Play Analysis and Digital Portfolio of Major Oil Reservoirs in the Permian Basin: Application and Transfer of Advanced Geological and Engineering Technologies for Incremental Production Opportunities

Final Report

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Mississippian Play

Mississippian Platform Carbonate (Play 108)

The Mississippian Platform Carbonate play is the smallest oil-producing play in the Permian Basin, having cumulative production of only 15.1 MMbbl (2.40×10^6 m^3) from five reservoirs (table 11). Because no Mississippian reservoirs had produced >10 MMbbl (1.59×10^6 m^3), this play was not included in the *Atlas of Major Texas Oil Reservoirs* (Galloway and others, 1983). The play is shown as extending across much of the Permian Basin (fig. 27) because smaller Mississippian reservoirs (<1 MMbbl [$<1.59 \times 10^5$ m^3]) cumulative production) are located throughout the area. The play does not include areas where the Mississippian was removed by erosion (fig. 27) (Ruppel, 1983; Frenzel and others, 1988; Ruppel, 1989). Production in the play is controlled by both structural and stratigraphic traps (Wright, 1979).

Little information is available about this play. Frenzel and others (1988) noted that Osage and Meramec carbonate strata in west Texas generally consist of finely crystalline, nonporous limestones. Hamilton and Asquith (2000) described the stratigraphy and facies of upper Mississippian (Meramec and Chester) deposits in New Mexico and adjacent West Texas. Upper Mississippian platform carbonates are the shelf equivalents of the Barnett Shale, which

Table 11. Mississippian Platform Carbonate play (play 108).

RRC RESN	RRC	FLDNAME	RESNAME	STATE	COUNTY	DISCYR	DEPTHTOP	2000 PROD	CUMPROD
11308333	8A	BRAHANEY	MISSISSIPPIAN	TX	YOAKUM	1960	10880	11,119	4,268,423
24377300	8A	DEROEN	MISSISSIPPIAN	TX	DAWSON	1981	10182	58,502	2,002,217
31690001	8A	FLUVANNA		TX	BORDEN	1951	8173	10,857	5,788,200
34961250	8A	GIN	MISS.	TX	DAWSON	1965	11403	5,984	1,148,179
51742333	8A	LAMESA, WEST	MISS.	TX	DAWSON	1959	11280	5,303	1,903,803
		Totals						**91,765**	**15,110,822**

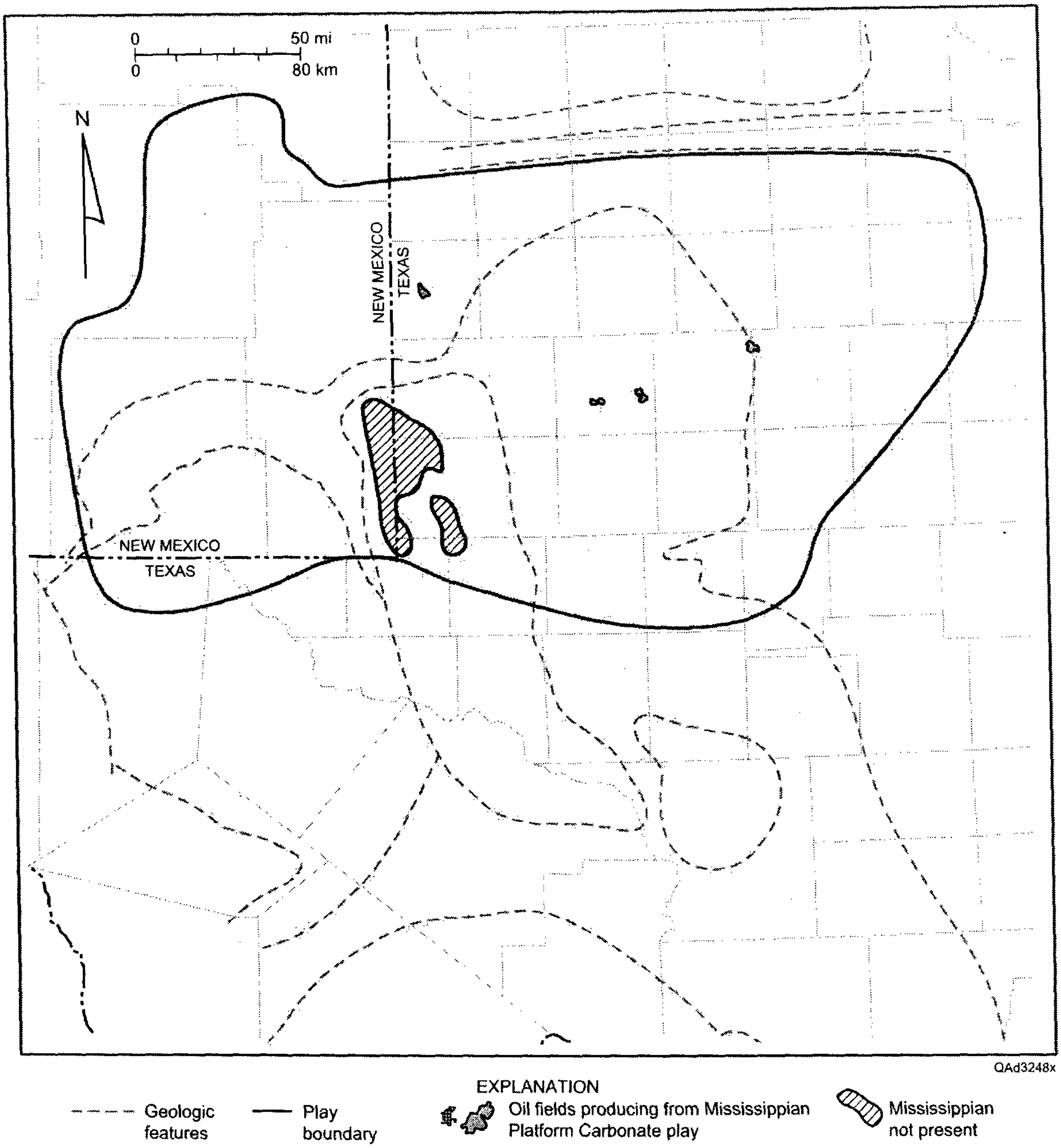

Figure 27. Play map for the Mississippian Platform Carbonate play, showing location of reservoirs having >1 MMbbl cumulative production, the play boundary, and geologic features. See figure 1 for county names and figure 2 for identification of geologic features.

was deposited in the deeper basin to the south and east (figs. 28, 29). Hamilton and Asquith (2000) studied the depositional and diagenetic history of Austin Upper Mississippian field, a gas

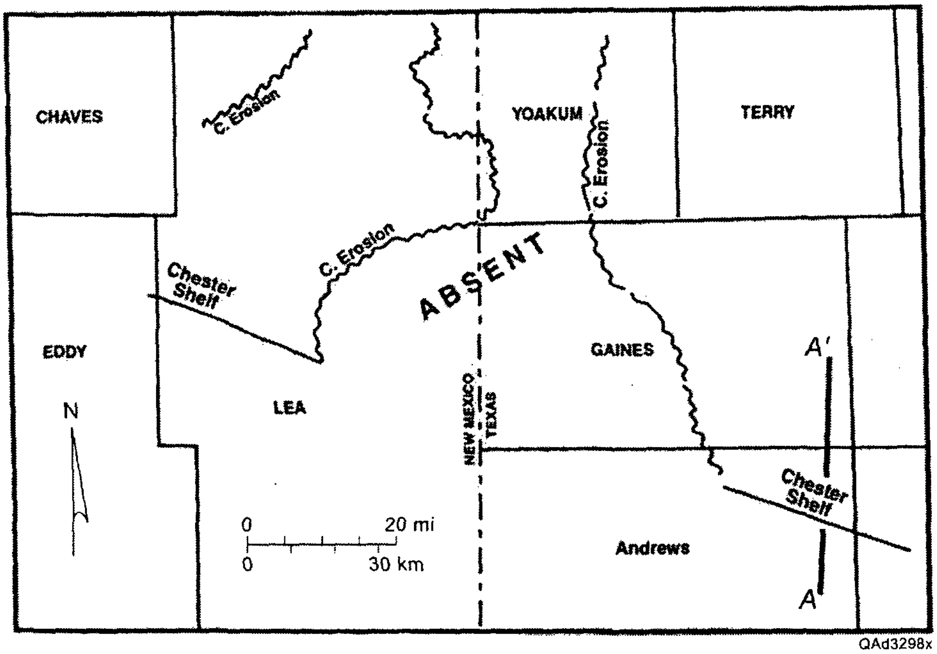

Figure 28. Map showing location of Chester limestone subcrop. From Hamilton and Asquith (2000). Upper Mississippian carbonates were deposited on the Chester platform while the Barnett Shale was deposited in the basin to the south. Cross section A-A′ shown in figure 29.

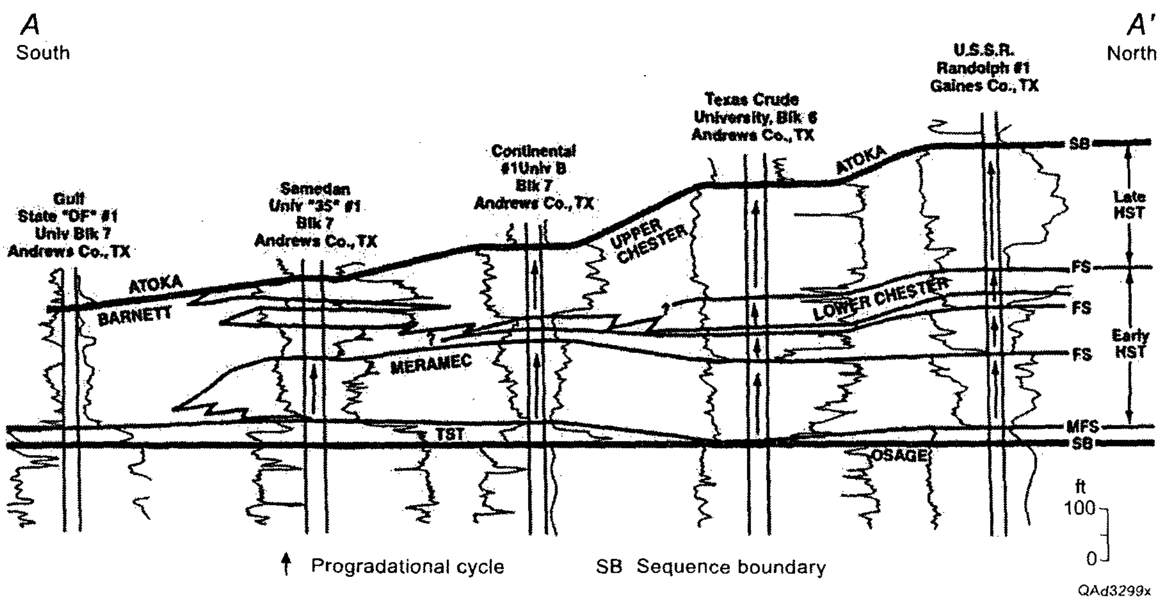

Figure 29. South-north cross section A-A′ of the upper Mississippian Meramec and Chester limestones. From Hamilton and Asquith (2000). Line of section shown in figure 28.

reservoir in Lea County. Production from Austin field is from ooid grainstones in the top 100 ft (30 m) of the upper Chester. Mississippian fields in eastern Gaines and western Dawson Counties are also interpreted as occurring in Chester ooid grainstones that developed landward of the platform margin (Hamilton and Asquith, 2000). The ooid grainstones form elongate lenticular trends perpendicular to the platform margin. Intergranular pores are preserved where precipitation of equant calcite cement was not complete.

Production from Mississippian limestone in Reeves and Pecos Counties is mainly from the upper Mississippian. Log analysis of a porous interval near the base of the Mississippian (Kinderhook?) suggests that it may represent an additional pay zone (Asquith and others, 1998).

West Lamesa field in Dawson County, Texas, produces from limestone and chert, whereas Brahaney field, Yoakum County, Texas, produces from dolomite and dolomitic limestone (Wright, 1979). Fluvanna field, Borden County, produces from weathered Mississippian chert at the top of the Mississippian section (Grimes, 1982). Mississippian reservoirs include fracture, vuggy, intercrystalline, and cavernous pores (Wright, 1979).

A wide range of porosity and permeability has been reported for Mississippian reservoirs. Porosity averages 7 percent in Gin field. Mississippian reservoir rocks in Brahaney field average 12 percent porosity and 5 md ($5 \times 10^{-3}\ \mu m^2$) permeability (Files of the Railroad Commission of Texas). Porosity in Fluvanna field averages 21 percent; permeability ranges from 4 to 181 md (4 to $181 \times 10^{-3}\ \mu m^2$) and averages 40 md ($40 \times 10^{-3}\ \mu m^2$) (Files of the Railroad Commission of Texas).

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Pennsylvanian Plays

The Pennsylvanian oil plays that occur completely, or partly, within the Permian Basin are: (1) Northwest Shelf Strawn Patch Reef, (2) Northwest Shelf Upper Pennsylvanian Carbonate, (3) Pennsylvanian Platform Carbonate, (4) Pennsylvanian and Lower Permian Horseshoe Atoll Carbonate, (5) Upper Pennsylvanian and Lower Permian Slope and Basinal Sandstone, (6) Pennsylvanian and Lower Permian Reef/Bank, and (7) Upper Pennsylvanian Shelf Sandstone. All Pennsylvanian oil plays that occur in Texas are delineated in the oil atlas (Galloway and others, 1983). Two of the original Texas play names have been modified slightly, and all play boundaries have been expanded; otherwise the play definitions have not been changed.

Oil in the Pennsylvanian and Lower Permian Reef/Bank play is produced from dispersed limestone buildups characterized by prominent depositional topography (Galloway and others, 1983). The Pennsylvanian and Lower Permian Reef/Bank play is not included in this portfolio of Permian Basin plays because most of the reservoirs in the play are located in the North-Central Texas geologic province. Ten fields in the play, however, are in the Permian Basin, in Kent, Crockett, Mitchell, and Irion Counties (table 12). The largest fields in the Permian Basin part of

Table 12. Pennsylvanian and Lower Permian Reef/Bank play.[1]

RRC RESN	RRC	FLDNAME	RESNAME	STATE	COUNTY	DISCYR	DEPTHTOP	2000 PROD	CUMPROD
10556500	8A	BOOMERANG	PENNSYLVANIAN REEF	TX	KENT	1955	6582	11,653	3,293,149
10560500	8A	BOOMERANG, S.	STRAWN LIME	TX	KENT	1964	6623	15,741	5,589,563
18436333	8A	CLAIREMONT	PENN., LOWER	TX	KENT	1950	6742	32,794	15,880,427
18437333	8A	CLAIREMONT, EAST	STRAWN	TX	KENT	1960	6494	12,607	1,456,046
45582666	8	JAMESON, NORTH	STRAWN	TX	MITCHELL	1953	5866	32,005	9,622,521
74505500	7C	RANCH	STRAWN	TX	CROCKETT	1953	8156	6,680	3,744,987
83873750	7C	SIXTY SEVEN	STRAWN REEF	TX	IRION	1956	6898	23,313	2,867,254
90315001	7C	TODD, DEEP		TX	CROCKETT	1940	5691	0	3,679,628
90315333	7C	TODD, DEEP	CRINOIDAL	TX	CROCKETT	1940	5778	169,638	37,338,101
98803500	7C	WORLD, WEST	STRAWN	TX	CROCKETT	1954	8190	10,752	8,632,607
		Totals						**315,183**	**92,104,283**

[1] This play is not included in the play portfolio because most of the play is in the North-Central Texas geologic province. Production listed here represents only the 10 reservoirs in the Permian Basin, as defined in figure 1.

the play are Todd, Deep (Crinoidal), which produced 37.3 MMbbl (5.93×10^6 m^3) of oil through 2000, and Clairemont (Penn., Lower), which produced 15.9 MMbbl (2.53×10^6 m^3). Total cumulative production from the 10 fields in the Permian Basin part of the play is 92.1 MMbbl (1.46×10^7 m^3) (table 12).

Similarly, the Upper Pennsylvanian Shelf Sandstone play is located mainly in North-Central Texas and thus is not described in this report. Five reservoirs in this play occur in the Permian Basin (table 13). These five reservoirs had cumulative production of 7.3 MMbbl (1.16×10^6 m^3) through 2000 (table 13).

Present structural features of the Permian Basin, including the Central Basin Platform and Midland and Delaware Basins (fig. 2), began forming in Early Pennsylvanian time (Frenzel and others, 1988). The thickness and distribution of Pennsylvanian rocks in the Permian Basin are quite variable owing to nondeposition and erosion over positive areas such as the Central Basin Platform. Pennsylvanian faulting formed many of the oil-producing anticlines in the area. Pennsylvanian rocks in the Permian Basin are commonly cyclic because they formed during a time of high-amplitude, high-frequency eustatic sea-level fluctuations caused by glaciation and deglaciation in the Southern Hemisphere (Heckel, 1986).

Table 13. Upper Pennsylvanian Shelf Sandstone play[1].

RRC RESN	RRC	FLDNAME	RESNAME	STATE	COUNTY	DISCYR	DEPTHTOP	2000 PROD	CUMPROD
2711001	8A	ANDREW NOODLE CREEK		TX	KENT	1969	4010	0	1,063,283
21959500	8A	CROTON CREEK, E.	TANNEHILL	TX	DICKENS	1969	4574	0	1,285,205
64626380	8A	NAVIGATOR	TANNEHILL B	TX	DICKENS	1996	4418	323,280	1,273,061
78525500	8A	ROUGH DRAW, N.	NOODLE CREEK	TX	KENT	1963	4140	4,050	1,620,751
91784700	8A	TUMBLEWEED, NW.	TANNEHILL	TX	DICKENS	1986	4108	99,226	2,021,841
				TX					
		Totals						**426,556**	**7,264,141**

[1] This play is not included in the play portfolio because most of the play is in the North-Central Texas geologic province. Production listed here represents only the five reservoirs in the Permian Basin, as defined in figure 1.

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Northwest Shelf Strawn Patch Reef (Play 109)

Reservoirs of the Northwest Shelf Strawn Patch Reef play lie in New Mexico on the Northwest Shelf of the Permian Basin and are also present within the Delaware Basin (fig. 30). Most reservoirs lie within a triangular trend formed roughly by the cities of Lovington, Carlsbad, and Artesia. Oil-productive reservoirs are found mainly in the eastern two-thirds of this triangular trend; gas reservoirs are found in the west part of the trend, as well as outside the main trends. The play boundary terminates on the west in the transition zone between oil and gas production, and the gas fields of the west part of the play are not shown in figure 30. There are 104 known, discovered Strawn reservoirs in the play, 13 of which have produced >1 MMbbl (1.59×10^5 m^3) of oil (fig. 30, table 14). Cumulative production from these 13 reservoirs was 69.9 MMbbl (1.11×10^7 m^3) as of 2000. Annual production from these 13 reservoirs was 1.06 MMbbl (1.69×10^5 m^3) during 2000. Production from this play has seen an overall decrease during the 1990's as production from existing reservoirs has matured.

Reservoirs are patch reefs of Strawn (Desmoinesian: Middle Pennsylvanian) age. The patch reefs grew on a south-dipping carbonate ramp that was present before the western Permian Basin segmented into the Northwest Shelf and the Delaware Basin. Reservoirs are principally

Table 14. Northwest Shelf Strawn Patch Reef play (play 109).

RRC RESN	RRC	FLDNAME	RESNAME	STATE	COUNTY	DISCYR	DEPTHTOP	2000 PROD	CUMPROD
		BIG EDDY	STRAWN	NM	EDDY	1966	11333	0	1,402,000
		BURTON FLAT EAST	STRAWN	NM	EDDY	1976	10600	67,662	2,990,681
		CASEY	STRAWN	NM	LEA	1975	11326	17,989	3,414,520
		CASS	PENNSYLVANIAN	NM	LEA	1944	7700	0	2,885,000
		GOLDEN LANE	STRAWN	NM	EDDY	1969	11098	18,432	1,448,602
		HUMBLE CITY	STRAWN	NM	EDDY	1972	11429	24,093	1,303,341
		HUMBLE CITY SOUTH	STRAWN	NM	LEA	1982	11520	20,520	3,444,361
		LOVINGTON NORTHEAST	PENNSYLVANIAN	NM	LEA	1952	11256	0	16,921,580
		LOVINGTON WEST	STRAWN	NM	LEA	1985	11594	479,493	5,162,551
		LUSK	STRAWN	NM	LEA & EDDY	1960	11168	38,447	20,682,947
		REEVES	PENNSYLVANIAN	NM	LEA	1956	10950	14,066	1,286,874
		SHIPP	STRAWN	NM	LEA	1985	11138	43,428	7,624,050
		SHOE BAR NORTH	STRAWN	NM	LEA	1973	11275	340,752	1,297,324
		Totals						**1,064,882**	**69,863,831**

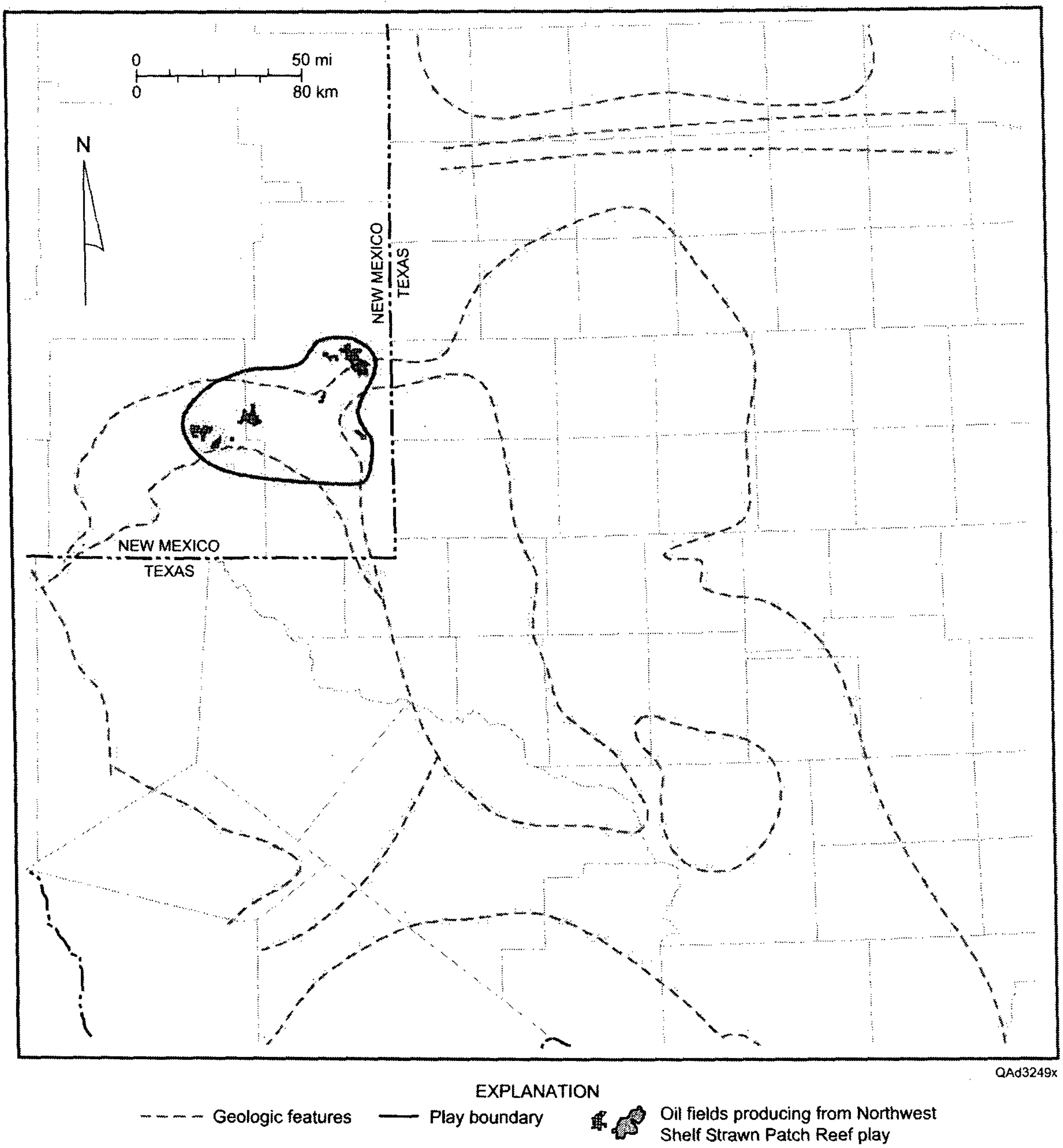

Figure 30. Play map for the Northwest Shelf Strawn Patch Reef play, showing location of reservoirs having >1 MMbbl cumulative production, the play boundary, and geologic features. See figure 1 for county names and figure 2 for identification of geologic features.

bioherms composed of phylloid algal, coralgal, and foraminiferal lime wackestones and packstones (Harris, 1990). Bioherm growth was localized on preexisting structures that had bathymetric expression (Thornton and Gaston, 1967; Harris, 1990). Seals are interbedded marine mudstones. The larger Strawn reservoirs are internally complex and exhibit intricate porosity variations (fig. 31).

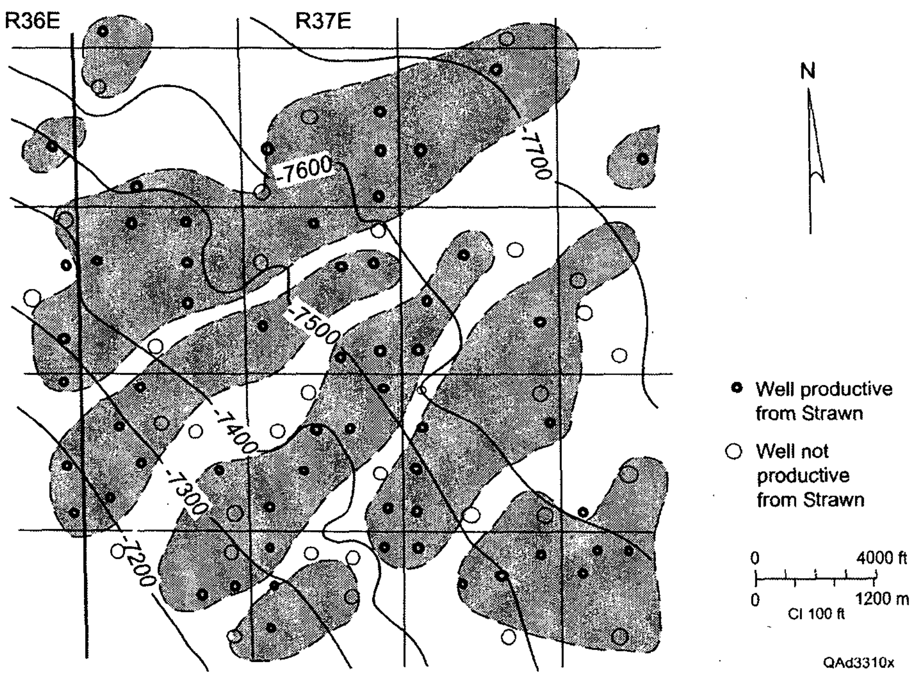

Figure 31. Map of Strawn structure and porosity at the Lovington Northeast reservoir. Shown is structure of the Strawn limestone. Contour interval is 50 ft. Shaded areas are where the Strawn has porosity ≥4 percent. Modified by Speer (1993) from Caughey (1988).

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Northwest Shelf Upper Pennsylvanian Carbonate (Play 110)

Reservoirs of the Northwest Shelf Upper Pennsylvanian Carbonate play lie on the Northwest Shelf of the Permian Basin, in New Mexico (fig. 32). The trend of reservoirs extends from the shelf edge near Carlsbad in Eddy County onto the shelf interior in Roosevelt and Chaves Counties. There are 197 known, discovered reservoirs in this play, 34 of which have produced >1 million bbl oil (1.59×10^5 m^3) (table 15). Cumulative production from these 34 reservoirs was 353.8 MMbbl (5.62×10^7 m^3) through 2000. During the 1990's, annual production from this play peaked at 11.2 MMbbl (1.78×10^6 m^3) during 1996 and has since

Table 15. Northwest Shelf Upper Pennsylvanian Carbonate play (play 110).

RRC RESN	RRC	FLDNAME	RESNAME	STATE	COUNTY	DISCYR	DEPTHTOP	2000 PROD	CUMPROD
		ALLISON	PENNSYLVANIAN	NM	LEA	1954	9673	29,526	23,833,082
		ANDERSON RANCH NORTH	CISCO CANYON	NM	LEA	1984	11498	9,827	1,321,870
		BAGLEY	PENNSYLVANIAN	NM	LEA	1949	9190	2,664	4,339,919
		BAGLEY NORTH	PERMO PENN	NM	LEA	1957	10000	143,913	52,951,956
		BAR-U	PENNSYLVANIAN	NM	LEA	1964	9100	42,021	1,364,117
		BAUM	UPPER PENNSYLVANIAN	NM	LEA	1955	9940	34,221	15,224,467
		BOUGH	PERMO PENN	NM	LEA	1949	9617	0	6,329,000
		CERCA	UPPER PENNSYLVANIAN	NM	LEA	1968	10397	0	1,975,473
		CROSSROADS	PENNSYLVANIAN	NM	LEA	1949	9750	0	2,170,000
		DAGGER DRAW NORTH	UPPER PENN	NM	EDDY	1974	7550	1,805,612	48,909,673
		DAGGER DRAW SOUTH	UPPER PENN	NM	EDDY	1971	7506	419,638	16,214,241
		DEAN	PERMO PENN	NM	LEA	1955	11500	15,455	6,165,150
		FLYING M SOUTH	BOUGH	NM	LEA	1965	9020	0	1,211,000
		HIGH PLAINS	PERMO PENN	NM	LEA	1985	10400	0	1,056,081
		HIGHTOWER EAST	UPPER PENNSYLVANIAN	NM	LEA	1959	10218	9,666	1,054,219
		INBE	PERMO PENN	NM	LEA	1962	9658	8,817	16,439,579
		INDIAN BASIN	UPPER PENNSYLVANIAN	NM	EDDY	1963	7370	1,914,766	13,274,441
		JENKINS	CISCO	NM	LEA	1963	9750	0	2,099,000
		LAZY J	PENNSYLVANIAN	NM	LEA	1952	9600	30,552	7,630,855
		LEAMEX	PENNSYLVANIAN	NM	LEA	1956	11340	3,770	1,367,438
		MILNESAND	PENNSYLVANIAN	NM	ROOSEVELT	1956	9202	0	1,001,000
		NONOMBRE	UPPER PENNSYLVANIAN	NM	LEA	1965	10345	0	1,077,000
		PRAIRIE SOUTH	CISCO	NM	ROOSEVELT	1960	9651	0	2,906,000
		RANGER LAKE	PENNSYLVANIAN	NM	LEA	1956	10300	7,025	5,084,059
		SAUNDERS	PERMO-UPPER PENN	NM	LEA	1980	9800	128,353	38,920,906
		SAUNDERS EAST	PERMO PENN	NM	LEA	1962	10363	5,004	2,716,804
		SHOE BAR	PENNSYLVANIAN	NM	LEA	1954	10440	0	1,056,568
		TOBAC	PENNSYLVANIAN	NM	CHAVES	1964	9058	14,957	9,227,853
		TRAVIS	UPPER PENNSYLVANIAN	NM	EDDY	1977	9825	101,059	1,986,681
		TRES PAPALOTES	PENNSYLVANIAN	NM	LEA	1970	10400	24,567	1,942,584
		TRES PAPALOTES WEST	PENNSYLVANIAN	NM	LEA	1972	10400	0	1,237,313
		TULK	PENNSYLVANIAN	NM	LEA	1965	9856	10,017	1,809,541
		VACUUM	UPPER PENNSYLVANIAN	NM	LEA	1964	10000	78,567	6,613,696
		VADA	PENNSYLVANIAN	NM	ROOSEVELT &	1967	9800	31,165	53,336,607
		Totals						**4,871,162**	**353,848,173**

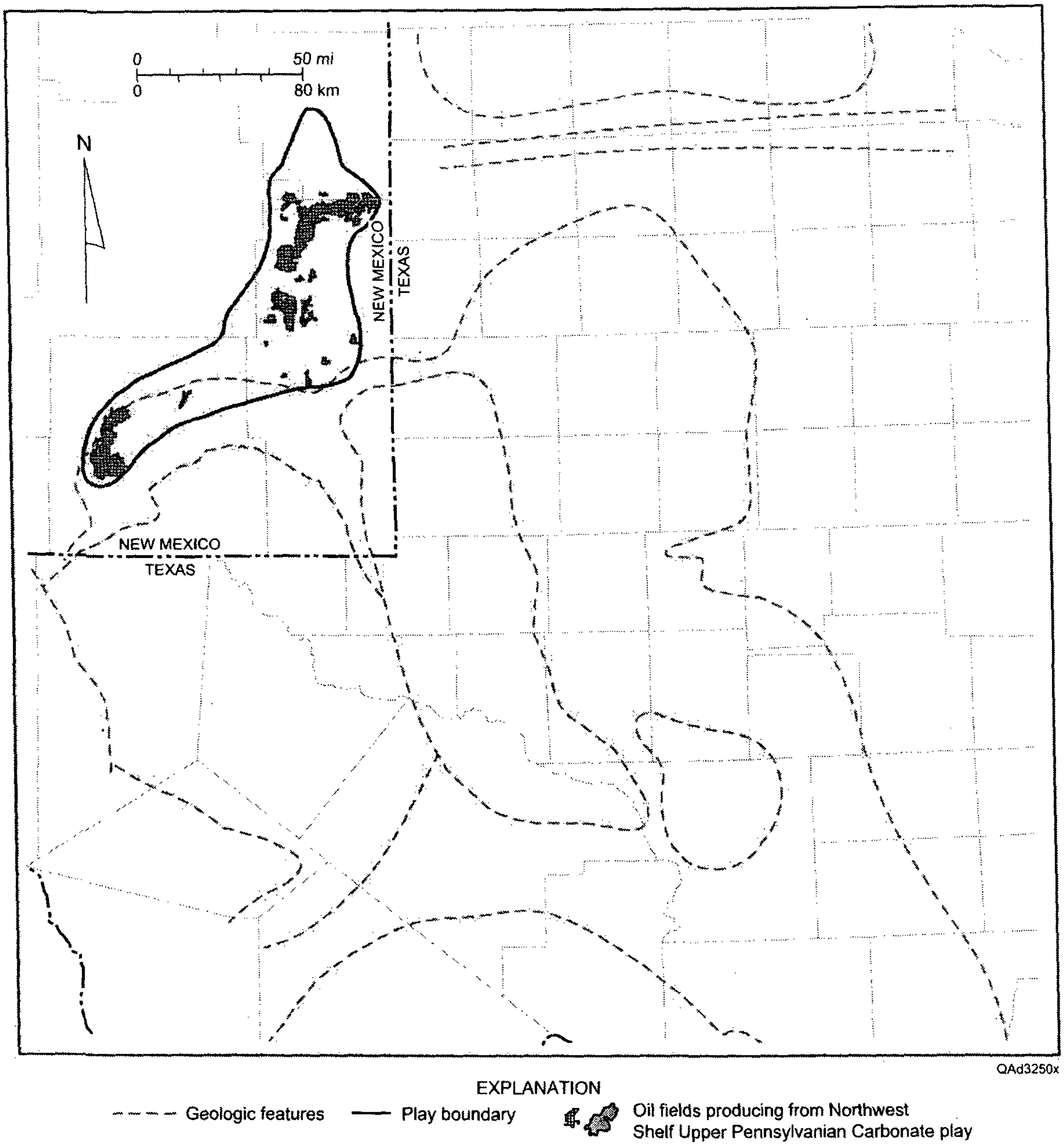

Figure 32. Play map for the Northwest Shelf Upper Pennsylvanian Carbonate play, showing location of reservoirs having >1 MMbbl cumulative production, the play boundary, and geologic features. See figure 1 for county names and figure 2 for identification of geologic features.

declined by 56 percent to 4.9 MMbbl (7.79×10^5 m^3) per year, largely as a result of production decline in the Dagger Draw North and Dagger Draw South reservoirs. Production increase during the early 1990's was a result of new oil brought online with redevelopment of the Dagger Draw reservoir.

Reservoirs are carbonates of Canyon (Upper Pennsylvanian: Missourian) age, the Cisco and Bough D zones of Virgilian (Upper Pennsylvanian) age, and the Bough B and C zones of earliest Wolfcampian (Permian) age (fig. 33). The exact age of Bough A, B, and C zones is problematic. They have been traditionally considered by the industry and regulatory entities as Virgilian in age, but fusulinid biostratigraphy indicates that they are of earliest Wolfcampian age (Cys and Mazzullo, 1985; Cys, 1986). More recent work based on correlation with conodonts has suggested that the Bough intervals may perhaps be of latest Virgilian age after all

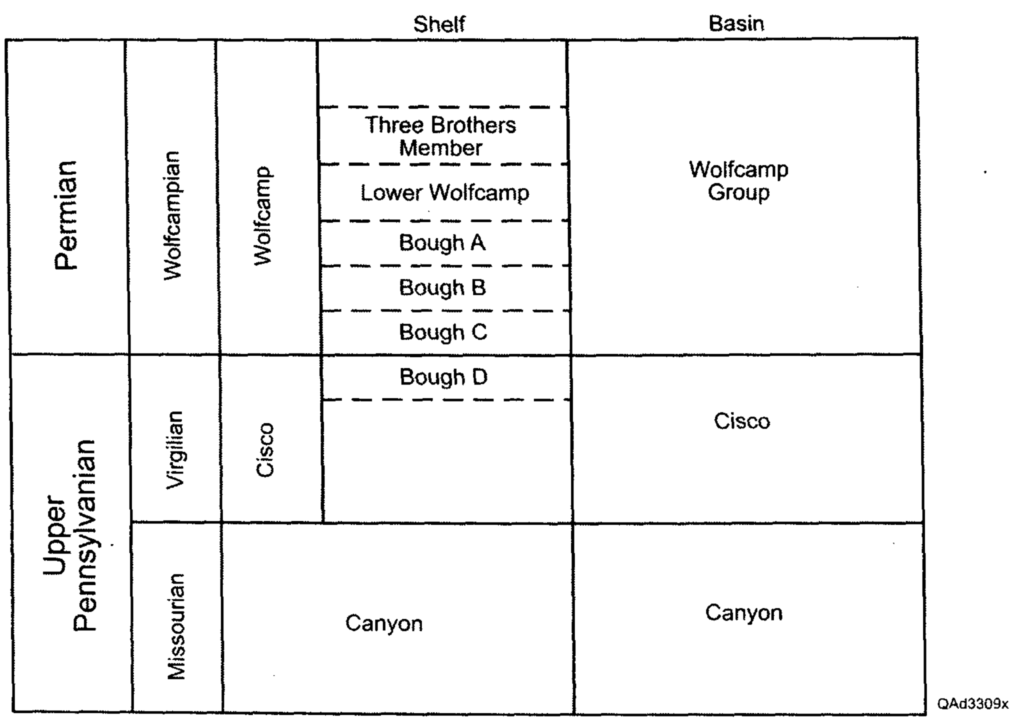

Figure 33. Stratigraphic column of Upper Pennsylvanian and Lower Permian strata, southeast New Mexico.

(see Wahlman, 2001). Whatever their correct age assignment, Bough B and C zones form major reservoirs in the trend on the Northwest Shelf from Saunders northward to Allison, although the underlying Bough D zone of definite Late Pennsylvanian age also contributes significant production in many of the reservoirs along this trend. The stratigraphic relationship of reservoirs in the Northwest Shelf part of this play to the reservoirs in the Wolfcamp Platform Carbonate play (play 114) is not well established, but available data indicate that the reservoirs assigned to the Wolfcamp Platform Carbonate play are younger than those assigned to this play. Wolfcamp Platform Carbonate play reservoirs produce mainly from Bough A and younger zones.

Traps in the Northwest Shelf Upper Pennsylvanian Carbonate play are primarily stratigraphic and are formed by phylloid algal mounds and associated grainstones and packstones (Cys, 1986; Speer, 1993; Cox and others, 1998; Mazzullo, 1998). Reservoirs on the Northwest Shelf are limestones. Wide, well-bedded phylloid algal banks grew across shallow-water bathymetric highs on shelf areas (Wahlman, 2001). The boundaries of many of the reservoirs on the Northwest Shelf are regulatory, and much of the oil has accumulated in essentially continuous stratigraphic traps that cross regulatory reservoir boundaries. Reservoirs at or near the shelf edge (for example, Dagger Draw, Dagger Draw South) are Missourian to Virgilian in age, older than on the Northwest Shelf, and they have generally been dolomitized. On the shelf edge, traps are formed primarily by massive phylloid algal mounds that grew along bathymetric breaks (Wahlman, 2001). Productive porosity is mostly intercrystalline, intergranular, and vugular; the porosity system is dominated by vugular porosity. Depth to production varies from 7,400 ft to 11,500 ft (2,250 to 3,505 m).

At Dagger Draw North and Dagger Draw South, production is obtained from a dolomitized fairway of shelf-edge algal mounds and intermound grainstones and packstones

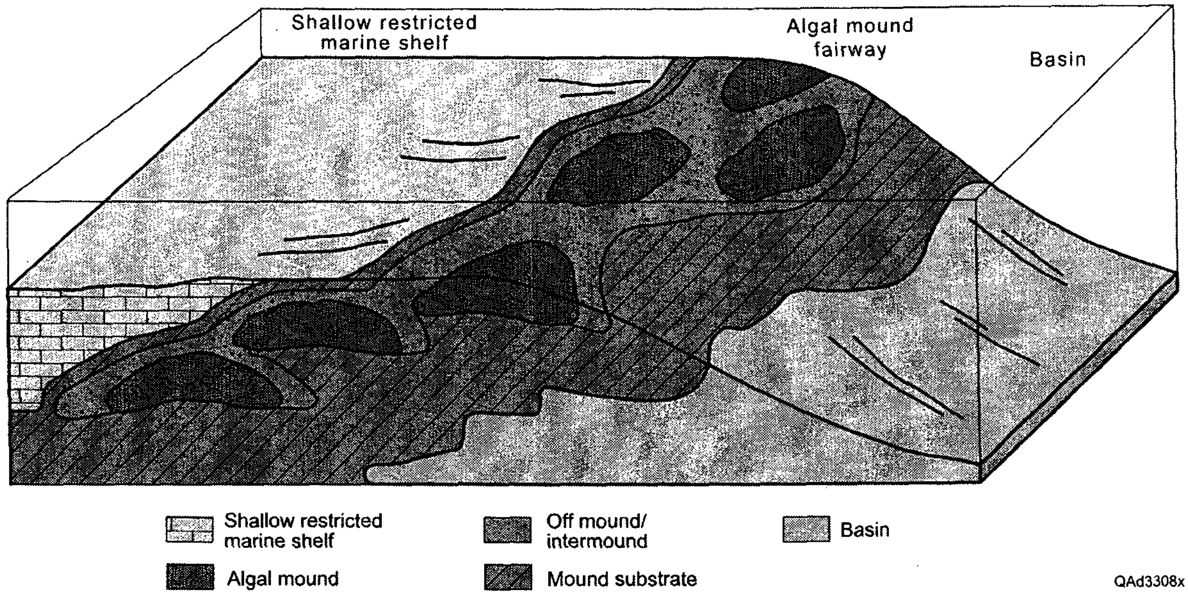

Figure 34. Depositional model for Upper Pennsylvanian algal-mound complex, South Dagger Draw reservoir. After Cox and others (1998).

(Cox and others, 1998; fig. 34). Impermeable, thinly bedded limestones lie shelfward and act as a seal on the shelf side of the algal mound trend. Impermeable basinal black shales, which may also act as source rocks for the algal mound complex, lie basinward.

Upper Pennsylvanian carbonate reservoirs on the Northwest Shelf have typically been discovered by drilling small, seismically defined anticlines. Initial development has generally been concentrated on the crests of the anticlines and, in most of the larger fields, generally has not extended into off-structure areas (Broadhead, 1999; fig. 35). However, in many cases, the anticlinal structures have little, if anything, to do with oil entrapment. Subsequent drilling in many reservoirs proceeded in discrete phases into off-structure areas, each with a corresponding

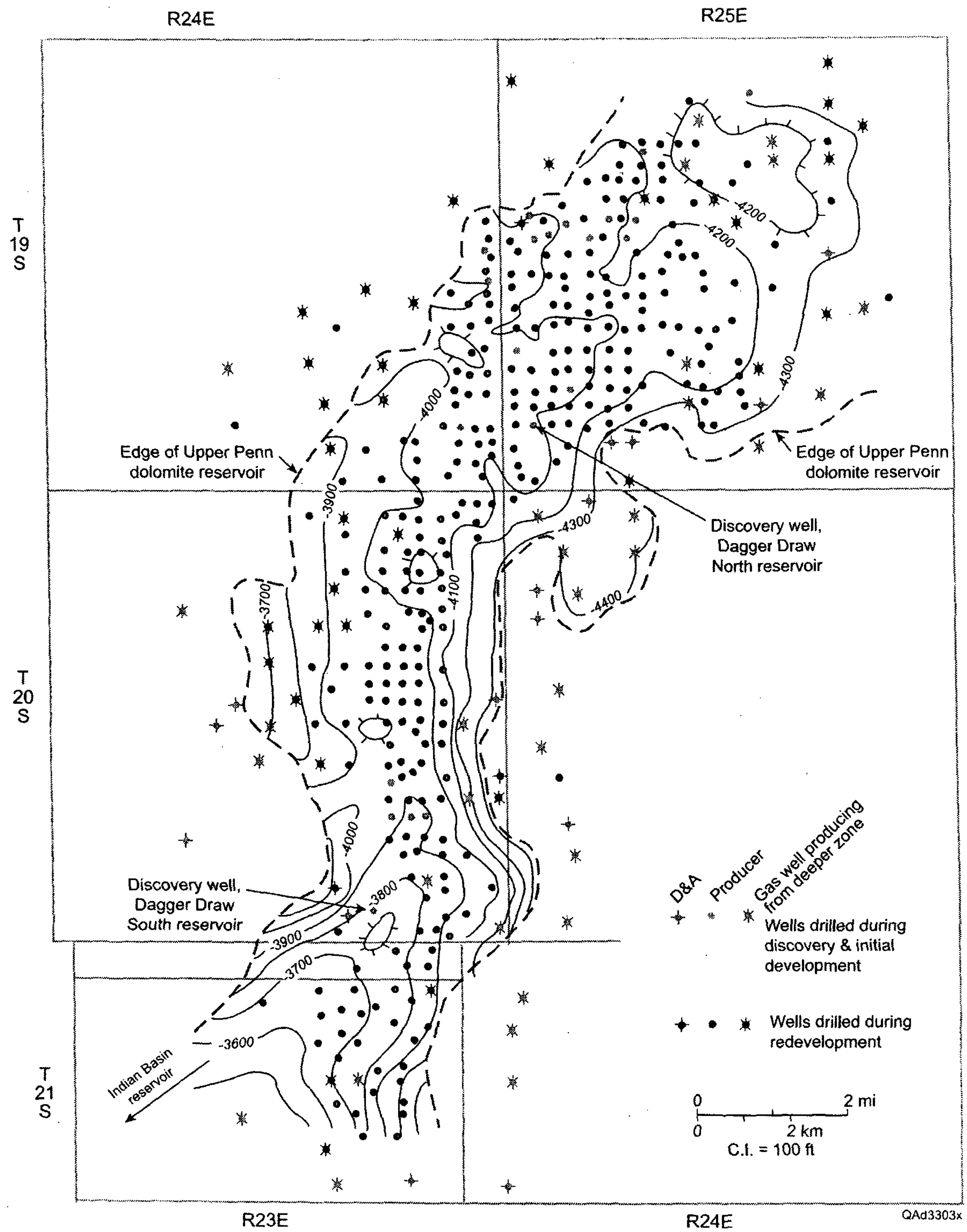

Figure 35. Structure-contour map on top of Upper Pennsylvanian dolostone reservoir and South Dagger Draw and North Dagger Draw reservoirs and time periods during which wells were drilled. After Broadhead (1999). Contours from Reddy (1995).

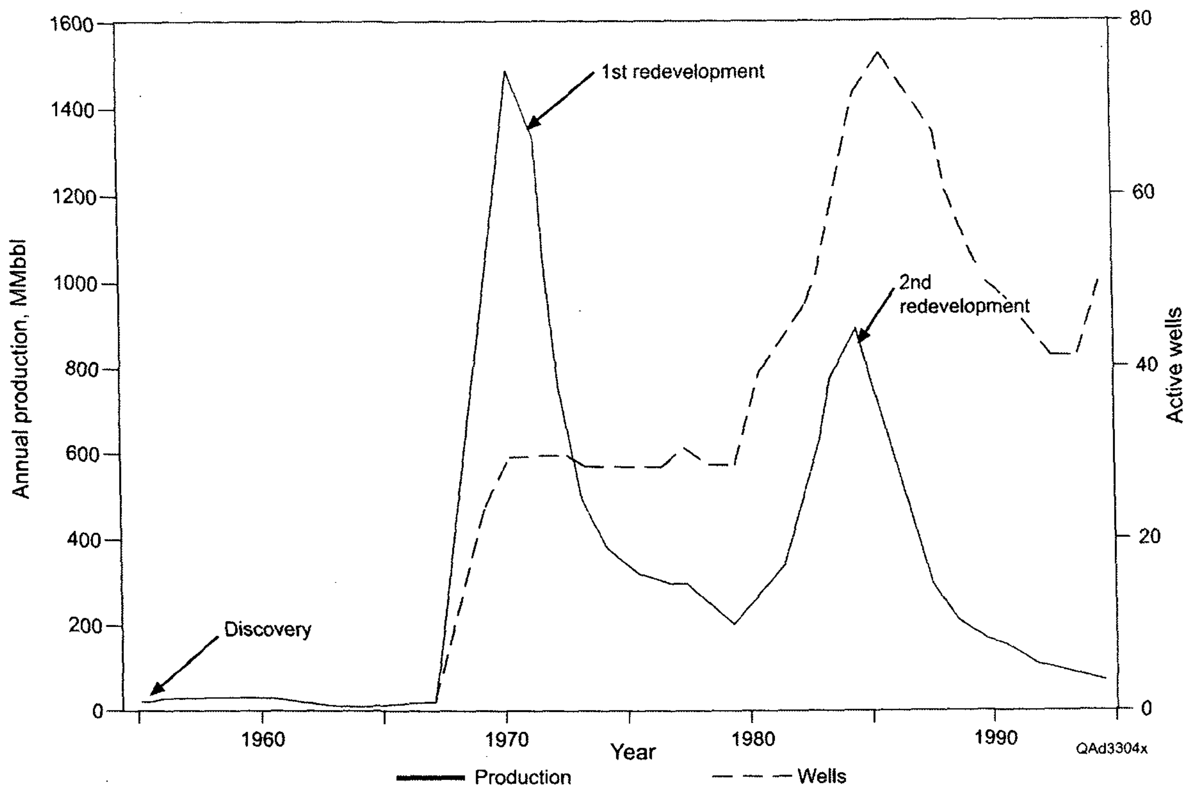

Figure 36. Historical annual oil production and number of productive wells active in any given year, Baum Upper Pennsylvanian reservoir. After Broadhead (1999).

increase in production (fig. 36). The stratigraphic nature of entrapment was often not recognized until large portions of the reservoir were drilled out many years after initial discovery. Recognition of the stratigraphic nature of these reservoirs early in development is necessary if the reservoir is to be developed efficiently and completely in the years immediately following discovery.

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Pennsylvanian Platform Carbonate (Play 111)

The Pennsylvanian Platform Carbonate play has been expanded both geographically and geologically from the Pennsylvanian Platform Carbonate play that was described in the *Atlas of Major Texas Oil Reservoirs* (Galloway and others, 1983). As originally defined by Galloway and others (1983), the play consisted of reservoirs that produce from Middle and Upper Pennsylvanian (Strawn, Canyon, and Cisco) carbonates located on the east edge of the Central Basin Platform. The play has been expanded in this report to include Atoka through Cisco reservoirs on the Texas part of the Northwest Shelf and Central Basin Platform and in the Midland Basin (fig. 37). The expanded play has produced 340.5 MMbbl (5.41×10^7 m^3) from 74 reservoirs (table 16).

The Central Basin Platform was an active, high-relief uplift during much of the Pennsylvanian (Frenzel and others, 1988). Lower Pennsylvanian Atoka deposits are interpreted to have been deposited before uplift of the Central Basin Platform (Tai and Dorobek, 1999). Upper Strawn strata may be the earliest synorogenic deposits, deposited on a carbonate ramp that prograded eastward (Tai and Dorobek, 1999). The most intensive uplift of the Central Basin Platform postdated the Strawn and continued from Middle Pennsylvanian to Early Permian time (Tai and Dorobek, 1999). Atokan and Desmoinesian carbonates in the Midland Basin were deposited on low-relief ramps at a time of relatively low regional subsidence, whereas Missourian and Virgilian deposits were deposited on higher-relief carbonate platforms at a time of higher rates of regional subsidence (Hanson and others, 1991; Mazzulo, 1997). High-frequency glacioeustatic sea-level fluctuations during the Pennsylvanian resulted in highly cyclic depositional sequences (Wahlman, 2001).

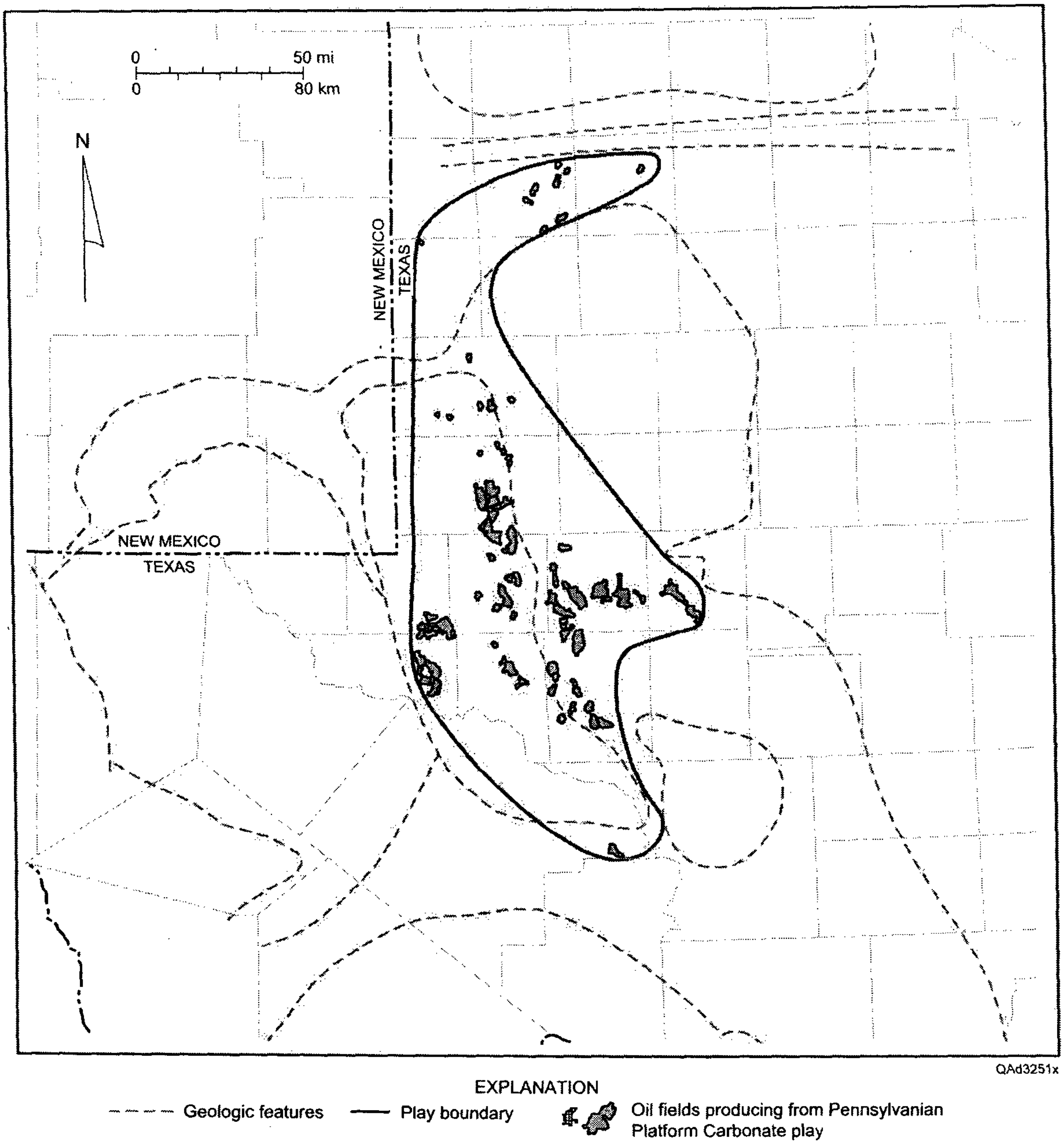

Figure 37. Play map for the Pennsylvanian Platform Carbonate play, showing location of reservoirs having >1 MMbbl cumulative production, the play boundary, and geologic features. See figure 1 for county names and figure 2 for identification of geologic features.

Table 16. Pennsylvanian Platform Carbonate play (play 111). Production shown for fields that have had others combined into them represents the totals; combined fields are highlighted.

RRC RESN	RRC	FLDNAME	RESNAME	STATE	COUNTY	DISCYR	DEPTHTOP	2000 PROD	CUMPROD
587166	7C	ADAMC	BEND	TX	UPTON	1958	9236	806	1,289,736
2207608	7C	AMACKER-TIPPETT	STRAWN	TX	UPTON	1954	9870	3,822	1,842,947
2212111	7C	AMACKER-TIPPETT, S.	BEND	TX	UPTON	1961	9848	11,984	6,908,189
2213250	7C	AMACKER-TIPPETT, SE	BEND 10600	TX	UPTON	1966	10637	19,801	4,159,301
2725500	8	ANDREWS	PENNSYLVANIAN	TX	ANDREWS	1954	9220	0	15,502,674
2727750	8	ANDREWS, NORTH	STRAWN	TX	ANDREWS	1959	9589	0	3,673,474
3177500	8A	ANTON, SOUTH	STRAWN	TX	HOCKLEY	1957	9952	3,914	1,178,657
3520500	8	ARENOSO	STRAWN DETRITUS	TX	WINKLER	1965	8567	100,645	22,076,851
4605080	8	AZALEA	ATOKA	TX	MIDLAND	1973	10898	25,979	2,996,387
5166555	8	BAKKE	PENN.	TX	ANDREWS	1956	8956	12,190	12,336,328
9359250	8	BLOCK 31, EAST	ATOKA	TX	CRANE	1965	8122	1,748	1,225,223
9362500	8	BLOCK 31, NW	PENN UPPER	TX	CRANE	1959	7967	22,107	4,489,768
9450200	7C	BLOCK 42	PENN	TX	UPTON	1956	9450	19,971	2,669,645
8958800	8	BLOCK A-34	STRAWN	TX	ANDREWS	1954	9916	0	1,100,472
11240500	8	BRADFORD RANCH	ATOKA	TX	MIDLAND	1979	11221	4,779	5,717,992
21287250	8	COWDEN	CISCO	TX	ECTOR	1955	8846	91,618	6,348,910
21289180	8	COWDEN, NORTH	CANYON	TX	ECTOR	1973	9094	37,950	1,428,470
21292750	8	COWDEN, SOUTH	PENNSYLVANIAN	TX	ECTOR	1955	8360	4,554	1,095,207
23131250	8	DARMER	CANYON	TX	WINKLER	1964	8500	42,577	2,323,635
23138500	8	DARMER, NE.	PENN.	TX	WINKLER	1978	8256	13,649	1,055,362
23907710	8	DEEP ROCK	PENN.	TX	ANDREWS	1961	9037	76,028	7,857,006
24396100	8	DESPERADO	ATOKA	TX	MIDLAND	1984	10845	56,793	3,642,912
24489380	8	DEWEY LAKE, S.	STRAWN	TX	GLASSCOCK	1985	10055	18,543	1,116,499
25395100	8	DORA ROBERTS	CONSOLIDATED	TX	MIDLAND	1995	10341	34,294	2,071,206
25585500	8A	DOSS	CANYON	TX	GAINES	1949	8850	0	1,712,794
28899747	8	EMMA	STRAWN	TX	ANDREWS	1958	9128	2,822	3,239,757
29507500	8	ESTES BLOCK 34	PENN.	TX	WARD	1957	8150	29,578	4,999,188
30394500	8	FASKEN	PENN.	TX	ECTOR	1956	10158	32,773	5,955,633
35653777	8	GOLDSMITH, E.	PENNSYLVANIAN	TX	ECTOR	1953	8621	4,224	1,655,075
38227333	8	HALLANAN	STRAWN	TX	MIDLAND	1952	10570	3,824	4,202,854
39176830	8	HARPER	STRAWN	TX	ECTOR	1962	9028	35,940	1,014,517
40295600	7C	HELUMA	PENN.	TX	UPTON	1956	8030	10,867	1,930,528
37821710	8	H.S.A.	PENNSYLVANIAN	TX	WARD	1960	8068	1,413	3,516,869
43083250	8A	HUAT	CANYON	TX	GAINES	1961	10470	51,032	6,037,105
44238500	8A	IDALOU	STRAWN	TX	LUBBOCK	1970	9264	10,230	2,063,298
46134250	8A	JENKINS, NORTH	CANYON	TX	GAINES	1952	8590	0	1,079,745
47007600	8	JOHNSON	PENN	TX	ECTOR	1973	9261	0	1,132,603
47267456	8	JORDAN	PENNSYLVANIAN	TX	CRANE	1953	7830	0	2,104,294
49415545	7C	KING MOUNTAIN, N.	CISCO	TX	UPTON	1975	8764	7,937	2,014,219
51812750	8A	LANDON	STRAWN	TX	COCHRAN	1947	10340	2,714	1,210,407
52567500	8	LAZY R	STRAWN DETRITUS	TX	ECTOR	1963	8307	2,689	1,211,321
53411710	8A	LEVELLAND	STRAWN	TX	HOCKLEY	1957	10120	0	1,044,056
53414500	8A	LEVELLAND, NE.	STRAWN	TX	HOCKLEY	1964	10084	15,627	3,448,189
59419498	8	MCFARLAND	PENNSYLVANIAN	TX	ANDREWS	1956	10423	15,707	5,053,412
60138500	8	MEANS, EAST	STRAWN	TX	ANDREWS	1954	10616	14,460	4,041,930
61473500	8	MILLER BLOCK B-29	PENN.	TX	WARD	1959	8104	3,428	2,737,993
62416666	8	MONAHANS, E.	PENN., LO.	TX	WINKLER	1964	8873	6,913	1,325,184
62418666	8	MONAHANS, NE.	PENN DETRITAL, UP	TX	WINKLER	1968	8128	14,434	3,878,539
62703400	8	MOONLIGHT	MISSISSIPPIAN	TX	MIDLAND	1984	11599	18,387	1,162,891
65766111	8	NOLLEY	CANYON	TX	ANDREWS	1967	10384	19,572	2,131,200
69193568	8	PARKER	PENNSYLVANIAN	TX	ANDREWS	1954	9087	13,914	8,334,854
69200500	8	PARKER, WEST	PENN.	TX	ANDREWS	1967	9046	5,109	1,151,180
69233498	8	PARKS	PENNSYLVANIAN	TX	MIDLAND	1950	10440	63,991	15,249,943
70279500	7C	PEGASUS	PENNSYLVANIAN	TX	UPTON	1951	10470	123,311	17,127,951
74590075	8A	RAND-PAULSON	CANYON	TX	HOCKLEY	1995	9638	39,819	1,123,263
78167001	8A	ROPES		TX	HOCKLEY	1950	9290	16,910	25,593,426
78175333	8A	ROPES, WEST	CISCO SAND	TX	HOCKLEY	1953	9875	5,449	7,217,081
79659700	8	SAINT LAWRENCE	STRAWN	TX	GLASSCOCK	1983	9890	11,994	1,469,268
81913750	8A	SEAGRAVES	STRAWN	TX	GAINES	1956	11243	7,155	1,049,161
82231540	8A	SEMINOLE, SE.	STRAWN	TX	GAINES	1973	10792	10,447	2,249,644
84347333	8A	SMYER, N.	CANYON	TX	HOCKLEY	1956	9630	0	5,195,857
84347666	8A	SMYER, N.	STRAWN	TX	HOCKLEY	1956	9968	0	6,354,886
87599568	8	SWEETIE PECK	PENNSYLVANIAN	TX	MIDLAND	1960	10342	5,911	2,158,236
89134750	7C	TEXEL	PENNSYLVANIAN	TX	UPTON	1954	9143	5,441	1,621,367
91350600	8	TRIPLE-N	PENN., UPPER	TX	ANDREWS	1958	8912	47,044	16,084,222
88071522	8	TXL	PENNSYLVANIAN	TX	ECTOR	1956	8450	0	1,045,392
92534500	8	UNIVERSITY BLOCK 9	PENN.	TX	ANDREWS	1954	8956	292,047	15,782,648
93458100	8	VIREY	CONSOLIDATED	TX	MIDLAND	1995	10844	57,783	3,429,592
94640500	8	WAGON WHEEL	PENN	TX	WARD	1979	8812	367,335	9,445,581
95138406	8	WARD, SOUTH	PENN. DETRI., UP.	TX	WARD	1963	7700	5,000	1,631,943
95108090	8	WAR-SAN	CONSOLIDATED	TX	MIDLAND	1995	10794	34,375	3,223,679
96408664	8A	WESCOTT	STRAWN	TX	GAINES	1954	11008	44,214	5,564,505
97834750	7C	WILSHIRE	PENNSYLVANIAN	TX	UPTON	1952	9810	4,304	1,374,833
99583600	8	YUCCA BUTTE, W	STRAWN	TX	PECOS	1975	8304	6,405	1,889,536
		Totals						**2,076,281**	**340,469,274**

Atokan reservoirs in the Midland Basin in Andrews and Midland Counties are composed of thin (15 to 20 ft [5 to 6 m]), silty to bioclastic-rich zones in the "Atoka" shale (Candelaria, 1990). During sea-level lowstands, carbonate detritus was carried from carbonate banks into relatively deeper water and deposited in extensive, sheetlike units up to 40 mi (64 km) long by 10 mi (16 km) wide (Candelaria, 1990). The Atoka reservoirs have porosity ranging from 6 to 8 percent; permeability is commonly less than 0.1 md ($0.1 \times 10^{-3}\ \mu m^2$). Natural fractures are interpreted to enhance storage capacity, continuity, and fluid transmissibility in these low-porosity, low-permeability reservoirs (Candelaria, 1990). Wells are typically stimulated by fracturing with diesel or lease crude oil to minimize formation damage by water and injecting 50,000 to 100,000 pounds of sand proppant. Simple acidizing treatments can damage Atoka reservoirs (Candelaria, 1990).

Some workers correlate the "Atoka" shale in this area to the Lower Pennsylvanian (Morrowan or Atokan), whereas others correlate it to the Upper Mississippian (Chester) Barnett Shale (Candelaria, 1990). The Atoka reservoirs have been included with the Pennsylvanian Platform Carbonate play in this report. Moonlight (Mississippian) reservoir has also been assigned to the Pennsylvanian Platform Carbonate play because, despite its name, it is interpreted as producing from a zone of bioclastic wackestones within the "Atoka" shale (Candelaria, 1990), similar to the Atoka reservoirs in fields such as Desperado and Azalea.

Strawn reservoirs on the Central Basin Platform and in the Midland Basin produce from shallow-marine, fossiliferous limestone; the traps are anticlines and faulted anticlines (Kosters and others, 1989). The reservoir in Seminole SE and other Strawn fields in Gaines County consist of *Chaetetes* (coral or sponge) biolithite and associated ooid and skeletal grainstones (Mazzullo, 1982). Strawn limestones also form reservoirs on the Northwest Shelf, in Hockley, Lubbock, and Cochran Counties (fig. 37). Strawn carbonates in the Wilshire Pennsylvanian reservoir, Upton County, were deposited on a shallow carbonate ramp that prograded eastward away from the incipient Central Basin Platform (Tai and Dorobek, 1999). Upper Strawn strata are missing at Wilshire field, probably because of post-Strawn uplift and erosion on the fault-bounded anticline that forms the trap (Tai and Dorobek, 1999). Several Strawn reservoirs in Ward, Winkler, and Ector Counties on the Central Basin Platform produce from detrital limestone, dolomite, chert, and sandstone, known as "Strawn Detritus." These detrital facies are attributed to erosion of older carbonates and cherts on exposed Pennsylvanian structures (Kosters and others, 1989; Van Der Loop, 1991; Tai and Dorobek, 1999). The largest of these fields is the Arenoso Strawn Detritus reservoir, which produces mainly from chert conglomerates and sandstones deposited in alluvial-fan, braided-stream, and shoreface environments (Van Der Loop, 1991).

On the east side of the Midland Basin, the Strawn produces in reservoirs such as the St. Lawrence from high-frequency, upward-shallowing cycles. Cycles are composed of low-energy, mud-rich facies at the base, overlain by high-energy, grain-rich facies that form the reservoirs (Sivils and Stoudt, 2001; Sivils, 2002). Core-measured porosity (maximum 10 percent) agrees well with log porosity. Correlation of cycles is possible because of the close tie between log signature of cycles and cycles observed in core (Sivils, 2002).

Many of the larger reservoirs in this play, such as the Andrews, Triple-N, and University Block 9, produce from Upper Pennsylvanian carbonates on the east side of the Central Basin Platform and in Hockley County (fig. 37). Detailed descriptions of a typical Upper Pennsylvanian platform-carbonate reservoir on the Central Basin Platform were published by Saller and others (1994, 1999a, b) and Dickson and Saller (1995). The Strawn through Cisco section represents one long-term regression on the east side of the Central Basin Platform, and a major unconformity occurs at the top of the Pennsylvanian (Saller and others, 1999b). These studies illustrate that the reservoirs are developed in highly cyclic successions of shallow-water carbonate-platform facies. The deposits thin to the west, indicating that the Central Basin Platform was a depositional high during the Late Pennsylvanian and Early Permian (Saller and others, 1999b). Stratigraphic heterogeneity is created by cyclic alternations of porous and nonporous limestone facies and shales (figs. 38, 39). Additional heterogeneity is contributed by karst-related diagenesis at and below cycle tops during sea-level-fall events (Dickson and Saller, 1995). Porosity in these rocks is developed primarily in phylloid algal boundstones, thick

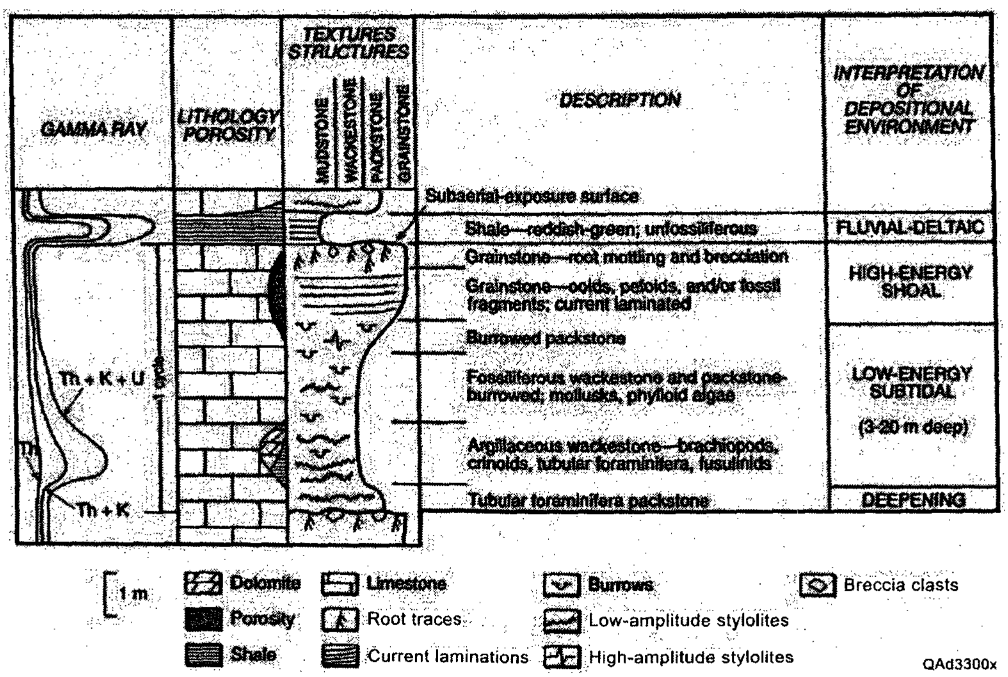

Figure 38. Idealized upward-shallowing cycle in Upper Pennsylvanian carbonates in the Southwest Andrews area. From Saller and others (1999b).

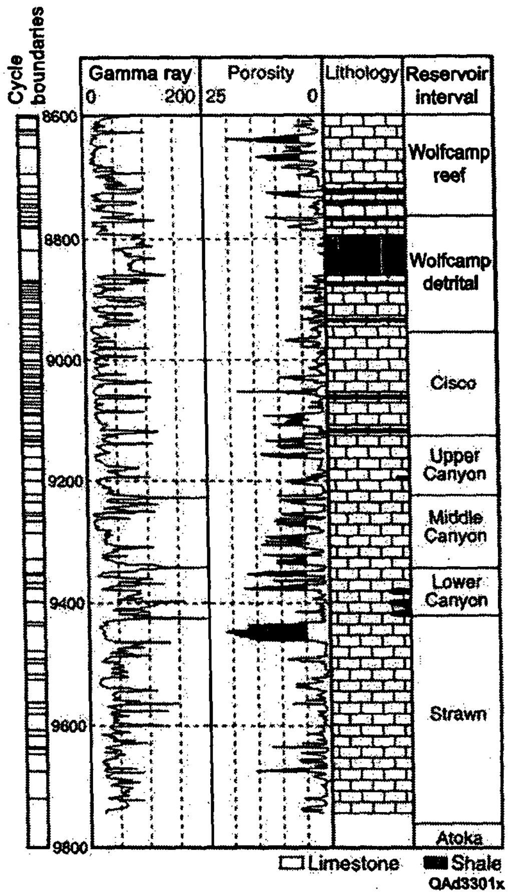

Figure 39. Core description and gamma-ray log through the producing interval in the X-1 well, Andrews field, Southwest Andrews area, Andrews County. After Saller and others (1999a), reprinted by permission of the AAPG, whose permission is required for further use. ©Copyright 1999. The American Association of Petroleum Geologists. All rights reserved. See Saller and others (1999a) for well location.

grainstones, and a few wackestone/packstones (Saller and others, 1999a). Phylloid algae were the dominant mound builders in shelf and shelf-margin areas during the Middle and Late Pennsylvanian (Wahlman, 2001). Phylloid-algal buildups developed during the late, highstand parts of Pennsylvanian depositional sequences and were commonly exposed to meteoric diagenesis when sea level fell (Wahlman, 2002).

Reservoir-grade porosity (>4 percent) occurs in 5 to 25 percent of the gross reservoir interval (fig. 40) (Saller and others, 1999a). Porosity is best developed in the upper part of cycles >6 ft (2 m) thick that were subjected to subaerial erosion for brief to moderate lengths of time

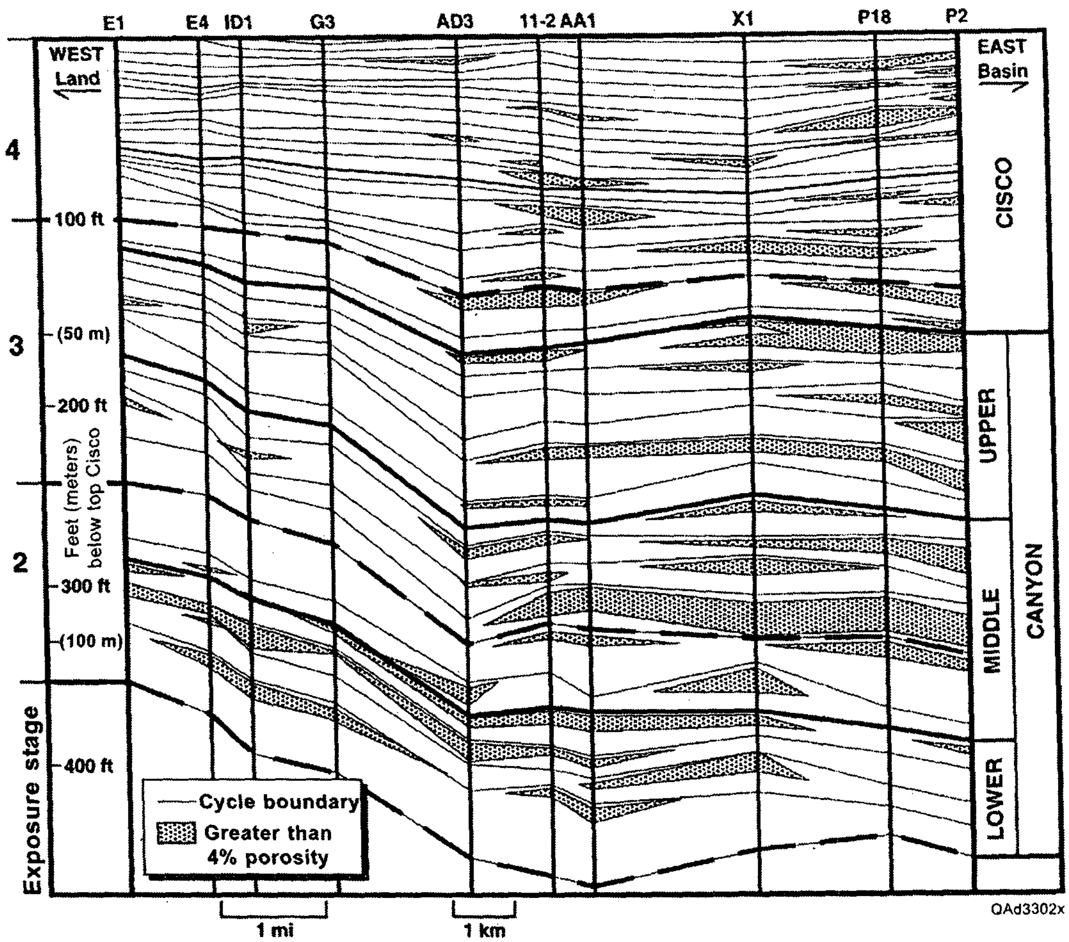

Figure 40. Stratigraphic cross section showing distribution of porous limestone in the Canyon and Cisco intervals in Deep Rock and Parker fields, southwest Andrews County. After Saller and others (1999a), reprinted by permission of the AAPG, whose permission is required for further use. ©Copyright 1999. The American Association of Petroleum Geologists. All rights reserved. See Saller and others (1999a) for location of cross section.

(Saller and others, 1999b). Reservoir porosity is largely determined by the amount of burial compaction and cementation and not by the amount of porosity created during subaerial exposure (Dickson and Saller, 1995). Porosity in Ropes field, which produces from a Canyon-Cisco limestone buildup, averages 8.5 percent; permeability averages 66 md ($66 \times 10^{-3}\ \mu m^2$) and ranges from 0.1 to 1,100 md (0.1 to $1,100 \times 10^{-3}\ \mu m^2$) (Godfrey, 1982; Collier and others, 1998).

Simple anticlinal closures form traps for most of these reservoirs. The traps are interpreted to be postdepositional, but productive areas within the structural traps are limited because of the irregular distribution of porous facies (Galloway and others, 1983). Ropes field produces from a stratigraphic trap (Godfrey, 1966; Collier and others, 1998).

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Pennsylvanian and Lower Permian Horseshoe Atoll Carbonate (Play 112)

This large play, the Pennsylvanian and Lower Permian Horseshoe Atoll Carbonate, has produced 2,699.2 MMbbl (4.29×10^8 m^3) from 70 reservoirs within the Horseshoe Atoll, a nonreefal, isolated, carbonate platform system in the northern Midland Basin (table 17, figs. 41, 42). Production is from stacked Strawn through Wolfcamp limestones and dolomitic limestones that aggraded from the floor of the basin in a northward-opening arc (Galloway and others, 1983). Deposition of the Horseshoe Atoll began on a broad Strawn carbonate platform that lay basinward of the clastic deposition in North-Central Texas (Vest, 1970). Isolated reservoirs produce from Strawn carbonates in Garza and Borden Counties, where carbonate mounds developed on local structural highs in the underlying Ellenburger (F. J. Lucia, personal communication, 2000). During lowstands, these mounds were subaerially exposed, and meteoric diagenesis developed moldic porosity.

Through time, isolated carbonate knolls and pinnacles evolved from the laterally continuous carbonate platform. Subsidence of the Midland Basin led to repeated backstepping of the platform from Strawn through Canyon and Cisco time, and considerable relief developed on the vertically accreting pinnacles (Vest, 1970; Galloway and others, 1983; Kerans, 2001b). Early-middle Canyon, high-frequency eustatic shifts produced systematic upward-coarsening, tight-to-porous cycles that cause strongly layered reservoir heterogeneity (fig. 43). In the later Canyon and Cisco, high-frequency cycles show higher amplitude eustatic shifts and cycle-scale karstification (Kerans, 2001b). The lithofacies that compose the Horseshoe Atoll include sponge-algal-bryozoan and phylloid-algal-mound wackestones and boundstones, crestal tidal-flat and peritidal wackestones, shoal and shoreface grainstones, shelf crinoidal wackestones, and debris-flow lithoclast packstones and wackestones (Galloway and others, 1983; Schatzinger, 1988).

Table 17. Pennsylvanian and Lower Permian Horseshoe Atoll Carbonate play (play 112). Production shown for fields that have had others combined into them represents the totals; combined fields are highlighted.

RRC RESN	RRC	FLDNAME	RESNAME	STATE	COUNTY	DISCYR	DEPTHTOP	2000 PROD	CUMPROD
450250	8A	ACKERLY, NORTH	CANYON REEF	TX	DAWSON	1958	9154	11,621	1,198,872
450375	8A	ACKERLY, NORTH	CISCO	TX	DAWSON	1972	8766	0	1,106,255
570500	8A	ADAIR	WOLFCAMP	TX	TERRY	1950	8505	41,192	52,422,109
573500	8A	ADAIR, NORTHEAST	WOLFCAMP	TX	TERRY	1954	8846	11,361	1,326,016
3250510	8A	APCLARK	STRAWN	TX	BORDEN	1996	8534	159,265	1,231,864
4690300	8	B.C.	CANYON	TX	HOWARD	1985	9041	15,035	1,226,734
12476400	8A	BROWNFIELD, S.	STRAWN	TX	TERRY	1981	10613	20,545	1,349,752
12469333	8A	BROWNFIELD, SOUTH	CANYON	TX	TERRY	1950	9330	5,381	5,252,940
14627666	8A	CAIN	STRAWN	TX	GARZA	1959	7652	10,735	1,047,176
14215250	8	C. C. GUNN	CANYON REEF	TX	HOWARD	1987	7564	30,109	1,006,890
19346142	8A	COGDELL	AREA	TX	KENT	1949	6796	600,930	264,228,838
19347250	8A	COGDELL, EAST	CANYON	TX	SCURRY	1958	6813	25,162	5,745,654
19351333	8A	COGDELL, SE.	CANYON 6800	TX	SCURRY	1970	6832	3,718	1,935,449
24562142	8A	DIAMOND -M-	CANYON LIME AREA	TX	SCURRY	1948	6569	1,076,585	248,878,432
25728500	8A	DOUBLE J	CANYON REEF	TX	BORDEN	1969	6641	82,743	4,335,241
25957600	8A	DOVER	STRAWN	TX	GARZA	1985	8123	54,320	1,268,004
28829500	8A	ELZON, W.	STRAWN 6950	TX	KENT	1967	6972	20	1,674,677
31690750	8A	FLUVANNA	STRAWN	TX	BORDEN	1954	7769	92,125	13,893,241
31697847	8A	FLUVANNA, SW.	STRAWN, UPPER	TX	BORDEN	1973	7902	8,245	3,048,201
33191250	8A	FULLER, EAST	CANYON	TX	SCURRY	1961	6846	20,059	2,016,286
34849500	8A	GILL	PENN. REEF 6900	TX	SCURRY	1970	6937	86,966	1,155,277
35738001	8A	GOOD		TX	BORDEN	1949	7905	97,619	49,768,450
35741500	8A	GOOD, NORTHEAST	CANYON REEF	TX	BORDEN	1953	8066	62,258	3,509,246
35744333	8A	GOOD, SE.	CANYON REEF	TX	BORDEN	1959	8123	0	1,095,717
38866666	8A	HAPPY	STRAWN	TX	GARZA	1958	7951	1,367	1,839,792
40716333	8A	HERMLEIGH	STRAWN	TX	SCURRY	1953	6530	27,627	1,051,427
41816333	8A	HOBO	PENNSYLVANIAN	TX	BORDEN	1951	7100	33,656	12,964,339
48583001	8A	KELLY-SNYDER		TX	SCURRY	1948	6795	3,183,905	1,264,215,085
49678500	8A	KIRKPATRICK	PENN.	TX	GARZA	1961	7902	1,367	1,534,724
55578500	8A	LUCY, NORTH	PENN	TX	BORDEN	1973	7830	13,944	2,259,712
55818333	8	LUTHER, NORTH	CANYON REEF	TX	HOWARD	1952	7950	15	1,789,764
55975500	8A	LYN KAY	6150	TX	KENT	1975	6164	27,520	1,157,730
61046250	8	MIDDLETON	CANYON REEF	TX	HOWARD	1986	8536	51,998	1,285,697
63799500	8A	MUNGERVILLE	PENNSYLVANIAN	TX	DAWSON	1951	8570	82,273	9,030,669
64217500	8A	MYRTLE, NW.	STRAWN	TX	BORDEN	1967	8030	125	1,013,491
64221666	8A	MYRTLE, W.	STRAWN	TX	BORDEN	1956	8072	3,498	2,662,450
66669500	8	OCEANIC	PENNSYLVANIAN	TX	HOWARD	1953	8140	136,138	24,059,565
66672500	8	OCEANIC, N.E.	PENNSYLVANIAN	TX	BORDEN	1968	8135	7,463	1,495,837
70661300	8	PERRIWINKLE	CANYON	TX	MARTIN	1985	9420	72,795	1,062,980
72213500	8A	POLAR, EAST	PENNSYLVANIAN	TX	KENT	1950	6855	0	1,993,424
72560500	8A	POST, WEST	STRAWN	TX	GARZA	1979	8482	0	1,099,724
75780001	8A	REINECKE		TX	BORDEN	1950	6791	562,858	85,247,005
75781500	8A	REINECKE, E.	CANYON	TX	BORDEN	1966	6794	2,329	1,281,886
79131666	8	RUWE-COB	PENN REEF	TX	HOWARD	1967	7424	12,681	1,207,162
79887001	8A	SALT CREEK		TX	KENT	1950	6200	5,792,610	356,369,037
79891500	8A	SALT CREEK, SOUTH	PENN., LOWER	TX	KENT	1952	6622	0	1,403,717
81021250	8	SARA-MAG	CANYON REEF	TX	HOWARD	1954	7580	250,936	3,937,283
81987400	8A	SEAN ANDREW	PENN.	TX	DAWSON	1994	8329	51,699	1,296,502
84470750	8A	SNYDER, N	STRAWN ZONE B	TX	SCURRY	1950	7300	9,371	7,936,335
85292750	8A	SPRABERRY, WEST	PENN.	TX	DAWSON	1953	8060	4,988	2,293,014
85743666	8A	STATEX	CISCO REEF	TX	TERRY	1952	10032	12,433	2,870,697
87646500	8A	SWENSON-GARZA	STRAWN	TX	GARZA	1971	7356	0	1,390,411
88611568	8A	TEAS	PENN. 8100	TX	GARZA	1958	8069	20,205	3,892,415
88760100	8A	TEN GALLON	CANYON LIME	TX	SCURRY	1992	6760	57,981	1,173,235
88977142	8A	TEX-HAMON	CANYON	TX	DAWSON	1962	10060	9,715	1,399,045
90268333	8A	TOBE	STRAWN	TX	GARZA	1951	7451	22,077	1,733,188
90697500	8A	TONTO, NE.	CISCO 5030	TX	SCURRY	1966	5046	6,147	1,700,852
91318500	8A	TRIPLE D	PENN. REEF	TX	DAWSON	1958	8497	1,913	1,088,474
91115500	8A	TRI-RUE	REEF	TX	SCURRY	1956	6862	100,444	6,516,418
91670700	8A	TUFBOW	STRAWN	TX	GARZA	1979	7599	21,027	1,300,773
92290666	8A	U-LAZY -S-	PENNSYLVANIAN	TX	BORDEN	1958	8084	4,390	3,015,323
93308001	8	VEALMOOR		TX	HOWARD	1948	7934	106,125	39,565,153
93310001	8	VEALMOOR, EAST		TX	HOWARD	1950	7414	154,771	62,692,195
93854500	8	VINCENT, N.	PENNSYLVANIAN REEF	TX	HOWARD	1957	7444	28,497	2,558,261
93857500	8	VINCENT, S.	STRAWN	TX	HOWARD	1964	7839	17,244	1,195,546
93860500	8	VINCENT, WEST	PENN.	TX	HOWARD	1957	7454	23,579	1,116,613
94114001	8A	VON ROEDER		TX	BORDEN	1959	6835	63,015	19,299,794
94114666	8A	VON ROEDER	WOLFCAMP	TX	BORDEN	1964	6063	9,091	1,020,734
94116001	8A	VON ROEDER, NORTH		TX	BORDEN	1954	6835	12,654	10,322,342
96180001	8A	WELLMAN		TX	TERRY	1950	9712	228,174	74,181,795
		Totals						13,686,639	2,699,242,936

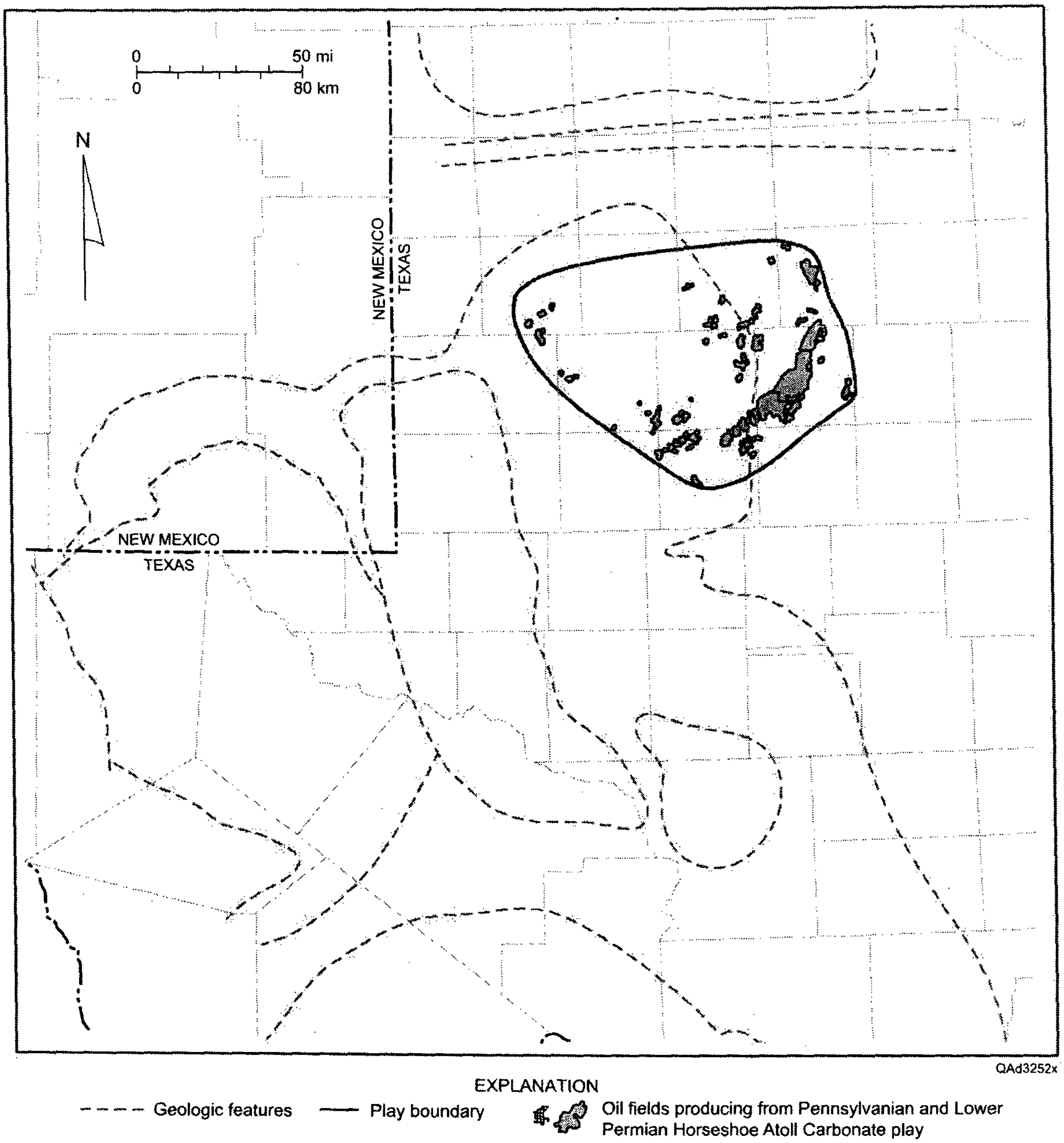

Figure 41. Play map for the Pennsylvanian and Lower Permian Horseshoe Atoll Carbonate play, showing location of reservoirs having >1 MMbbl cumulative production, the play boundary, and geologic features. See figure 1 for county names and figure 2 for identification of geologic features.

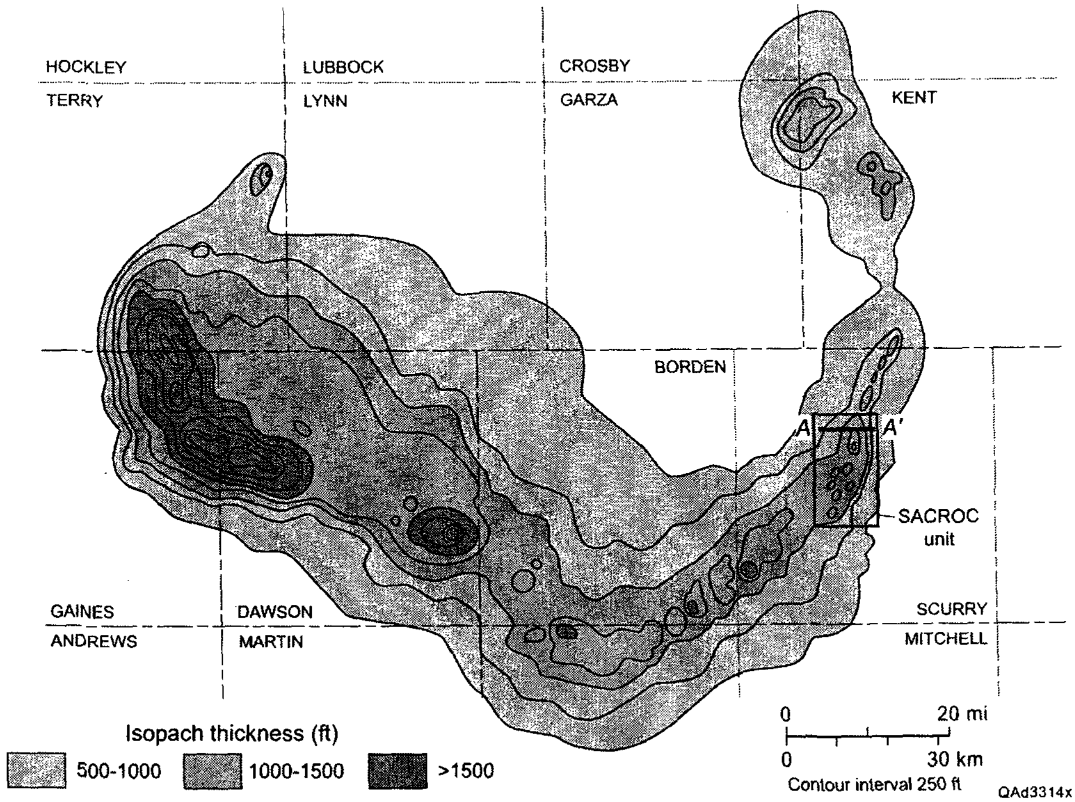

Figure 42. Isopach map of the Horseshoe Atoll carbonate. Modified from Galloway and others (1983); after Vest (1970). The thickest carbonate buildup is along the western margin, which is structurally lower, and where active atoll accretion continued into Early Permian time (Galloway and others, 1983). Cross section A-A′ shown in figure 44.

Prevailing winds and ocean currents influenced the distribution of carbonate facies (Walker and others, 1991; 1995). Percentages of grainstones are highest in the northeast, windward part of the platform, whereas mud-dominated facies predominate to the southwest (Schatzinger, 1988; Walker and others, 1991; 1995).

Because the Horseshoe Atoll was deposited under icehouse conditions during a time of peak glaciation, there were high-frequency oscillations of sea level by 65 to 460 ft (20 to 140 m) (Reid and Reid, 1999; C. Kerans, personal communication, 2002). Fresh water percolated through the carbonate platform during sea-level lowstands, resulting in the development of

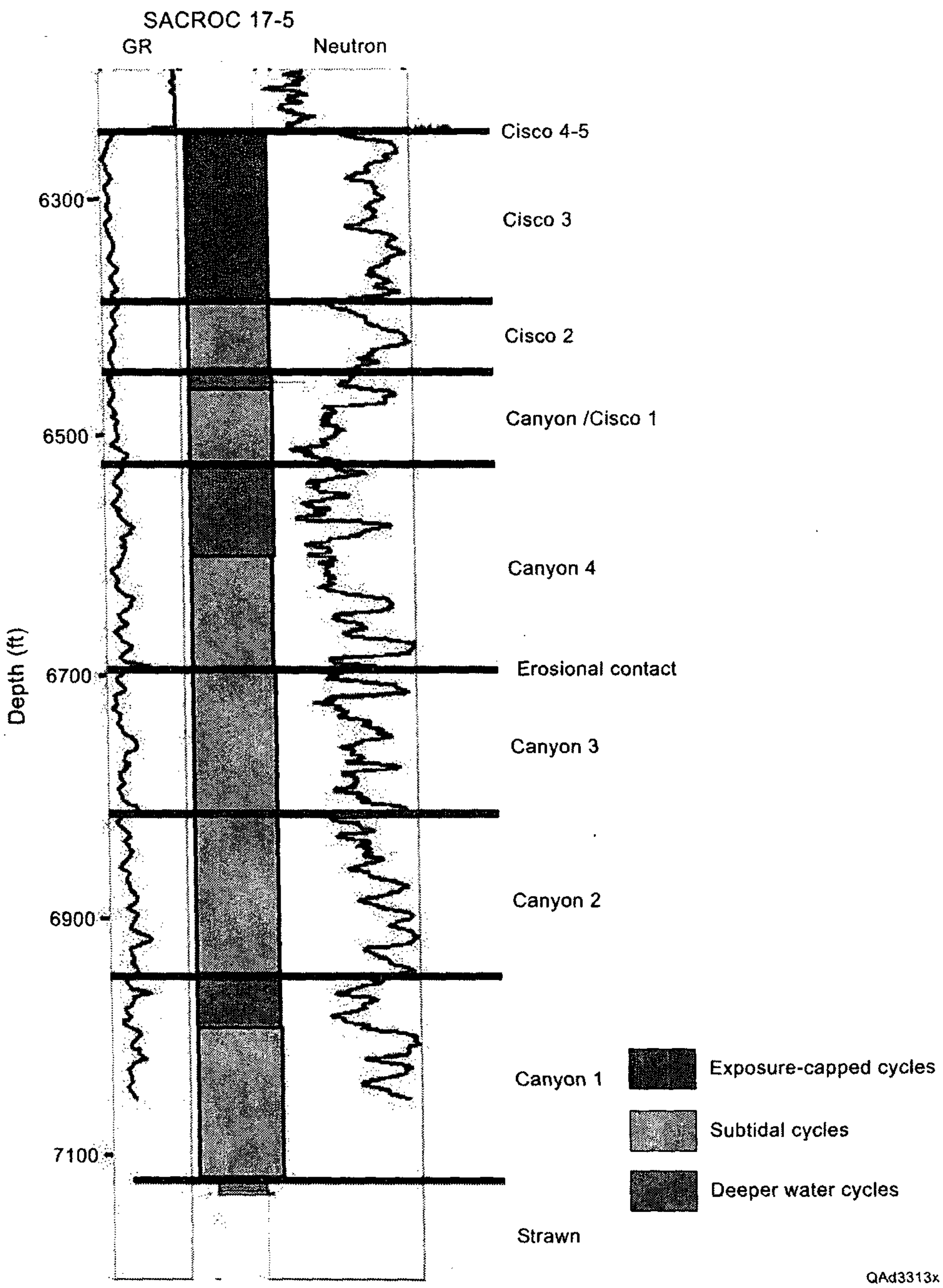

Figure 43. Typical log from the center of the Horseshoe Atoll in the SACROC unit showing high-frequency sequences.

caves, karst, and fractures, as well as fabric-selective moldic porosity (Reid and Reid, 1991; Mazzullo, 1997; C. Kerans, personal communication, 2002). Prolonged exposure in the middle

Cisco terminated platform growth locally (Kerans, 2001b). Exposure and erosion at sequence boundaries produced a series of truncation surfaces, with local development of lowstand/ transgressive wedges on the flanks of the platform. The Horseshoe Atoll was buried beneath prograding slope and basin clastic sediments from the east; Wolfcamp shales provide top and lateral seals.

A few of the reservoirs in this play were deposited south of the Horseshoe Atoll during sea-level lowstands, including BC Canyon in Howard County, Perriwinkle Canyon in Martin County, and Tex-Hamon Canyon in Dawson County (Reid and others, 1990; Mozynski and Reid, 1992; Mazzullo, 1997, 2000). Reservoirs occur in both in situ carbonate buildups and reworked limestone-clast breccias derived from the exposed carbonate platform. These shallow-water carbonates were deposited during lowstands in areas that were relative deepwater-slope environments during sea-level highstands (Mazzullo, 1997). Because the lowstand carbonate reservoirs are included, the play boundary extends farther south than is commonly shown for the outline of the Horseshoe Atoll.

Detailed reservoir studies have been conducted of the SACROC unit (Kerans, 2001a, b; Raines and others, 2001). The SACROC (Scurry Area Canyon Reef Operators Committee) unit, which incorporates nearly all of Kelly-Snyder field and part of Diamond -M- field, is the largest producing unit of the Horseshoe Atoll play. (Horseshoe Atoll production is listed in table 17 under Railroad Commission of Texas reservoir names and not by units. Thus, production from the SACROC unit is listed under the Kelly-Snyder reservoir, and production from the Sharon Ridge unit is listed under the Diamond -M- (Canyon Lime Area) reservoir.) Since discovery in the 1940's, primary, secondary, and tertiary recovery activities in the SACROC unit have been extensive, including the first CO_2 flood in west Texas.

The north part of the SACROC unit is depositionally and diagenetically complex (Raines and others, 2001). In this area, the 700-ft-thick (310-m) reservoir column consists of Canyon and Cisco carbonates that change from layered, open-shelf subtidal cycles having minimal diagenetic overprint (lower and mid-Canyon) to high-energy, shoal-related cycles having frequent exposure surfaces (upper Canyon–lower Cisco) and increased evidence of cycle and sequence-scale erosion (fig. 44) (Kerans, 2001a, b). Early Cisco deposition was characterized by dramatic changes in depositional style, including growth of pinnacle reefs and formation of complex, fractured, muddy, crinoid-dominated facies that resemble Waulsortian deeper-water buildups (Wilson, 1975). Porosity in the SACROC unit ranges from 4.0 to 20.0 percent and averages 9.8 percent; permeability ranges from 1 md to 1,760 md (1 to 1,760 $\times 10^{-3}\ \mu m^2$) and averages 19 md (19 $\times 10^{-3}\ \mu m^2$) (Wingate, 1996).

Seismic data were used extensively in constructing the stratigraphic framework of the SACROC unit and allowed significant advances in our understanding of the stratigraphic architecture that were not possible with logs alone. The result of this modeling is a 3-D volume that is drastically different from that previously generated. Huge volumes of the platform previously modeled as laterally continuous layers can be shown to consist of erosionally generated slope wedges associated with major icehouse eustatic sea-level falls (fig. 44). Complex promontories and reentrants similar to the present-day Bahama platform mark the edges of the field, and large windward-leeward asymmetries control reservoir-quality distribution. Muddy zones are extensive across the entire reservoir and have a large impact on flow (C. Kerans, personal communication, 2002). This modern model of the north part of the SACROC unit should greatly aid ongoing efforts for enhanced recovery using water-alternating-with-gas (WAG) processes and related practices. An estimated 700 MMbbl ($1.11 \times 10^8\ m^3$) of

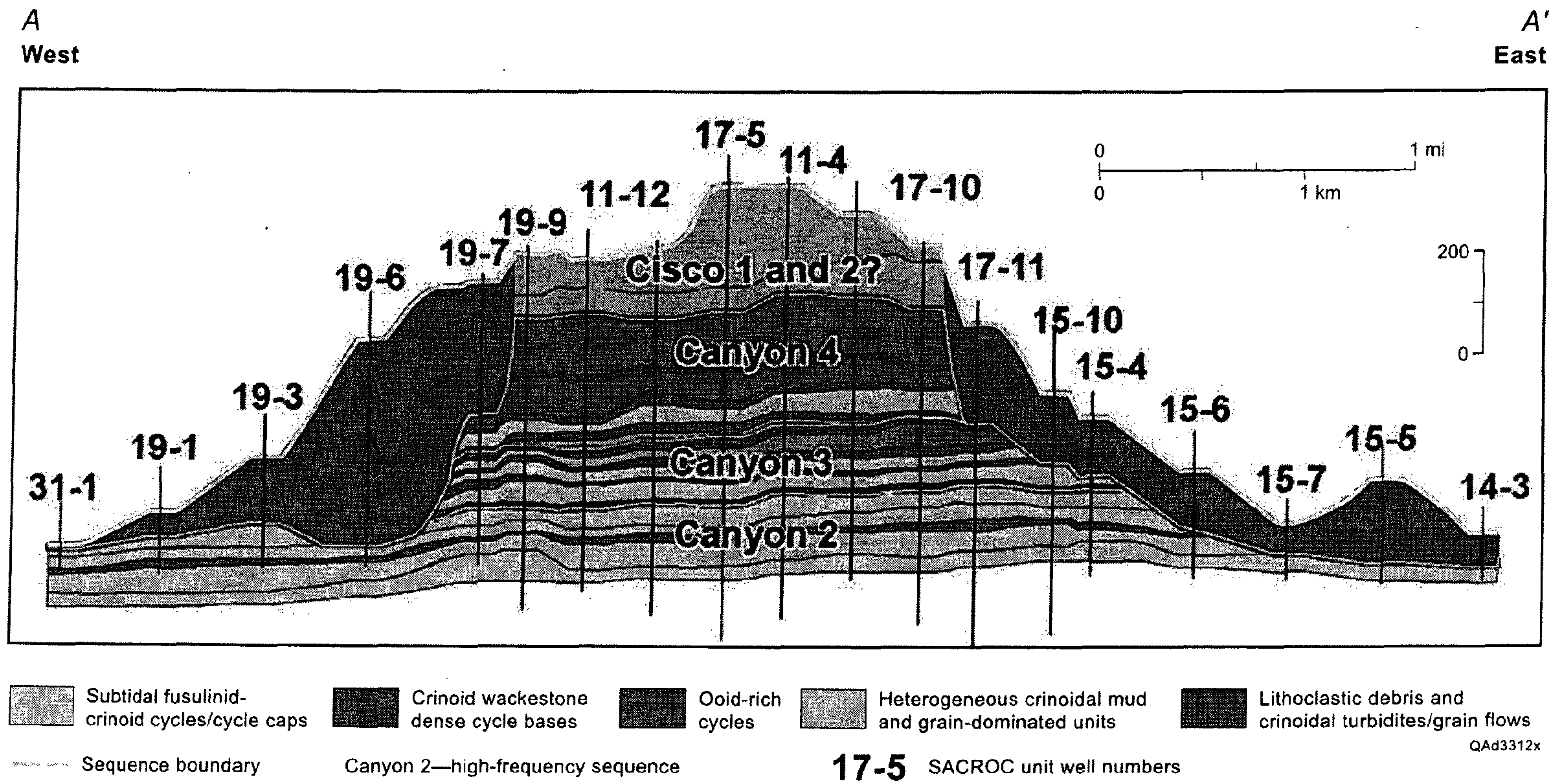

Figure 44. East-west cross section A-A′ of the north part of SACROC unit. Location of section shown in figure 42.

unrecovered mobile oil remains in the Pennsylvanian and Lower Permian Horseshoe Atoll Carbonate play (Tyler and Banta, 1989).

The SACROC unit has undergone CO_2 flooding since 1972, but recent modifications to the CO_2-flood design in the central part of the unit have increased production by ~6,000 bbl/d (9.54×10^2 m^3) (Raines and others, 2001). Unit production in 2002 was at an 8-year high of 11,000 bbl/d (1.75×10^3 m^3) (Raines, 2002). The changes to the flood include (Raines and others, 2001)

(1) Targeting oil that is residual to the earlier waterflood, instead of attempting to recover oil unswept by the earlier waterflood.

(2) Ensuring that the pressure inside areas to be flooded is above minimum miscibility pressure before CO_2 injection begins. If water is injected to raise the pressure in the area, it is injected below the parting pressure so that the formation is not fractured.

(3) Using smaller, injection-centered 5-spot patterns of about 40 acres.

(4) Containing the CO_2 project area by a row of water-curtain wells beyond the producers to reduce CO_2 migration outside the pattern. Mass-balance analysis indicated that approximately 50 percent of injected CO_2 was being lost out of intended patterns.

(5) Increasing the volume of CO_2 injected to ~70 percent of the hydrocarbon pore volume in the pattern area.

(6) Using a multiphase Water Alternating with Gas (WAG) injection scheme instead of one or two continuous CO_2 slugs. WAG injection slows down the CO_2 flood front to delay breakthrough and reduces costs.

(7) Acquiring 4-D (time-lapse) cross-well seismic data to track CO_2 in the reservoir by comparing seismic velocity profiles between wells after less-dense CO_2 has replaced oil and water (Raines, 2003).

The revised CO_2 flood has arrested production decline in the SACROC unit. In 2001 the central area that is undergoing the CO_2 flood contributed ~75 percent of total unit production (Raines and others, 2001). Many of the lessons learned at the SACROC unit should be applicable both to CO_2 floods in other reservoirs in this play and carbonate reservoirs in other plays in the Permian Basin. CO_2 floods are also being conducted in other fields producing from the Horseshoe Atoll, including Salt Creek, Cogdell, Diamond -M-, the Sharon Ridge unit of Diamond -M- field (Kinder Morgan, personal communication, 2002), and Cogdell field (S. Pennell, personal communication, 2002). Phase 1 CO_2 flood at the north end of Cogdell field started in late 2001 and has increased production from an average of 369 bopd in 2001 to 2500 bopd in November 2002. Salt Creek field has undergone secondary waterflooding and tertiary CO_2 flooding that have achieved a recovery of more than 50 percent of OOIP; ultimate recovery may be as high as 60 percent of OOIP (Genetti and others, 2002).

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Upper Pennsylvanian and Lower Permian Slope and Basinal Sandstone (Play 113)

The Upper Pennsylvanian and Lower Permian Slope and Basinal Sandstone play, called Upper Pennsylvanian Slope Sandstone in the oil atlas (Galloway and others, 1983), has produced 271.4 MMbbl (4.31×10^7 m^3) from 59 reservoirs in the Midland Basin and along the Eastern Shelf (table 18, fig. 45). Much of the play is in the North-Central Texas geologic province, but because a significant part of the play is located in the Permian Basin, the entire play is included in this portfolio. Of the 59 reservoirs in the play (fig. 45), 28 are in the Permian Basin and 31 are in North-Central Texas. The reservoirs in the Permian Basin had cumulative production of 108.3 MMbbl (1.72×10^7 m^3), compared with 163.1 MMbbl (2.59×10^7 m^3) from the North-Central Texas reservoirs.

As the Eastern Shelf prograded into the Midland Basin during Cisco and Wolfcamp deposition, a sequence of submarine fans accumulated at the base of offlapping slope wedges (fig. 46) (Galloway and Brown, 1972; Galloway and others, 1983; Brown and others, 1987, 1990). Reservoir sand bodies were deposited in lower parts of the slope wedges along a broad north-south-trending belt. As a result of miscorrelation of slope and basin reservoirs with older shelf units, the "Canyon" sandstone reservoirs of this play are commonly correlative with Cisco or Wolfcamp strata on the Eastern Shelf (Galloway and others, 1983; Neuberger, 1987).

The sandstones of this play were interpreted by Brown and others (1987, 1990) and Whitsitt (1992b) to have been deposited during periods of sea-level lowstand. Rapid fall of relative sea level eroded submarine canyons and produced Type 1 unconformities; basin-floor fans were deposited on the unconformities. During maximum fall of relative sea level and earliest relative rise, lowstand slope fans and deltaic/slope wedge systems prograded into the Midland Basin (fig. 47) (Brown and others, 1990). The reservoirs are developed within large,

Table 18. Upper Pennsylvanian and Lower Permian Slope and Basinal Sandstone play (play 113). Production shown for fields that have had others combined into them represents the totals; combined fields are highlighted.

RRC RESN	RRC	FLDNAME	RESNAME	STATE	COUNTY	DISCYR	DEPTHTOP	2000 PROD	CUMPROD
2718400	7C	ANDREW A.	CANYON	TX	IRION	1979	7390	58,724	3,321,404
3602550	7C	ARLEDGE	PENN SAND	TX	COKE	1974	5270	7,065	1,191,965
4170666	7B	ASPERMONT LAKE	CANYON SAND	TX	STONEWALL	1951	4862	9,193	2,236,772
5143300	7C	BAKER RANCH	CANYON	TX	IRION	1978	7010	24,266	2,298,589
8630400	7C	BLOODWORTH, NE	5750 CANYON	TX	NOLAN	1957	8,124	8,124	3,710,179
12175852	7C	BRONTE	4800 SAND	TX	COKE	1952	4838	0	6,075,918
12244075	7C	BROOKS	CANYON K	TX	IRION	1973	6494	19,495	1,072,548
17991500	7C	CHRISTI	CANYON 6800	TX	IRION	1971	6824	5,798	1,192,011
18799498	7B	CLAYTONVILLE	CANYON SD. 5200	TX	FISHER	1955	5197	3,458	2,094,750
19346284	8A	COGDELL	FULLER SAND	TX	KENT	1950	4985	0	1,234,509
20097700	8	CONGER	PENN	TX	GLASSCOCK	1978	7739	222,782	20,406,219
20101500	7C	CONGER, SW	PENN	TX	REAGAN	1979	8134	19,879	2,675,544
25930284	7C	DOVE CREEK	CANYON -C-	TX	TOM GREEN	1965	6497	11,268	1,205,124
25930426	7C	DOVE CREEK	CANYON -D-	TX	IRION	1965	6540	30,509	3,140,304
31628250	7B	FLOWERS	CANYON SAND	TX	STONEWALL	1951	4024	99,721	31,076,719
31634500	7B	FLOWERS, W.	CANYON SAND	TX	STONEWALL	1952	4270	9,629	5,653,948
32653400	7B	FRANKIRK	CANYON SAND	TX	STONEWALL	1952	4587	18,389	1,526,680
32654332	7B	FRANKIRK, EAST	CANYON SD	TX	STONEWALL	1960	4406	6,874	1,940,490
33190001	8A	FULLER		TX	SCURRY	1951	5147	18,667	7,431,645
33191500	8A	FULLER, EAST	FULLER -B-	TX	SCURRY	1961	4935	15,763	1,251,629
33196332	8A	FULLER, SE.	FULLER	TX	SCURRY	1957	5032	6,292	1,233,168
33196498	8A	FULLER, SE.	FULLER -C-	TX	SCURRY	1961	5029	23,956	1,356,946
37328333	7B	GUEST	CANYON SAND	TX	STONEWALL	1951	4557	47,833	10,548,187
44042125	7C	I. A. B.	HARRIS SAND	TX	COKE	1970	5275	1,894	1,097,186
44042750	7C	I. A. B.	PENN 5070	TX	COKE	1957	5063	323	1,023,437
44045600	7C	I. A. B., NE.	PENN 5150	TX	COKE	1951	5192	12,038	2,950,613
45580666	7C	JAMESON	STRAWN	TX	COKE	1952	5800	113,419	42,408,749
45991666	8A	JAYTON, WEST	STRAWN SAND	TX	KENT	1963	6466	8,681	1,938,821
47542250	7B	JUDY GAIL	CANYON SAND	TX	FISHER	1953	4546	66,486	2,726,433
48422500	7B	KEELER-WIMBERLY	CANYON SD.	TX	FISHER	1952	4528	9,894	1,116,777
48583498	8A	KELLY-SNYDER	CISCO SAND	TX	SCURRY	1952	6160	12,666	15,359,384
51592500	7B	LAKE TRAMMEL, S.	CANYON	TX	NOLAN	1951	5130	48,488	3,686,833
51595333	7B	LAKE TRAMMEL, W.	CANYON	TX	NOLAN	1953	5217	97,316	12,832,787
56382200	8A	MABEN	CISCO	TX	KENT	1989	5664	112,246	1,481,691
60496500	7B	MENGEL, E.	CANYON SAND	TX	STONEWALL	1961	4276	107,241	2,081,076
60989200	8A	MICHELLE KAY	CISCO	TX	KENT	1983	5835	86,782	2,252,054
65821666	7B	NOODLE, N.	CISCO, LOWER	TX	JONES	1953	3669	9,738	2,102,487
65823400	7B	NOODLE, NW.	CANYON SD. 4000	TX	JONES	1955	3950	3,208	1,071,443
67999333	7C	OZONA, NW.	CANYON	TX	CROCKETT	1963	6675	17,508	1,913,927
68698166	7B	PARDUE	CANYON	TX	FISHER	1949	4415	10,699	3,231,747
71779001	7B	PITZER		TX	JONES	1946	4655	22,741	3,484,394
73243500	7C	PROBANDT	CANYON	TX	TOM GREEN	1975	7169	8,505	1,468,833
74863200	7B	RAVEN CREEK	CANYON SAND	TX	FISHER	1954	4228	2,079	1,602,581
76360500	7B	RICE BROS.	CANYON	TX	FISHER	1975	4486	11,095	1,511,631
77622500	7C	ROCK PEN	CANYON	TX	IRION	1976	7145	35,014	3,205,731
78567125	7B	ROUND TOP	CANYON	TX	FISHER	1953	4568	6,197	2,862,869
78819500	7B	ROYSTON	CANYON	TX	FISHER	1953	4460	3,751	1,358,151
83873250	7C	SIXTY SEVEN	CANYON	TX	IRION	1966	6684	3,002	1,081,381
78303666	8A	S-M-S	CANYON SAND	TX	KENT	1954	6100	17,465	11,405,716
87015881	7C	SUGG RANCH	CANYON	TX	STERLING	1987	7860	166,487	7,615,629
87018550	8	SUGG RANCH	CANYON DIST 08	TX	STERLING	1987	7860	89,130	6,483,258
87613500	7B	SWEETWATER	CANYON SAND	TX	FISHER	1955	5230	3,757	4,807,189
87920500	7C	T. D.	6575	TX	TOM GREEN	1982	6592	17,388	1,001,559
90383250	7B	TOLAR	CANYON	TX	FISHER	1953	4502	5,203	1,524,888
90674375	7B	TOMPKINS	CANYON SD. 4900	TX	STONEWALL	1956	4824	0	1,452,542
90674875	7B	TOMPKINS	STRAWN SAND	TX	STONEWALL	1955	5347	0	2,154,676
90694125	8A	TONTO	CANYON SAND	TX	SCURRY	1955	6690	16,982	3,093,714
93410710	7C	VELREX	HENDERSON UPPER	TX	SCHLEICHER	1964	6406	14,060	1,008,498
99658500	7C	ZAN-ZAN	MID. CANYON	TX	IRION	1988	6014	23,815	1,174,262
		Totals						**1,802,373**	**271,448,389**

elongate, fan-shaped lobes of sandstone that thin up depositional and structural dip and lap out against the slope and shelf margin.

In Flowers (Canyon Sand) field, production is from turbidite sandstones deposited in submarine-fan channel, lobe, and overbank/levee environments (Neuberger, 1987). Sandstones

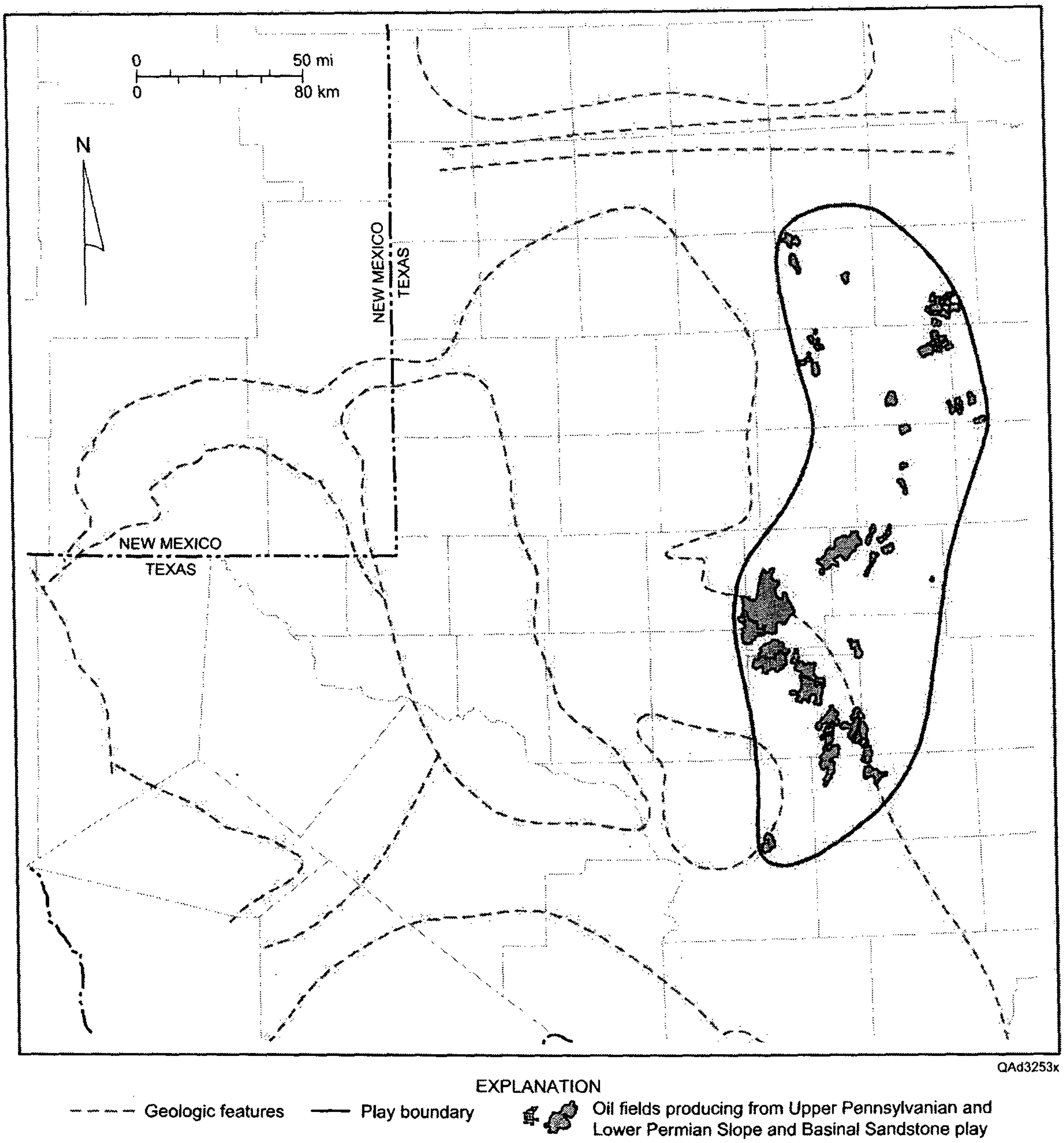

Figure 45. Play map for the Upper Pennsylvanian and Lower Permian Slope and Basinal Sandstone play, showing location of reservoirs having >1 MMbbl cumulative production, the play boundary, and geologic features. See figure 1 for county names and figure 2 for identification of geologic features.

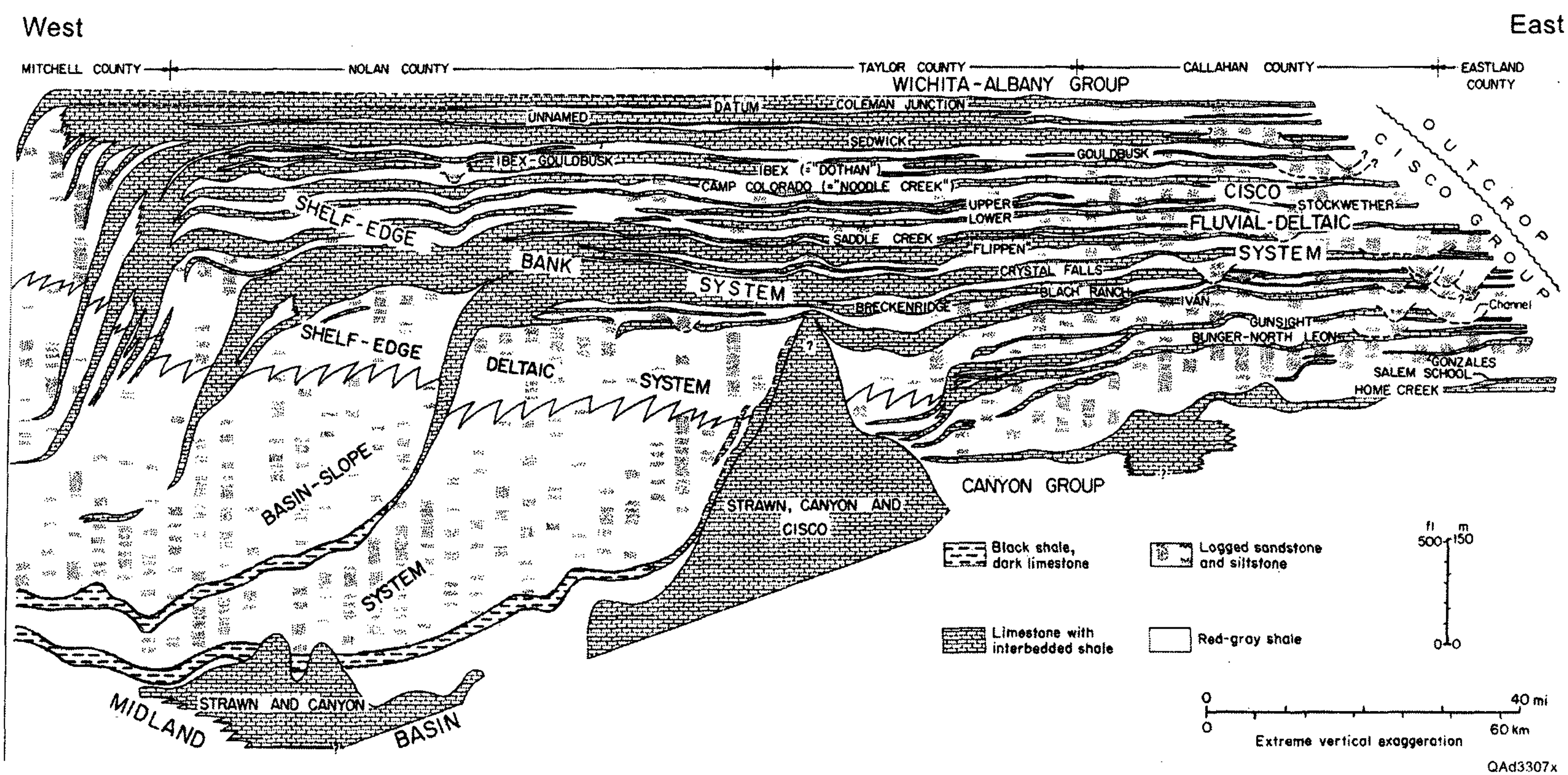

Figure 46. Generalized west-east dip cross section, Virgilian and Wolfcampian Series, from the Eastern Shelf in North-Central Texas into the Midland Basin. Horizontal scale approximate. From Brown and others (1990); modified from Brown (1969).

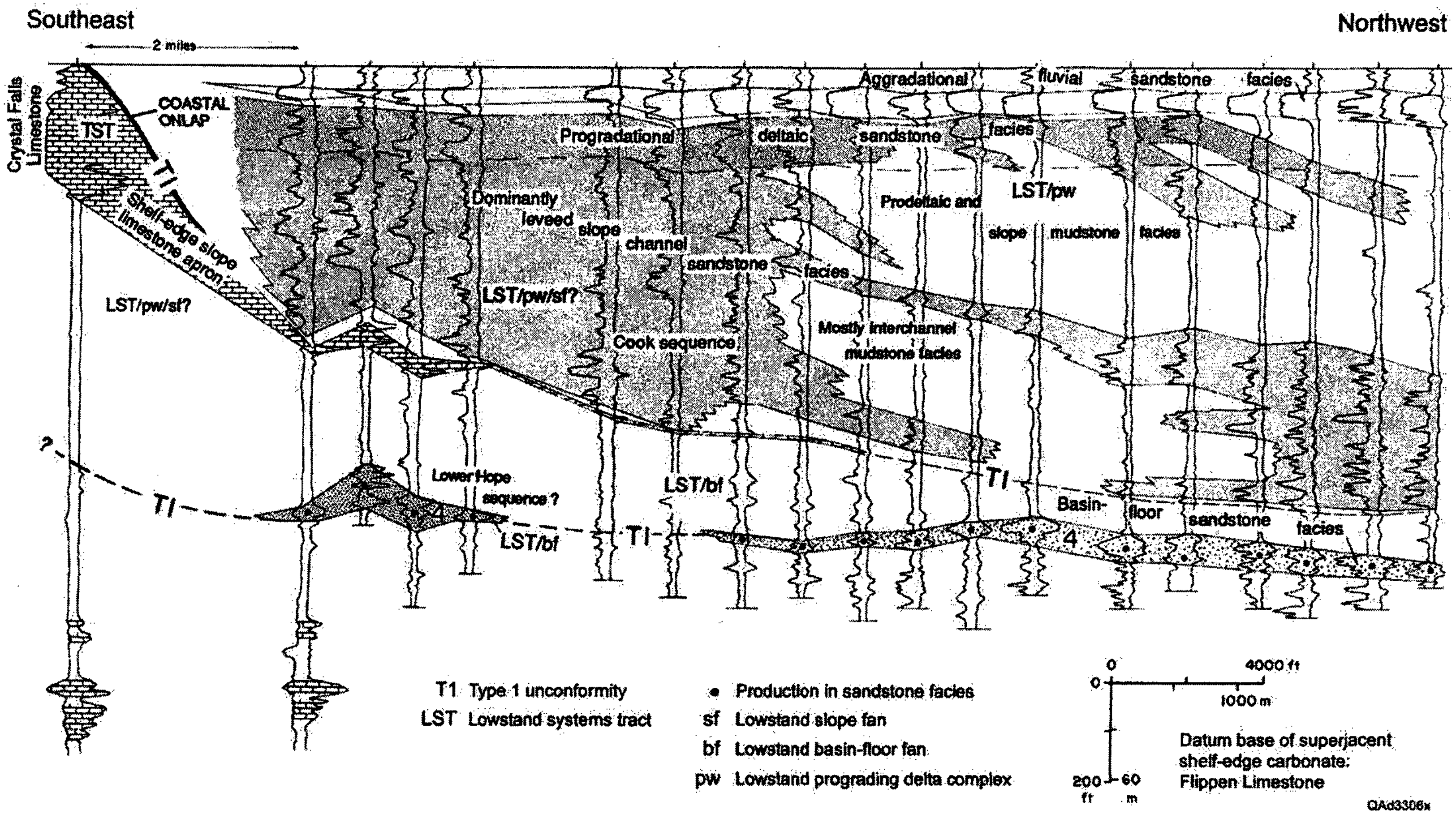

Figure 47. Southeast-northwest cross section of Lake Trammel, S., and Lake Trammel, W., fields, Nolan County, showing lowstand detached basin-floor submarine fans and lowstand slope-fan and prograding-delta complex. Modified from Brown and others (1990); based on original figure of Galloway and Brown (1972).

are fine- to very fine grained, thin- to thick-bedded turbidites (Neuberger, 1987). The reservoir zone is a complex of vertically separated, laterally discontinuous, lobate to elongate sandstones (Galloway and others, 1983). The reservoir at Zan Zan (Middle Canyon) field in Irion County is composed of thin- to medium-bedded, fine-grained sandstone (Whitsitt, 1992a).

The southern boundary of the play (fig. 45) represents the transition to predominantly gas production instead of oil. Slope and basinal sandstones continue south into Schleicher, Sutton, Crockett, Val Verde, and Edwards Counties, where they produce gas in the Upper Pennsylvanian and Lower Permian Slope and Basinal Sandstone gas play (Kosters and others, 1989).

Reservoir sandstones in the play have average porosity ranging from 12 to 19 percent and average permeability ranging from 2 to 117 md (2 to 117 × 10^{-3} μm^2) (Galloway and others, 1983). Log-calculated water saturation in productive intervals of Zan Zan (Middle Canyon) field is commonly >50 percent, but these values may be in error because siderite cement in the sandstones may increase resistivity or because of the presence of abundant water in micropores (Whitsitt, 1992a). Core data should be used to supplement well logs to accurately evaluate reservoir properties of these low-resistivity sandstones (Whitsitt, 1992a).

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Lower Permian Plays

Five plays in the Permian Basin produce from Lower Permian (Wolfcampian and Leonardian) reservoirs: (1) Wolfcamp Platform Carbonate, (2) Wolfcamp/Leonard Slope and Basinal Carbonate, (3) Leonard Restricted Platform Carbonate, (4) Abo Platform Carbonate, and (5) Spraberry/Dean Submarine-Fan Sandstone. Only three of these plays (1, 3, and 5) were described in the oil atlas (Galloway and others, 1983). The Wolfcamp/Leonard Deepwater Carbonate play was defined by Kosters and others (1989) as a gas play and by Tyler and others (1991) as an oil play. The Abo Platform Carbonate play was defined by Holtz and others (1993). The Leonard Restricted Platform Carbonate play was called the Clear Fork Platform Carbonate play in the oil atlas.

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Wolfcamp Platform Carbonate (Play 114)

The Wolfcamp Platform Carbonate play, which lies on the Central Basin Platform and Northwest Shelf in Texas and New Mexico (fig. 48), has produced 460.5 MMbbl (7.32×10^7 m^3) through 2000 from 54 reservoirs (table 19). The play is split into two parts by the San Simon Channel (figs. 2, 48). Many of the reservoirs in the play are located along the east margin of the Central Basin Platform; the west part of the Central Basin Platform remained exposed

Table 19. Wolfcamp Platform Carbonate play (play 114). Production shown for fields that have had others combined into them represents the totals; combined fields are highlighted.

RRC RESN	RRC	FLDNAME	RESNAME	STATE	COUNTY	DISCYR	DEPTHTOP	2000 PROD	CUMPROD
1964666	8A	ALSABROOK	WOLFCAMP	TX	GAINES	1953	9125	0	1,053,164
2725750	8	ANDREWS	WOLFCAMP	TX	ANDREWS	1953	8596	0	22,785,915
2725760	8	ANDREWS	WOLFCAMP-PENN.	TX	ANDREWS	1995	9380	666,442	3,692,443
2730852	8	ANDREWS, SOUTH	WOLFCAMP	TX	ANDREWS	1953	9183	63,186	15,169,599
5166888	8	BAKKE	WOLFCAMP	TX	ANDREWS	1956	8492	178,729	25,048,339
21292125	8	COWDEN, SOUTH	CANYON 8790	TX	ECTOR	1966	9202	534,499	43,011,248
21292250	8	COWDEN, SOUTH	CANYON 8900	TX	ECTOR	1968	8993	57,366	13,270,487
22576333	8A	D E B	WOLFCAMP	TX	GAINES	1980	9200	495,459	22,609,269
22576668	8A	D E B	WOLFCAMP, ZONE B	TX	GAINES	1980	8400	15,297	1,468,007
26538830	8	DUNE	WOLFCAMP	TX	CRANE	1957	7710	11,083	7,564,044
27779500	8	EDWARDS -04-, S.	7900	TX	CRANE	1967	7925	0	2,312,280
27746500	8	EDWARDS, WEST	CANYON	TX	ECTOR	1970	8962	65,268	23,979,851
30394750	8	FASKEN	WOLFCAMP	TX	ANDREWS	1952	8571	60,615	7,451,167
30394875	8	FASKEN	WOLFCAMP, NORTH	TX	ANDREWS	1956	8290	6,240	1,343,663
30398875	8	FASKEN, SOUTH	WOLFCAMP	TX	ECTOR	1960	8475	27,596	1,298,246
31768666	8	FLYING -W-	WOLFCAMP	TX	WINKLER	1955	8190	21,904	1,525,905
33235750	8	FULLERTON, SOUTH	WOLFCAMP	TX	ANDREWS	1955	8245	23,569	4,217,011
45726550	8A	JANICE	WOLFCAMP	TX	YOAKUM	1981	8937	33,269	1,577,530
59419830	8	MCFARLAND	WOLFCAMP	TX	ANDREWS	1955	9134	72,720	8,558,308
60142750	8	MEANS, SOUTH	WOLFCAMP	TX	ANDREWS	1956	9378	85,212	7,257,075
61118830	8	MIDLAND FARMS	WOLFCAMP	TX	ANDREWS	1954	9539	77,430	15,397,011
65766666	8	NOLLEY	WOLFCAMP	TX	ANDREWS	1951	9227	213,962	30,459,183
69193710	8	PARKER	WOLFCAMP	TX	ANDREWS	1953	8554	338,613	5,501,626
80473868	8	SAND HILLS	WOLFCAMP	TX	CRANE	1958	5684	27,310	2,537,187
82225568	8A	SEMINOLE	WOLFCAMP LIME	TX	GAINES	1963	9259	14,592	1,455,586
82225710	8A	SEMINOLE	WOLFCAMP REEF	TX	GAINES	1962	9162	27,292	1,452,509
82570600	8	SHAFTER LAKE	WOLFCAMP	TX	ANDREWS	1951	8405	2,330	12,195,348
84819850	7C	SOUTHWEST MESA	WOLFCAMP	TX	CROCKETT	1988	6268	24,833	1,463,139
88969800	8A	TEX-FLOR	WOLFCAMP	TX	GAINES	1977	9152	11,066	1,810,349
90196666	7C	TIPPETT, W.	WOLFCAMP LO.	TX	CROCKETT	1967	5564	0	1,365,836
90196333	7C	TIPPETT, WEST	HUECO	TX	CROCKETT	1968	5012	5,579	1,469,047
88071928	8	T X L	WOLFCAMP, NORTH	TX	ECTOR	1959	7535	9,903	4,584,422
92534750	8	UNIVERSITY BLOCK 9	WOLFCAMP	TX	ANDREWS	1953	8430	183,250	28,350,317
95397800	8A	WASSON	WOLFCAMP	TX	GAINES	1956	8448	18,923	6,060,592
96291666	8	WEMAC	WOLFCAMP	TX	ANDREWS	1953	8708	4,009	4,239,021
96296500	8	WEMAC, SOUTH	WOLFCAMP	TX	ANDREWS	1962	8786	2,577	1,701,980
96756800	8	WHEELER	WOLFCAMP	TX	ECTOR	1959	7604	60,959	5,753,930
		ANDERSON RANCH	WOLFCAMP	NM	LEA	1953	9760	19,061	4,235,028
		ANDERSON RANCH NORTH	WOLFCAMP	NM	LEA	1960	9823	30,797	6,652,176
		BRONCO	WOLFCAMP	NM	LEA	1953	9600	994	2,086,478
		CAUDILL	PERMO PENN	NM	LEA	1956	10285	6,593	1,979,249
		DENTON	WOLFCAMP	NM	LEA	1950	9240	242,272	41,755,373
		GLADIOLA	WOLFCAMP	NM	LEA	1950	9578	14,524	4,144,627
		HENSHAW	WOLFCAMP	NM	EDDY	1960	8822	11,483	3,401,748
		KEMNITZ	LOWER WOLFCAMP	NM	LEA	1956	10742	18,731	16,608,371
		KEMNITZ WEST	WOLFCAMP	NM	LEA	1963	10678	2,748	1,029,531
		KING	WOLFCAMP	NM	LEA	1951	9300	21,755	1,369,908
		LANE	WOLFCAMP	NM	LEA	1955	9700	0	1,028,000
		MORTON	WOLFCAMP	NM	LEA	1964	10310	8,430	2,605,976
		MORTON EAST	WOLFCAMP	NM	LEA	1970	10506	21,786	1,781,208
		TODD	WOLFCAMP	NM	ROOSEVELT	1971	7580	31,769	1,115,408
		TOWNSEND	PERMO-UPPER PENN	NM	LEA	1952	10400	124,759	24,101,823
		TULK	WOLFCAMP	NM	LEA	1951	9700	15,862	2,429,801
		Totals						**4,012,646**	**457,405,339**

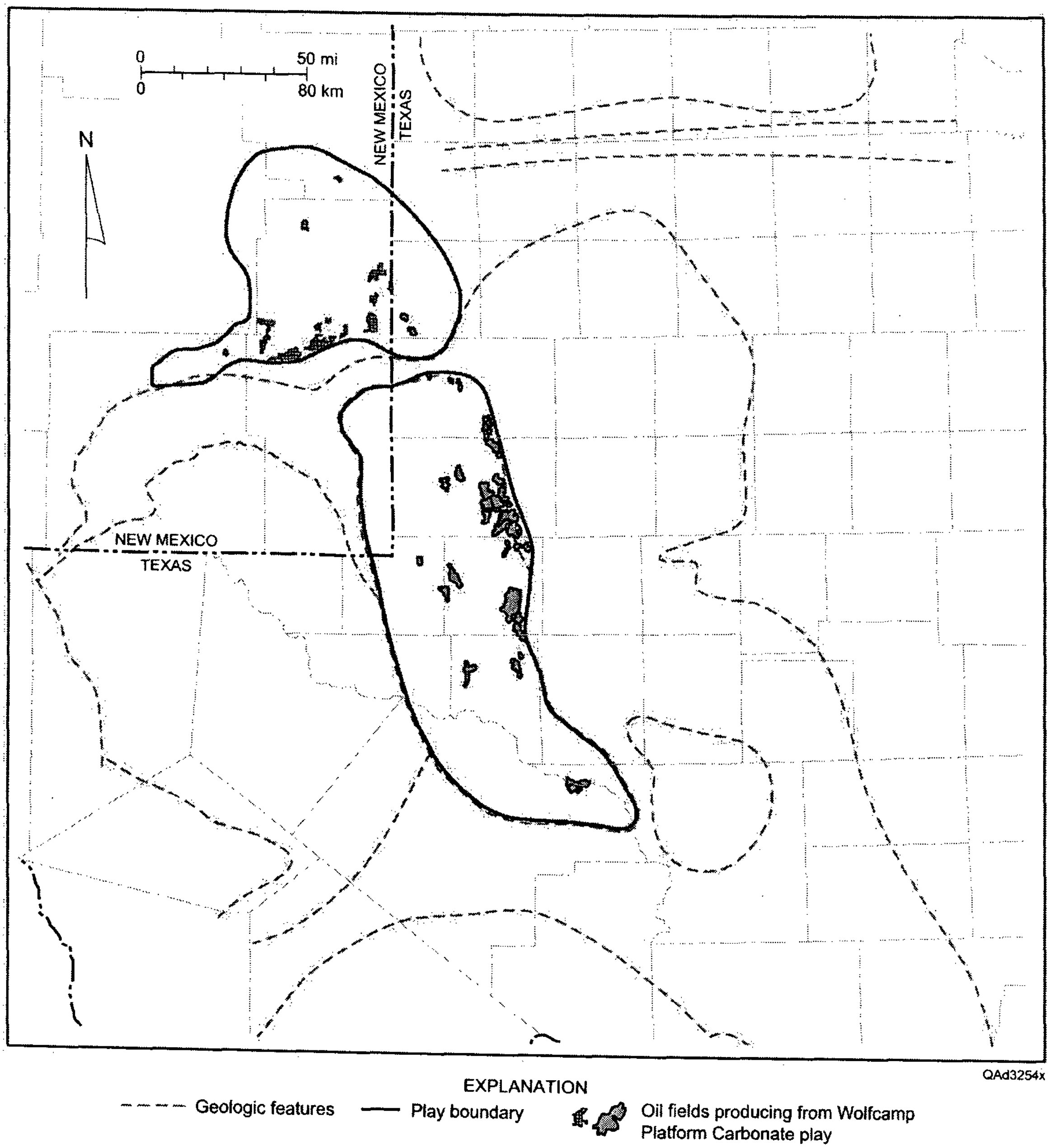

Figure 48. Play map for the Wolfcamp Platform Carbonate play, showing location of reservoirs having >1 MMbbl cumulative production, the play boundary, and geologic features. See figure 1 for county names and figure 2 for identification of geologic features.

throughout the Wolfcamp (Wright, 1979). Wolfcamp Platform Carbonate reservoirs in New Mexico were deposited on the shelf and shelf margin of the northern Delaware Basin. Although similar in age and depositional setting to reservoirs in the Northwest Shelf Upper Pennsylvanian Carbonate play (play 110), the reservoir strata in the Wolfcamp Platform Carbonate play in New Mexico are generally thought to be slightly younger and are traditionally grouped into a separate play. Carbonate-debris beds, which were derived from Wolfcamp platform-margin buildups, are found in downslope basinal deposits in the Midland and Delaware Basins and compose the Wolfcamp/Leonard Slope and Basinal Carbonate play (play 115).

Fusulinid biostratigraphy indicates that reservoirs in the Wolfcamp Platform Carbonate play occur mostly in Lower and Middle Wolfcamp strata (Candelaria and others, 1992; Saller and others, 1999b). Two of the largest reservoirs in the play, Edwards West and South Cowden (table 19), are interpreted as producing from the Wolfcamp on the basis of biostratigraphy, despite having been reported and named as producing from Canyon reservoirs (Candelaria and others, 1992).

Large-scale stratigraphic relations and facies of the Wolfcamp were documented along the east margin of the Central Basin Platform (Candelaria and others, 1992) and the northern Midland Basin (Mazzullo and Reid, 1989). Recent studies of typical Wolfcamp fields on the Central Basin Platform show that, like many reservoirs in the Pennsylvanian Platform Carbonate Play, these reservoirs are composed of highly cyclic shallow-water carbonate facies that are variably overprinted by diagenesis that took place at and below cycle tops during sea-level-fall events (Candelaria and others, 1992; Saller and others, 1994, 1999a, b; Dickson and Saller, 1995; Ruppel, 2001). Although reservoirs developed in Wolfcamp platform carbonates are commonly referred to as reefs because of their geometries, recent studies have illustrated that many of the reservoirs are composed of cyclic deposits of interbedded skeletal and ooid-bearing grainstones and organic-rich wackestones and packstones (fig. 49) (Mazzullo, 1982; Saller and others, 1994;

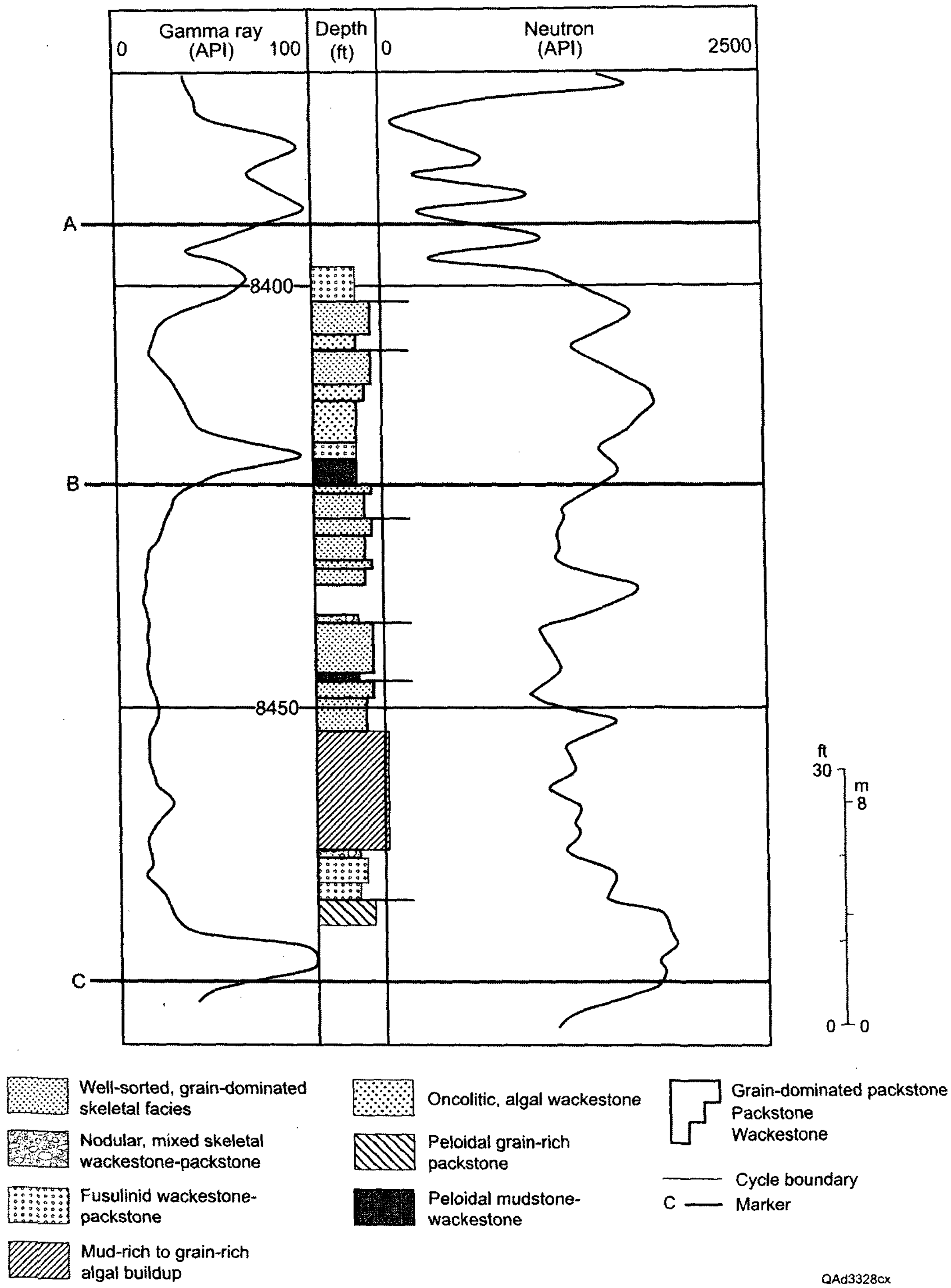

Figure 49. Typical vertical Wolfcamp facies succession in the Wolfcamp Platform Carbonate play. From Ruppel (2001). Core and log are from University Block 9 field, Andrews County, from the Shell 9A No. 1 well (Cross Timbers 11 SA No. 1 well). See Ruppel (2001) for location of well.

Ruppel, 2001). Shelf-margin organic buildups in the Wolfcamp are micrite dominated and composed of phylloid algae, foraminifera, and *Tubiphytes* (Mazzullo and Reid, 1989; Wahlman, 2001). These buildups generally do not have reservoir-quality porosity, but porosity is well developed in flanking and capping bioclastic packstone-grainstone facies (Wahlman, 2001).

Correlation of the Wolfcamp succession and identification of facies, cycles, and karst intervals are difficult using wireline logs alone (Ruppel, 2001). Image logs calibrated to core can be used to resolve major depositional facies, cycle boundaries, and karst diagenesis (fig. 50) and develop an accurate reservoir model.

Traps are structural and stratigraphic (Galloway and others, 1983; Candelaria and others, 1992). Structural closure forms the trap in many fields, including Andrews, Bakke, Midland Farms, and University Block 9. Updip facies change and porosity pinch-out create the stratigraphic traps at the Dune and Nolley Wolfcamp reservoirs, and dolomitization of platform-margin facies at Seminole Wolfcamp Reef reservoir forms a diagenetic stratigraphic trap (Tyler and others, 1991; Candelaria and others, 1992). Expected ultimate recovery per well in the play ranges from 60,000 bbl (9.54×10^3 m^3) to >500,000 bbl (7.95×10^4 m^3) (Candelaria and others, 1992). In the grainstone facies that is the main reservoir facies, porosity can be as high as 12 to 15 percent, and permeability can be 40 to 60 md ($40–60 \times 10^{-3}$ μm^2) (Candelaria and others, 1992). However, in many fields in this play the reservoir facies average 5 to 8 percent porosity and <1 md ($<1 \times 10^{-3}$ μm^2) matrix permeability (Ruppel, 2001; Stoudt and others, 2001). Permeability in Edwards West field is due mainly to fractures associated with karst because matrix permeability is <1 md ($<1 \times 10^{-3}$ μm^2) (Stoudt and others, 2001).

Reservoirs in New Mexico are located on or shelfward (northward) of the east-west-trending Wolfcampian shelf margin (fig. 2; see Malek-Aslani, 1970). Although some reservoirs

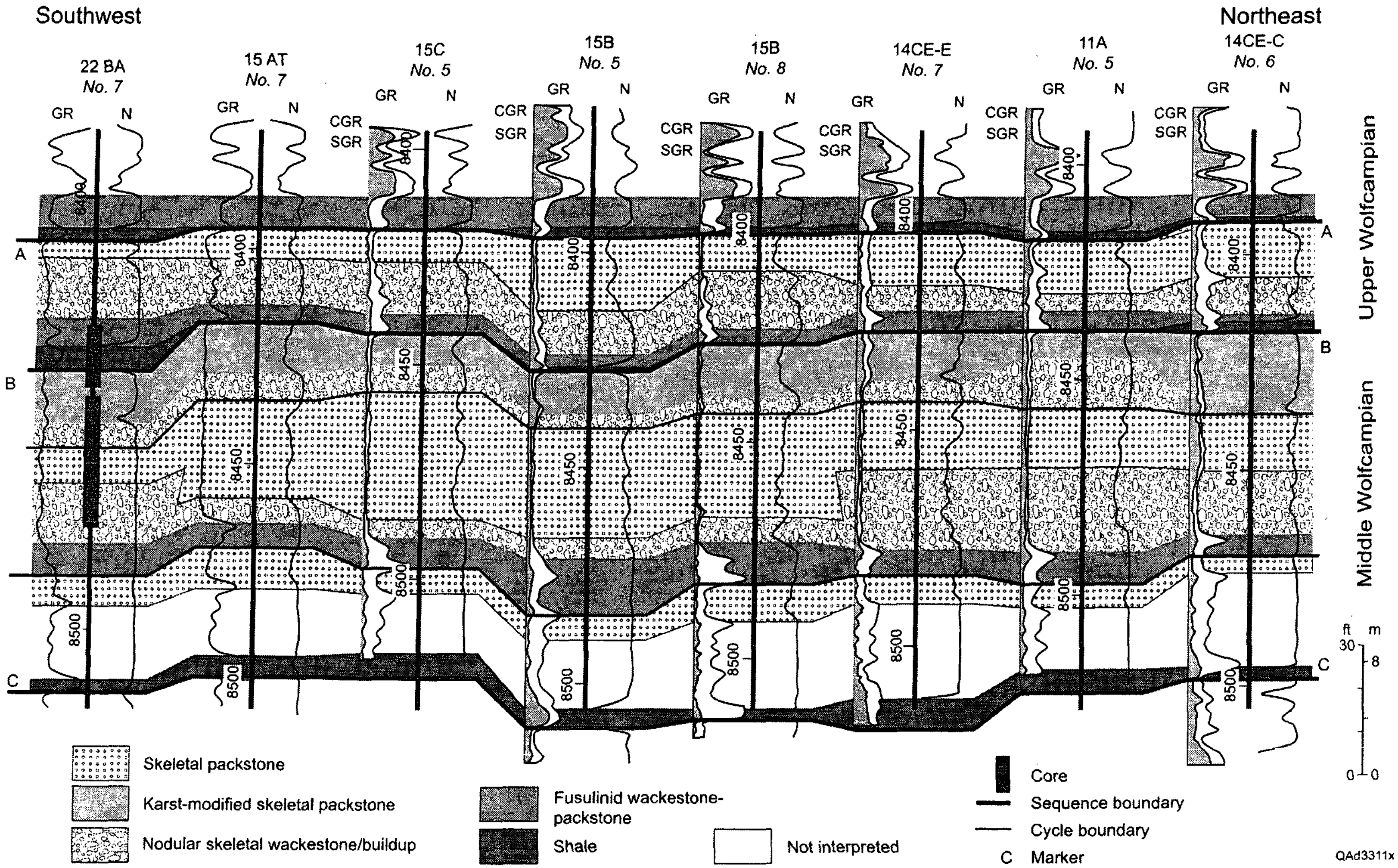

Figure 50. Southwest-northeast cross section of University Block 9 field, showing Wolfcamp stratigraphy, cycles, and facies as interpreted from core-calibrated image logs. From Ruppel (2001). See Ruppel (2001) for location of cross section.

are found well north of the shelf margin, most are clustered on or near the shelf margin. Production is derived largely from lower Wolfcamp units. Shelf-margin reservoirs are interpreted to lie within a barrier-reef complex, with lithologies consisting of reefal (hydrozoan boundstones), backreef (skeletal grainstones), and forereef (talus slope) facies (Malek-Aslani, 1970). The northern shelf area reservoirs are composed of shallow-marine limestone facies, with most accumulations found in phylloid-algal bioherms developed on preexisting paleobathymetric highs or as grainstones capping and flanking the bioherms (Cys and Mazzullo, 1985; Malek-Aslani, 1985; Cys, 1986).

Traps on the shelf in New Mexico are largely stratigraphic, with porosity pinch-outs formed from porous biohermal and grainstone facies that grade laterally into low-porosity nonbiohermal facies. On the shelf margin, traps are combinations of structural ridges and stratigraphic pinch-outs (porous reefal facies laterally juxtaposed with lower porosity nonreef strata). The structural ridges trend generally north-south and are thought to be bounded by low-relief faults. Because of the relationship of Wolfcamp reservoirs to positive structural elements that have a tectonic origin, it is common to find Wolfcamp reservoirs stacked atop structurally controlled reservoirs in older, deeper strata.

Two Wolfcamp reservoirs in New Mexico, Vacuum and Corbin, have been assigned to the Wolfcamp/Leonard Slope and Basinal Carbonate play (115) on the basis of their location south of the Wolfcamp shelf margin as mapped by Malek-Aslani (1970, 1985; figs. 48, 51; tables 19, 20). The mapped shelf margin is based on lower Wolfcamp facies. Vacuum is productive from both the upper and lower parts of the Wolfcamp, and Corbin South is productive from the upper and middle parts of the Wolfcamp. The lower and middle Wolfcamp in this area comprise interbedded dark shales and limestones and are basinal facies. The upper Wolfcamp, however, comprises dominantly light-colored carbonates. At the Vacuum reservoir, the upper Wolfcamp has a mound-shaped appearance, and crosswell seismic tomography indicates that the productive interval has internal clinoformal bedding (Martin and others, 2002). On the basis of overall shape and internal bedding surfaces, Martin and others (2002) suggested that the upper Wolfcamp reservoir may be an isolated algal mound deposited on the Wolfcamp shelf. If this is the case, then the upper parts of the Vacuum and Corbin South reservoirs are in the Wolfcamp Platform Carbonate play (114) and the shelf edge prograded southward at least 10 to 12 miles during Wolfcamp time from the Kemnitz reservoir (fig. 48) to a position south of the Vacuum reservoir (fig. 51). If the upper part of the Vacuum reservoir is a shelf deposit, then general location and lithologic composition suggest that the upper part of the Corbin South reservoir was also deposited on the Wolfcamp shelf and not in the basin. Alternatively, the southward-prograding clinoforms seen via crosswell seismic tomography in the Vacuum reservoir may indicate southward-prograding slope deposits.

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Wolfcamp/Leonard Slope and Basinal Carbonate (Play 115)

The Wolfcamp/Leonard Slope and Basinal Carbonate play, which is located in the Midland and Delaware Basins adjacent to the Central Basin Platform and Eastern Shelf (fig. 51), has produced 191.9 MMbbl (3.05×10^7 m^3) from 41 reservoirs (table 20). None of the reservoirs in the play had produced >10 MMbbl (1.59×10^6 m^3) of oil by 1982, so the play is not included in the *Atlas of Major Texas Oil Reservoirs* (Galloway and others, 1983). Although the reservoirs in Glasscock County have been named Wolfcamp (table 20), regional fusulinid biostratigraphy shows that they are actually Lower Leonardian (Mazzullo, 1997) (fig. 52).

Table 20. Wolfcamp/Leonard Slope and Basinal Carbonate play (play 115). Production shown for fields that have had others combined into them represents the totals; combined fields are highlighted.

RRC RESN	RRC	FLDNAME	RESNAME	STATE	COUNTY	DISCYR	DEPTHTOP	2000 PROD	CUMPROD
2207912	7C	AMACKER-TIPPETT	WOLFCAMP	TX	UPTON	1954	9090	161,453	5,567,355
2220900	7C	AMACKER-TIPPET, SW	9100	TX	UPTON	1980	9344	583,285	5,264,842
2220700	7C	AMACKER-TIPPETT, SW	WOLFCAMP	TX	UPTON	1977	9218	2,593,888	16,046,136
2220710	7C	AMACKER-TIPPETT, SW.	WOLFCAMP A	TX	UPTON	1988	9069	201,693	4,442,155
4228664	8	ATHEY	WOLFCAMP 10900	TX	PECOS	1967	11263	60,615	2,411,926
5229500	8A	BALE, EAST	WOLFCAMP	TX	GAINES	1972	10005	2,665	1,636,763
8735500	8	BLALOCK LAKE, E.	WOLFCAMP	TX	GLASSCOCK	1971	7914	188,510	5,978,078
8739500	8	BLALOCK LAKE, S.	WOLFCAMP	TX	GLASSCOCK	1974	8246	389,662	10,256,922
8740500	8	BLALOCK LAKE, SE	WOLFCAMP	TX	GLASSCOCK	1981	8245	229,826	9,974,801
19235700	8	COBRA	WOLFCAMP	TX	GLASSCOCK	1984	7947	1,080,278	10,587,410
20844500	7C	CORVETTE	WOLFCAMP	TX	UPTON	1991	9388	110,532	4,826,776
21362875	8	COYANOSA	WOLFCAMP	TX	PECOS	1970	11614	2,768	6,290,774
21597250	8	CREDO	WOLFCAMP	TX	STERLING	1962	7334	12,169	3,951,915
21597500	8	CREDO	WOLFCAMP, LOWER -B-	TX	STERLING	1962	7430	735	2,497,526
24488650	8	DEWEY LAKE	WOLFCAMP	TX	GLASSCOCK	1982	8449	6,970	1,395,910
24562710	8A	DIAMOND -M-	WOLFCAMP	TX	SCURRY	1952	5310	0	2,596,809
34001750	8	GARDEN CITY, W.	WOLFCAMP 7880	TX	GLASSCOCK	1966	7920	286,123	3,479,124
35708670	8	GOMEZ	WOLFCAMP UPPER	TX	PECOS	1977	10620	3,144	1,227,066
38866600	8A	HAPPY	SPRABERRY LIME	TX	GARZA	1989	4970	976,132	7,336,714
42971684	8	HOWARD-GLASSCOCK	WOLFCAMP 7400	TX	HOWARD	1970	7441	78,590	6,178,414
43926600	8	HUTTO, SOUTH	WOLFCAMP	TX	HOWARD	1964	7421	36,345	3,330,447
48338500	8A	KAY	WOLFCAMP REEF	TX	GAINES	1959	10349	0	1,976,465
57324650	8	MARALO	WOLFCAMP	TX	PECOS	1984	11055	11,421	1,200,187
72810500	8	POWELL	8300	TX	GLASSCOCK	1982	8552	12,202	2,181,282
78279300	8	ROSE CREEK, N	WOLFCAMP	TX	STERLING	1982	5084	70,894	1,582,370
85279400	7C	SPRABERRY	TREND AREA CL. FK.	TX	REAGAN	1955	6194	79,408	11,327,959
85280400	8	SPRABERRY	TREND AREA CL. FK.	TX	MIDLAND	1955	7000	21,289	3,375,768
85447300	7C	SRH	CLEAR FORK	TX	REAGAN	1995	4837	129,667	1,266,029
90369666	8A	TOKIO, SOUTH	WOLFCAMP	TX	TERRY	1953	9860	15,016	3,114,383
91336498	8	TRIPLE M	WOLFCAMP UPPER	TX	STERLING	1963	6746	6,623	3,109,333
91424475	7C	TRIUMPH	WOLFCAMP	TX	UPTON	1992	8530	183,282	3,362,056
95129600	8	WAR-WINK, S.	WOLFCAMP	TX	WARD	1976	12758	270,499	12,741,227
95130900	8	WAR-WINK, W.	WOLFCAMP	TX	WARD	1976	11545	604,798	2,865,482
		BAISH	WOLFCAMP	NM	LEA	1962	9800	28,315	1,068,654
		BURTON FLAT NORTH	WOLFCAMP	NM	EDDY	1975	9160	0	3,226,531
		CORBIN SOUTH	WOLFCAMP	NM	LEA	1967	11000	127,055	6,609,050
		JOHNSON RANCH	WOLFCAMP	NM	LEA	1985	13500	291,937	1,380,757
		SCHARB	WOLFCAMP	NM	LEA	1980	10519	16,981	1,199,917
		SHOE BAR NORTH	WOLFCAMP	NM	LEA	1973	10456	15,877	1,706,095
		VACUUM	WOLFCAMP	NM	LEA	1963	9950	78,821	6,660,250
		VACUUM NORTH	LOWER WOLFCAMP	NM	LEA	1967	10690	1,093	1,952,599
		WANTZ	GRANITE WASH	NM	LEA	1963	7270	77,637	7,782,243
		Totals						**9,046,188**	**194,975,500**

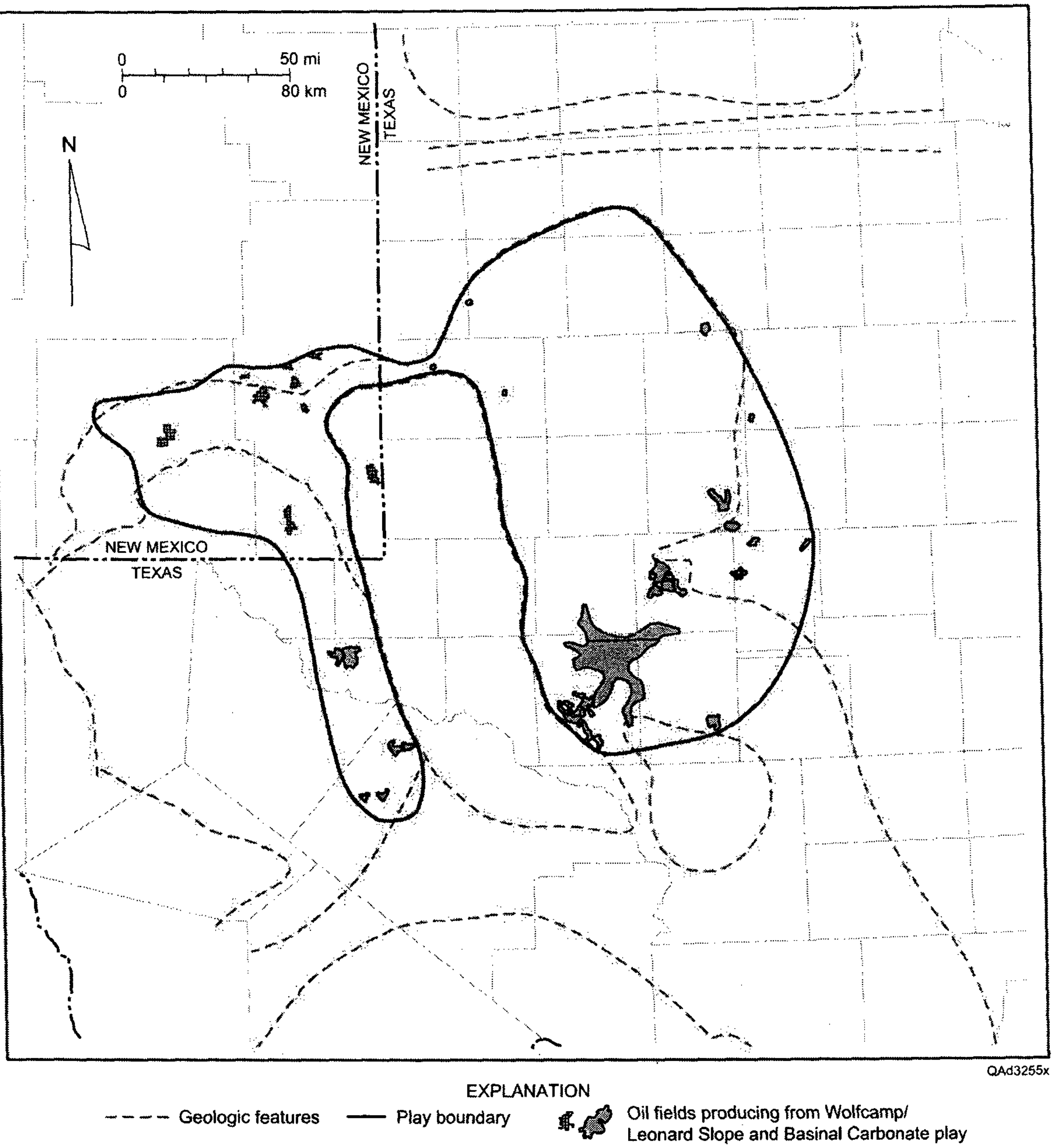

Figure 51. Play map for the Wolfcamp/Leonard Slope and Basinal Carbonate play, showing location of reservoirs having >1 MMbbl cumulative production, the play boundary, and geologic features. See figure 1 for county names and figure 2 for identification of geologic features.

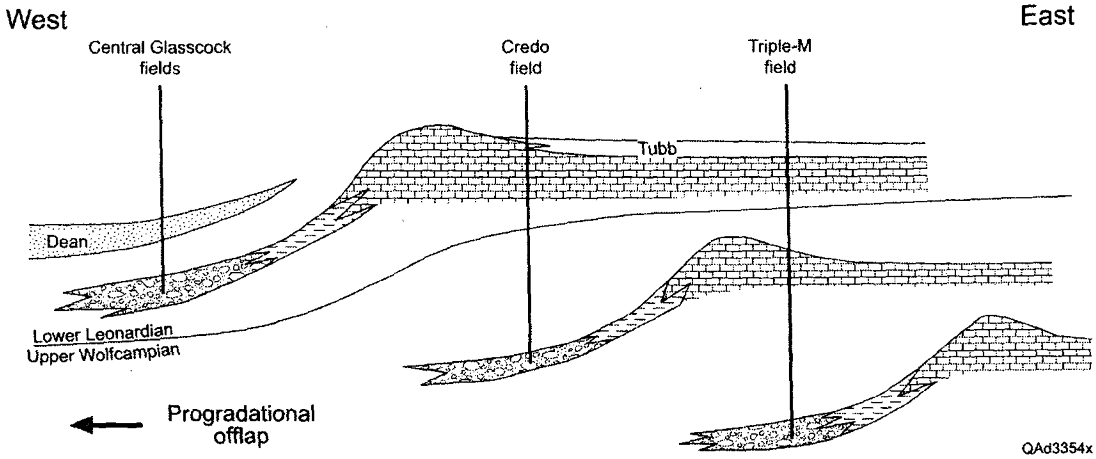

Figure 52. West-east cross section illustrating progradation of the Eastern Shelf margin and fields producing from Wolfcamp and Leonard periplatform carbonates in Glasscock and Sterling fields. From Mazzullo (1997).

Wolfcamp and Lower Leonard deposits in the Midland and Delaware Basins are composed primarily of dark shales and interbedded detrital carbonate (Wilson, 1975; Hobson and others, 1985a, b; Mazzullo and others, 1987; Mazzullo and Reid, 1989). Carbonate interbeds consists of a variety of resedimented deposits, including breccias, sand, and muds deposited by debris flows, turbidity currents, grain flow, and bottom currents on the lower slope and basin floor (Hobson and others, 1985a, b; Loucks and others, 1985; Mazzullo and Reid, 1987; Montgomery, 1996; Mazzullo, 1997). These rocks contain clasts of shallow-water facies identical to those observed in platform and platform-margin sequences, including skeletal grainstones and wackestones and ooid grainstones, indicating that they were derived by downslope transport from the platform margin. Large detached blocks of dolostone are also common, particularly in proximal parts of the debris flows (Mazzullo and Reid, 1987). Traps are largely stratigraphic, with reservoirs encased in dark-gray to black, kerogen-rich basinal shales, which act as both the seal and the source rock.

Mazzullo (1997, 2000) interpreted Wolfcamp and Leonard resedimented carbonates as having been deposited during periods of sea-level highstand. Other workers have interpreted the basinal carbonate debris as having been shed into the basins during both highstands and lowstands (Becher and von der Hoya, 1990; Pacht and others, 1995; Simo and others, 2000). Pacht and others (1995) concluded that although much of the basinal carbonate debris was deposited during highstand time, porous debris flows were best developed in lowstand systems tracts along the northwest margin of the Midland Basin.

The allochthonous carbonates of this play are distributed in distinct lobes that trend normal to the shelf edge. Considerable vertical and lateral heterogeneity within these sequences has been created by the irregular stacking of discrete depositional units (Hobson and others, 1985a, b; Becher and von der Hoya, 1990). Cores of Wolfcamp and Leonard deepwater carbonates are illustrated and described in Kaufman and others, 2001; Merriam, 2001; Sivils, 2001; Sivils and Stoudt, 2001). Amacker Tippett Wolfcamp field produces mainly from fusulinid algal grainstones and large slide blocks (fig. 53) (Van Der Loop, 1990). Pay zones have porosity of ≥3 percent and gamma-ray values of ≤25 API units. The reservoir facies at Powell Wolfcamp field are packstones and grainstones located in channels that incise into brecciated carbonate debris flows and shales. Porosity, which ranges from 6 to 22 percent, is composed of interparticle, moldic, and fracture pores (Montgomery, 1996). Reservoir permeability ranges from 100 to 500 md (100 to 500 $\times 10^{-3}\ \mu m^2$).

Three-dimensional seismic surveys have successfully imaged productive channels in northwestern Glasscock County by identifying zones of thicker Wolfcamp isochrons and lower amplitudes. Use of 3-D seismic surveys has increased rates of drilling success in the Powell Ranch area to >70 percent (Dufford and Holland, 1993; Montgomery, 1996).

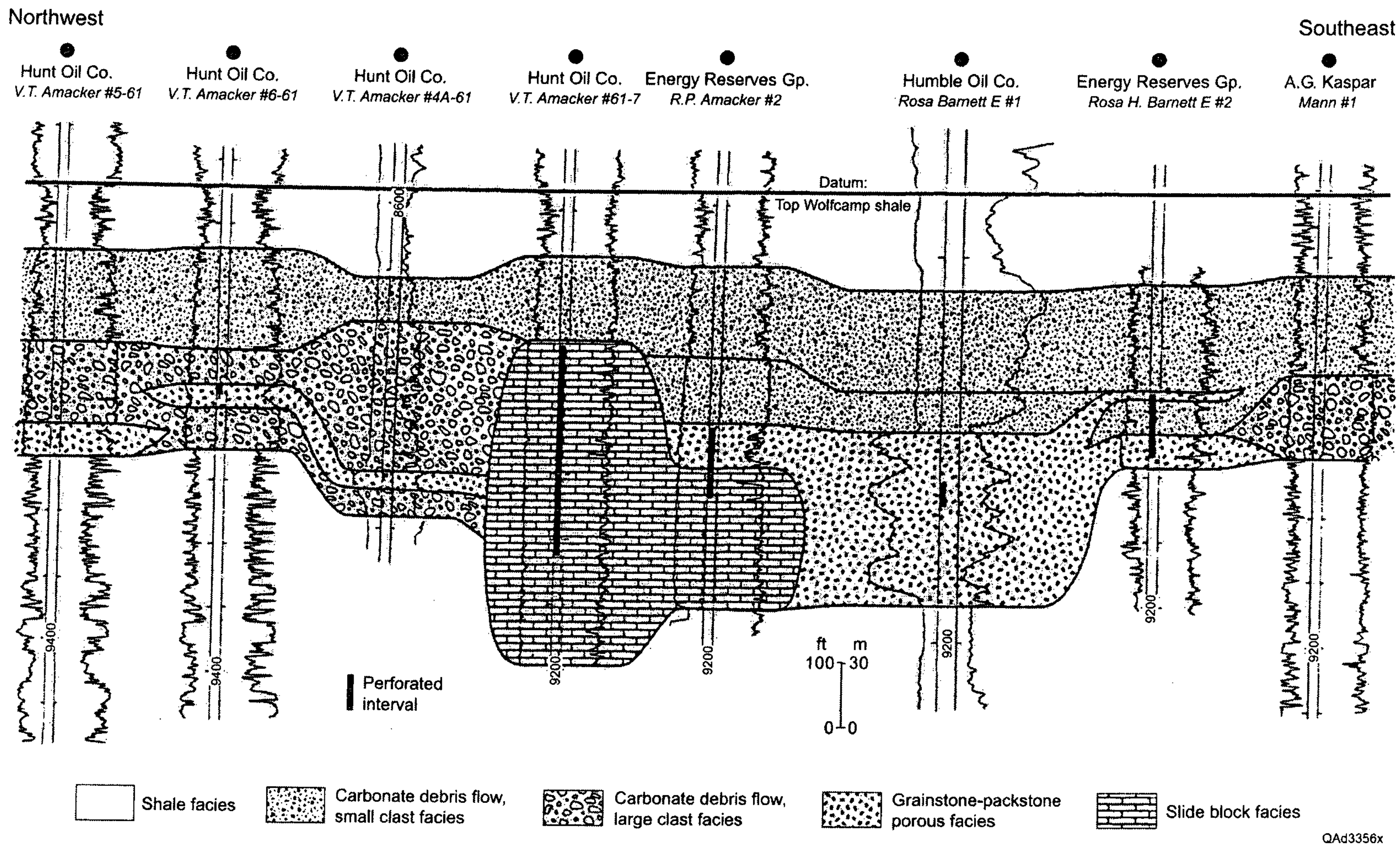

Figure 53. Northwest-southeast stratigraphic cross section showing producing zones in Amacker Tippett Wolfcamp field, Upton County. From Van Der Loop (1990). See Van Der Loop (1990) for location of cross section.

New Mexico reservoirs in this play are located basinward of the Wolfcamp shelf margin (fig. 2). The Wolfcamp shelf margin appears to be roughly coincident with the overlying, younger Abo shelf margin but in some places may be seaward of it or landward of it by as much as 1 mile. Production is derived largely from limestones in the lower Wolfcamp, although limestones in the middle to upper Wolfcamp are productive in some reservoirs. Most productive strata appear to be carbonate debris flows derived from the shelf margin (see Loucks and others, 1985) or possibly the slope.

Two lower Wolfcampian reservoirs in New Mexico (Vacuum North, Shoe Bar North) were placed in this play because they lie immediately south of the shelf edge as mapped by Malek-Aslani (1970). The lithology and depositional setting of these reservoirs are not well known, so it is conceivable that they are actually platform-margin reservoirs deposited during temporally limited progradation of the shelf margin. However, their position in terms of known paleobathymetry indicates that they should be included in the Wolfcamp/Leonard Slope and Basinal Carbonate play rather than in the Wolfcamp Platform Carbonate play. Farther south, the Scharb reservoir is formed by allochthonous debris flow carbonates deposited on the Wolfcamp paleoslope (Mazzullo and Arrant, 1988). Burton Flat North is productive from basinal carbonates in a shale-rich part of the Wolfcamp. The Wolfcamp at Johnson Ranch is a basinal facies composed of interbedded brown limestone and brown shale. Two Wolfcamp reservoirs in New Mexico, Vacuum and Corbin, have been assigned to the Wolfcamp/Leonard Slope and Basinal Carbonate play (115) on the basis of their location south of the Wolfcamp shelf margin as mapped by Malek-Aslani (1970, 1985; figs. 48, 51; tables 19, 20). The mapped shelf margin is based on lower Wolfcamp facies. Vacuum is productive from both the upper and lower parts of the Wolfcamp, and Corbin South is productive from the upper and middle parts of the

Wolfcamp. The lower and middle Wolfcamp in this area comprise interbedded dark shales and limestones and are basinal facies. The upper Wolfcamp, however, is composed dominantly of light-colored carbonates. At the Vacuum reservoir, the upper Wolfcamp has a mound-shaped appearance, and crosswell seismic tomography indicates that the productive interval has internal clinoformal bedding (Martin and others, 2002). On the basis of overall shape and internal bedding surfaces, Martin and others (2002) suggested that the upper Wolfcamp reservoir may be an isolated algal mound deposited on the Wolfcamp shelf. If this is the case, then the upper parts of the Vacuum and Corbin South reservoirs are in the Wolfcamp Platform Carbonate play (114) and the shelf edge prograded southward at least 10 to 12 miles during Wolfcamp time from the Kemnitz reservoir (fig. 48) to a position south of the Vacuum reservoir (fig. 51). If the upper part of the Vacuum reservoir is a shelf deposit, then general location and lithologic composition suggest that the upper part of the Corbin South reservoir was also deposited on the Wolfcamp shelf and not in the basin. Alternatively, the southward-prograding clinoforms seen via crosswell seismic tomography in the Vacuum reservoir may indicate southward-prograding slope deposits.

One New Mexico reservoir included in the play, Wantz Granite Wash, is productive from granite-wash clastics. Reservoirs in the Granite Wash subplay are productive from laterally discontinuous Wolfcampian-age conglomerates and "granite wash" arkosic sandstones deposited on the flanks of structural highs of Early Permian age and in paleotopographic lows on top of structural highs of Early Permian age (Bowsher and Abendshein, 1988; Speer, 1993). The sandstones are encased in shales that seal the sandstone and conglomerate reservoirs. Examination of drill cuttings and logs indicates that a part of the reservoir resides in fractured Precambrian granite that underlies the granite wash (A.L. Bowsher, cited in Speer, 1993). Low-displacement, high-angle faults, acting in concert with the lenticular geometry of reservoir sands and conglomerates, compartmentalize reservoirs. Compartmentalization has perhaps prevented optimal development, with standard vertical wells drilled on 40-acre spacing.

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