir stratum for formal designation by the FERC as a tight gas formation over all of Lea County (138,240 acres).

Trapping at Austin Mississippian appears to be controlled primarily by stratigraphic pinchout of reservoir facies, although some structural control is evident as the reservoir lies on the western flank of a faulted anticline. Porosity development is discontinuous, exhibiting both primary (interparticle) and secondary (intercrystalline, moldic, and/or vugular) fabric. Some cavernous porosity has been described on sample strip logs.

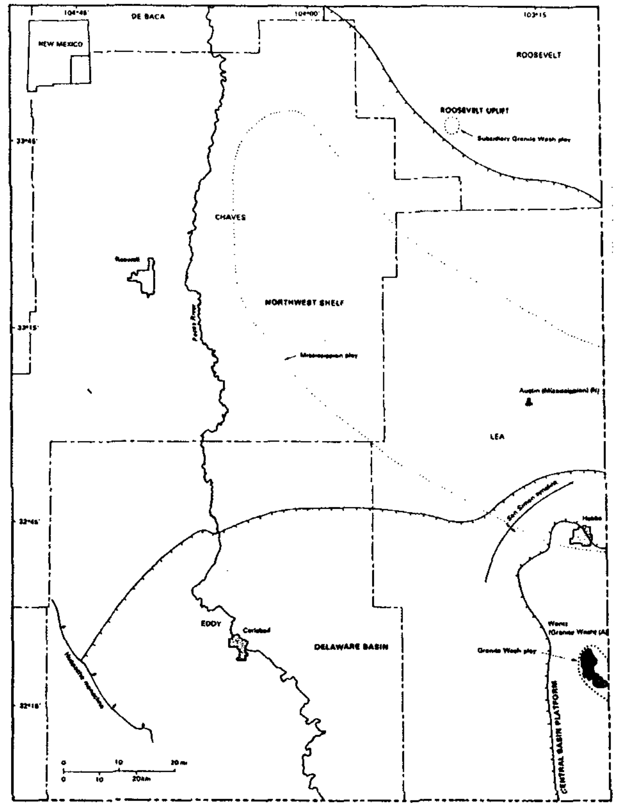


FIGURE PP-5.1—Reservoirs in the Granite Wash and Mississippian plays.

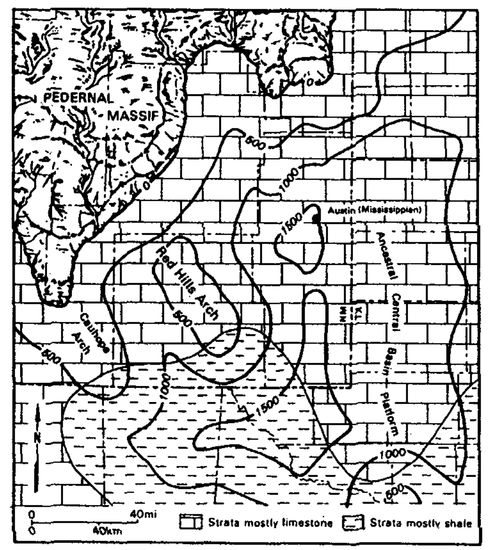


FIGURE PP-5.2—Composite Mississippian paleogeographic-isopach-lithofacies map of southeast New Mexico. Isopach values are depositional and do not reflect erosion from structurally uplifted areas. Modified from Wright, 1979.

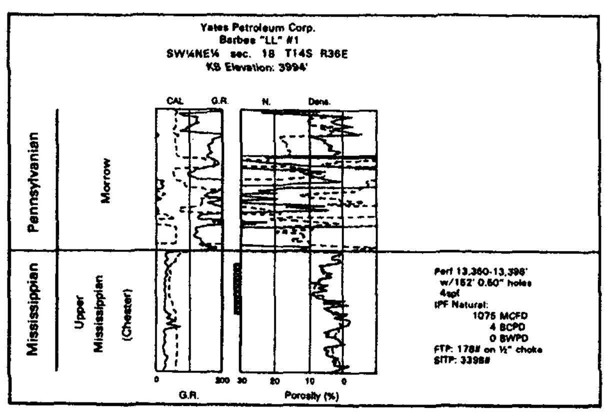


FIGURE PP-5.4—Representative neutron-density porosity log in Austin Mississippian reservoir. Note the clean GR response and mudcake buildup, but relatively low porosity values found in the pay zone. This well was completed in 1979 and through 1990 has produced 1.82 BCF gas, 30.8 MB condensate, and 2.4 MB water.

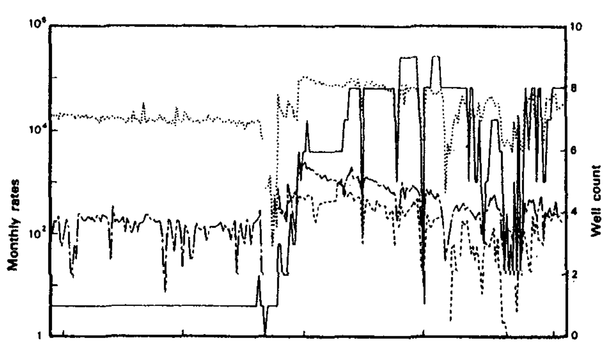


FIGURE PP-5.3—Historical production from the Austin Mississippian reservoir. ···, gas (MCF); — - —, condensate (BBLS); ---, water (BBLS); —, wells. From INTERA Bergeson; data source, Dwight's Energydata, Inc.

PB-10. GRANITE WASH (PERMIAN)

Stephen W. Speer

The Granite Wash play (Fig. PP-5.1) is confined to lower Permian clastic sediments deposited on or immediately adjacent to localized uplifts that remained in southeast New Mexico during early Permian time. The most prominent of these is the Eunice High, the apparent Precambrian crest of the Central Basin platform (Fig. PB-10.2). Granite Wash reservoirs here were developed in response to the final phase of uplift and burial of the highest portions of the Central Basin platform during early Wolfcampian time (Hills, 1984). The uplift and subsequent erosional unroofing and exposure of its granitic core resulted in the deposition of associated alluvial-fan and fluvial sediments in adjacent low areas (Bowsher and Abendshein, 1988) with the eventual burial of the high as it foundered in its own debris.

Wantz Granite Wash (Table PB-10.1, Fig. PB-10.3) is the only one of three reservoirs in this play to have cumulative production exceeding 5 BCF gas. Discovered in 1963, it has yielded 32 BCF of associated gas from 117 wells (Fig. PB-10.4). It is classified as an oil reservoir, having produced more than 6.6 MMBBLS of sweet, high-gravity oil (38–42° API). Average depth to the reservoir is 7,200 ft with most wells penetrating approximately 80 ft of gross pay interval and reaching total depth 50 ft into the Precambrian granite basement. The reservoir is normally pressured with most wells drilled with mud and completed through perforations in production casing. Moderately sized fracture completion treatments are utilized if necessary to improve production performance.

Traps for this play are generally structural-stratigraphic combinations. Hydrocarbons have migrated to this high area of the platform and are trapped in discontinuous sands and conglomerates surrounded by impermeable shales. Minor faulting within the reservoir, as evidenced by local areas of tight structure contours (Fig. PB-10.4), appears to have complicated the trapping mechanism by compartmentalizing the reservoir. Recently, reinterpretation of drill cuttings, log responses, and other reservoir characteristics indicates that much of the reservoir facies previously described as granite wash may be in situ fractured Precambrian granite (A. L. Bowsher, pers. comm. 1991).

Specific reservoir lithologies range from sandy conglomerates composed of gravelly unroofed sedimentary cover (limestone and dolomite) and granitic core material to immature, poorly sorted, medium- to coarse-grained sandstones. Net pay averages 28 ft with 14% intergranular porosity and 1.6 md horizontal permeability. Average hydrocarbon saturation is 45% (Bowsher and Abendshein, 1988).

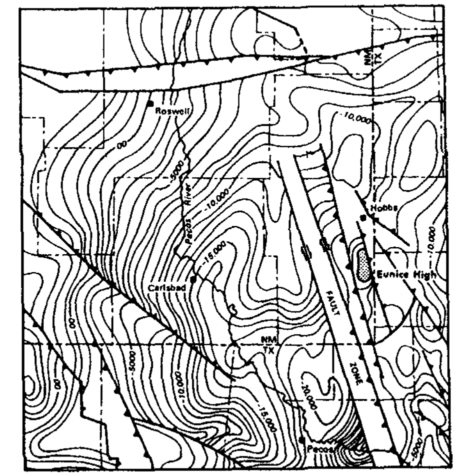


FIGURE PB-10.2—Precambrian basement structure map in the Permian Basin showing the Eunice High on the Central Basin platform. Datum is sea level. Contour interval is 1,000 ft. Modified from Hills, 1984.

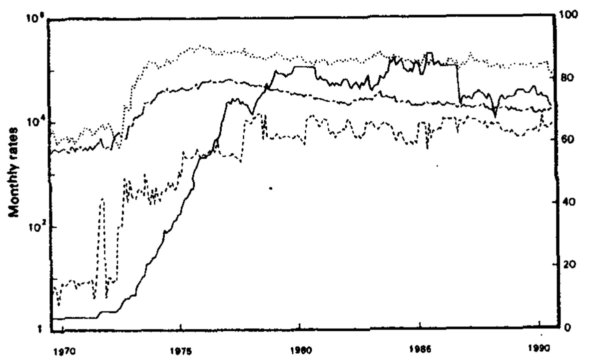


FIGURE PB-10.3—Historical production from the Wantz Granite Wash reservoir. ···, gas (MCF); — - —, oil (BBLS); —, water (BBLS); —, wells. From INTERA Bergeson; data source, Dwight's Energydata, Inc.

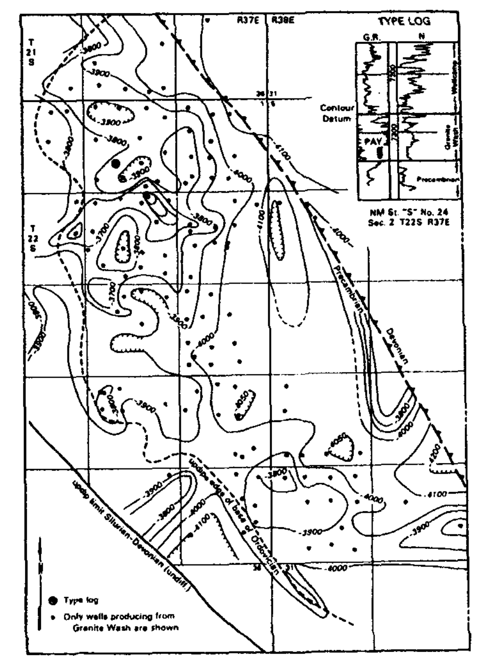


FIGURE PB-10.4—Structure map contoured on top of Granite Wash interval in Wantz reservoir. Irregular relief across the reservoir is due to the uneven underlying erosional surface combined with variable Granite Wash interval thicknesses. Datum is sea level. Modified from Bowsher and Abendshein, 1988.

TABLE PB-10.1—Geologic, engineering, and production data for the Granite Wash and Mississippian plays. Heads explained on last page.

St	County	Reservoir	Ty	Disc	Wells	Aban	Spa	Acres	Depth	Trap	Dri	Lith	DeEn	PostD	Por	Perm	Temp	PrGr	CumBCF	PDR
NM	Lea	Wantz (Granite Wash)	G	1963	83	34	40	9000	7200	Spm	SG	Siun	Afun	Coce	0.14	1.600	135	0.430	32.300	7.8
NM	Lea	Austin (Mississippian)	N	1957	8	2	320	2900	13310	Spm	PD	Gran	Pesb	Gren	0.06		191	0.430	10.600	3.0

’-6. SILURO–DEVONIAN

Stephen W. Speer

ıe Siluro–Devonian play primarily produces oil (over 435 BBLS) in southeast New Mexico with 81% of the 118 de- d reservoirs classified as oil productive. Regardless, 15 res- ıirs have produced more than 5 BCF gas each for a total 59 BCF (Table PP-6.1). Nine of these produce nonassociated from deep, closed structures (9,900–17,450 ft) off the crest ıe Central Basin platform (Fig. PP-6.1). Analysis of histor- production trends (Fig. PP-6.2) show that, except for the tively recent Langley discovery in 1978, a steady decline iluro–Devonian production is occurring caused by deple- of existing reservoirs combined with no significant new overies. It is apparent that additional drilling, specifically ıe deeper parts of the Delaware Basin, is needed to reverse trend in gas production. Related reservoirs in the west ıs portion of the Permian Basin are discussed in plays SD- rough SD-4 in the *Atlas of Major Texas Gas Reservoirs* (Bebout Garrett, 1989).

ıe Siluro–Devonian section is divided into four distinct tigraphic units (Fig. PP-6.3). They consist, in ascending ɜr, of 1) Lower to Middle Silurian Fusselman Formation ɔonates and cherts; 2) Upper Silurian Wristen formation es and limestones; 3) Lower to Middle Devonian Thirtyone nation carbonates and cherts; and 4) Upper Devonian to ɾer Mississippian Woodford formation shales (Hills and ·nig, 1979). Reservoirs are found in fractured, vugular, and eous, fine- to coarse-crystalline dolomites of both the ·tyone and Fusselman formations. Porosity development rimarily diagenetic through karst processes as both pay rvals are overlain by major unconformities and contain ıificant internal exposure surfaces.

nticlines, often bounded on one or more sides by high- le faults, are the dominant trapping mechanism for the ority of known Siluro–Devonian reservoirs (Fig. PP-6.4). vever, in reservoirs near the crest of the Central Basin plat- n, traps are formed by the burial of erosional subcrop pat- s around paleostructure peneplains. The numerous episodes xposure and erosion within the Siluro–Devonian section iously have the potential to form several types of subtle complex stratigraphic-structural traps that are not easily ɔgnized by conventional geological and geophysical meth- (Fig. PP-6.3; Mazzullo, 1990). It is probable that further lerstanding of these patterns and their genesis, as applied n exploration plan, will add significantly to the successful ·ch for future Siluro–Devonian reserves.

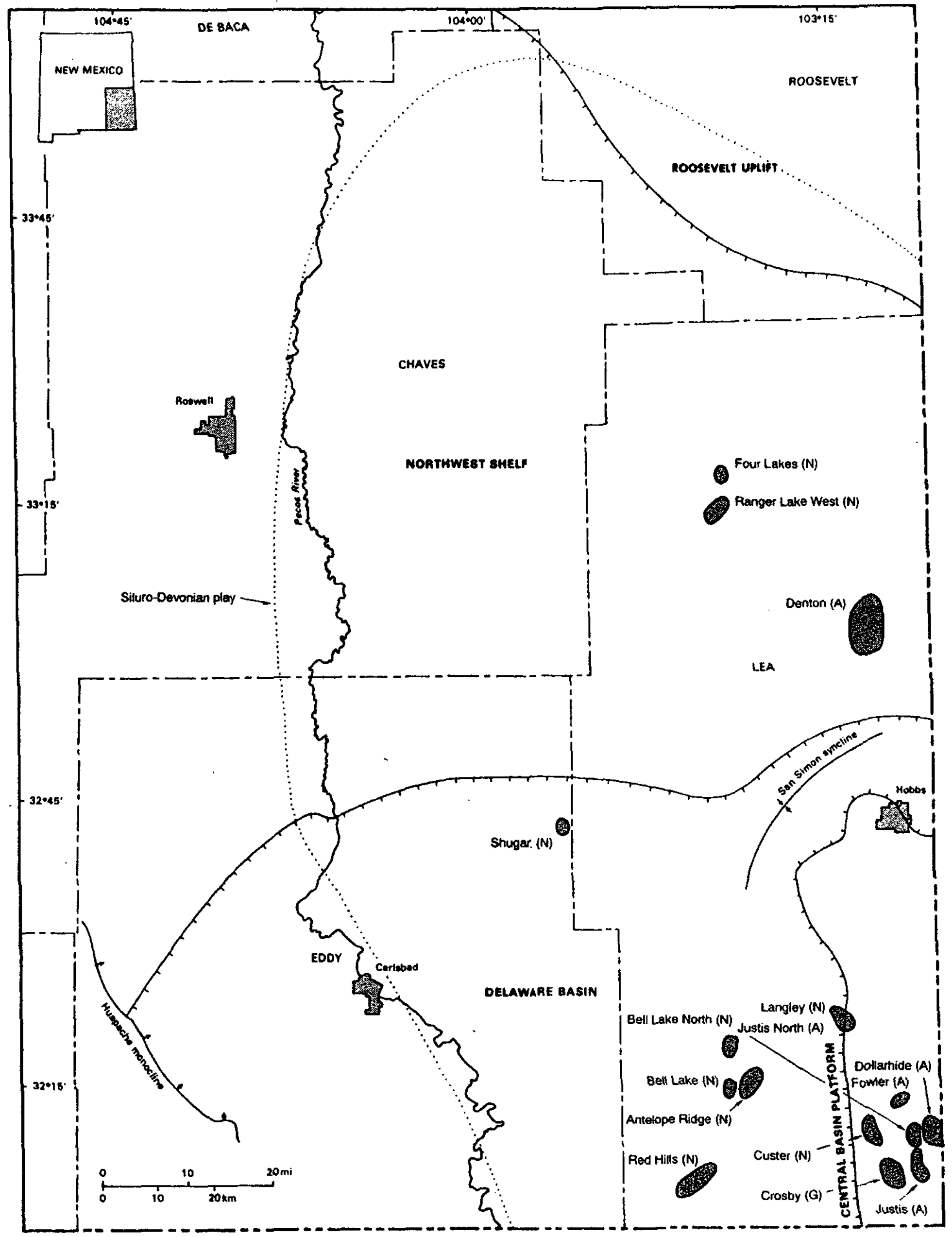


FIGURE PP-6.1—Reservoirs in the Siluro–Devonian play.

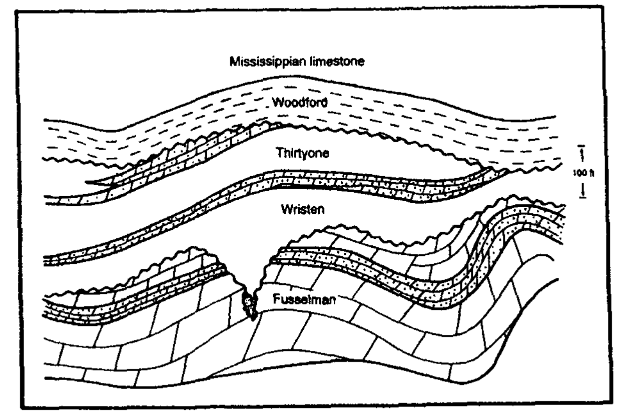


FIGURE PP-6.3—Schematic stratigraphic section of the Siluro–Devonian interval in the Permian Basin emphasizing interpreted stratigraphic and structural relationships related to potential trapping mechanisms. Modified from Mazzullo, 1990.

TABLE PP-6.1—Geologic, engineering, and production data for the Siluro–Devonian play. Heads explained on last page.

County	Reservoir	Ty	Disc	Wells	Aban	Spa	Acres	Depth	Trap	Dri	Lith	DeEn	PostD	Por	Perm	Temp	PrGr	CumBCF	PDR
Lea	Antelope Ridge (Devonian)	N	1964	4	1	640	2560	14650	Af	PD	Dolo	Ssre	Dolo	0.06	4.500	217	0.440	35.040	
Lea	Bell Lake (Devonian)	N	1956	0	3	160	640	14700	Af	PD	Dolo	Ssre	Dolo	0.07		200	0.430	17.790	
Lea	Bell Lake N (Devonian)	N	1960	1	0	640	1280	14560	Ant	PD	Dolo	Ssre	Dolo	0.07		200	0.440	28.460	
Lea	Crosby (Devonian)	G	1955	2	14	160	2560	8300	Af	CO	Dolo	Ssre	Dolo	0.04	36.000	134	0.390	94.590	
Lea	Custer (Devonian)	N	1975	4	0	320	1280	9900	Af	PD	Dolo	Ssre	Dolo	0.05		160	0.410	42.630	11.3
Lea	Denton (Devonian)	A	1949	72	46	40	10400	12000	Af	WD	Dolo	Ssre	Dolo	0.08	9.600	170	0.420	51.270	
Lea	Dollarhide (Devonian)	A	1952	28	13	40	3360	7725	Af	CO	Dolo	Ssre	Dolo	0.14	9.000	132	0.420	10.580	1.1
Lea	Four Lakes (Devonian)	N	1956	2	3	160	640	12400	Ant	PD	Dolo	Ssre	Dolo	0.05		165	0.400	7.410	0.0
Lea	Fowler (Devonian)	A	1955	2	6	40	800	7550	Uld	SG	Dolo	Ssre	Dolo	0.06		102	0.430	6.460	0.1
Lea	Justis (Fusselman)	A	1958	18	19	40	1760	6550	Uld	SG	Dolo	Ssre	Dolo	0.05		106	0.400	13.660	1.8
Lea	Justis N (Devonian)	A	1962	7	11	40	1440	6950	Uld	SG	Dolo	Ssre	Dolo	0.05		108	0.370	5.180	
Lea	Langley (Devonian)	N	1979	6	0	320	1920	12150	Af	PD	Dolo	Ssre	Dolo	0.03		175	0.400	12.020	3.2
Lea	Ranger Lake W (Devonian)	N	1967	0	7	320	2080	12850	Ant	SG	Dolo	Ssre	Dolo	0.06		143	0.390	9.190	
Lea	Red Hills (Devonian)	N	1980	2	0	640	3520	17450	Ant	PD	Dolo	Ssre	Dolo	0.05		257	0.430	5.340	2.3
Eddy	Shugart (Siluro Devonian)	N	1957	1	1	160	320	12350	Af	PD	Dolo	Ssre	Dolo	0.04	115.320	160	0.430	19.750	1.0

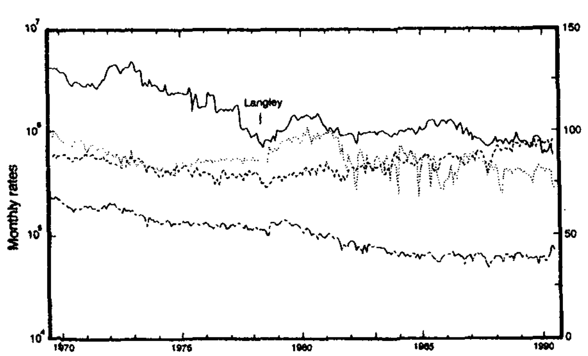


FIGURE PP-6.2—Historical production from the Siluro–Devonian play. Note the steady decline in hydrocarbon production before the Langley (Devonian) discovery in 1978. ···, gas (MCF); — - —, oil (BBLS); ---, water (BBLS); —, wells. From INTERA Bergeson; data source, Dwight's Energydata, Inc.

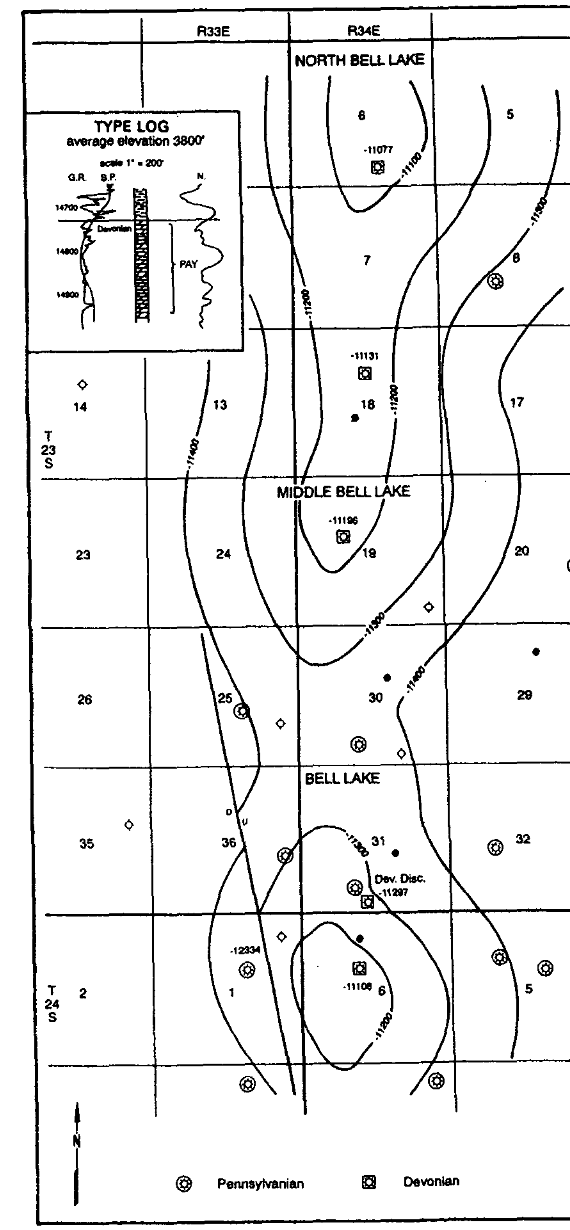


FIGURE PP-6.4—Structure contours on top of Devonian dolomite in the Bell Lake reservoir complex, Lea County. This deep structural trend, discovered in 1956, is representative of the type of structure and trap in many Siluro–Devonian reservoirs. Modified from Harvard, 1967.

PP-7. ORDOVICIAN

Stephen W. Speer

Ordovician reservoirs in southeast New Mexico are associated primarily with closed structures on the Central Basin platform. Most were discovered and developed between 1945 and 1960 as operators began the search for deeper pays in areas of known structure with shallow production (Helmig, 1956). Even though the majority are primarily high-gravity oil reservoirs (with total production exceeding 115 MMBBLS), ten of the 37 reservoirs have produced at least 5 BCF gas (Table PP-7.1), and more importantly, the more recent finds show potential for significant quantities of nonassociated gas in areas off the platform (Fig. PP-7.1). The Ordovician play is equivalent to adjacent OR-1, OR-2, and OR-3 plays of the *Atlas of Major Texas Gas Reservoirs* (Bebout and Garrett, 1989).

Several pays are found in the Ordovician section, which consists of the Ellenburger, Simpson, and Montoya Groups (Fig. PP-7.2). The Ellenburger ranges in depth from 7,700 ft on the platform at Brunson to more than 15,000 ft off its western edge at Langley. Most pay zones are typically vugular, fine- to coarse-crystalline, slightly siliceous dolomites exhibiting high permeability in a brecciated, fracture-enhanced porosity system. Although originally deposited in a stable restricted-shelf setting, subsequent diagenetic alteration and dissolution by erosional and karst processes (Fig. PP-7.2) primarily account for the excellent productivity of Ellenburger pays (Kerans, 1988; Verseput, 1989). In some reservoirs, other fractures may relate directly to the late Paleozoic tectonic stresses that formed the associated structures.

Montoya reservoirs are quite similar to those in the Ellenburger in that they also are slightly siliceous, fine- to medium-crystalline dolomites exhibiting excellent permeability from fracture-enhanced intercrystalline and vugular porosity. These dolomites were deposited in a setting similar to that of the Ellenburger and appear to have undergone a comparable burial and diagenetic history (Wright, 1979). Where the Montoya is productive, depths range from 6,200 ft at Foor Ranch on the Northwest shelf to 6,900 ft at Justis on the Central Basin platform.

Simpson reservoirs are unlike the other Ordovician pays in that they are composed of rounded and friable, fine- to coarse-grained blanket sandstones. These make up approximately 5% of the Simpson Group, range from 20 to 250+ ft thick, and represent a time of siliciclastic input into the ancestral Tobosa Basin from the Pedernal landmass to the north and west. Principal producing horizons, ranging in depth from 7,500 to 9,600 ft, include the Connell, Waddell, and McKee sands, all of which were deposited as a series of coalescing shoreline accumulations (Wright, 1979).

Traps for the Ordovician play almost always show a strong relationship to associated structural features as a result of the laterally extensive nature of the reservoir facies. In many cases, trapping occurs on fault-bound anticlinal closures (Fig. PP-7.3), but where the reservoirs have been truncated around localized uplifts by late Pennsylvanian and early Permian erosion (such as at Brunson, Foor Ranch, Hare, and Justis), trapping occurs at the unconformity along the subcrop edge of the reservoir.

A significant potential for the discovery of additional nonassociated Ordovician gas still exists. Development of the play remains in two areas:) deeper structures west of the Central Basin platform, such as at Langley (Figs. PP-7.1, PP-7.4), and 2) subcrop areas on the Northwest shelf, such as at Foor Ranch (Fig. PP-7.1). Although Montoya production at Foor Ranch has been commingled with lower Pennsylvanian, it is apparent that a significant play exists and remains to be developed in this area.

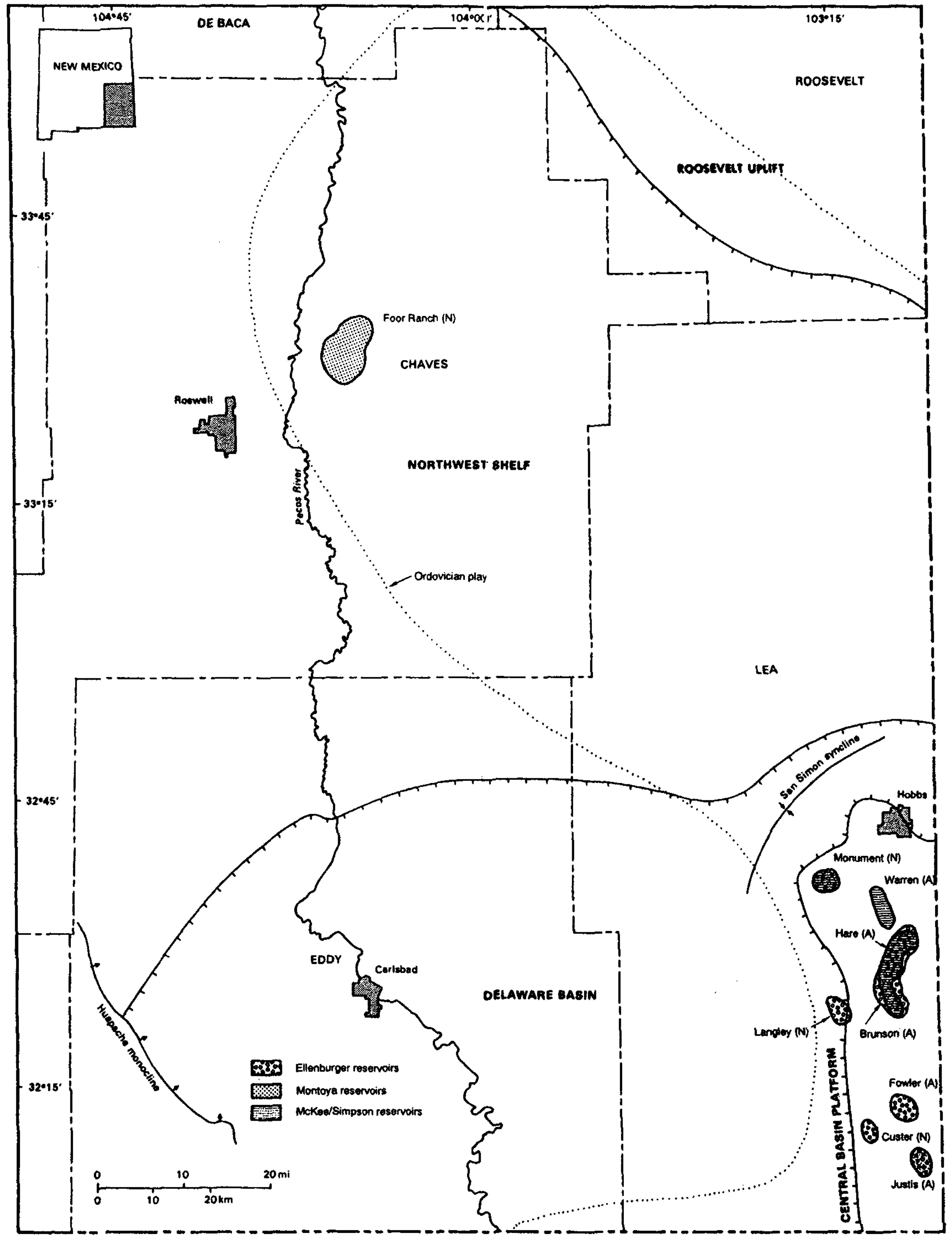


FIGURE PP-7.1—Reservoirs in the Ordovician play.

TABLE PP-7.1—Geologic, engineering, and production data for the Ordovician play. Heads explained on last page.

St	County	Reservoir	Ty	Disc	Wells	Aban	Spa	Acres	Depth	Trap	Dri	Lith	DeEn	PostD	Por	Perm	Temp	PrGr	CumBCF	PDR
NM	Chaves	Foor Ranch (PrePermian)	N	1981	31	3	320	12480	6200	Uld	PD	Dolo	Ssre	Dolo	0.12		120	0.390	16.730	
NM	Lea	Brunson (Ellenburger)	A	1945	11	140	40	9600	7700	Cou	SG	Dolo	Ssre	Dolo	0.04		122	0.390	18.130	1.6
NM	Lea	Custer (Ellenburger)	N	1960	2	1	320	960	12500	Af	PD	Dolo	Ssre	Dolo	0.04		197	0.480	20.000	0.6
NM	Lea	Fowler (Ellenburger)	A	1949	9	14	80	2880	9900	Af	SG	Dolo	Ssre	Dolo	0.08		130	0.420	10.600	2.6
NM	Lea	Hare (Simpson)	A	1947	27	96	40	8400	7550	Cou	SG	Sand	Spun	Coce	0.14		120	0.400	21.030	1.6
NM	Lea	Justis (Ellenburger)	A	1957	4	21	40	1600	7800	Af	SG	Dolo	Ssre	Dolo	0.03	2.000	115	0.420	9.120	0.8
NM	Lea	Justis (Montoya)	A	1958	11	12	40	1440	6900	Cou	SG	Dolo	Ssre	Dolo	0.06	5.000	107	0.380	10.060	
NM	Lea	Langley (Ellenburger)	N	1978	3	2	320	1600	15100	Af	PD	Dolo	Pesu	Dolo	0.04		201	0.400	23.820	3.8
NM	Lea	Monument (McKee Elln)	N	1953	6	4	160	2720	9600	Ant	PD	Sand	Spun	Coce	0.14		120	0.340	62.340	1.9
NM	Lea	Warren (McKee Simpson)	A	1952	43	6	40	3120	9000	Ant	SG	Sand	Spun	Coce	0.14	36.600	115	0.380	19.080	

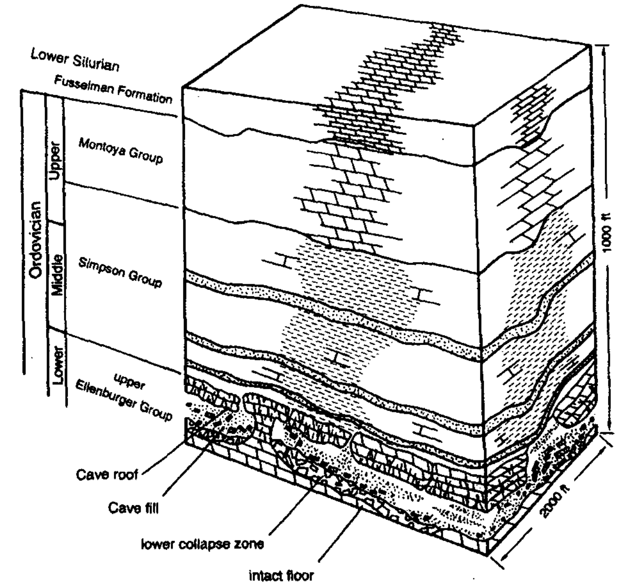


FIGURE PP-7.2—Schematic stratigraphic section of Ordovician producing horizons in southeast New Mexico. This figure emphasizes a depositional/diagenetic model for reservoir development in the Ellenburger carbonates through karst-related processes and their resultant facies. Note the effect of Ellenburger dissolution on the overlying units. Modified from Kerans, 1988.

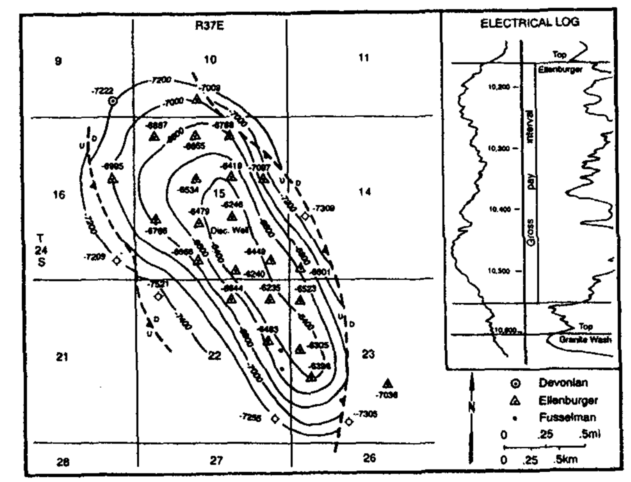


FIGURE PP-7.3—Structure contours on top of Ellenburger in Fowler reservoir. Fowler was discovered in 1949 and represents the structure and trap common to many of the lower Paleozoic fields on the Central Basin platform. Modified from Wilson, 1956.

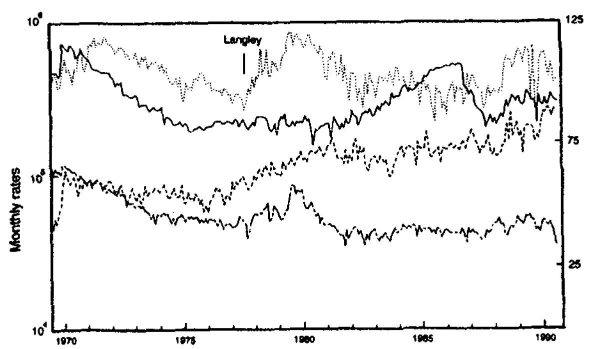


FIGURE PP-7.4—Historical production from the Ordovician play. Note effect on production curve of deep, high-volume discovery at Langley Ellenburger in 1978. ···, gas (MCF); — · —, oil (BBLS); ---, water (BBLS); —, wells. From INTERA Bergeson; data source, Dwight's Energydata, Inc.