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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ABSTRACT

The Permian Basin of west Texas and southeast New Mexico has produced >30 Bbbl (4.77×10^9 m^3) of oil through 2000, most of it from 1,339 reservoirs having individual cumulative production >1 MMbbl (1.59×10^5 m^3). These significant-sized reservoirs are the focus of this report. Thirty-two Permian Basin oil plays were defined, and each of the 1,339 significant-sized reservoirs was assigned to a play. The reservoirs were mapped and compiled in a Geographic Information System (GIS) by play. Associated reservoir information within linked data tables includes Railroad Commission of Texas reservoir number and district (Texas only), official field and reservoir name, year reservoir was discovered, depth to top of the reservoir, production in 2000, and cumulative production through 2000. Some tables also list subplays. Play boundaries were drawn for each play; the boundaries include areas where fields in that play occur but are <1 MMbbl (1.59×10^5 m^3) of cumulative production. This report contains a summary description of each play, including key reservoir characteristics and successful reservoir-management practices that have been used in the play. The CD accompanying the report contains a pdf version of the report, the GIS project, pdf maps of all plays, and digital data files.

Oil production from the reservoirs in the Permian Basin having cumulative production >1 MMbbl (1.59×10^5 m^3) was 301.4 MMbbl (4.79×10^7 m^3) in 2000. Cumulative Permian Basin production through 2000 from these significant-sized reservoirs was 28.9 Bbbl (4.59×10^9 m^3). The top four plays in cumulative production are the Northwest Shelf San Andres Platform Carbonate play (3.97 Bbbl [6.31×10^8 m^3]), the Leonard Restricted Platform Carbonate play (3.30 Bbbl [5.25×10^8 m^3), the

Pennsylvanian and Lower Permian Horseshoe Atoll Carbonate play (2.70 Bbbl [4.29×10^8 m^3]), and the San Andres Platform Carbonate play (2.15 Bbbl [3.42×10^8 m^3]).

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EXECUTIVE SUMMARY

The target of this PUMP project was the Permian Basin of west Texas and southeast New Mexico, which is still one of the largest petroleum-producing basins in the United States. More than in any other region, increased use of preferred management practices in Permian Basin oil fields will have a substantial impact on domestic production because of the large remaining oil resource. The Bureau of Economic Geology (BEG) and the New Mexico Bureau of Geology and Mineral Resources (NMBGMR) teamed up to conduct this play analysis of the Permian Basin. The objectives of the project were to (1) develop an up-to-date portfolio of oil plays in the Permian Basin of west Texas and southeast New Mexico, (2) study key reservoirs from some of the largest or most active plays to incorporate information on improved practices in reservoir development in the portfolio, and (3) widely disseminate the play portfolio to the public.

The Permian Basin oil-play portfolio has been completed and is presented in this final project report. Thirty-two oil plays covering both the Texas and New Mexico parts of the Permian Basin were defined on the basis of reservoir stratigraphy, reservoir lithology, depositional environment, and structural and tectonic setting. The 1,339 significant-sized reservoirs in the Permian Basin, defined as reservoirs that had cumulative production >1 MMbbl (1.59×10^5 m^3) of oil through December 31, 2000, were each assigned to a play. A reservoir database was established that lists by play the Railroad Commission of Texas (RRC) reservoir number and district (Texas only), official field and reservoir name, year the reservoir was discovered, depth to the top of the reservoir, production during 2000, and cumulative production through 2000. In Texas, cumulative production is listed only under the final reservoir name into which one or more other reservoirs had been transferred.

All significant-sized oil reservoirs in the Permian Basin were mapped in a Geographic Information System (GIS). Different procedures were used for reservoirs in Texas and New Mexico because of different data available in each state. In both states, mapping of the reservoir outlines was done by play in ArcView™GIS. The GIS play maps from Texas and New Mexico were merged to form digital data files, or shapefiles, of each play in the Permian Basin. Play boundaries were drawn for each play, which include areas where fields in that play occur but reservoirs are <1 MMbbl (1.59×10^5 m^3) of cumulative production. The final reservoir shapefile for each play contains the geographic location of the reservoirs in the play and all associated reservoir information within the linked dBASE data table. The final GIS product of this process is an ArcView project file containing the base map, the series of play-specific reservoir shapefiles, and the play-boundary shapefile.

Analysis of production data indicates that the Permian Basin remains a major oil-producing region. Oil production from the significant-sized reservoirs in the Permian Basin having cumulative production >1 MMbbl (1.59×10^5 m^3) was 301.4 MMbbl (4.79×10^8 m^3) in 2000. The top four oil-producing plays in 2000 were the Northwest Shelf San Andres Platform Carbonate play (50.7 MMbbl [(8.06×10^6 m^3)]), the Leonard Restricted Platform Carbonate play (49.9 MMbbl [(7.93×10^6 m^3)]), the Spraberry/Dean Submarine-Fan Sandstone play (27.6 MMbbl [(4.39×10^6 m^3)]), and the San Andres Platform Carbonate play (26.4 MMbbl [(4.20×10^6 m^3)]). Cumulative Permian Basin production through 2000 was 28.9 Bbbl (4.79×10^9 m^3). The top four plays in cumulative production are the Northwest Shelf San Andres Platform Carbonate play (3.97 Bbbl [6.31×10^8 m^3]), the Leonard Restricted Platform Carbonate play (3.30 Bbbl [5.25×10^8 m^3]), the Pennsylvanian and Lower Permian Horseshoe Atoll Carbonate play (2.70 Bbbl [4.29×10^8 m^3]), and the San Andres Platform Carbonate play (2.15 Bbbl [3.42×10^8 m^3]).

Reservoir-characterization studies of key reservoirs from three of the largest or most active plays in the Permian Basin were conducted. Detailed studies were made of the following reservoirs: Kelly-Snyder (SACROC unit) in the Pennsylvanian and Lower Permian Horseshoe Atoll Carbonate play, Fullerton in the Leonardian Restricted Platform Carbonate play, and Barnhart (Ellenburger) in the Ellenburger Selectively Dolomitized Ramp Carbonate play. The geologic heterogeneity in these reservoirs was investigated to better understand production constraints that would apply to all reservoirs in that play. For each of these detailed reservoir studies, technologies for further, economically viable exploitation were investigated. Information on improved practices in reservoir development was incorporated into the portfolio.

The play portfolio presented in this report contains a summary description of each of the 32 oil plays, including key reservoir characteristics and preferred management practices. A map of each play locates all significant-sized reservoirs in the play. Page-sized maps are presented in hard copy in the report, and large play maps are included as pdf files on the CD that accompanies the report. The CD also contains a pdf version of the report, the GIS project, and a digital spreadsheet of the reservoir database. The GIS project links the play maps to a database listing cumulative production and other reservoir information.

INTRODUCTION

This report summarizes the results of research conducted as part of the DOE Identification and Demonstration of Preferred Upstream Management Practices for the Oil Industry (PUMP II) program. The project, "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," focused on the Permian Basin of west Texas and southeast New Mexico (figs. 1, 2), a major petroleum-producing basin in the United States. The Bureau of Economic Geology (BEG) and the New Mexico Bureau of Geology and Mineral Resources (NMBGMR) teamed up to conduct this play analysis of the Permian Basin. The objectives of the project were to (1) develop an up-to-date portfolio of oil plays in the Permian Basin of West Texas and southeast New Mexico, (2) study key reservoirs from some of the largest or most active plays to incorporate information on improved practices in reservoir development in the portfolio, and (3) widely disseminate the play portfolio to the public. The oil-play portfolio contains play maps that locate all significant-sized reservoirs in the play having a cumulative production of >1 MMbbl (1.59×10^5 m^3) through December 31, 2000. Play maps are linked to a database listing cumulative production and other reservoir information. The portfolio also includes a summary description of each play, including key reservoir characteristics and preferred management practices, where possible.

The Permian Basin produced 17 percent of the total U.S. oil production in 2002, and it contains an estimated 22 percent of the proved oil reserves in the United States (Energy Information Administration, 2003). Moreover, this region has the biggest potential for additional oil production in the country, containing 29 percent [17.6 Bbbl (2.80×10^9 m^3)] of estimated future oil reserve growth (Root and others, 1995). Original oil in place (OOIP) in the

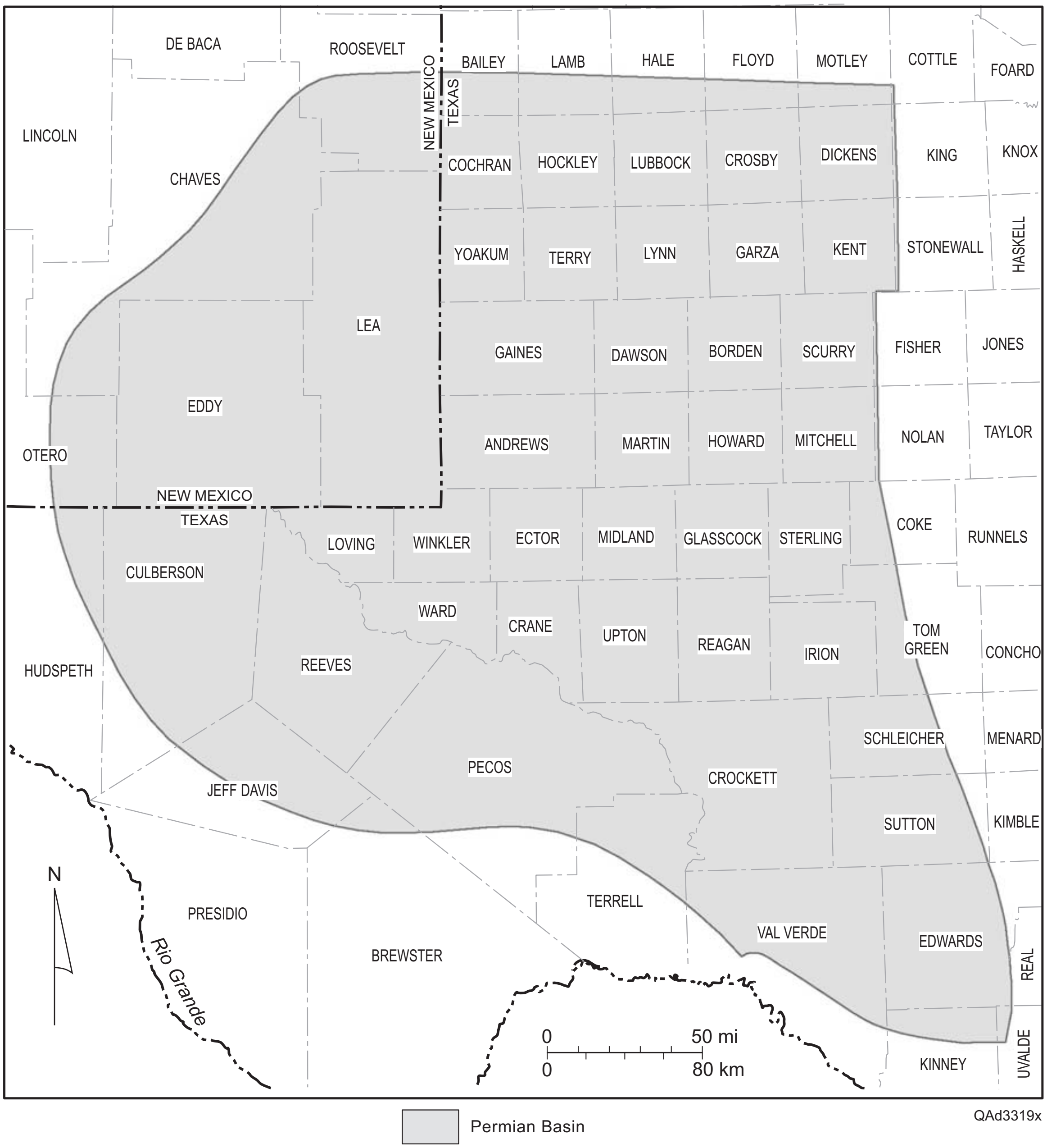

Figure 1. Counties in Texas and New Mexico in the Permian Basin geologic province.

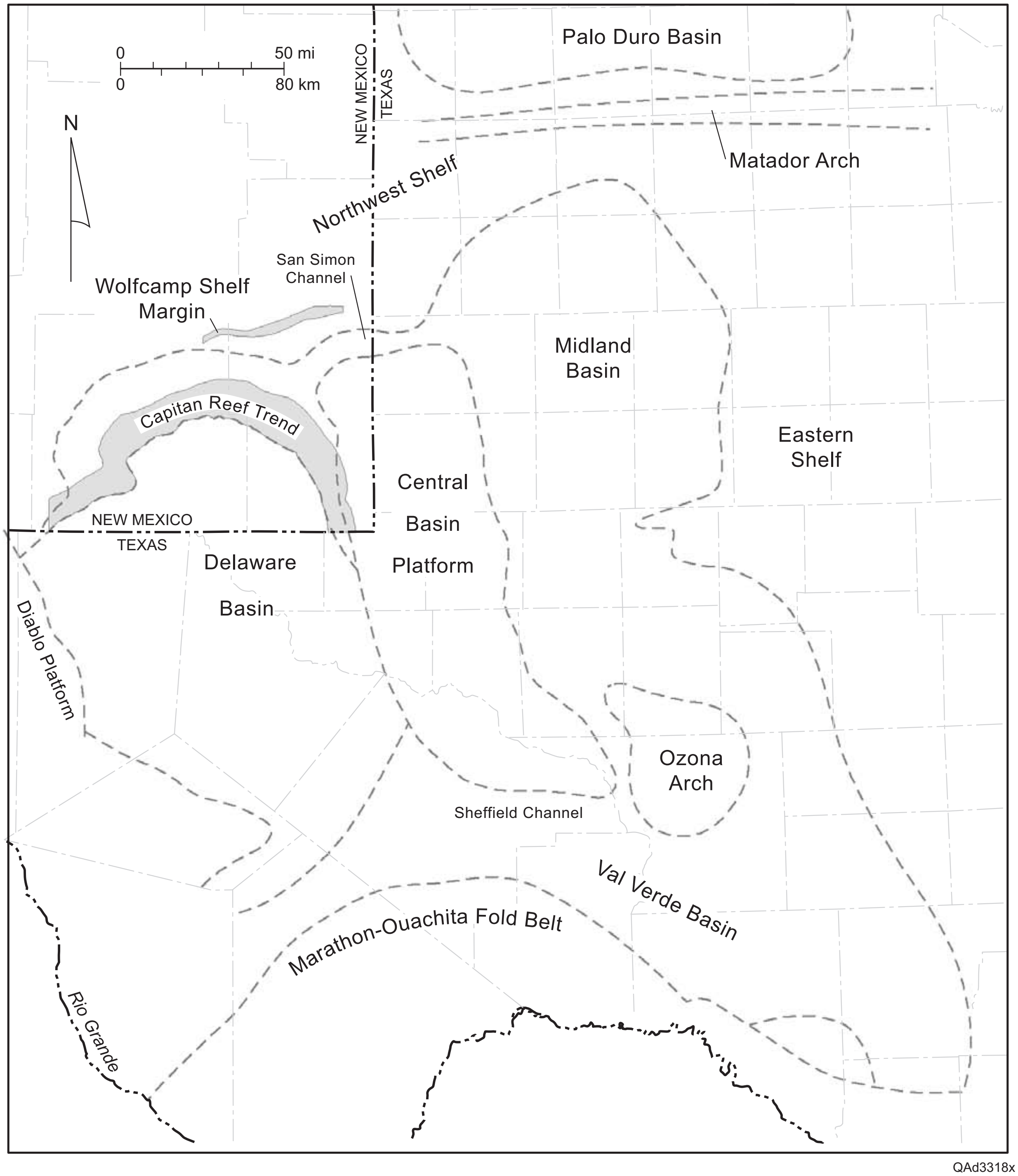

Figure 2. Major subdivisions and boundaries of the Permian Basin in west Texas and southeast New Mexico. Modified from Silver and Todd (1969), Hills (1984), Frenzel and others (1988), Kosters and others (1989), Ewing (1990), Tyler and others (1991), Kerans and Fitchen (1995). The Permian Basin is divided into the Northwest Shelf, Delaware Basin, Central Basin Platform, Midland Basin, Ozona Arch, Val Verde Basin, and Eastern Shelf.

Permian Basin was ~106 Bbbl (1.69×10^{10} m^3) of oil (Tyler and Banta, 1989). After reaching a peak production of >665 MMbbl (1.06×10^8 m^3) per year in the early 1970's, Permian Basin oil production has continuously fallen. By 2000, production had fallen to 301.4 MMbbl (4.79×10^7 m^3), or less than half its peak production. Despite the continuing fall in production, the Permian Basin still holds a significant volume of recoverable oil. Although ~29 Bbbl (4.61×10^9 m^3) of oil has been produced to date, this production represents only ~27 percent of the OOIP. Of the huge remaining resource in the basin, as much as 30 Bbbl (4.77×10^9 m^3) of mobile oil and 45 Bbbl (7.15×10^9 m^3) of residual oil remains as a target for improved technology and recovery strategies (Tyler and Banta, 1989). More than in any other region, increased use of preferred management practices in Permian Basin oil fields will have a substantial impact on domestic production because of the large remaining oil resource.

The Permian Basin is a mature area in which much of its future production will result from improved recovery from existing fields. One way of increasing recovery in a reservoir is to apply methods that have been used successfully in similar reservoirs. In order to do so, however, it is necessary to understand how reservoirs group naturally into larger families, or plays. A play is an assemblage of geologically similar reservoirs exhibiting the same source, reservoir, and trap characteristics (White, 1980). Plays are delineated primarily according to the original depositional setting of the reservoirs or, less commonly, their relation to regional erosional surfaces or diagenetic facies (Galloway and others, 1983). Because of their relative geologic homogeneity, reservoirs in the same play have similar production characteristics. Characteristics of better known reservoirs may be extrapolated with relative confidence to other reservoirs within the same play. Reservoir development methods that have been demonstrated to work well in one reservoir should be applicable to other reservoirs in the play.

This report updates and expands information in the pioneering volume *Atlas of Major Texas Oil Reservoirs* (Galloway and others, 1983), which was published by the Bureau of Economic Geology in 1983. Publication of the Texas oil atlas was a milestone in the application of geologic and engineering play analysis, but that volume is now out of date. The data in the atlas represent oil production only through December 31, 1981. Furthermore, the atlas included only reservoirs in the Texas part of the Permian Basin that had produced >10 MMbbl (1.59×10^6 m^3) of oil. Finally, since publication of the oil atlas, there has been considerable additional geologic and engineering investigation of oil reservoirs in the Permian Basin.
As a result of this work, many of the Permian Basin oil plays defined in the *Atlas of Major Texas Oil Reservoirs* needed to be revised and renamed. This new Permian Basin oil-play portfolio provides that revision and update.

EXPERIMENTAL METHODS

No experimental methods or equipment were used for this study. Information was obtained from published and publicly available sources and from commercially available databases. Reservoir locations in Texas were derived from producing-well location information in Landmark Graphic’s Datastar™ and DrillingInfo.com, Inc. The ArcView™ GIS software package was used for mapping the reservoirs.

RESULTS AND DISCUSSION

Definition of the Permian Basin

Oil production in the Permian Basin occurs from reservoirs in Paleozoic strata, from Ordovician through Permian age (fig. 3). For plays to be defined in the Permian Basin, it was necessary to determine the basin boundaries. The Permian Basin is subdivided into the Northwest Shelf, Delaware Basin, Central Basin Platform, Midland Basin, Ozona Arch, Val Verde Basin, and Eastern Shelf, (fig. 2). In the west, the basin is bounded by the Guadalupe, Sacramento, Sierra Blanca, and Capitan Mountains in New Mexico and the Diablo Plateau in Texas. To the north, the Permian Basin is bounded by the Sin Nombre Arch of DeBaca County and the Roosevelt Uplift of Roosevelt County in New Mexico. In Texas the Matador Arch forms the northern boundary and separates the Midland Basin from the Palo Duro Basin. The southern boundary is the Marathon-Ouachita Fold Belt.

The eastern boundary is more difficult to define. Reservoirs on the Eastern Shelf of the Midland Basin are traditionally considered to be in the Permian Basin geologic province (Galloway and others, 1983). The Eastern Shelf, however, grades eastward onto the Concho Platform and Bend Arch in the North-Central Texas geologic province, with no clearly defined eastern limit. For this study, the eastern boundary of the Permian Basin was selected to follow the approximate position of the shelf edge during early Wolfcampian (Cisco Saddle Creek Limestone) time (Brown and others, 1987, 1990). The counties that occur in the Permian Basin are shown in figure 1. This definition of the Permian Basin is similar to that of Hills (1984).

The current structural features of the Permian Basin (fig. 2) developed during Late Mississippian and Early Pennsylvanian time (Hills, 1984; Frenzel and others, 1988). Prior to this

(a)

System	Epoch/ Series/ Stage	Time (m.y.)	Delaware Basin	NW Shelf New Mexico	NW Shelf Texas	Central Basin Platform	Midland Basin
PENNSYLVANIAN	Virgilian	302	Cisco	Cisco	Cisco	Cisco	Cisco
	Missourian		Canyon	Canyon	Canyon	Canyon	Canyon
	Desmoinesian		Strawn	Strawn	Strawn	Strawn	Strawn
	Atokan		Atoka	Atoka	Atoka	Atoka	Atoka/Bend
	Morrowan		Morrow	Morrow	Morrow		
MISSISSIPPIAN	Chesterian	323	Barnett	Barnett	Barnett	Barnett	Barnett
	Meramecian		Mississippian	Mississippian	Mississippian	Mississippian	Mississippian
	Osagean						
	Kinderhookian						
DEVONIAN	Famennian	363	Woodford	Woodford	Woodford	Woodford	Woodford
	Frasnian						
	Givetian						
	Eifelian						
	Emsian						
	Pragian		Thirtyone		Thirtyone	Thirtyone	Thirtyone
	Lochkovian						
SILURIAN	Pridolian	417	Wristen Group	Wristen Group	Wristen Group	Wristen Group	Wristen Group
	Ludlovian						
	Wenlockian						
	Llandoverian		Fusselman	Fusselman	Fusselman	Fusselman	Fusselman
ORDOVICIAN	Ashgillian	443	Montoya	Montoya	Montoya	Montoya	Sylvan / Montoya
	Caradocian		Simpson Gp.: Bromide, Tulip Creek			Simpson Gp.: Bromide, Tulip Creek	Simpson Gp.: Bromide, Tulip Creek
	Llandeilian		McLish			McLish	McLish
	Llanvirnian		Oil Creek, Joins			Oil Creek, Joins	Oil Creek, Joins
	Arenigian		Ellenburger	Ellenburger	Ellenburger	Ellenburger	
	Tremadocian						
		495	Bliss	Bliss	Bliss		
CAMBRIAN						Cambrian	Cambrian

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Figure 3a. Stratigraphic nomenclature for the Cambrian through Pennsylvanian section in the Permian Basin.

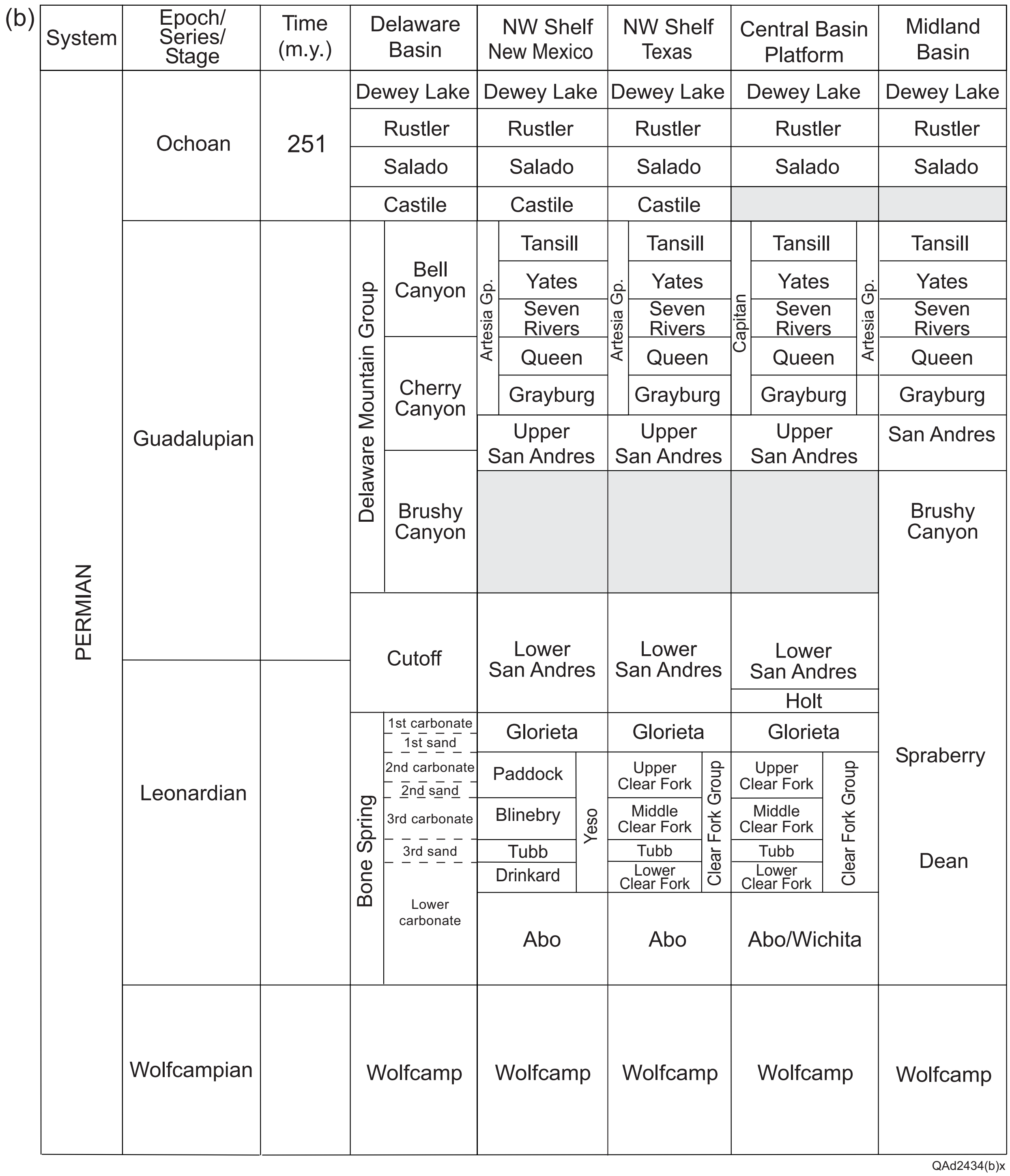

Figure 3b. Stratigraphic nomenclature for the Permian section in the Permian Basin.

time, a shallow, downwarped area was centered in Pecos and Terrell Counties during Simpson time, which was named the Tobosa Basin (Galley, 1958).

Some plays extend from the Permian Basin east into North-Central Texas. So that truncating plays can be avoided, plays that occur mainly in the Permian Basin are presented in their entirety, even though some of the reservoirs in the play actually occur in counties in the North-Central Texas geologic province. Plays that occur mainly in North-Central Texas are not included in this project, even if a few of the reservoirs within the plays are in the Permian Basin. However, so that cumulative production for the Permian Basin can be totaled, reservoirs having production of >1 MMbbl (1.59×10^5 m^3) that are assigned to a North-Central Texas play but occur in Permian Basin counties are identified in tables in the database. These reservoirs are in the Pennsylvanian and Lower Permian Reef/Bank play and the Upper Pennsylvanian Shelf Sandstone play in North-Central Texas.

Identification of Significant-Sized Reservoirs

This play portfolio includes significant-sized reservoirs, which are defined herein as having cumulative production of >1 MMbbl (1.59×10^5 m^3) of oil through December 31, 2000. Cumulative production data sources used to identify these reservoirs differed in Texas and New Mexico.

Texas

Production records of the Railroad Commission of Texas (RRC) were used to identify all reservoirs in the Texas part of the Permian Basin that had produced >1 MMbbl (1.59×10^5 m^3) of oil through 2000. Cumulative production data were obtained from the *2000 Oil and Gas*

Annual Report (Railroad Commission of Texas, 2001), along with official field and reservoir name, RRC District, year the reservoir was discovered, and depth to the top of the reservoir. The RRC unique reservoir number was obtained for each reservoir using the online database at http://driller.rrc.state.tx.us/Apps/WebObjects/acti. Condensate production was not included. A total of 1,040 reservoirs have produced >1 MMbbl (1.59×10^5 m^3) of oil in the Texas part of the Permian Basin.

Many reservoirs were initially designated as separate reservoirs by the RRC but subsequently transferred into another reservoir. In this report, cumulative production is listed only under the final reservoir name (as of 2000) into which one or more other reservoirs had been transferred. Reservoirs that had other reservoirs transferred into them are highlighted by gray shading in the play tables. Cumulative production values listed for these reservoirs represent total production, including production both before and after reservoirs were combined.

This method of reporting differs from that of the RRC in its annual reports. RRC reports list production from a reservoir from the time of discovery until its transfer into another reservoir. Once the reservoir is combined with another, production from the original reservoir continues to be listed year after year, never increasing because all new production is assigned to the new reservoir. We chose not to follow this method because some production that should be reported as part of total production from a reservoir would be lost if the reservoir had not produced >1 MMbbl (1.59×10^5 m^3) before it was transferred into another reservoir.

An example should help clarify this compilation method. Conger (Penn) reservoir in Glasscock County is listed in the *2000 Oil & Gas Annual Report* (Railroad Commission of Texas, 2001) as having produced 19,249,341 bbl (3.06×10^6 m^3) of oil through 2000. In the play tables, however, Conger (Penn) is listed as having produced 20,406,213 bbl

(3.24×10^6 m^3). This difference occurs because three other reservoirs were transferred into Conger (Penn)—Big Salute (Canyon), Conger (Canyon), and Conger (Cisco). Big Salute produced 872,144 bbl (1.39×10^5 m^3) of oil from the time it was discovered in 1974 until it was transferred into Conger (Penn) in 1978. Conger (Canyon) and Conger (Cisco) reservoirs produced 49,631 and 235,127 bbl (7.89×10^3 m^3 and 3.74×10^4 m^3), respectively, before they were transferred into the Conger (Penn) reservoir. Because the goal of this report is to show total production from significant-sized oil reservoirs, we have added production from these three reservoirs to the total shown for Conger (Penn). Otherwise, this production would not have been included because none of these three reservoirs produced >1 MMbbl (1.59×10^5 m^3) before being transferred into Conger (Penn).

New Mexico

Cumulative production data for each reservoir in New Mexico through December 31, 1993, were obtained from the *1993 Annual Report of the New Mexico Oil and Gas Engineering Committee* (New Mexico Oil and Gas Engineering Committee, 1993). Annual oil production data for each reservoir for years subsequent to 1993 were obtained from the 1994, 1995, 1996, 1997, 1998, 1999, and 2000 annual reports of the New Mexico Oil and Gas Engineering Committee. Cumulative production for each reservoir was calculated by taking the annual production from 1994 through 2000 and adding it to the cumulative production data obtained from the 1993 annual report. This approach was used because cumulative production data tabulated by reservoir in reports of the New Mexico Oil and Gas Engineering Committee through 1993 are valid. Cumulative production data in the post-1993 reports are not valid because they do not include historical production from several types of wells (Dutton and others, 2003), although the annual oil production data in these reports are valid. A total of 299 reservoirs in the New Mexico part of the Permian Basin had production >1 MMbbl (1.59×10^5 m^3) through 2000.

Total Permian Basin Production

The 1,339 significant-sized reservoirs in the Permian Basin produced a total of 28.9 Bbbl (4.59×10^9 m^3) of oil through 2000—24.4 Bbbl (3.88×10^9 m^3) from 1,040 reservoirs in Texas and 4.5 Bbbl (7.15×10^8 m^3) from 299 reservoirs in New Mexico. The production from these reservoirs accounts for 95 percent of total Permian Basin production of 30.4 Bbbl (4.83×10^9 m^3) through 2000. Total production from all reservoirs in the Texas part of the Permian Basin (all reservoirs in RRC Districts 7C, 8, and 8A) was 25.6 Bbbl (4.07×10^9 m^3) through 2000 (Railroad Commission of Texas, 2001). Total production from all reservoirs in the New Mexico part of the Permian Basin was 4.8 Bbbl (7.63×10^8 m^3) through 2000.

The value of 30.4 Bbbl (4.83×10^9 m^3) cumulative oil production from the Permian Basin differs from that of the U.S. Geological Survey (USGS) 1995 assessment (U.S. Geological Survey, 1995, 1996). That study indicates that total Permian Basin oil production through 1990 was 34.9 Bbbl (5.55×10^9 m^3). The reason for the difference is that the USGS study covered a larger area, extending farther east into North-Central Texas and farther northwest in New Mexico.

Play Definitions

A major goal of this project is to define oil plays in the Permian Basin. Plays can generally be considered as groups of reservoirs that have similar geologic parameters, such as a common stratigraphic unit, reservoir lithology, reservoir depositional environment, structural and tectonic setting, or trapping mechanism. Gas plays were not included in this project.

Thirty-two oil plays covering both the Texas and New Mexico parts of the Permian Basin were defined (tables 1, 2). In most cases, the play names established in Texas can also be used in New Mexico because of identical stratigraphy, tectonic setting, and depositional environments. Twelve of the plays contain reservoirs in both Texas and New Mexico. Fifteen plays contain reservoirs in Texas only, and five plays contain reservoirs in New Mexico only. The plays have been extensively modified from those defined in the *Atlas of Major Texas Oil Reservoirs* (Galloway and others, 1983) on the basis of the past 20 years of research on Permian Basin reservoirs. The oil atlas and more recent play assessments of the Permian Basin by Kosters and others (1989), Tyler and others (1991), Holtz and Kerans (1992), Holtz and others (1992), Holtz (1993), Holtz and others (1993), New Mexico Bureau of Mines and Mineral Resources (1993), Ruppel and Holtz (1994), and Dutton and others (2000b) provided the foundation on which the play assessment was based.

Play Designations of Reservoirs

A total of 1,040 reservoirs in Texas and 299 reservoirs in New Mexico had produced >1 MMbbl (1.59×10^5 m^3) of oil through 2000, and each of these reservoirs was assigned to a play. Reservoirs were assigned to plays on the basis of productive stratal unit (formation), depositional setting, tectonic and structural location within the Permian Basin, reservoir lithology, postdepositional karstification, and trapping mechanism of the reservoir. Reservoir assignments are listed, by play, in the tables that accompany the play summaries. A digital version of the play tables is on the CD that is included with this report. The plays have all been given a play code—a number from 101 to 132—to facilitate sorting by plays in the digital data tables.

Table 1. Production in 2000 and cumulative production through December 31, 2000, of oil plays in the Permian Basin, listed by reservoir age.

PLAY	PLAY CODE	STATE	2000 PROD (MMbbl)	CUMPROD (MMbl)
Guadalupian				
Artesia Platform Sandstone	132	TX & NM	6,526,676	1,855,409,025
Queen Tidal-Flat Sandstone	131	TX	1,517,501	179,600,166
Delaware Mountain Group Basinal Sandstone	130	TX & NM	9,208,247	351,912,395
Grayburg High-Energy Platform Carbonate—Ozona Arch	129	TX	1,968,685	298,378,769
Grayburg Platform Carbonate	128	TX	10,104,204	1,271,232,325
Grayburg Platform Mixed Clastic/Carbonate	127	TX	7,806,840	669,727,337
San Andres/Grayburg Lowstand Carbonate	126	TX	9,357,241	681,131,877
Upper San Andres and Grayburg Platform Mixed—Artesia Vacuum Trend	125	NM	11,392,997	796,416,386
Upper San Andres and Grayburg Platform Mixed—Central Basin Platform Trend	124	NM	5,790,360	808,957,693
San Andres Platform Carbonate	123	TX	26,420,818	2,151,296,650
San Andres Karst-Modified Platform Carbonate	122	TX	11,460,129	1,567,103,814
Eastern Shelf San Andres Platform Carbonate	121	TX	6,613,837	706,897,011
Northwest Shelf San Andres Platform Carbonate	120	TX & NM	50,666,870	3,969,256,500
			158,834,405	**15,307,319,948**
Leonardian				
Spraberry/Dean Submarine-Fan Sandstone	119	TX	27,576,283	1,287,098,237
Bone Spring Basinal Sandstone and Carbonate	118	NM	2,455,154	70,703,460
Leonard Restricted Platform Carbonate	117	TX & NM	49,928,957	3,297,197,998
Abo Platform Carbonate	116	TX & NM	6,105,583	541,459,683
			86,065,977	**5,196,459,378**
Wolfcampian				
Wolfcamp/Leonard Slope and Basinal Carbonate	115	TX & NM	9,046,188	194,975,500
Wolfcamp Platform Carbonate	114	TX & NM	4,012,646	457,405,339
			13,058,834	**652,380,839**
Pennsylvanian				
Upper Pennsylvanian and Lower Permian Slope and Basinal Sandstone*	113	TX	1,802,373	271,448,389
Pennsylvanian and Lower Permian Horseshoe Atoll Carbonate	112	TX	13,686,639	2,699,242,936
Pennsylvanian Platform Carbonate	111	TX	2,076,281	340,469,274
Northwest Shelf Upper Pennsylvanian Carbonate	110	NM	4,871,162	353,848,173
Northwest Shelf Strawn Patch Reef	109	NM	1,064,882	69,863,831
Pennsylvanian and Lower Permian Reef/Bank**	25	TX	315,183	92,104,283
Upper Pennsylvanian Shelf Sandstone#	24	TX	426,556	7,264,141
			24,243,076	**3,834,241,027**
Mississippian				
Mississippian Platform Carbonate	108	TX	91,765	15,110,822
			91,765	**15,110,822**
Devonian				
Devonian Thirtyone Ramp Carbonate	107	TX	1,747,319	110,249,504
Devonian Thirtyone Deepwater Chert	106	TX & NM	6,786,521	785,929,988
			8,533,840	**896,179,492**
Silurian				
Wristen Buildups and Platform Carbonate	105	TX & NM	4,773,912	888,757,885
Fusselman Shallow Platform Carbonate	104	TX & NM	2,046,889	356,268,389
			6,820,801	**1,245,026,274**
Ordovician				
Simpson Cratonic Sandstone	103	TX & NM	420,651	103,228,356
Ellenburger Karst-Modified Restricted Ramp Carbonate	102	TX & NM	2,802,096	1,487,309,287
Ellenburger Selectively Dolomitized Ramp Carbonate*, ##	101	TX	537,120	163,734,910
			3,759,867	**1,754,272,553**
Total			**301,408,565**	**28,900,990,333**

*Includes all reservoirs in this play, including ones in North-Central Texas geologic province.

**Not included in play portfolio because most of play is in North-Central Texas geologic province. Production listed here represents only the 10 reservoirs in the Permian Basin part of the play.

#Not included in play portfolio because most of play is in North-Central Texas geologic province. Production listed here represents only the 5 reservoirs in the Permian Basin part of the play.

##Does not include ~21 MMbbl of production from Ellenburger reservoir at Big Lake field. All production from Big Lake field was assigned to the Grayburg by the RRC.

Table 2. Cumulative production of oil plays in the Permian Basin, ranked by production. Production is through December 31, 2000.

Oil plays	**Cum. prod. (MMbbl)**
Northwest Shelf San Andres Platform Carbonate	3,969.3
Leonard Restricted Platform Carbonate	3,297.2
Pennsylvanian and Lower Permian Horseshoe Atoll Carbonate	2,699.2
San Andres Platform Carbonate	2,151.3
Artesia Platform Sandstone	1,855.4
San Andres Karst-Modified Platform Carbonate	1,567.1
Ellenburger Karst-Modified Restricted Ramp Carbonate	1,487.3
Spraberry/Dean Submarine-Fan Sandstone	1,287.1
Grayburg Platform Carbonate	1,271.2
Wristen Buildups and Platform Carbonate	888.8
Upper San Andres and Grayburg Platform Mixed—Central Basin Platform Trend	809.0
Upper San Andres and Grayburg Platform Mixed—Artesia Vacuum Trend	796.4
Devonian Thirtyone Deepwater Chert	785.9
Eastern Shelf San Andres Platform Carbonate	706.9
San Andres/Grayburg Lowstand Carbonate	681.1
Grayburg Platform Mixed Clastic/Carbonate	669.7
Abo Platform Carbonate	541.5
Wolfcamp Platform Carbonate	457.4
Fusselman Shallow Platform Carbonate	356.3
Northwest Shelf Upper Pennsylvanian Carbonate	353.8
Delaware Mountain Group Basinal Sandstone	351.9
Pennsylvanian Platform Carbonate	340.5
Grayburg High-Energy Platform Carbonate—Ozona Arch	298.4
Upper Pennsylvanian and Lower Permian Slope and Basinal Sandstone**	271.4
Wolfcamp/Leonard Slope and Basinal Carbonate	195.0
Queen Tidal-Flat Sandstone	179.6
Ellenburger Selectively Dolomitized Ramp Carbonate**,##	163.7
Devonian Thirtyone Ramp Carbonate	110.2
Simpson Cratonic Sandstone	103.2
Pennsylvanian and Lower Permian Reef/Bank*	92.1
Bone Spring Basinal Sandstone and Carbonate	70.7
Northwest Shelf Strawn Patch Reef	69.9
Mississippian Platform Carbonate	15.1
Upper Pennsylvanian Shelf Sandstone#	7.3
Total Permian Basin Production	**28,901.0**

**Includes all reservoirs in this play, including ones in North-Central Texas geologic province.

*Not included in play portfolio because most of play is in North-Central Texas geologic province. Production listed here represents only the 10 reservoirs in the Permian Basin part of the play.

#Not included in play portfolio because most of play is in North-Central Texas geologic province. Production listed here represents only the five reservoirs in the Permian Basin part of the play.

##Does not include approximately 21 MMbbl of production from Ellenburger reservoir at Big Lake field. All production from Big Lake field is assigned to the Grayburg by the RRC.

The names listed in the tables are the official field and reservoir names designated by the RRC or the Oil Conservation Division (OCD) of the New Mexico Energy, Minerals and Natural Resources Department. In some cases the official reservoir name that was assigned is now interpreted as not being accurate. For example, Moonlight (Mississippian) reservoir in Midland County, Texas, has been assigned to the Pennsylvanian Platform Carbonate play. Despite its official reservoir name, it is interpreted as producing from the Pennsylvanian Atoka interval (Candelaria, 1990).

Assignment of reservoirs to one of the 27 plays in Texas was based primarily on published information and information in hearing files of the RRC. Publications of the BEG, West Texas Geological Society, and Permian Basin Section SEPM, as well as discussions with BEG researchers, were used to make play assignments. The field summaries published by the Bureau of Economic Geology (1957) and the West Texas Geological Society (1982, 1987, 1990, 1994, 1996) and previous studies by Holtz and others (1993) and Dutton and others (2000b) were particularly helpful.

Oil and gas reservoirs (pools) in New Mexico are named according to rules promulgated by the OCD of the New Mexico Energy, Minerals and Natural Resources Department. For most New Mexico reservoirs, most or all production has been obtained from a single stratigraphic unit or formation. In these cases, assignment of a reservoir to a play is straightforward because most plays have a stratigraphic component to their definition. In some reservoirs, however, the OCD has permitted significant commingling of oil and gas production across formational boundaries. In these cases, the stratigraphic component of the pool name contains two or more formational names (for example, the Justis Blinebry Tubb Drinkard pool). In cases where both formational names have been assigned to the same play (for example, production from the Blinebry, Tubb, and Drinkard Members of the Yeso Formation is assigned in entirety to the Leonard Restricted Platform Carbonate play), assignment of a reservoir to a play is straightforward.

However, if the formations were assigned to different plays (for example, the Loco Hills Queen Grayburg San Andres pool), then production from the reservoir is divided between two plays. For these pools, records of numerous individual wells were examined to ascertain whether one constituent formation provided the overwhelming percentage of the production or whether all listed formations contributed major percentages of production. In most cases, it was found that one formation contributed the dominant amount of production, and the pool was assigned to the play associated with that formation. This assignment is apparent if only a few wells were completed in a second formation or if wells completed solely in one of the formations recovered only minor volumes of oil (stripper-type wells).

In a few cases, however, it became apparent that multiple formations are major contributors to production from a single pool. In such cases, these pools are cross-listed in multiple plays because it is not possible to assign fractional parts of commingled production to a single reservoir stratum. These cross-listed pools are generally very large, and it has been ascertained that each of the constituent formations has contributed >1 MMbbl (1.59×10^5 m^3) cumulative production.

Finally, a complication occurs in some lower Paleozoic reservoirs (mainly Devonian and Silurian) where the formational name is inaccurate with respect to modern stratigraphic interpretations. For example, reservoirs that produce from what is now recognized as the Silurian Wristen Group have been historically called Devonian, and this Devonian descriptor is used in the pool name. Because these name designations are official, they are left unchanged in the database.

The task of assigning reservoirs to plays in New Mexico was also done on the basis of previous studies and published work. Information on reservoir lithology was obtained primarily from field summaries published by the Roswell Geological Society (Roswell Geological Society, 1956, 1960, 1967, 1977, 1988, 1995). Major sources of data are the well records, sample descriptions, and logs on file at the Subsurface Library of the NMBGMR. Descriptions of some reservoirs and plays have been published (LeMay, 1960, 1972; Malek-Aslani, 1985; Gawloski, 1987; Grant and Foster, 1989; New Mexico Bureau of Mines and Mineral Resources, 1993; Baldonado and Broadhead, 2002). Data on depositional environments of reservoirs were obtained from published studies.

Mapping Reservoirs in GIS

Each of the 1,339 oil reservoirs in the Permian Basin having cumulative production of >1 MMbbl (1.59×10^5 m^3) was mapped and compiled in a Geographic Information System (GIS) by play. Different procedures were used for reservoirs in Texas and New Mexico because of the different data available in each state. Final ArcView™ GIS files were produced that illustrate all reservoirs in each play, play boundaries, state and county lines, legal land grid, and boundaries of major geologic elements that relate to play trends and production.

Texas

Numerous data sources were utilized for mapping reservoirs in Texas. The initial dataset accessed was from Landmark Graphic’s Datastar™ product. The Datastar™ product, compiled from data maintained by Whitestar Corporation, provides oil and gas well spots, land grids, and cultural information for the entire U.S. After initial mapping of reservoirs (Dutton and others, 2004), well-location data obtained from DrillingInfo.com, Inc., were used to verify locations by comparing mapped reservoirs. Other nondigital maps that were used for data verification include BEG oil and gas atlases (Galloway and others, 1983; Kosters and others, 1989), Geomap Company Permian Basin Executive reference map (Geomap Company, 1998), Structurmaps, Ltd., Permian Basin structure map (Structurmaps Ltd., 1970), and Midland Map Company Permian Basin regional base map (Midland Map Company, 1997). Well production was compared using Lasser Inc.'s Texas production database (Lasser Texas Production CD, 2003), as well as RRC production reports (Railroad Commission of Texas, 2001).

Actual mapping of reservoir outlines was done entirely in ArcView™ GIS using Texas abstract and county-line shapefiles as the base map (Dutton and others, 2004). In order to keep the distance from well locations to the reservoir boundary consistent for each reservoir mapped, selected wells were buffered by 0.5 mi. Reservoir outlines generated by this process are intended to show approximate location, size, and shape of each reservoir, but they are not precise boundaries. Reservoir shapes, therefore, should not be used to calculate subsurface reservoir area for accurate volumetric determinations.

The final reservoir shapefile for each play contains the geographic location of each reservoir and all associated information within the linked dBASE data table, including play name (PLAY), play code (PLAY_CODE), RRC unique reservoir number (RRC RESN), RRC district (RRC), field name (FLDNAME), reservoir name (RESNAME), state, county, discovery year (DISCYR), depth in feet to top of the reservoir (DEPTHTOP), 2000 production (2000 PROD) in barrels, and cumulative production (CUMPROD) in barrels through 2000. Some tables also list subplays. The final GIS product of this process is an ArcView project file containing base maps, the newly created series of play-specific reservoir shapefiles, and play-boundary shapefiles. The GIS project is included on the CD that accompanies this report. Data tables for each play are included in the play summaries and are available in digital form on the CD.

New Mexico

Those reservoirs with >1 MMbbl (1.59×10^5 m^3) production were placed into geologic plays and entered into ArcView™ GIS using pool (reservoir) shapefiles outlining field boundaries copied from the New Mexico pools project (Read and others, 2000). Oil pool boundaries indicated on these maps are the legal boundaries of the pools, as provided by the New Mexico Oil Conservation Division. The rectilinear boundaries of New Mexico reservoirs thus reflect the legal definition of the fields. Data tables for New Mexico reservoirs contain the same headers as for Texas, except for RRC unique reservoir number and district.

Play Boundaries and Play Maps

The GIS play maps from Texas and New Mexico were merged to form digital data files, or shapefiles, of each play in the Permian Basin. Play boundaries for each play were drawn to include areas where reservoirs in that play occur but are <1 MMbbl (1.59×10^5 m^3) of cumulative production. These areas should be considered as part of the play, even if no reservoirs from the play have yet produced >1 MMbbl (1.59×10^5 m^3).

Page-sized play maps, showing reservoirs in the play, play boundaries, and geologic features, are included in the play summaries in this report. These maps are useful in depicting the overall trend of the play and distribution of reservoirs. Reservoir names could not be shown on the page-sized maps because of space limitations. In the GIS project included on the CD accompanying this report, field names are available within the associated attribute table. In addition, pdf versions of the play maps are included on the CD, and they have the fields named. Only field names are included, except in cases where reservoir names are also shown for clarity.

Contents of the CD

A CD is included with this report. It contains a pdf version of the report, pdf maps of all plays, the GIS project, and a digital spreadsheet of the reservoir database. In order for the GIS project to be used, ArcExplorer freeware from ESRI has been included on the CD. A user who has a copy of ArcView 3.1 or higher (a Desktop ESRI GIS software package) can use the full capability of the GIS project. For those not capable of running these GIS applications or those that want printed output, the play maps may also be viewed as pdf files (require Adobe Acrobat Reader version 6.0—freeware, which is also included on the CD).

The GIS project consists of the ArcView™ project file (DOE_PUMPII.apr) and the DOE PUMP II GIS database, which is contained in the GIS2003 subfolder. Basemap data, contained in the basemap folder, include shapefiles such as state and county lines, legal land grid, and boundaries of major geologic elements. Each of the 32 play-boundary shapefiles, contained in the play_bnd folder, appears as a separate layer within the ArcView™ project, and each of these layers is linked to a play-production data table. The Texas and New Mexico reservoir data shapefiles are contained in two separate folders, named data_nm and data_tx. These shapefiles appear in the ArcView™ project as separate layers because of discrepancies within the data due to how the data were generated. There are 21 New Mexico reservoir data layers and 27 Texas reservoir data layers. Each reservoir data layer is color coded and linked to a corresponding data table.

The digital spreadsheet is an Excel™ file called Reservoir Database. It contains multiple sheets: (1) Master, (2) By plays, (3) By plays ann prod, (4) By plays cum prod, and (5) By age. The data in the sheets "Master" and "By plays" include all data associated with each reservoir, including play name (PLAY), play code (PLAY_CODE), RRC unique reservoir number (RRC_RESN), RRC district (RRC), field name (FLDNAME), reservoir name (RESNAME), state, county, discovery year (DISCYR), depth in feet to top of the reservoir (DEPTHTOP), 2000 production (2000 PROD) in barrels, and cumulative production (CUMPROD) in barrels through 2000. Some tables also list subplays (SUB_PLAY).

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PLAY SUMMARIES

Each of the 32 oil plays in the Permian Basin was summarized using information from published literature and illustrated by selected appropriate diagrams. The play descriptions include key characteristics of the play, summarize and illustrate the reservoir heterogeneity that characterizes reservoirs in the play, and detail preferred management practices that have been used successfully in the play. Page-size play maps, showing reservoirs in the play, play boundaries, and geologic features, are included in each play summary. A table of all reservoirs in the play that had produced >1 MMbbl (1.59×10^5 m^3) through 2000 is also included. Reservoirs that had other reservoirs transferred into them are highlighted by gray shading in the play tables. Cumulative production values listed for these combined reservoirs represent total production, including production both before and after the reservoirs were combined. A list of combined reservoirs, sorted by plays, is shown in table 3.

Reservoir-characterization studies of key reservoirs from three of the largest or most active plays in the Permian Basin were conducted as part of this project. The reservoirs studied were Kelly-Snyder (SACROC unit) in the Pennsylvanian and Lower Permian Horseshoe Atoll Carbonate play, Fullerton in the Leonard Restricted Platform Carbonate play, and Barnhart (Ellenburger) in the Ellenburger Selectively Dolomitized Ramp Carbonate play. The geologic heterogeneity in these reservoirs was investigated so that production constraints that would apply to other reservoirs in that play could be better understood. For each of these detailed reservoir studies, technologies for further, economically viable exploitation were investigated. Information developed during these investigations was incorporated into the play summaries.

Many maps, cross sections, logs, and data tables are contained in the *Atlas of Major Texas Oil Reservoirs* (Galloway and others, 1983) and the *Atlas of Major Texas Oil Reservoirs: Data Base* (Holtz and others, 1991) but are not reproduced in this report. Although the play assignment of reservoirs in the original oil atlas differs from that of this report, the atlas remains a good source of information about the 194 largest reservoirs in the Permian Basin, those that had produced >10 MMbbl (1.59×10^6 m^3) through 1981. The atlas includes data tables listing trap type, drive mechanism, thickness of oil column, porosity, permeability, water saturation, oil gravity, initial reservoir pressure and temperature, well spacing, residual oil saturation, original oil in place, ultimate recovery, and recovery efficiency. These data were compiled digitally by Holtz and others (1991).

Table 3. Texas reservoirs in each play that have been combined with others; top name for each entry is final reservoir name, and indented name(s) listed below are reservoirs that have been combined into the top reservoir. Cumulative production in play tables is given for all combined fields and is listed only under the final reservoir name. For example, Barron Ranch (Ellen.) and Swenson-Garza (Ellen.) were combined into Swenson-Barron (Ellen.), and cumulative production from all three reservoirs is listed under Swenson-Barron (Ellen.) in the play table.

Play 101 Ellenburger Selectively Dolomitized Ramp Carbonate

- Swenson-Barron (Ellen.)
  - Barron Ranch (Ellen.)
  - Swenson-Garza (Ellen.)

Play 102 Ellenburger Karst-Modified Restricted Ramp Carbonate

- Emma (Ellenburger)
  - Triple-N (Ellenburger)
- Magutex (Ellenburger)
  - Andrews, Northeast (Ellen.)
- Metz, East (Ellenburger)
  - Metz (Ellenburger)
- Nelson (Ellenburger)
  - Freund
- Norman (Ellenburger, District 8)
  - Norman (Ellen., District 8A)

Play 103 Simpson Cratonic Sandstone

- Running W (Waddell)
  - Block B-21 (Waddell)
  - Block B-27 (Waddell)
  - Reed (Waddell, Middle)
  - Reed, N. (Waddell, MI.)

Play 104 Fusselman Shallow Platform Carbonate

- Corrigan
  - Nystel
- Inez Deep
  - Inez (Atoka)
  - Inez (Fusselman)
  - Midland Farms (Dev.)
- Midland Farms Deep
  - Midland Farms (Fusselman)
  - Midland Farms, West (Dev.)

Play 105 Wristen Buildups and Platform Carbonate

- Breedlove
  - Breedlove, North (Dev.)
- Hutex (Devonian)
  - Prichard (Devonian)
- Magutex (Devonian)
  - Andrews, Northeast (Dev.)
- Norman (Devonian) (District 8)
  - Norman (Dev.) (District 8A)
- Seagraves (Siluro-Devonian)
  - Seagraves, W. (Devonian)

Play 106 Devonian Thirtyone Deepwater Chert

- Block 31
  - Block 31, East (Devonian)
- Crossett, S. (Detrital)
  - El Cinco (Detrital)
- Crossett, S. (Devonian)
  - El Cinco (Devonian)
- King Mountain (Devonian)
  - King Mountain, S. (Dev.)

Play 107 Devonian Thirtyone Ramp Carbonate

- Harper (Devonian)
  - Harper, West (Devonian)

Play 111 Pennsylvanian Platform Carbonate

- AdamC (Bend)
  - McElroy (Penn. 8)
- Arenoso (Strawn Detritus)
  - Sealy Smith (Strawn)
- Block 31, NW. (Penn. Upper)
  - Block 31, NW. (Penn.)
- Block 42 (Penn)
  - Block 42 (Strawn)
  - Block 42 (Strawn, Lo.)

Dewey Lake, S. (Strawn)
- Arlis (Strawn)

Dora Roberts (Consolidated)
- Dora Roberts (Strawn)
- Dora Roberts (Penn.)
- Headlee (Wolfcamp)

Emma (Strawn)
- Triple-N (Penn., Lower)

Fasken (Penn.)
- Cowden, N. (Penn.)

H. S. A. (Pennsylvanian)
- Estes Block B-19 (Penn.)

Virey (Consolidated)
- Virey (Pennsylvanian)
- Virey (Strawn)
- Virey (Wolfcamp, Lower)
- Virey (Wolfcamp, Upper)

War-San (Consolidated)
- War-San (Pennsylvanian)
- War-San (Wolfcamp, Lower)

Play 112 Pennsylvanian and Lower Permian Horseshoe Atoll Carbonate

Fluvanna (Strawn)
- Fluvanna, N. (Strawn Reef)

Kelly-Snyder
- Snyder, North
- Kelly

Synder, N. (Strawn Zone B)
- Snyder, North (Strawn Zone C)

Play 113 Upper Pennsylvanian and Lower Permian Slope and Basinal Sandstone

Baker Ranch (Canyon)
- Cal, South (Canyon)

Bloodworth, NE (5750 Canyon)
- Bloodworth, NE. (5650
- Bloodworth, NE. (5800 Canyon)
- Panther Gap, N. (Canyon 5660)

Conger (Penn)
- Big Salute (Canyon)
- Conger (Canyon)
- Conger (Cisco)

I. A. B., NE. (5150 Canyon)
- Sanco (Canyon)

Jameson (Strawn)
- Fuller-Coke (Strawn)
- Fuller-Coke, North (Strawn)
- Fuller-Coke, South (Strawn)

Kelly-Snyder (Cisco Sand)
- Brown (Cisco Sand)
- George Parks (Cisco Sand)

Lake Trammel, W. (Canyon)
- Lake Trammel (Canyon)

Pardue (Canyon)
- Pardue

S-M-S (Canyon Sand)
- Casey (Canyon Sand)

Play 114 Wolfcamp Platform Carbonate

Cowden, South (Canyon 8790)
- Cowden, South (Cisco 8640)

D. E. B. (Wolfcamp)
- Bottenfield (Wolfcamp)
- Toby-Jo (Wolfcamp)

D. E. B. (Wolfcamp, Zone B)
- Bottenfield (Wolfcamp, Zone B)

Nolley (Wolfcamp)
- Norman (Wolfcamp)
- Norman, S. (Wolfcamp)
- Norman, S. (Wolfcamp -B-)

Tippett, West (Hueco)
- Tippett (Hueco)
- Tippett (Wolfcamp)
- Tippett, W. (Detrital 5000)

Wemac (Wolfcamp)
- Bakke, North (Penn.)
- Wemac, N. (Wolfcamp Reef)

Play 115 Wolfcamp/Leonard Slope and Basinal Carbonate

Athey (Wolfcamp 10900)
- Athey, East (Wolfcamp 11,500)

Coyanosa (Wolfcamp)
- Athey (Wolfcamp 11,500)

Howard-Glasscock (Wolfcamp 7400)
- Howard Glasscock (Wolfcamp 7325)

Spraberry (Trend Area Cl. Fk.)
- Block 39, South (Clear Fork)
- Hirsch (Clear Fork)
- Spraberry (Trend Area Cl. Fk. S.)

Play 116 Abo Platform Carbonate

Kingdom (Abo Reef)
- Kingdom, N. (Abo)
- Slaughter (Abo)

Play 117 Leonard Restricted Platform Carbonate

Bayview (Glorieta)
- Bayview (Glorieta, Upper)

Block A-28 (Wichita-Albany)
- Block A-28 (Drinkard, Lo.)

Brown & Thorp (Clear Fork)
- Krasner (Clear Fork)

Crossett (3000 Clear Fork)
- Crossett (Tubb)
- Crossett (3200)

Deep Rock (Glorieta 5950)
- Deep Rock (Glorieta)

Diamond –M- (Clear Fork)
- Diamond –M- (San Andres)

Dorward
- Dorward (San Andres)
- Justiceburg (Glorieta)

Flanagan (Clearfork, Cons.)
- Flanagan (Clear Fork)
- Flanagan (Clear Fork, Upper)
- Westlund (Clear Fork, Upper)

Fullerton
- Fullerton (Clear Fork, Upper)

Garza (Glorieta, S. Deep)
- Garza (Glorieta, S., Z-1)
- Garza (Glorieta, S., Z-5)

Giebel (CFA)
- Giebel (Clearfork, Lower)
- Rudy (Witchita-Albany) [sic]

Goldsmith (5600)
- TXL (Clear Fork, Upper)

H & L (Glorieta)
- P-M-A (Glorieta)
- Post, NW. (Glorieta)

Hoople (Clear Fork)
- Ha-Ra (Clear Fork)
- Ridge (Clear Fork)
- Ridge, South (Clear Fork)

Lee Harrison
- Stennett

Leeper (Glorieta)
- D-L-S (Clear Fork)

Lyles (Clear Fork)
- Lyles (Clear Fork 3150)
- Lyles (Clear Fork 3400)
- Roberdeau (Clear Fork, 3400)
- Roberdeau, N. (Clear Fork 3150)
- Roberdeau, N. (Clear Fork 3400)
- Roberdeau, N. (Glorieta)

Martin (Consolidated)
- Block 11 (Wichita, Lo.)
- Martin (Clear Fork)
- Martin (Clear Fork, Lo.)
- Martin (Wichita)

Ownby
- Waples Platter

Post (Glorieta)
- Justiceburg, NW. (Glorieta)
- O. S. Ranch (Glorieta)
- Post

Prentice (6700)
- Cobb (6700)

Prentice (Clear Fork, Lower)
- Clanahan (Clear Fork, Lower)

Prentice
- Cobb

Roberdeau (Clear Fork, Upper)
- Roberdeau (Clear Fork, Middle)
- Crossett, West (Clear Fork, Mi.)
- Roberdeau (Clearfork, Lower)

Roberdeau, S. (Tubb)
- Roberdeau, S. (Clear Fork M.)
- Roberdeau, S. (Clear Fork 2800)
- Roberdeau, S. (Clear Fork 3400)

Robertson, N. (Clear Fork 7100)
- Robertson (Clear Fork, Lo.)

Sharon Ridge (Clear Fork)
- Sharon Ridge (2400)

Wasson 72
- Wasson (Glorieta)
- Wasson, NE. (Wichita-Albany)
- Wasson 66

Play 119 Spraberry/Dean Submarine-Fan Sandstone

Ackerly, North (Spraberry)
- Christine (Spraberry)

Felken (Spraberry)
- Snowdon (Spraberry)

Jo-Mill (Spraberry)
- Arthur (Spraberry)
- Canon (Spraberry)
- Fowel (Spraberry, Lower)

Key (Spraberry, Upper)
- Key (Spraberry)

Lamesa, West (Spraberry)
- Huddle-Manning

Parks (Spraberry)
- Parks (Wolfcamp 9335)
- R & W (Clear Fork)

Reo (Jo Mill, Lower)
- Borden (Spraberry)

Spraberry (Trend Area) (District 7C)
- Aldwell (Spraberry)
- Calvin (Dean)
- Calvin (Spraberry)
- Centralia Draw (Dean)
- Pembrook
- Pembrook, North (Spraberry)
- Stiles (Spraberry)
- Sugg, North (Clean Fork)
- Weiner-Floyd (Spraberry)

Spraberry (Trend Area) (District 8)
- Billington (Spraberry)
- Driver (Spraberry Sand)
- Germania
- Glass (Spraberry)
- Midkiff (Spraberry Sand)
- Playa (Spraberry)
- Stanton (Spraberry)
- Tex-Harvey (Floyd Sand)

Spraberry, W. (Deep, Spraberry)
- Spraberry, West (Deep)
- Spraberry, West (Deep, Spbry, Lo)

Sulphur Draw (Dean 8790)
- Sulphur Draw (Spraberry)

Play 120 Northwest Shelf San Andres Platform Carbonate

Brahaney
- Brahaney, West (San Andres)
- Chambliss (San Andres)

Wasson
- Russell (San Andres)

Play 121 Eastern Shelf San Andres Platform Carbonate

Garza (San Andres, Deep)
- Garza (San Andres -B-)
- Garza (San Andres -C-)
- Garza (San Andres -D-)
- Garza (San Andres -E-)

Guinn (San Andres)
- Block L (San Andres, Middle)

Howard Glasscock
- Albaugh (Yates Sd.)

McDowell (San Andres)
- McDowell (San Andres, Lo.)
- McDowell (San Andres Middle)

P.H.D.
- P.H.D. (San Andres, Lo.)

Sharon Ridge (1700)
- Coleman Ranch (San Andres)

Suniland
- Suniland (Glorieta)
- Suniland (San Andres)
- Suniland (San Andres, Lower)

Play 123 San Andres Platform Carbonate

Goldsmith, N. (San Andres Con.)
- Goldsmith, North

Parker (Grayburg, San Andres)
- Parker
- Parker, West (Grayburg)

Play 126 San Andres/Grayburg Lowstand Carbonate

Welch
- Welch, South (San Andres)

Play 127 Grayburg Platform Mixed Clastic/Carbonate

Cowden, North
- Block 9 (San Andres)

Fuhrman-Mascho
- Deep Rock
- Nix (Dolomite 4400)

Play 128 Grayburg Platform Carbonate

Double -H- (Grayburg)
- Edwards, North (San Andres)

Dune
- Dune (San Andres)

McElroy
- Church
- Gulf-McElroy
- McClintic
- McElroy, East (San Andres)

Play 129 Grayburg High-Energy Platform Carbonate—Ozona Arch

Farmer
- Amigo (San Andres)
- Block 46, East (Grayburg)

Play 130 Delaware Mountain Group Basinal Sandstone

Block 17, Southeast (Delaware)
- Block 18 (Delaware)

Geraldine (Ford)
- Ford (Delaware Sand)

Ken Regan (Delaware)
- Allar-Marks (Delaware Sand)

Twofreds (Delaware)
- Hazida (Delaware)

Waha, W. (Consolidated Delaware)
- Waha, West (Delaware 5500)
- Waha, West (Delaware 5800)

Play 131 Queen Tidal-Flat Sandstone

Means (Queen Sand)
- Nolley (Queen Sand)

Play 132 Artesia Platform Sandstone

Fort Stockton (Yates Lower)
- Fort Stockton (Yates 3300)

Halley
- Emperor

Keystone (Colby)
- Keystone (Lime)

Monahans (Queen Sand)
- Monahans, W. (Queen 3075)

Scarborough
- Eaves
- Leck

Ward, South
- Dobbs

Ward-Estes, North
- Estes
- H. S. A. (O'Brien Sand, Lower)
- H. S. A., North (O'Brien, Upper)

Ordovician Plays

Three oil plays in the Permian Basin produce from Ordovician reservoirs: Ellenburger Selectively Dolomitized Ramp Carbonate, Ellenburger Karst-Modified Restricted Ramp Carbonate, and Simpson Cratonic Sandstone (table 1). A third Ellenburger play, Ellenburger Tectonically Fractured Dolostone, lies along the eastern side of the Delaware Basin and in the Val Verde Basin (Holtz and Kerans, 1992). The reservoirs in this play produce gas, however, and are not included in this report. All Ellenburger reservoirs were grouped into one play called Ellenburger Fractured Dolomite in the *Atlas of Major Texas Oil Reservoirs* (Galloway and others, 1983). Simpson reservoirs were included in the Central Basin Platform Unconformity play in the oil atlas.

The Lower Ordovician Ellenburger Group (fig. 3) was deposited on a restricted carbonate ramp, resulting in a thick (up to 1,700 ft [520 m]), areally extensive sequence of mud-dominated carbonates with localized grainstones (Kerans and others, 1989). The basinward direction was to the southeast. Sea-level fall in the early Middle Ordovician resulted in exposure of the ramp and development of widespread karst terrain (Kerans, 1990). Transgression in the Middle Ordovician flooded the area, and the shales, carbonates, and sandstones of the Simpson Group (fig. 3) were deposited. A shallow, downwarped area centered in Pecos and Terrell Counties (fig. 1) during Simpson time was named the Tobosa Basin by Galley (1958). The Upper Ordovician in the Permian Basin is represented by limestones and dolostones of the Montoya Formation (fig. 3) (Wright, 1979; Frenzel and others, 1988). A few Montoya reservoirs have produced >1 MMbbl (1.59×10^5 m^3) of oil, but they are included with the Silurian Fusselman Shallow Platform Carbonate play.

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Ellenburger Selectively Dolomitized Ramp Carbonate (Play 101)

The Ellenburger Selectively Dolomitized Ramp Carbonate play consists of 31 reservoirs in Texas that had produced >1 MMbbl (1.59×10^5 m^3) of oil through 2000; cumulative production from the play was 163.7 MMbbl (2.60×10^7 m^3) (table 4). The play is located along the south and east margins of the Midland Basin (fig. 4), in the area of the Ozona Arch and the Eastern Shelf (fig. 2). In most of the area, the Ellenburger is overlain by Permian, Pennsylvanian, or Mississippian strata (Holtz and Kerans, 1992). The Ellenburger has been partly truncated by pre-Pennsylvanian erosion (Britt, 1988). Traps are formed by simple anticlines, truncated flanks of anticlines, permeability barriers across anticlines, and locally fractured low-permeability dolostones along faults and steep flexures (Britt, 1988; Mazzullo, 1989).

Table 4. Ellenburger Selectively Dolomitized Ramp Carbonate play (play 101). 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
5783001	7C	BARNHART		TX	REAGAN	1941	9008	20,274	16,446,688
6621250	7B	BECKHAM	ELLENBURGER	TX	NOLAN	1967	6183	6,815	1,351,572
	7C	BIG LAKE	ELLENBURGER	TX	REAGAN	1928	8890		*
8629500	7B	BLACKWELL, NORTH	ELLENBURGER	TX	NOLAN	1953	6540	16,029	2,083,547
25377568	7B	DORA, NORTH	ELLENBURGER	TX	NOLAN	1953	5914	21	4,299,502
26606333	8A	DUNIGAN	ELLENBURGER	TX	BORDEN	1958	8737	1,859	1,136,041
28393333	7C	ELKHORN	ELLENBURGER	TX	CROCKETT	1951	7185	11,036	12,109,347
30414500	7B	FAVER, NORTH	ELLENBURGER	TX	NOLAN	1953	6006	0	1,340,294
31690250	8A	FLUVANNA	ELLENBURGER	TX	BORDEN	1952	8358	5,108	3,079,237
31697166	8A	FLUVANNA, SW.	ELLEN.	TX	BORDEN	1968	8306	3,395	1,559,708
32449400	7C	FRADEAN	ELLENBURGER	TX	UPTON	1959	10186	0	2,154,464
32653800	7B	FRANKIRK	ELLENBURGER	TX	STONEWALL	1958	5928	11,298	5,488,629
38866333	8A	HAPPY	ELLENBURGER	TX	GARZA	1958	8281	90,740	3,075,019
40295400	7C	HELUMA	ELLENBURGER	TX	UPTON	1956	10590	2,957	4,097,691
42341500	7C	HOLT RANCH	ELLENBURGER	TX	CROCKETT	1965	7897	5,772	2,380,554
44717500	7C	IRION 163	ELLEN	TX	IRION	1977	8916	7,885	2,605,958
45582200	8	JAMESON N.	ELLEN	TX	MITCHELL	1978	7157	3,680	1,602,269
49413400	7C	KING MOUNTAIN	ELLENBURGER	TX	UPTON	1955	11775	235	6,890,744
61204001	7C	MIDWAY LANE		TX	CROCKETT	1947	7596	2,984	4,555,520
63756333	7B	MULLEN RANCH	ELLENBURGER	TX	STONEWALL	1955	6440	7,624	1,093,028
67388500	7B	ONYX	ELLENBURGER	TX	STONEWALL	1957	6489	0	1,697,041
69098332	7B	PARDUE	ELLENBURGER	TX	FISHER	1949	5962	28,247	6,011,033
72214500	8A	POLAR, NORTH	ELLENBURGER	TX	KENT	1950	7780	0	1,439,914
72225500	8A	POLLAN	ELLENBURGER	TX	GARZA	1978	7733	0	2,931,773
82864664	8	SHEFFIELD	ELLENBURGER	TX	PECOS	1952	9272	0	2,366,006
87019200	7B	SUGGS	ELLENBURGER	TX	NOLAN	1982	6482	81,452	9,683,164
87640500	8A	SWENSON-BARRON	ELLEN.	TX	GARZA	1977	8000	0	13,153,109
88611142	8A	TEAS	ELLENBURGER	TX	GARZA	1958	8396	4,761	1,100,062
90315666	7C	TODD, DEEP	ELLENBURGER	TX	CROCKETT	1940	6232	209,230	44,300,279
92290333	8A	U-LAZY -S-	ELLENBURGER	TX	BORDEN	1957	8633	0	2,338,392
98297500	7B	WITHERS	ELLENBURGER	TX	NOLAN	1979	6520	15,718	1,364,325
		Totals						**537,120**	**163,734,910**

*Estimated production of Big Lake field from Ellenburger reservoir is 21 million bbl.
All production from Big Lake field is assigned to the Grayburg by the RRC (see Play 129 Grayburg High-Energy Platform Carbonate--Ozona Arch play).

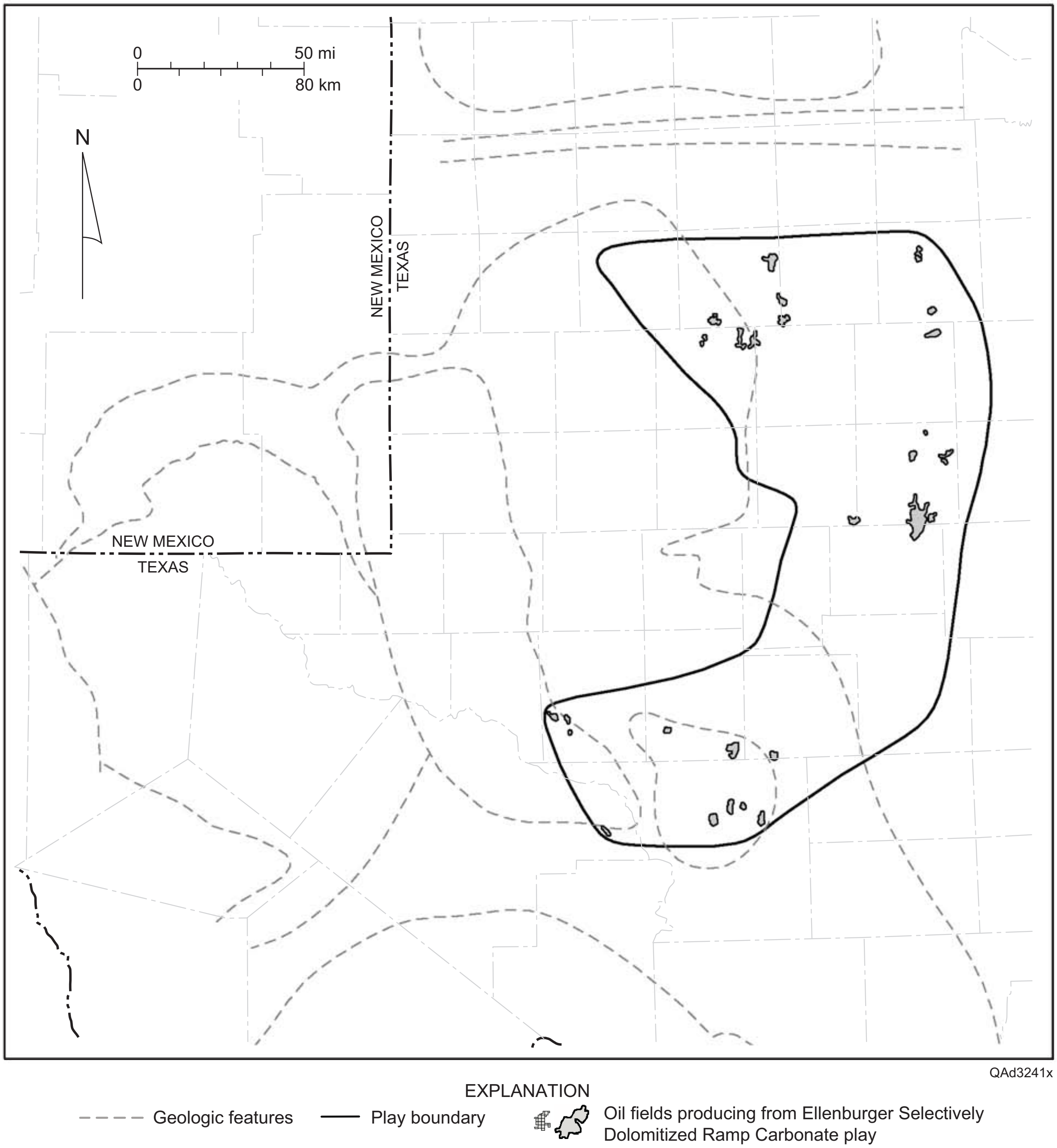

Figure 4. Play map for the Ellenburger Selectively Dolomitized Ramp Carbonate play, showing location of reservoirs having >1 MMbbl cumulative production, the play boundary, and geologic features. See figure 1 for county names and figure 2 for identification of geologic features.

The carbonates of this play were deposited in a mid- to outer-ramp setting (Holtz and Kerans, 1992); their present composition is mainly dolostone, with lesser amounts of limestone

(Holtz and Kerans, 1992; Hunt, 2000). Reservoirs are composed of one or more upward-shallowing sequences that contain subtidal, peloid-ooid packstone-grainstone at the base, overlain by burrowed wackestones and peritidal, cryptalgal laminated mudstones (Holtz and Kerans, 1992). Early tidal-flat dolomitization by seepage reflux and late-burial dolomitization were more localized in the rocks in this play than in the Ellenburger Karst-Modified Restricted Ramp Carbonate play, where dolomitization was pervasive (Holtz and Kerans, 1992).

Ellenburger rocks in this play experienced several episodes of exposure, karstification, and fracturing. Porosity development appears to be controlled by a combination of primary depositional facies distribution, localized karsting, fracturing, and selective dolomitization (Tyler and others, 1991; Combs and others, 2003). The processes and products of karst-related diagenesis in these Ordovician reservoirs were detailed by Loucks (1999, 2003). Much of the reservoir porosity is made up of secondary intercrystalline pores that resulted from selective, late-stage burial dolomitization of grainstones (Kerans, 1990; Kupecz and Land, 1991; Holtz and Kerans, 1992). Fractures probably provided pathways for migrating dolomitizing fluids and still contribute to reservoir porosity and permeability. Two sets of fractures, oriented NE-SW and NW-SE, have been identified, but the NW-SE set is dominant in most horizons (Gomez and others, 2001).

Net-pay thickness ranges from 4 to 223 ft (1 to 68 m) and averages 43 ft (13 m) (Holtz and Kerans, 1992). Porosity, mostly intercrystalline and interparticle, ranges from 1 to 20 percent and averages 6.4 percent. Permeability values range from 0.2 to 48 md (0.2 to 48 $\times 10^{-3}$ μm^2) and are log-normally distributed around a geometric mean value of 12 md (12 $\times 10^{-3}$ μm^2).

Known production from the major reservoirs in this play is 163.7 MMbbl (2.60 $\times 10^7$ m^3) (table 4), but this figure does not include production from the Big Lake (Ellenburger) reservoir.

The Ellenburger reservoir at Big Lake field was discovered in 1928, but production from the Ellenburger was combined with production from the Grayburg interval in the annual reports of the Railroad Commission of Texas. Anderson and others (1954) reported that the Ellenburger reservoir had produced 18.8 MMbbl (2.99×10^6 m^3) of oil through October 1, 1953, and projected that ultimate recovery would be 20.9 MMbbl (3.32×10^6 m^3) of oil. Galloway and others (1983) reported 21 MMbbl (3.34×10^6 m^3) had been produced in Big Lake (Ellenburger) through 1981, and Tyler and others (1991) showed 21.2 MMbbl (3.37×10^6 m^3) of cumulative production through 1987. Because it is not possible to accurately calculate Ellenburger production at Big Lake, we have followed the precedent set by the RRC and assigned all production from Big Lake to the Grayburg (see play 129, Grayburg High Energy Platform Carbonate—Ozona Arch). It should be kept in mind that ~21 MMbbl (3.34×10^6 m^3) of that production actually came from the Ellenburger.

A new technique for recovering additional oil—high-pressure air injection (HPAI)—is being tested in Barnhart field in Reagan County. Barnhart field is a structural trap having four-way closure and a top seal formed by Wolfcamp shale (figs. 5, 6) (Hunt, 2000). The pore network in the reservoir is influenced by local development of collapsed paleocave facies (Combs and others, 2003). Distribution of paleocave facies can be defined by log response calibrated with core (fig. 7). The Barnhart reservoir is interpreted as having at least two east-trending regions of paleocave facies that may complicate fluid flow in the field (Combs and others, 2003).

HPAI, a tertiary oil-recovery technology, creates downhole combustion of oxygen and oil, producing flue gas (nitrogen and carbon dioxide) that serves to repressurize and flood the reservoir. The HPAI process pumps air into the reservoir under high temperature and pressure.

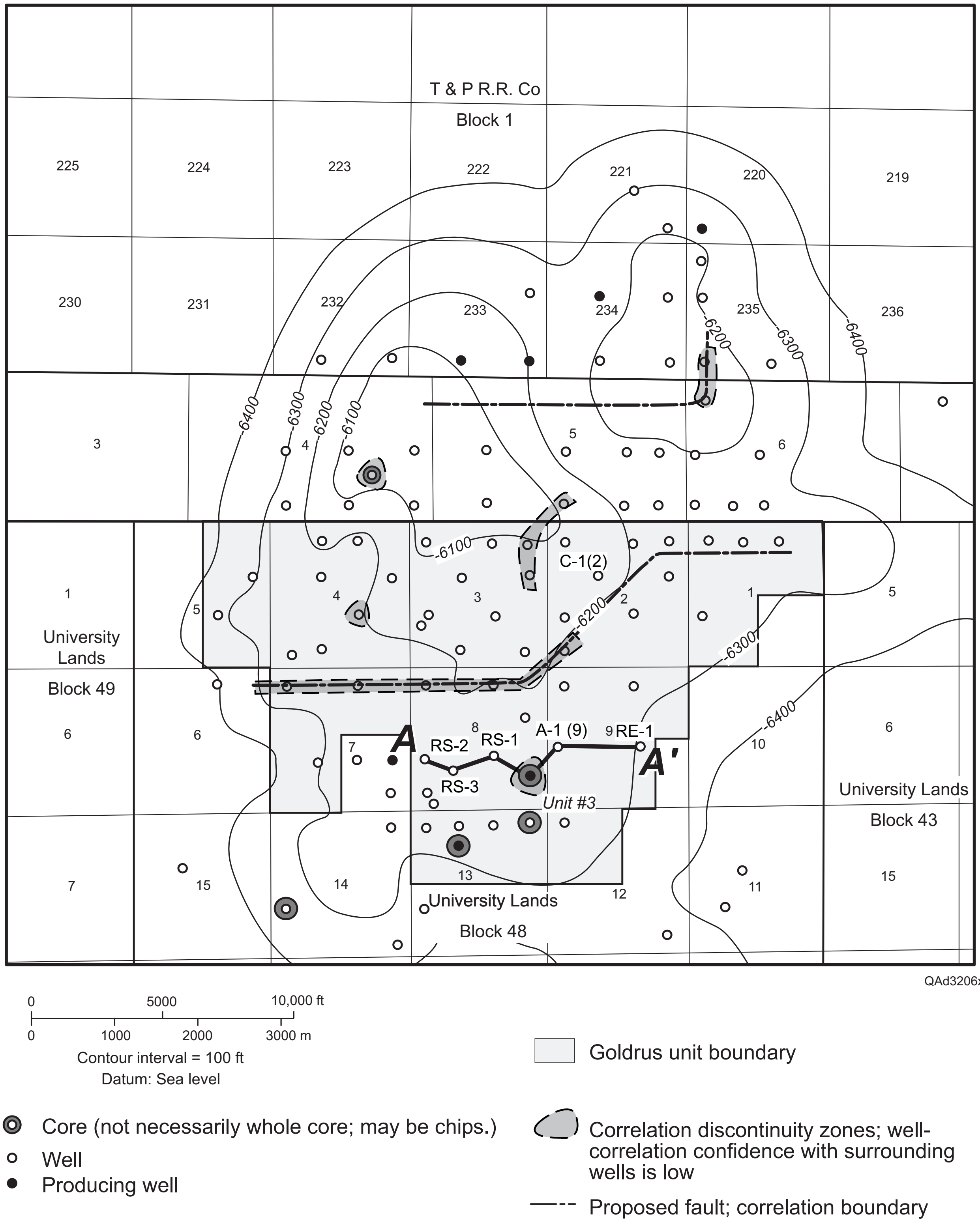

Figure 5. Map of Barnhart field, Reagan County, Texas, showing structure at the top of the Ellenburger reservoir and interpreted correlation discontinuities caused by faults and karsted zones. From Combs and others (2003); after Cotton (1966). Cross section A-A´ shown in figure 7.

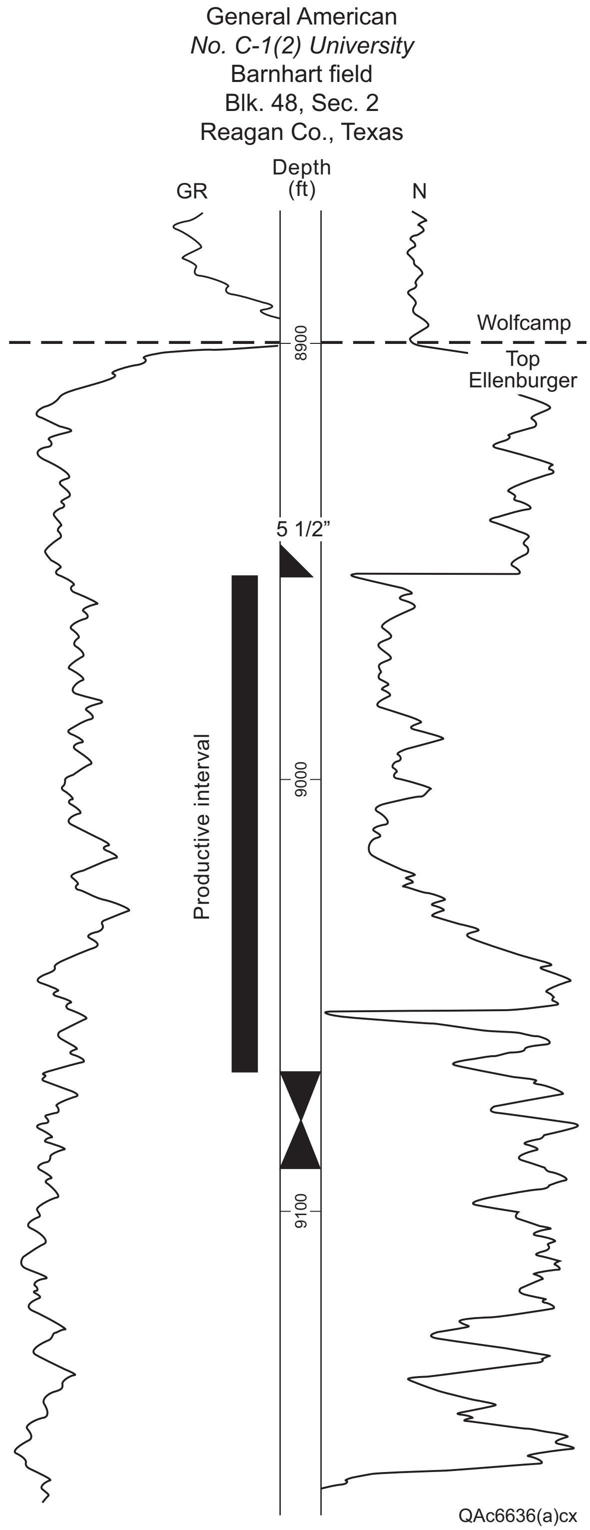

Figure 6. Typical log of the Ellenburger reservoir in Barnhart field, Reagan County, Texas. After Cotton (1966).

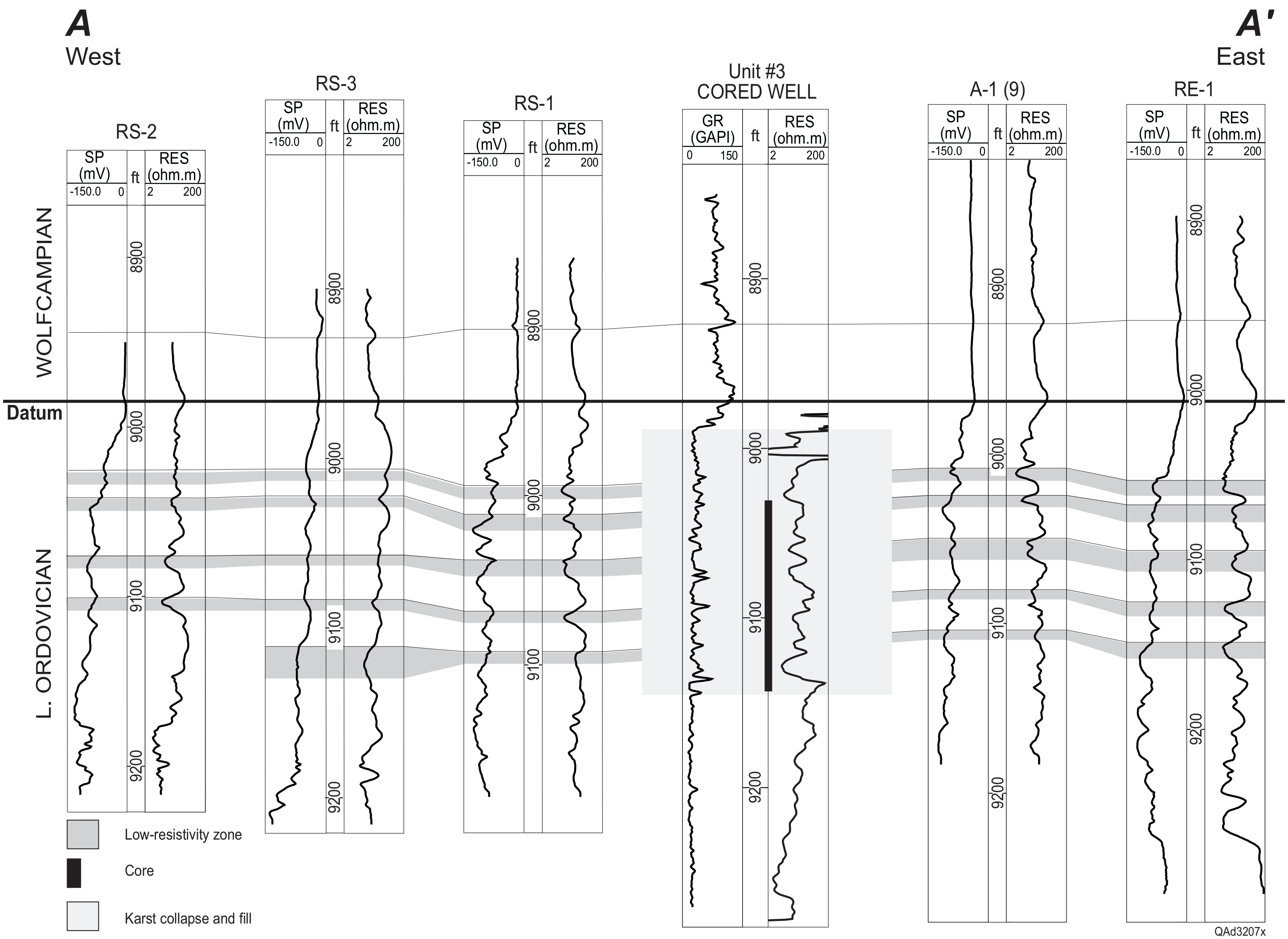

Figure 7. West-east cross section of Barnhart field showing karsted and nonkarsted zones. Line of section shown in figure 5. From Combs and others (2003).

The oxygen causes combustion of 4 to 5 percent of the residual oil in the depleted reservoir (J. Olsen, personal communication, 2003). Oil recovery is improved because the process (1) lowers the viscosity of the oil, (2) creates thermally generated microfractures in the reservoir, and (3) increases reservoir pressure.

The process has been used mainly in low-permeability reservoirs. The HPAI process has been successful in reservoirs of the Red River Formation (Ordovician dolostones and limestones) in the Williston Basin of South Dakota, North Dakota, and Montana (Kumar and others, 1995; Fassihi and others, 1996; Watts and others, 1997; Glandt and others, 1998), but it is being tried for the first time in the Permian Basin in Barnhart field (S. Ruppel, personal communication, 2003). A pilot was conducted that increased production to three to five times the rates observed before HPAI, and now a larger demonstration is planned. Barnhart field produced only 16.5 MMbbl (2.62×10^6 m^3) of an estimated 116 MMbbl (1.84×10^7 m^3) of OOIP during primary production (S. Ruppel, personal communication, 2003). The goal of combining HPAI with an array of vertical and horizontal injection and producer wells is to restore energy to this pressure-depleted reservoir and thus recover large additional volumes of the remaining resource.

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Ellenburger Karst-Modified Restricted Ramp Carbonate (Play 102)

The Ellenburger Karst-Modified Restricted Ramp Carbonate play consists of 86 reservoirs in Texas and New Mexico that had produced >1 MMbbl (1.59×10^5 m^3) of oil through 2000; cumulative production from the play was 1,487.3 MMbbl (2.36×10^8 m^3) (table 5). This play is located mainly on the Central Basin Platform (fig. 8) and is restricted to the area where the Ellenburger is overlain by the Simpson Group (Holtz and Kerans, 1992). Traps are mostly faulted anticlines, but simple anticlines are interpreted to be traps for some fields (Galloway and others, 1983).

Geologic interpretation of reservoirs in the Lower Ordovician Ellenburger Group in west Texas and southeast New Mexico has been presented in numerous papers, including Kerans (1988, 1989, 1990), Clemons (1989), Kerans and Lucia (1989), Mazzullo (1989), Loucks and Handford (1992), Goldhammer and others (1993), Lucia (1995), Hammes and others (1996), and Loucks (1999). Petrophysical information is summarized in Kerans and others (1989) and Holtz and Kerans (1992).

The reservoir rocks of the Ellenburger Group in west Texas and southeast New Mexico are dolostones that were deposited on a restricted carbonate ramp and substantially modified by erosion and karstification (Kerans, 1990). The Ellenburger exhibits a range of mostly low-energy, mud-rich facies representing supratidal to shallow-marine environments. Production from several of the Andrews County Ellenburger reservoirs comes from an ooid-peloid grainstone facies assemblage (Kerans, 1990; Tyler and others, 1991). Mud-dominated Ellenburger lithologies generally have <2 percent matrix porosity; rare grainstone facies contain intergranular porosity as high as 10 percent locally.

Table 5. Ellenburger Karst-Modified Restricted Ramp Carbonate play (play 102). 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
587498	7C	ADAMC	ELLENBURGER	TX	UPTON	1953	11575	19,257	1,162,037
2207380	7C	AMACKER-TIPPETT	ELLENBURGER	TX	UPTON	1953	11890	9,398	17,917,650
2596200	8	ANDECTOR	ELLENBURGER	TX	ECTOR	1946	8545	276,880	177,718,593
2727500	8	ANDREWS, NORTH	ELLENBURGER	TX	ANDREWS	1959	12349	0	28,873,225
3278001	8	APCO-WARNER		TX	PECOS	1939	4600	12,911	12,564,506
5166444	8	BAKKE	ELLENBURGER	TX	ANDREWS	1956	12400	0	23,722,974
5859333	8	BARROW	ELLENBURGER	TX	ECTOR	1955	13578	4,170	1,436,411
6671332	8	BEDFORD	ELLENBURGER	TX	ANDREWS	1950	11018	16,151	7,884,926
9202332	8	BLOCK 9	ELLENBURGER	TX	ANDREWS	1958	12508	3,980	3,542,455
9250400	8	BLOCK 12	ELLENBURGER	TX	ANDREWS	1952	10884	24,613	4,705,759
9251333	8	BLOCK 12, EAST	ELLENBURGER	TX	ANDREWS	1953	10117	0	9,262,118
9358540	8	BLOCK 31	ELLENBURGER	TX	CRANE	1945	10291	28,860	6,266,474
8958200	8	BLOCK A-34	ELLENBURGER	TX	ANDREWS	1954	13250	7,233	4,378,343
8990666	8	BLOCK A-49	ELLENBURGER	TX	ANDREWS	1962	11200	8,041	1,623,307
18254600	8	CIRCLE BAR	ELLEN	TX	ECTOR	1962	12758	17,161	3,816,623
21292875	8	COWDEN, SOUTH	13800	TX	ECTOR	1966	13900	12,831	2,744,404
21292625	8	COWDEN, SOUTH	ELLENBURGER	TX	ECTOR	1954	12883	0	5,459,419
21577270	8	CRAWAR	ELLENBURGER	TX	CRANE	1954	8236	0	1,111,683
23380300	7C	DAVIS	ELLENBURGER	TX	UPTON	1950	13050	0	1,370,746
23907284	8	DEEP ROCK	ELLENBURGER	TX	ANDREWS	1954	12252	23,030	14,245,387
25188600	8	DOLLARHIDE	ELLENBURGER	TX	ANDREWS	1947	10137	57,387	26,460,708
25189400	8	DOLLARHIDE, EAST	ELLENBURGER	TX	ANDREWS	1959	12610	61,894	6,432,601
25395332	8	DORA ROBERTS	ELLENBURGER	TX	MIDLAND	1954	12835	46,740	50,731,918
28843222	8	EMBAR	ELLENBURGER	TX	ANDREWS	1942	7977	8,143	22,646,307
28899249	8	EMMA	ELLENBURGER	TX	ANDREWS	1953	13307	26,198	54,500,181
30394375	8	FASKEN	ELLENBURGER	TX	ANDREWS	1953	12604	22,691	3,641,104
31768333	8	FLYING -W-	ELLEN	TX	WINKLER	1970	11768	0	1,003,126
33230400	8	FULLERTON	ELLENBURGER	TX	ANDREWS	1945	9945	0	2,067,603
33231250	8	FULLERTON, EAST	ELLEN.	TX	ANDREWS	1967	11428	3,077	1,236,825
33232510	8	FULLERTON, NORTH	ELLENBURGER	TX	ANDREWS	1991	9872	2,179	1,054,548
33235250	8	FULLERTON, SOUTH	ELLENBURGER	TX	ANDREWS	1948	10600	112,479	13,774,543
35197380	8	GLASCO	ELLENBURGER	TX	ANDREWS	1985	13806	36,343	2,830,825
35652248	8	GOLDSMITH	ELLENBURGER	TX	ECTOR	1947	9495	10,560	2,136,727
35654332	8	GOLDSMITH, N.	ELLENBURGER	TX	ECTOR	1954	8896	15,938	5,595,412
35659375	8	GOLDSMITH, W.	ELLENBURGER	TX	ECTOR	1954	9428	22,927	4,018,423
39176498	8	HARPER	ELLENBURGER	TX	ECTOR	1962	12436	101,351	23,900,923
39182666	8	HARPER, SE.	ELLEN.	TX	ECTOR	1965	12505	17,884	1,829,238
39969600	8	HEADLEE	ELLENBURGER	TX	ECTOR	1953	13106	0	38,326,414
44521498	8	INEZ	ELLENBURGER	TX	ANDREWS	1961	12505	0	16,436,191
47267228	8	JORDAN	ELLENBURGER	TX	ECTOR	1947	8914	47,880	31,726,443
49038071	8	KERMIT	ELLENBURGER	TX	WINKLER	1943	10744	34,730	5,521,825
49129330	8	KEYSTONE	ELLENBURGER	TX	WINKLER	1943	9524	266,296	146,847,044
49411500	8	KING LAKE	ELLENBURGER	TX	ECTOR	1988	11082	36,121	2,059,844
52624300	8	LEA	ELLENBURGER	TX	CRANE	1953	8165	19,653	20,496,500
53009500	8	LEHN-APCO, SOUTH	ELLEN	TX	PECOS	1977	4740	789	1,210,952
55256284	8	LOWE	ELLENBURGER	TX	ANDREWS	1957	13314	17,643	11,896,530
56822250	8	MAGUTEX	ELLENBURGER	TX	ANDREWS	1952	13840	41,194	17,610,065
57774332	8	MARTIN	ELLENBURGER	TX	ANDREWS	1946	8400	7,899	36,536,319
59339500	8	MCELROY, NORTH	ELLENBURGER	TX	CRANE	1973	12024	11,415	3,430,675
59419166	8	MCFARLAND	ELLENBURGER	TX	ANDREWS	1961	13898	21,201	5,636,171
60874500	8	METZ, EAST	ELLENBURGER	TX	ECTOR	1961	9046	5,571	2,984,224
61118332	8	MIDLAND FARMS	ELLENBURGER	TX	ANDREWS	1952	12672	88,495	50,853,026
61121666	8	MIDLAND FARMS, NE.	ELLENBURGER	TX	ANDREWS	1953	12540	8	7,643,557
62415332	8	MONAHANS	ELLENBURGER	TX	WARD	1942	10550	0	5,318,009
62417360	8	MONAHANS, N.	ELLENBURGER	TX	WINKLER	1955	11990	128,738	8,663,172
62703200	8	MOONLIGHT	ELLENBURGER	TX	MIDLAND	1983	13325	0	1,014,717
64890500	8	NELSON	ELLENBURGER	TX	ANDREWS	1946	10384	1,336	5,070,077
65766444	8	NOLLEY	ELLEN.	TX	ANDREWS	1968	13939	0	2,678,693
65967600	8	NORMAN	ELLENBURGER	TX	GAINES	1970	13865	120,891	2,195,849
70279250	7C	PEGASUS	ELLENBURGER	TX	UPTON	1949	12530	122,277	96,008,159
70537330	8	PENWELL	ELLENBURGER	TX	ECTOR	1946	8888	15,718	14,203,574
73103666	8	PRICHARD	ELLENBURGER	TX	ANDREWS	1953	13475	14,572	1,061,819
74793333	8	RATLIFF	ELLENBURGER	TX	ECTOR	1954	13559	21,980	3,368,635
80474500	8	SAND HILLS, EAST	ELLENBURGER	TX	CRANE	1968	5703	54,158	2,253,367
80475500	8	SAND HILLS, N.	ELLENBURGER	TX	CRANE	1957	6030	24,284	1,177,511
82570300	8	SHAFTER LAKE	ELLENBURGER	TX	ANDREWS	1948	11685	8,945	6,629,516
87599284	8	SWEETIE PECK	ELLENBURGER	TX	MIDLAND	1950	13128	34,388	10,038,376
88071290	8	TXL	ELLENBURGER	TX	ECTOR	1949	9600	70,397	129,551,707

Table 5, continued. Ellenburger Karst-Modified Restricted Ramp Carbonate play (play 102).

RRC RESN	RRC	FLDNAME	RESNAME	STATE	COUNTY	DISCYR	DEPTHTOP	2000 PROD	CUMPROD
92548500	8	UNIVERSITY BLOCK 13	ELLEN.	TX	ANDREWS	1960	10800	56,641	14,978,243
92618250	8	UNIVERSITY WADDELL	ELLENBURGER	TX	CRANE	1947	10620	0	9,039,824
93485300	8	VENTEAM	ELLENBURGER	TX	ECTOR	1995	13250	262,356	1,996,282
93958250	8	VIREY	ELLENBURGER	TX	MIDLAND	1954	13276	71,711	30,877,195
95108375	8	WAR-SAN	ELLENBURGER	TX	MIDLAND	1954	13070	46,946	14,916,750
96291333	8	WEMAC	ELLENBURGER	TX	ANDREWS	1954	13306	1,627	5,847,947
96756400	8	WHEELER	ELLENBURGER	TX	WINKLER	1942	10697	5,997	17,952,199
97834500	7C	WILSHIRE	ELLENBURGER	TX	UPTON	1951	11944	0	41,080,326
94439400	8	W. T. FORD	ELLENBURGER	TX	ECTOR	1991	12260	0	1,072,228
99275375	8	YARBROUGH & ALLEN	ELLENBURGER	TX	ECTOR	1947	10490	23,234	40,502,338
99409500	8	YORK	ELLENBURGER	TX	ECTOR	1955	12395	11,603	2,636,804
		BRUNSON	ELLENBURGER	NM	LEA	1945	8059	12,588	27,654,212
		DOLLARHIDE	ELLENBURGER	NM	LEA	1951	10135	10,815	3,512,341
		FOWLER	ELLENBURGER	NM	LEA	1949	9505	65,094	17,012,002
		JUSTIS	ELLENBURGER	NM	LEA	1957	8115	6,598	7,663,268
		STATELINE	ELLENBURGER	NM	LEA	1965	12100	0	4,191,567
		TEAGUE	ELLENBURGER	NM	LEA	1950	9700	0	2,485,768
		TEAGUE NORTH	ELLENBURGER	NM	LEA	1988	10200	0	1,772,980
		Totals						**2,802,096**	**1,487,309,287**

Intercrystalline and intergranular porosity does not contribute significantly to production in most Ellenburger reservoirs. The main control on porosity distribution in Ellenburger reservoirs in this play is extensive erosion and karstification that occurred during the early Middle Ordovician (post-Sauk) lowstand (Kerans, 1988; Lucia, 1995). Dominant pore types in most Ellenburger reservoirs are secondary, fracture/touching vugs associated with karst development (Kerans, 1989; Tyler and others, 1991).

Reservoir heterogeneity is mainly the result of extensive dissolution, cave formation, and subsequent infilling (Kerans, 1988). Ellenburger platform carbonates were subaerially exposed when sea level fell at the end of Ellenburger Group sedimentation, and a regionally extensive, water-table karst system developed. The cave systems collapsed and were infilled during sea-level rise associated with deposition of the overlying Middle Ordovician Simpson Group. The resulting karst-facies stratigraphy includes, from top to bottom, cave-roof (50 to 150 ft [15 to 45 m] thick), cave-fill (50 to 150 ft [15 to 45 m] thick), and lower-collapse-zone (20 to 400 ft [6 to 122 m] thick) facies (figs. 9, 10). The cave-roof facies is composed of intact dolostone and

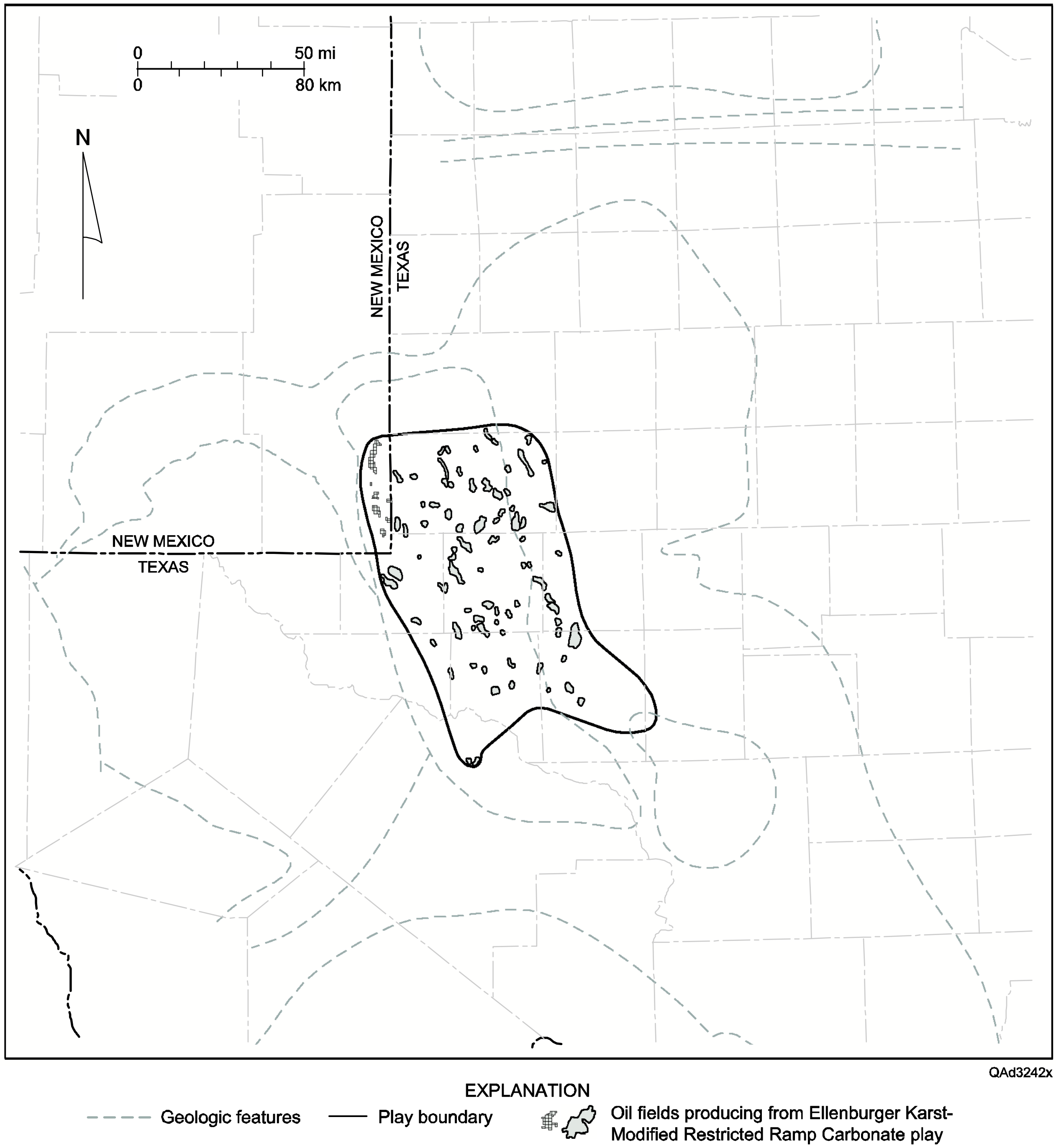

Figure 8. Play map for the Ellenburger Karst-Modified Restricted Ramp Carbonate play, showing location of reservoirs having >1 MMbbl cumulative production, the play boundary, and geologic features. See figure 1 for county names and figure 2 for identification of geologic features.

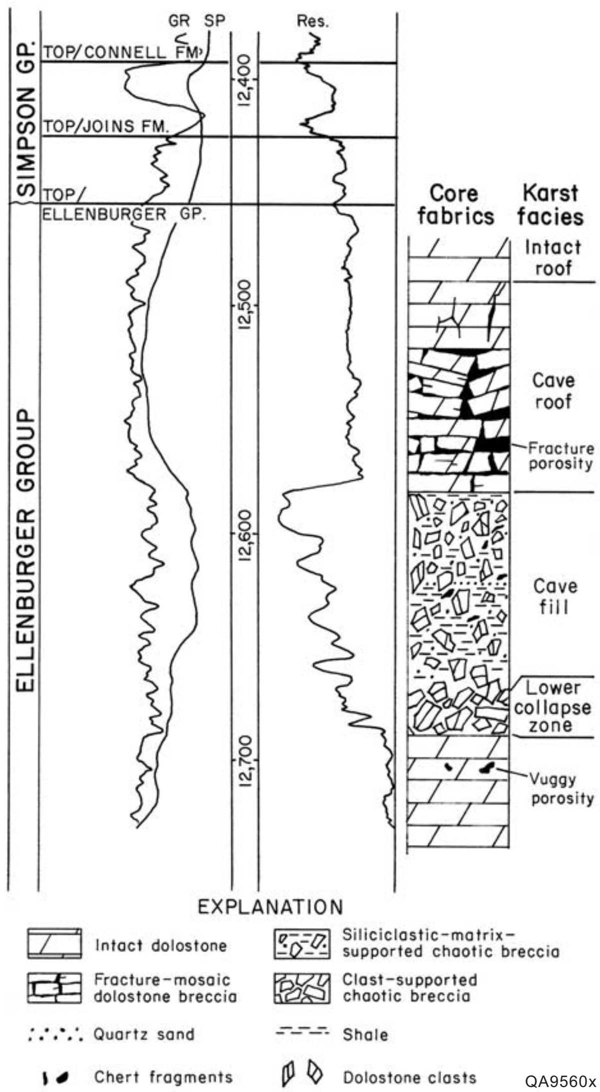

Figure 9. Karst facies and associated log signatures in the Gulf 000-1 TXL well, northeast Emma Ellenburger field, Andrews County, Texas. From Kerans (1988), reprinted by permission of the AAPG, whose permission is required for further use. ©Copyright 1988. The American Association of Petroleum Geologists. All rights reserved.

dolostone fracture and mosaic breccia. The cave-fill deposits are siliciclastic-matrix-supported chaotic breccia, and the cave-floor facies is a carbonate-clast-supported chaotic breccia (Kerans, 1988). Tectonic fractures probably enhance the permeability created by karst-related fractures and touching-vug pores (Kosters and others, 1989; Kerans, 1990; Loucks, 1999).

Pressure-test data in Emma field, Andrews County, indicate that cave-roof and lower-collapse zones are permeable intervals separated by low-permeability cave-fill facies (Kerans,

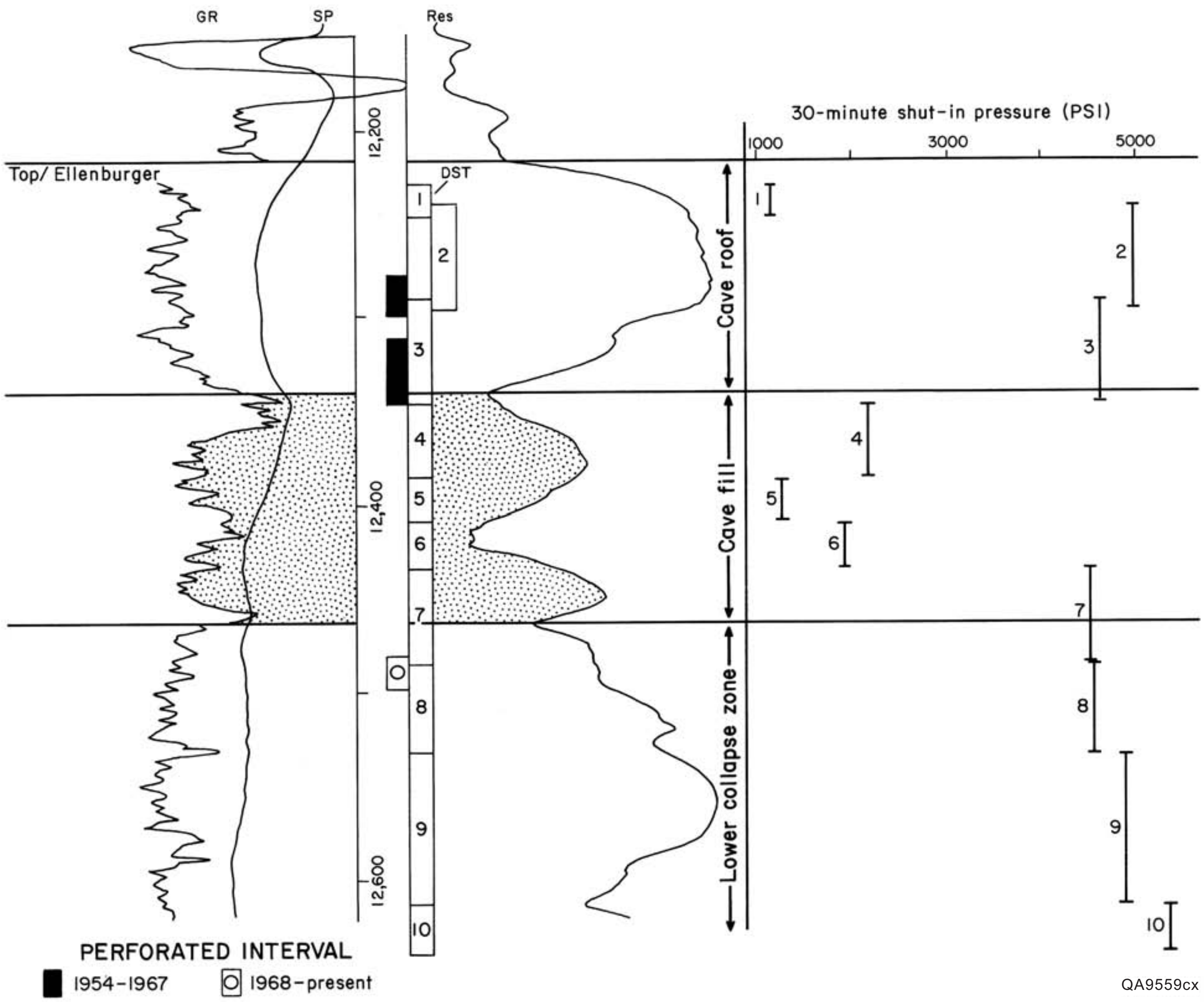

Figure 10. Log signatures and shut-in pressures in the Mobil 36-1 University well in Ellenburger Emma field, Andrews County, Texas. Results of shut-in pressure tests show that the cave-fill facies is a low-permeability zone separating cave-roof and lower-collapse-zone reservoir units. Recompletion in the lower-collapse zone in 1968 resulted in production of an additional 200,000 bbl of oil that would not have been produced by the initial completion in the cave-roof facies. From Kerans (1988), reprinted by permission of the AAPG, whose permission is required for further use.

1988). The cave-fill facies thus acts as an internal flow barrier separating cave-roof and lower-collapse reservoir zones. This flow barrier is located between 100 and 200 ft (30 and 60 m) below the erosional top of the Ellenburger Group, probably reflecting the presence of a paleo-water table. Adjacent low-permeability host rocks may also contribute to the vertical permeability barrier formed by cave-fill deposits (Loucks, 1999). Wells that were completed only in the top 50 to 100 ft (15 to 30 m) of the Ellenburger to avoid problems associated with water coning may leave lower permeable units undrained (Kerans, 1988, 1989, 1990).

The Ellenburger Formation in New Mexico is a restricted inner-platform cyclic dolomite having extensive subaerial diagenesis associated with changes in relative sea level (Clemons, 1989; Kerans and Lucia, 1989; Goldhammer and others, 1993). Although dolomitized, the Langley Ellenburger reservoir in Lea County contains identifiable intertidal to supratidal facies successions that include alternations of laminated mudstone/wackestone, peloid/ooid grainstone, peloid-algal mat boundstone, and intraclast and pebble breccia (Verseput, 1989). (Langley is not listed in table 5 because it had only produced 779,000 bbl (1.24×10^5 m^3) through 2000).

Ellenburger porosity types include intercrystalline matrix, vugs, major karst dissolution, and fractures (Mazzullo, 1989), the most significant type being dissolution and collapse breccia karst (see Loucks, 1999). In addition, isolated high-porosity zones are preserved in some deeper water muddy-carbonate facies that underwent late burial dolomitization, resulting in coarse-grained textures (Kerans and Lucia, 1989). In the Langley reservoir, maximum intergranular porosity in the peloid-algal mat boundstone and peloid/ooid grainstone facies is 5 percent and permeability is 0.5 md (0.5×10^{-3} μm^2) (Verseput, 1989). Non-fabric-selective fractures and solution-collapse breccia also occur and enhance both porosity (up to 8 percent) and permeability (up to 50 md [50×10^{-3} μm^2]). In the Stateline reservoir in Lea County, the Ellenburger is composed completely of fabric-destructive dolomite (Amthor and Friedman, 1989). Largely low-permeability upper Ellenburger strata are underlain by lower units interpreted as cave-roof facies that contain abundant stylolites, fractures, molds, vugs, and dissolution cavities that increase porosity to as high as 15 percent (Amthor and Friedman, 1989).

Net-pay thickness in the Ellenburger Karst-Modified Restricted Ramp Carbonate play ranges between 20 and 410 ft (6 and 125 m) and averages 180 ft (55 m) (Holtz and Kerans, 1992). Porosity ranges from 1 to 8 percent and averages 3.2 percent; production is controlled by the fracture and touching-vug pore systems, not by the low matrix porosity. Permeability is highly variable, ranging from 2 to 750 md (2 to 750 $\times 10^{-3}$ μm^2), and the geometric mean is 32 md (32 $\times 10^{-3}$ μm^2) (Holtz and Kerans, 1992).

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Simpson Cratonic Sandstone (Play 103)

The Simpson Cratonic Sandstone play consists of 19 reservoirs that had produced >1 MMbbl (1.59×10^5 m^3) of oil through 2000; cumulative production from the play was 103.2 MMbbl (1.64×10^7 m^3) (table 6). Reservoirs of the Simpson Cratonic Sandstone play are distributed along the Central Basin Platform (fig. 11), where they are associated with local structures. The Middle Ordovician Simpson Group was deposited in the Tobosa Basin, a shallow, downwarped area centered in Pecos and Terrell Counties during Simpson time (Galley, 1958).

Reservoirs in the play are found within three regionally extensive sandstones of the Simpson Group—the Connell, Waddell, and McKee (Wright, 1979). The Connell sandstone occurs at the base of the Oil Creek Formation, the Waddell sandstone at the base of the McLish Formation, and the McKee sandstone at the base of the Tulip Creek Formation (fig. 12) (Gibson, 1965). These three formations are composed mostly of green shales; the productive sandstones

Table 6. Simpson Cratonic Sandstone play (play 103). 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
292001	8	ABELL		TX	PECOS	1940	5400	2,308	8,106,194
293625	8	ABELL, EAST	MCKEE	TX	PECOS	1956	5415	6,553	2,322,612
293875	8	ABELL, EAST	WADDELL, W. SEG.	TX	PECOS	1957	6090	7,800	2,014,539
296500	8	ABELL, NORTHWEST	MCKEE SAND	TX	PECOS	1949	5432	0	1,435,103
2596400	8	ANDECTOR	MCKEE	TX	ECTOR	1948	7635	7,650	3,374,471
2596800	8	ANDECTOR	WADDELL	TX	ECTOR	1948	7835	9,882	2,029,953
9358270	8	BLOCK 31	CONNELL	TX	CRANE	1948	10170	0	1,083,545
21577810	8	CRAWAR	WADDELL	TX	WARD	1955	7645	1,737	1,587,021
47267076	8	JORDAN	CONNELL SAND	TX	ECTOR	1948	8830	0	4,445,230
52624200	8	LEA	CONNELL	TX	CRANE	1953	8178	8,501	3,431,877
57774498	8	MARTIN	MCKEE	TX	ANDREWS	1945	8300	32,417	6,816,298
78936800	8	RUNNING W	WADDELL	TX	CRANE	1954	6148	67,370	25,266,119
80473372	8	SAND HILLS	ORDOVICIAN	TX	CRANE	1936	6300	14,256	13,143,342
88073500	8	T X L, NORTH	WADDELL	TX	ECTOR	1961	9386	4,291	2,716,712
91630001	8	TUCKER		TX	CRANE	1946	5770	124	2,241,122
99275750	8	YARBROUGH & ALLEN	WADDELL	TX	ECTOR	1950	10110	2,850	1,235,313
		HARE	SIMPSON	NM	LEA	1947	7550	38,743	17,193,665
		JUSTIS	MCKEE	NM	LEA	1957	7700	0	1,312,000
		TEAGUE	SIMPSON	NM	LEA	1948	9340	216,169	3,473,240
		Totals						**420,651**	**103,228,356**

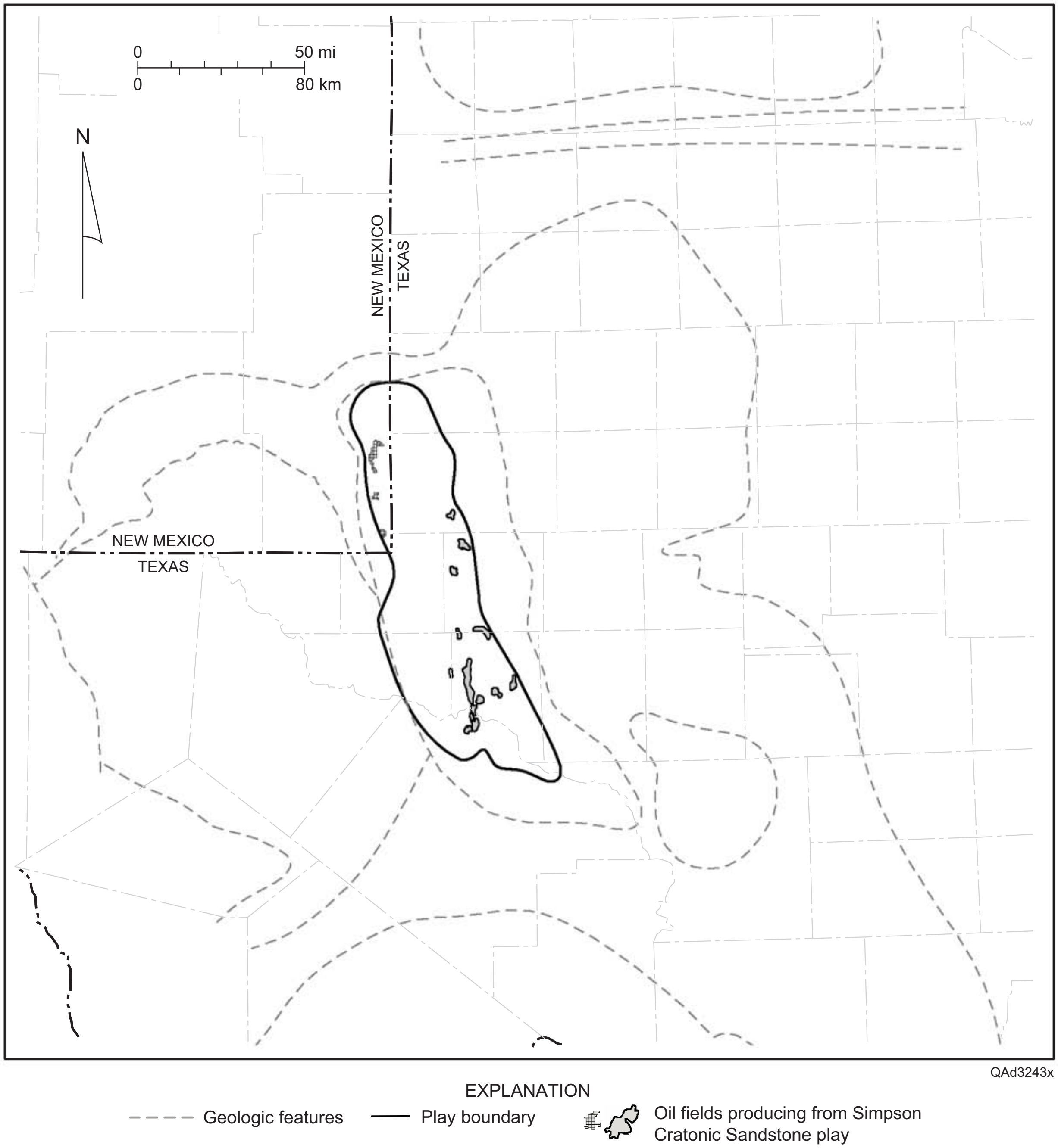

Figure 11. Play map for the Simpson Cratonic Sandstone play, showing location of reservoirs having >1 MMbbl cumulative production, the play boundary, and geologic features. See figure 1 for county names and figure 2 for identification of geologic features.

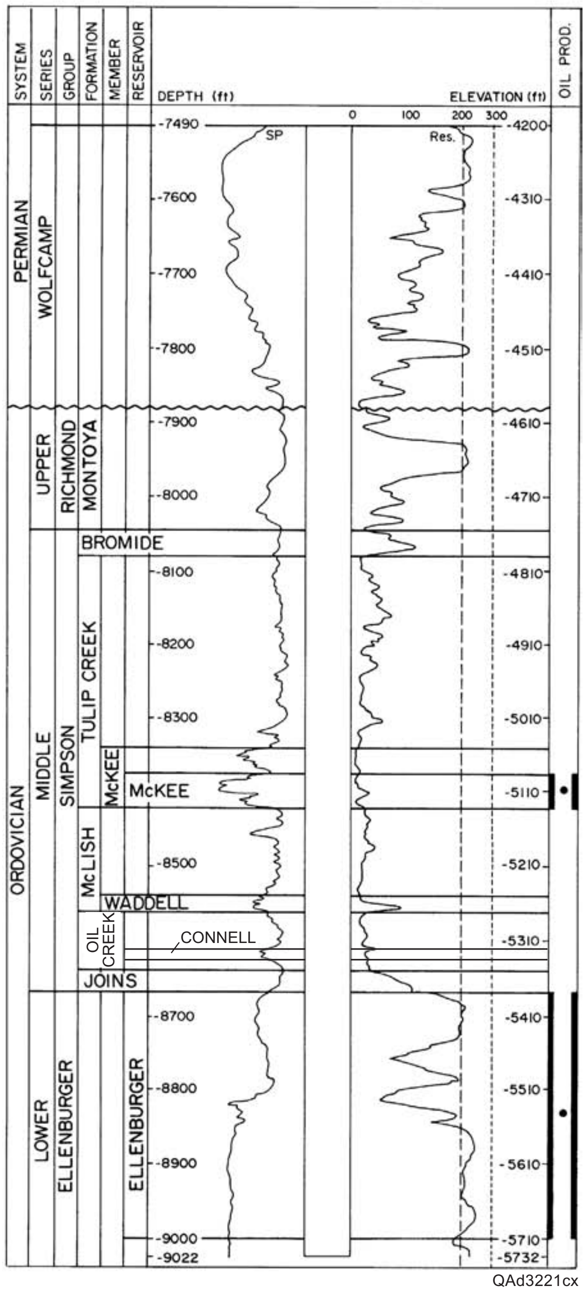

Figure 12. Log of Ordovician and Permian strata from a well in Martin McKee field, Andrews County, Texas, showing McKee producing interval. From Galloway and others (1983); after Herald (1957).

are ~20 to 50 ft (~6 to 15 m) thick (Galley, 1958). The Joins and Bromide Formations (fig. 12) are largely nonproductive. The sediment source was interpreted to be the Transcontinental Arch to the northwest. There is no evidence that the Central Basin Platform was a positive feature during deposition of the Simpson sandstones (Frenzel and others, 1988).

The Simpson Group was deposited when sea level rose in the Middle Ordovician and marine transgression ended the period of exposure and karstification of the underlying Ellenburger (Kerans, 1988). Rocks of the Simpson Group are composed of interbedded shale, limestone, and sandstone; sandstones make up ~5 percent of the total thickness of the Simpson Group. Little has been published about the origin of Simpson sandstones. Connell sandstones in outcrop in Culberson County, Texas, consist of fine- to coarse-grained sandstone composed of frosted, rounded quartz grains (Suhm and Ethington, 1975). Cements include variable amounts of quartz overgrowths and dolomite cement (Suhm and Ethington, 1975). The Connell sandstone is interpreted as having been deposited in high-energy shoreface and nearshore environments, to more distal and lower energy marine environments (Suhm and Ethington, 1975). Simpson sandstones of the southern Midcontinent were interpreted by Candelaria and others (1994) as strandline sandstones deposited during sea-level lowstands. The sands were transported into the basin by fluvial and eolian processes (Candelaria and others, 1994). As sea level rose, a series of widespread, back-stepping, shoreface complexes represented the transgressive systems tract.

Oil is trapped in the producing sandstones of the Simpson Group along folded and faulted structures of the Central Basin Platform, with Simpson shales providing the seal. High-angle faults on the flanks of the anticlines may form part of the trapping mechanism, as at the Teague McKee reservoir (Sharp, 1956). Other reservoirs produce where the Simpson sandstones are truncated by erosion along the flanks of anticlines underneath a major regional unconformity (fig. 13). The seal is provided by overlying post-Simpson rocks, mainly Pennsylvanian and Permian shales and carbonates (Symposium Committee, 1956; Gibson, 1965; Wright, 1979; Galloway and others, 1983). The unconformity was formed during major late Paleozoic uplift that formed the Central Basin Platform and the smaller structures associated with Simpson traps.

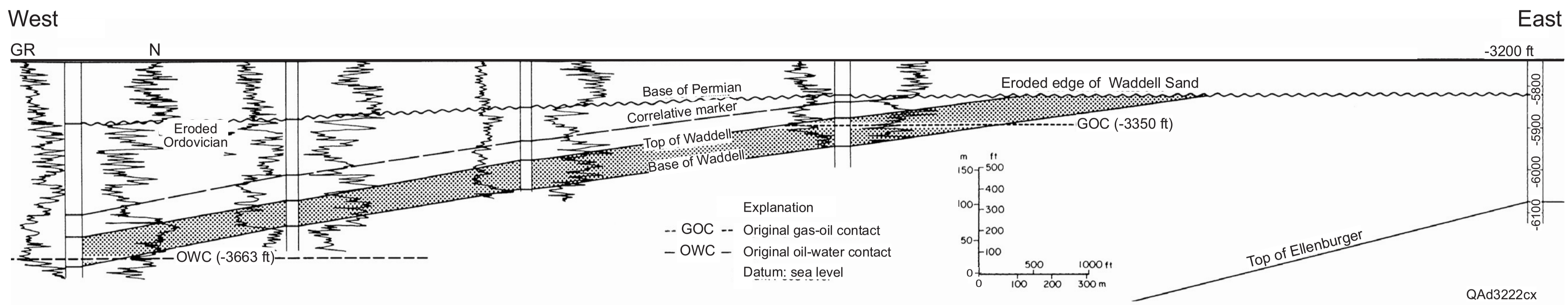

Figure 13. West-east cross section from Running W Waddell field, Crane County, Texas, showing updip erosion of Waddell sandstone. From Galloway and others (1983). See Galloway and others (1983) for location of cross section.

The Running W (Waddell) reservoir in Crane County produces where erosional pinch-out of the Waddell sandstone is overlain by Permian rocks (Galloway and others, 1983). Crawar Waddell field produces from a north-south-trending anticline that is bound on the east by a northwest-southeast-trending reverse fault (Wojcik, 1990). Candelaria and others (1994) suggested that stratigraphic traps may occur in retrogradational Simpson shoreface sandstones that are laterally discontinuous and vertically segregated.

Porosity ranges from 11 percent in Crawar Waddell field to 16 percent at Martin McKee. Permeability averages 45 md (45×10^{-3} μm^2) in Crawar Waddell (Wojcik, 1990) and 164 md (164×10^{-3} μm^2) in Running W Waddell field (Galloway and others, 1983).

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Silurian Plays

Carbonate and chert rocks of Silurian and Devonian age (fig. 3) constitute a thick succession (as much as 2,000 ft [610 m]) of platform and deeper water slope and basin deposits that underlies most of the Permian Basin (Ruppel and Holtz, 1994). Most previous studies have grouped large parts of this succession as the Siluro-Devonian because of uncertainty over the stratigraphic and temporal interrelationships of these deposits. In the *Atlas of Major Texas Oil Reservoirs* (Galloway and others, 1983) Siluro-Devonian reservoirs were grouped into three plays: Siluro-Devonian Ramp Carbonate, Siluro-Devonian Ramp Carbonate (South Central Basin Platform), and Siluro-Devonian Ramp Carbonate (North Central Basin Platform). Regional stratigraphic analysis of these deposits by Ruppel and Holtz (1994) and more recent biostratigraphic studies by Barrick and others (1993) and Barrick (1995) have more clearly defined the stratigraphy of these rocks. In this report the “Siluro-Devonian” has been subdivided into four plays—two that are dominantly Silurian and two Devonian.

Reservoirs productive from Silurian rocks can be subdivided into two distinct lithologic successions: the Fusselman Formation (which actually ranges from Upper Ordovician to Middle Silurian) and the Wristen Group (Middle to Upper Silurian) (fig. 3). The two Silurian plays are the Fusselman Shallow Platform Carbonate and the Wristen Buildups and Platform Carbonate. The few Upper Ordovician Montoya reservoirs that have produced >1 MMbbl (1.59×10^5 m^3) of oil are included in the Fusselman play. Devonian reservoirs are grouped in the Devonian Thirtyone Deepwater Chert and Devonian Thirtyone Ramp Carbonate plays.

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Fusselman Shallow Platform Carbonate (Play 104)

The Fusselman Shallow Platform Carbonate play lies over a large area of west Texas and southeast New Mexico (fig. 14). This reservoir group consists of 63 reservoirs that had produced >1 MMbbl (1.59×10^5 m^3) of oil through 2000; cumulative production from the play was 356.3 MMbbl (5.66×10^7 m^3) (table 7). A large number of smaller reservoirs that have not produced >1 MMbbl (1.59×10^5 m^3) are also productive from the Fusselman. Ruppel and Holtz (1994) documented a total of 233 productive reservoirs in the Fusselman in 1989, only 47 of which had produced >1 MMbbl (1.59×10^5 m^3) at that time. A few reservoirs that produce from the Upper Ordovician Montoya Formation are also included in the play.

The Fusselman in the subsurface is Late Ordovician to Early Silurian in age (fig. 3) (Barrick and others, 1993). Fusselman rocks are widespread, extending across much of west Texas and southeast New Mexico (Ruppel and Holtz, 1994). Throughout almost all of this area, the Fusselman is composed of limestones and dolostones that were deposited on an open-marine, shallow-water carbonate platform that extended over much of the Midcontinent region. The Fusselman is primarily dolostone and cherty dolostone in the north half of its distribution, whereas limestone is more common in the south (Ruppel and Holtz, 1994). In New Mexico the formation is largely of shallow-water origin, dolomitized, and commonly brecciated. Differentiation of the Fusselman from the bounding Montoya Formation and Wristen Group is difficult in New Mexico owing to the similar dolostone content of each.

Fusselman reservoirs include stratigraphic pinch-out traps, simple anticlinal traps, and fault-bounded anticlinal traps (Tyler and others, 1991). The Woodford Shale (fig. 3) acts as a source rock (Comer, 1991) and, where it directly overlies the Fusselman, as a seal. Fusselman

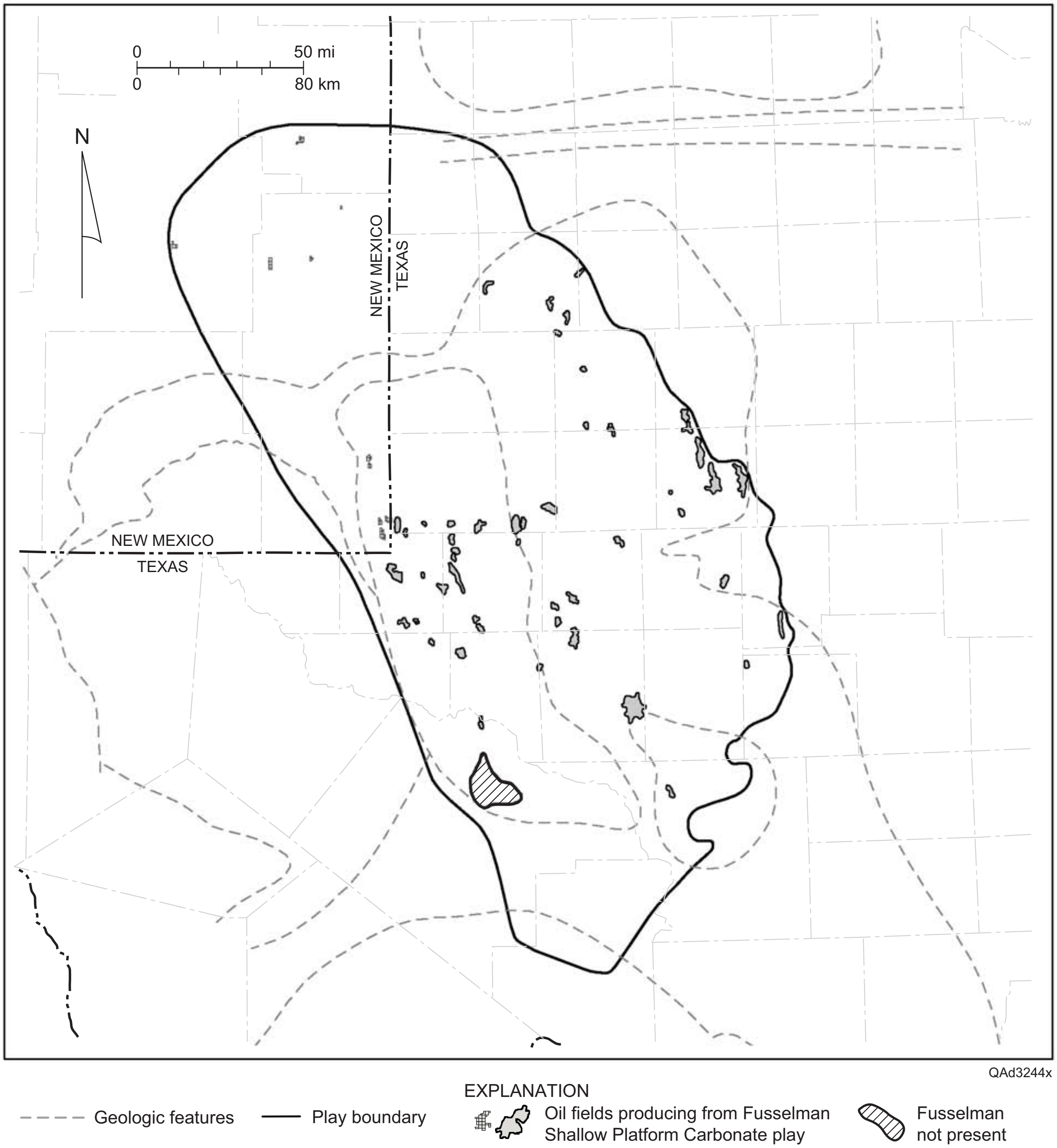

Figure 14. Play map for the Fusselman Shallow Platform Carbonate play, showing location of reservoirs having >1 MMbbl cumulative production, the play boundary, and geologic features. See figure 1 for county names and figure 2 for identification of geologic features.

rocks are productive in two major settings in Texas: (1) along the northwest-southeast-trending Fusselman subcrop margin from Terry to Sterling Counties, Texas, and (2) on major structures in

Table 7. Fusselman Shallow Platform Carbonate play (play 104). 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
292667	8	ABELL	SILURIAN-MONTOYA	TX	PECOS	1948	4936	0	12,619,167
292725	8	ABELL	SILURIAN - MONTOYA, N. W.	TX	CRANE	1962	5110	6,772	1,432,119
3644852	8	ARMER	6350	TX	CRANE	1955	6340	15,822	4,779,874
250750	8	A. W.	FUSSELMAN	TX	WINKLER	1964	9717	0	1,348,292
6671498	8	BEDFORD	FUSSELMAN	TX	ANDREWS	1951	9702	4,906	1,854,661
7109500	7C	BENEDUM	FUSSELMAN	TX	UPTON	1966	11110	50,999	2,931,937
8044400	8	BIG SPRING	FUSSELMAN	TX	HOWARD	1955	9589	34,539	7,238,047
9230426	8	BLOCK 11	FUSSELMAN	TX	ANDREWS	1961	7956	1,836	1,069,231
12469666	8A	BROWNFIELD, S.	FUSSELMAN	TX	TERRY	1968	12020	81,018	5,524,831
18535500	8A	CLARA GOOD	FUSSELMAN	TX	BORDEN	1956	9740	9,383	1,158,807
19113750	8	COAHOMA, N.	FUSSEL	TX	HOWARD	1969	8791	16,167	2,778,608
20787001	8A	CORRIGAN		TX	TERRY	1950	11475	14,547	4,235,262
20788500	8A	CORRIGAN, EAST	FUSSELMAN	TX	TERRY	1952	11615	102,547	4,669,363
25188800	8	DOLLARHIDE	SILURIAN	TX	ANDREWS	1947	8345	157,860	40,980,095
25189600	8	DOLLARHIDE, EAST	SILURIAN	TX	ANDREWS	1949	11000	0	1,337,356
26706333	8A	DUPREE	FUSSELMAN	TX	DAWSON	1960	11670	11,175	1,608,926
28899332	8	EMMA	FUSSELMAN	TX	ANDREWS	1954	11288	0	1,933,151
29292400	7C	ESCONDIDO	FUSSELMAN	TX	CROCKETT	1963	8560	2,398	1,060,327
30398500	8	FASKEN, S.	FUSSELMAN	TX	ECTOR	1957	12270	8,983	1,655,361
33989001	8	GARDEN CITY		TX	GLASSCOCK	1946	9740	727	1,128,766
35652434	8	GOLDSMITH	FUSSELMAN	TX	ECTOR	1954	7763	1,595	4,696,451
35654830	8	GOLDSMITH, N.	SILURIAN	TX	ECTOR	1948	8255	3,464	1,524,694
35659500	8	GOLDSMITH, W.	FUSSELMAN	TX	ECTOR	1955	8294	1,621	2,672,229
35744666	8A	GOOD, SE.	FUSSELMAN	TX	BORDEN	1958	9692	50,928	10,453,193
38255464	8	HALLEY	MONTOYA	TX	WINKLER	1956	10350	0	2,969,405
44521350	8	INEZ	DEEP	TX	ANDREWS	1989	11500	34,595	4,349,034
47267304	8	JORDAN	FUSSELMAN	TX	ECTOR	1951	7420	1,481	1,704,012
49129660	8	KEYSTONE	SILURIAN	TX	WINKLER	1955	8500	131,446	30,949,283
54590300	7C	LONE JOE DEEP	FUSSELMAN	TX	IRION	1987	9046	123,223	8,076,439
55256710	8	LOWE	SILURIAN	TX	ANDREWS	1953	12818	27,168	14,948,341
55822500	8	LUTHER, SE.	SILURIAN-DEVONIAN	TX	HOWARD	1953	9855	440,822	28,797,594
59339700	8	MCELROY, NORTH	SILURIAN	TX	CRANE	1973	11049	30,508	1,015,002
61130001	8	MIDLAND FARMS DEEP		TX	ANDREWS	1986	11924	140,003	13,227,411
61143400	8	MID-MAR, EAST	FUSSELMAN	TX	MIDLAND	1982	11711	8,750	2,750,895
62415415	8	MONAHANS	FUSSELMAN	TX	WARD	1954	8336	0	1,262,546
62417450	8	MONAHANS, NORTH	FUSSELMAN	TX	WINKLER	1957	10026	46,718	1,944,511
62417630	8	MONAHANS, NORTH	MONTOYA	TX	WINKLER	1956	10080	4,616	1,036,863
62711300	8	MOORE	DEEP FSLM	TX	HOWARD	1982	10032	33,495	5,073,129
63289500	8A	MOUND LAKE	FUSSELMAN	TX	TERRY	1962	11320	0	2,532,705
69233400	8	PARKS	FUSSELMAN-MONTOYA	TX	MIDLAND	1983	12405	21,273	1,143,084
69563250	8A	PATRICIA	FUSSELMAN	TX	DAWSON	1959	12020	23,626	3,983,286
70279375	7C	PEGASUS	FUSSELMAN	TX	MIDLAND	1958	12100	29,675	3,378,847
70537396	8	PENWELL	FUSSELMAN	TX	ECTOR	1953	7490	0	1,848,684
88977426	8A	TEX-HAMON	FUSSELMAN	TX	DAWSON	1962	11574	26,123	16,869,275
88977710	8A	TEX-HAMON	MONTOYA	TX	DAWSON	1962	11675	0	4,833,739
90365300	8A	TOKIO	FUSSELMAN	TX	TERRY	1979	12871	11,722	1,415,477
88071638	8	TXL	SILURIAN	TX	ECTOR	1946	8465	13,427	9,307,489
93958375	8	VIREY	FUSSELMAN	TX	MIDLAND	1955	12234	8,041	1,425,380
94187200	8	W.A.M., SOUTH	FUSSELMAN	TX	STERLING	1965	8677	7,778	2,470,860
95108500	8	WAR-SAN	FUSSELMAN	TX	MIDLAND	1954	12514	916	2,095,899
96756600	8	WHEELER	SILURIAN	TX	WINKLER	1945	9300	4,486	2,711,661
99733500	8	ZEBULON		TX	HOWARD	1988	10324	54,676	1,448,904
		BOUGH	DEVONIAN	NM	LEA	1965	11920	7356	3,798,039
		BRUNSON	FUSSELMAN	NM	LEA	1980	7200	0	1,162,659
		CAPROCK EAST	DEVONIAN	NM	LEA	1951	10450	56435	23,613,469
		CHISUM	DEVONIAN	NM	CHAVES	1950	6490	33089	1,222,275
		DOLLARHIDE	FUSSELMAN	NM	LEA	1952	8710	9930	6,620,935
		FOUR LAKES	DEVONIAN	NM	LEA	1956	12809	0	1,865,501
		JUSTIS	FUSSELMAN	NM	LEA	1958	5900	37687	10,987,716
		JUSTIS	MONTOYA	NM	LEA	1958	6886	6872	4,772,033
		JUSTIS NORTH	FUSSELMAN	NM	LEA	1961	7050	14529	3,356,310
		MCCORMACK	SILURIAN	NM	LEA	1947	7145	10268	1,222,210
		PETERSON SOUTH	FUSSELMAN	NM	ROOSEVELT	1978	7800	68868	3,386,739
		Totals						**2,046,889**	**356,268,389**

the south part of the area (Ruppel and Holtz, 1994). Stratigraphic traps, which are most common along the eastern subcrop margin, are the result both of facies changes over local topographic highs and local truncation of the Fusselman beneath the overlying Wristen Group (fig. 15)

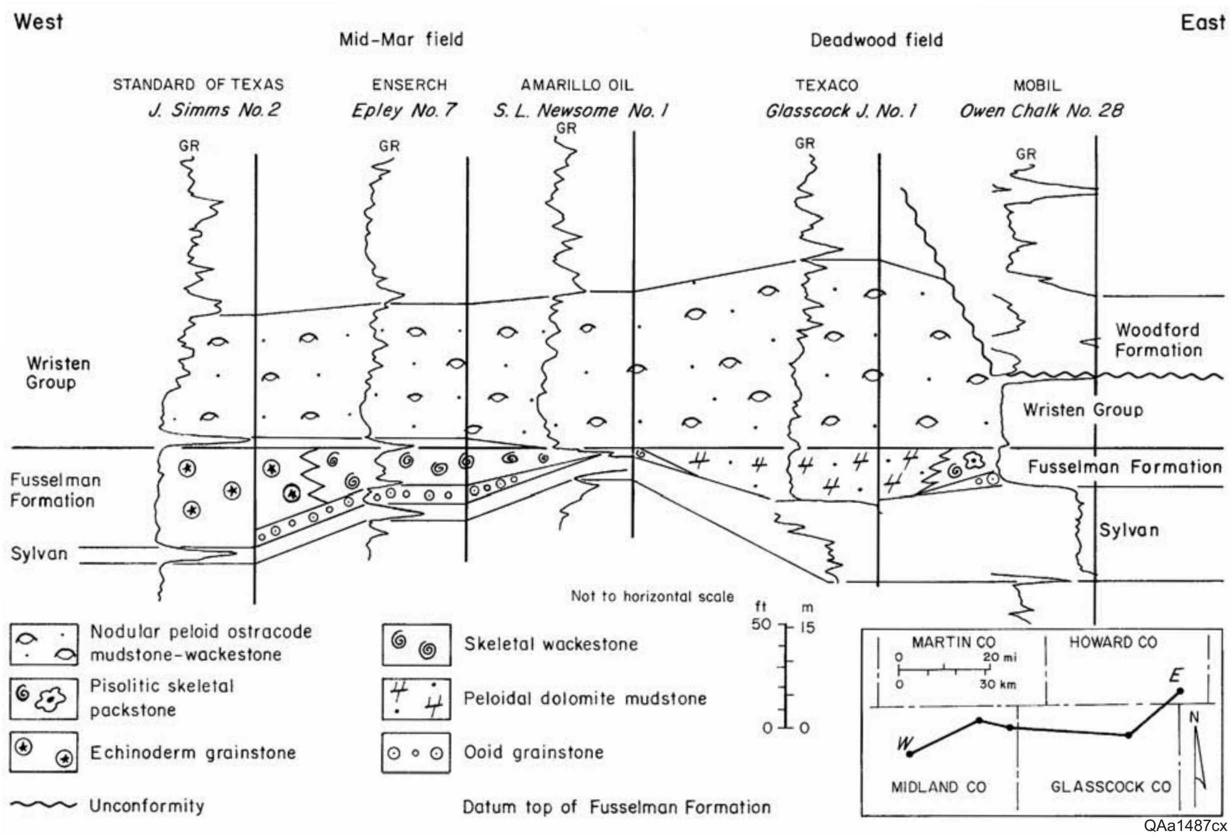

Figure 15. West-east cross section showing facies changes in the Fusselman Formation associated with a paleotopographic high near the eastern subcrop. From Ruppel and Holtz (1994); after Garfield and Longman (1989).

(Ruppel and Holtz, 1994; Mazzullo, 1997). Structural traps predominate in the rest of the play area. New Mexico production occurs in three provinces: on the Northwest Shelf where the Woodford Shale lies directly on the Fusselman (three reservoirs), to the southeast where Wristen Group rests on the Fusselman (one reservoir), and within fault-bounded structural highs on the Central Basin Platform (seven reservoirs). On the Northwest Shelf the Fusselman is beveled by the pre-Woodford unconformity along a northeast-southwest trend in Roosevelt and Chaves Counties. Thicknesses ranging from >600 ft (180 m) in southeast Lea County to zero east of

Roswell, with a meandering zero line from approximately T12S R25E to T4S R28E. The formation is also eroded locally across highs on the Central Basin Platform.

Fusselman reservoir facies were described by Garfield and Longman (1989), Geesaman and Scott (1989), Canter and others (1992), and Ruppel and Holtz (1994). The base of the Fusselman is composed of ooid grainstone and packstone (Ruppel and Holtz, 1994) (figs. 15, 16) that are probably of Late Ordovician age (Barrick, 1995). Porosity in these rocks is principally intergranular, and therefore permeability is commonly relatively high. Overlying these rocks are thin deposits of carbonate mudstone and skeletal wackestone of early Silurian age (Barrick, 1995). The upper part of the Fusselman is composed of pelmatozoan grainstone and packstone; some local carbonate buildups occur in this part of the section (fig. 16). Interparticle pore space in these rocks is commonly filled with cements, but vuggy and intercrystalline porosity developed by leaching is locally significant. Porosity development was enhanced by diagenesis associated with high-frequency sea-level fall and exposure during and after Fusselman deposition (Ruppel and Holtz, 1994). At the top of the Fusselman is wispy-laminated to nodular-bedded wackestone.

Paleokarst has been identified in Fusselman reservoirs in the Permian Basin (Mazzullo and others, 1989; Mazzullo and Mazzullo, 1992; Mazzullo, 1997; Ball, 2002), and collapse breccias and dissolution-enhanced fractures contribute to reservoir porosity. Outcrops in the Franklin Mountains contain three unconformity-bounded sequences, with the uppermost surface heavily karsted (LeMone, 1996), whereas four major sea-level falls are documented in Oklahoma and the subsurface of West Texas (Johnson, 1987; Ruppel and Holtz, 1994). Fractures in Fusselman core from Dollarhide field are concentrated in karsted intervals (Ball, 2002). Tectonic fractures were identified in parts of the Dollarhide reservoir with image logs, but tectonic

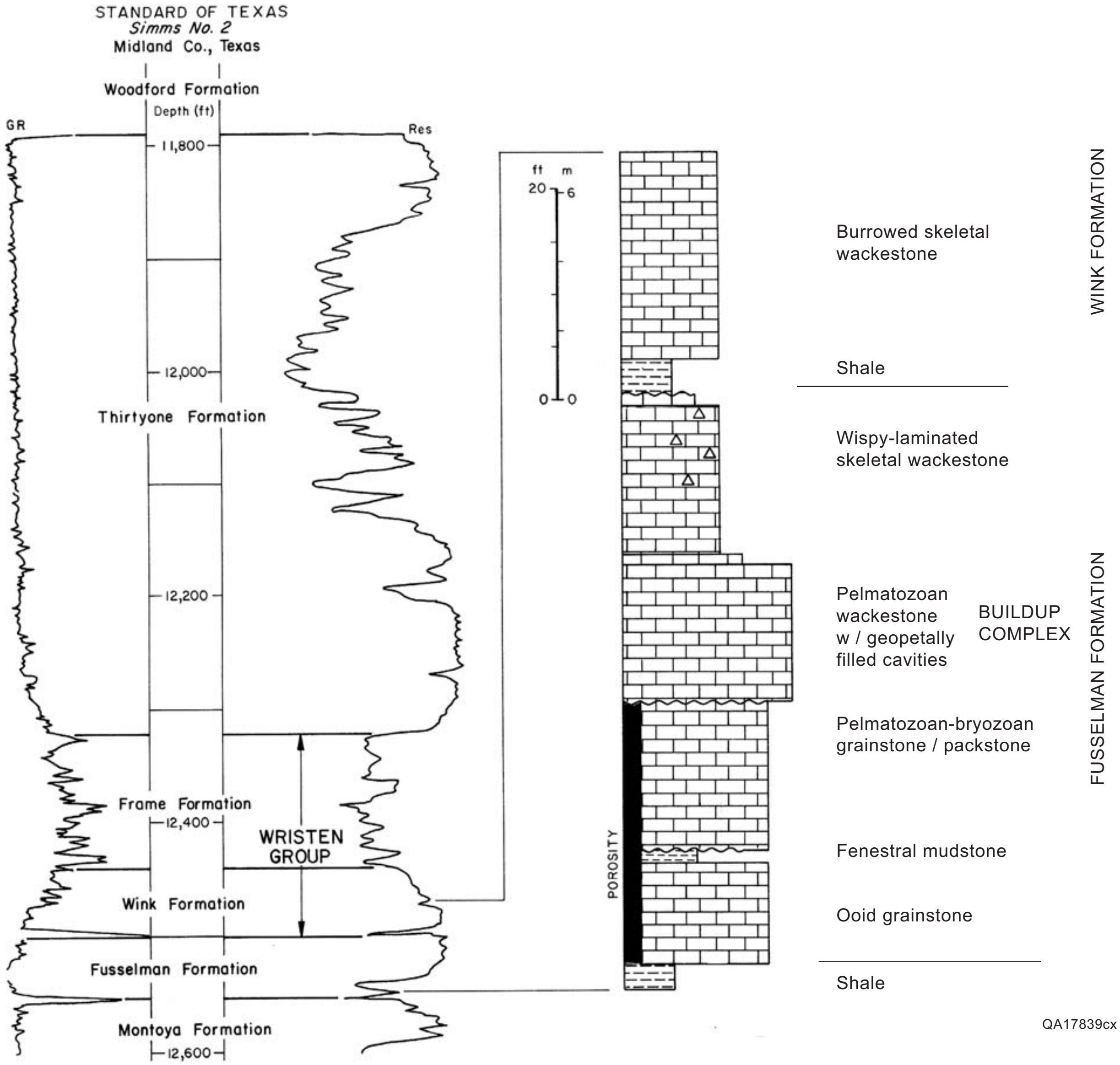

Figure 16. Wireline response of the Upper Ordovician-Devonian stratigraphic section in the Standard of Texas Simms No. 2 well, Midland County. The Fusselman facies succession is typical of much of the play area. From Ruppel and Holtz (1994).

fractures are not dominant (Ball, 2002, 2003). Trapping at Dollarhide field is both structural and stratigraphic. Porous intervals pinch out laterally and vertically into rock that is nonporous and unfractured or that has cement-filled fractures (Ball, 2002, 2003). Core and borehole-imaging logs have been helpful in identifying internal complexity within the Dollarhide reservoir.

Some of the reservoirs included in this play produce from the Montoya Formation, a thin succession of Upper Ordovician shallow-water limestones and dolostones that underlies the Fusselman. Montoya deposition began during the Late Ordovician on an extensive shallow-water platform. Fusselman Formation carbonates reflect the continued growth and development of this shallow-water platform from the Late Ordovician into the Early Silurian (Ruppel and Holtz, 1994). Early Montoya shallow, subtidal carbonates were deposited in normal marine conditions, whereas later Montoya deposition occurred in a peritidal setting (Ball, 2002; Behnken, 2003). Sea-level fluctuations resulted in early dolomitization and several karsting events (Ball, 2002). Distinction of the Montoya from the Fusselman where the Sylvan Shale is not present is difficult. The Sylvan Shale is a gray-green shale that occurs in parts of the Midland Basin between the Montoya and Fusselman (fig. 3); it was interpreted as being of Late Ordovician age by Ruppel and Holtz (1994). Because the Montoya and the Fusselman are similar lithologically, they are combined into one play for this report.

Porosity in Fusselman reservoirs averages 8 percent and ranges from 1 to 18 percent. Mean permeability is 12 md ($12 \times 10^{-3}\ \mu m^2$) and ranges from 0.6 to 85 md (0.6 to $85 \times 10^{-3}\ \mu m^2$) (Ruppel and Holtz, 1994). Core porosity in open-marine deposits of the lower Montoya is higher (average 6.2 percent) than in upper Montoya peritidal deposits (average 2.5 percent) (Behnken, 2003).

Production from mature Dollarhide field has been increased by the program of recompletions and infill drilling at 20-acre spacing (Ball, 2003). Field production had fallen to 400 bbl/day (63.6 m^3/d), but targeting of bypassed pay zones identified on behind-pipe hydrocarbon logs has increased production to 1,200 bbl/day (191 m^3/d) (Ball, 2003). Completions in the Montoya dolomite intervals have been improved by using casing perforations instead of open-hole completions, selectively perforating the Montoya interval, and treating the interval with a larger volume of acid or gelled acid (Ball, 2003). Water production has decreased from 21,000 to 19,000 bbl/day (3.34×10^3 to 3.02×10^3 m^3/d) by squeezing wet and depleted zones.

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Wristen Buildups and Platform Carbonate (Play 105)

The Wristen Buildups and Platform Carbonate play consists of 85 reservoirs in Texas and New Mexico (fig. 17) that had produced >1 MMbbl (1.59×10^5 m^3) of oil through 2000; cumulative production from the play was 888.8 MMbbl (1.41×10^8 m^3) (table 8). Rocks of the Silurian Wristen Group were deposited across most of the Permian Basin in a platform-to-basin setting that developed during the Middle Silurian (fig. 18) (Ruppel and Holtz, 1994). The Wristen platform margin trended east-west across southern Andrews and northern Midland Counties, and it marks the southern limit of the play (fig. 19).

The Wristen Group was divided into the Wink, Frame, and Fasken Formations by Ruppel and Holtz (1994) (fig. 18). Facies of the Wristen Group were described by Canter and others (1992) and Ruppel and Holtz (1994). South of central Andrews County, the Wristen is generally <500 ft (150 m) thick (Ruppel and Holtz, 1994), and it is composed of slope and basin mudstones and wackestones of the Wink and Frame Formations. To the north, the Wristen is composed of a diverse assemblage of shallow-water platform carbonates that constitute the Fasken Formation. The Fasken reaches thicknesses of >1,200 ft (>365 m) in Texas (Ruppel and Holtz, 1994). The transition from the platform facies of Fasken in the north to the deeper water facies of the Wink and Frame in the south defines the general position of the Wristen platform margin (fig. 19). Wristen production is derived nearly entirely from the shallow-water Fasken facies in the north.

Production from reservoirs assigned in this report to the Silurian Wristen Group has in the past been assigned to a variety of Silurian and Devonian units. Many Wristen reservoirs, for example, are officially named “Silurian,” Devonian,” or “Siluro-Devonian.” Recent biostratigraphy (Barrick and others, 1993; Barrick, 1995) and regional stratigraphic analysis

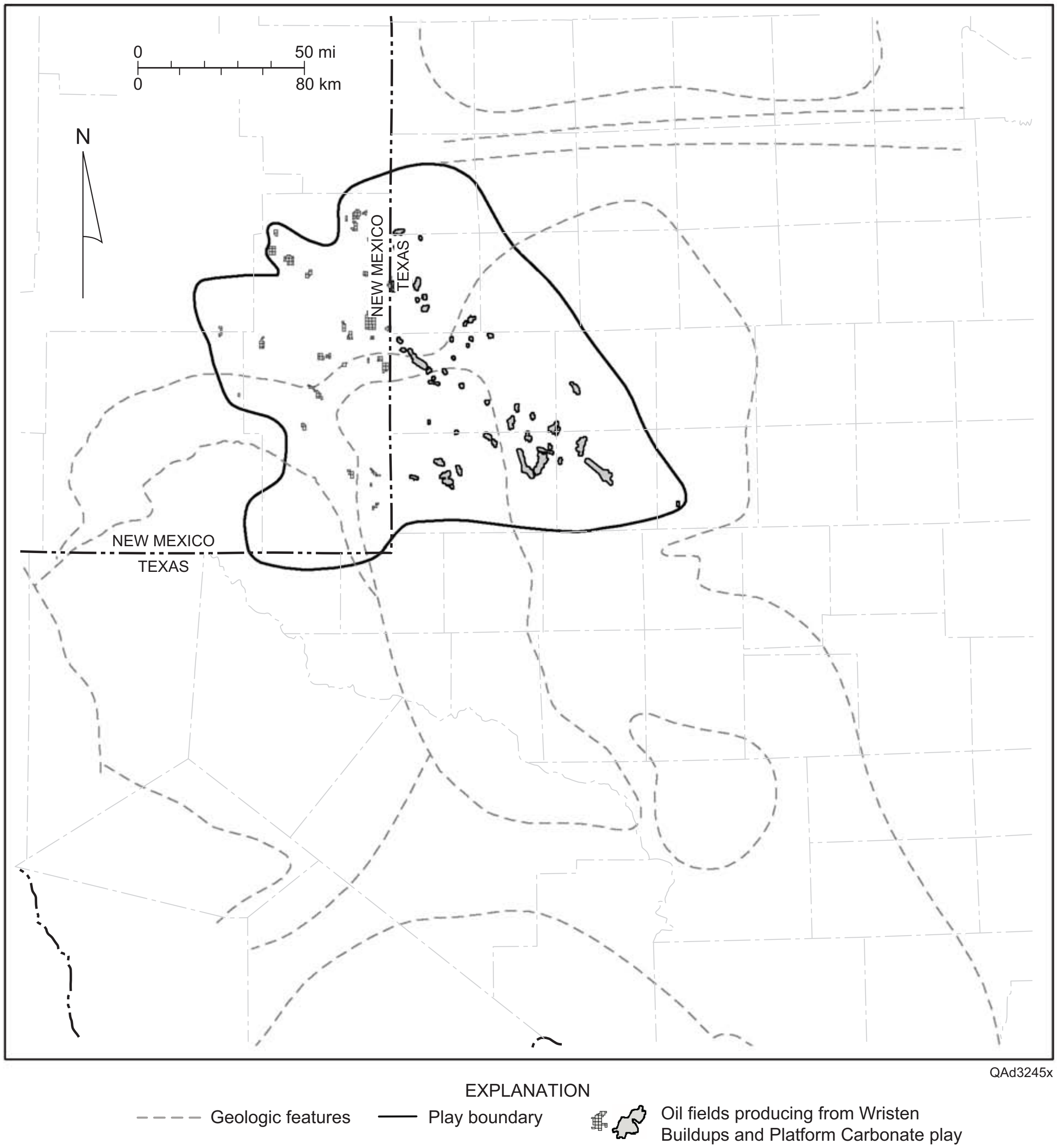

Figure 17. Play map for the Wristen Buildups and Platform Carbonate play, showing location of reservoirs having >1 MMbbl cumulative production, the play boundary, and geologic features. See figure 1 for county names and figure 2 for identification of geologic features.

(Ruppel and Holtz, 1994) indicates that Devonian strata do not extend north of the extreme south part of Lea County. The vast majority of dolomitic carbonates present in southeast New Mexico

Table 8. Wristen Buildups and Platform Carbonate play (play 105). 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
1964333	8A	ALSABROOK	DEVONIAN	TX	GAINES	1953	11135	0	3,815,802
2404333	8A	AMROW	DEVONIAN	TX	GAINES	1954	12628	81,826	15,980,351
9172250	8	BLOCK 6	DEVONIAN	TX	ANDREWS	1952	12530	28,758	4,478,026
9175500	8	BLOCK 6, NE	SILURIAN	TX	ANDREWS	1974	12471	79,329	3,623,929
9188250	8	BLOCK 7	DEVONIAN	TX	MARTIN	1950	12280	56,478	5,209,687
8930333	8A	BLOCK A-7	DEVONIAN	TX	GAINES	1959	11100	34,318	1,699,349
8990333	8	BLOCK A-49	DEVONIAN	TX	ANDREWS	1965	8637	32,136	2,088,379
9060333	8A	BLOCK D	DEVONIAN	TX	YOAKUM	1957	11923	71,104	1,931,322
11308200	8A	BRAHANEY	DEVONIAN	TX	YOAKUM	1979	11372	28,021	8,824,267
11313300	8A	BRAHANEY, NORTHWEST	DEVONIAN	TX	YOAKUM	1982	11893	125,499	14,748,050
11314200	8A	BRAHANEY, W.	DEV	TX	YOAKUM	1981	11645	29,944	1,447,939
11334300	8A	BRALLEY	SILURIAN	TX	YOAKUM	1991	13108	167,650	1,927,011
11751001	8	BREEDLOVE		TX	MARTIN	1951	12078	147,679	31,736,195
12160600	8A	BRONCO	SILURO-DEVONIAN	TX	YOAKUM	1952	11692	107,639	14,292,254
12978600	8	BUCKWHEAT	SILURO-DEVONIAN	TX	HOWARD	1989	10182	50,716	1,488,718
16860333	8A	CHAMPMON	DEV.	TX	GAINES	1959	12735	31,725	1,334,656
25243500	8A	DOMINION	SILURIAN	TX	TERRY	1979	13342	14,927	1,005,286
28873500	8A	EMERALD	SILURIAN	TX	YOAKUM	1988	12372	152,558	1,550,264
30776500	8A	FIELDS	DEVONIAN	TX	YOAKUM	1954	12030	6,799	4,042,266
31222600	8A	FLANAGAN	DEVONIAN	TX	GAINES	1949	10345	29,621	2,600,285
33230900	8	FULLERTON	8500	TX	ANDREWS	1944	8658	181,239	51,119,358
33230300	8	FULLERTON	DEVONIAN	TX	ANDREWS	1987	8276	101,222	2,734,646
35197333	8	GLASCO	DEVONIAN	TX	ANDREWS	1953	12543	116,288	21,207,037
38832333	8A	HAP	DEVONIAN	TX	GAINES	1955	12356	69,274	1,588,017
43878800	8	HUTEX	DEVONIAN	TX	ANDREWS	1953	12509	263,951	48,354,343
46132001	8A	JENKINS		TX	GAINES	1948	9100	9,959	1,441,170
47187001	8A	JONES RANCH		TX	GAINES	1945	11200	12,589	7,849,382
51812500	8A	LANDON	DEVONIAN	TX	COCHRAN	1949	10913	3,013	1,676,236
56822125	8	MAGUTEX	DEVONIAN	TX	ANDREWS	1953	12504	229,455	48,627,371
58027500	8A	MARY TWO	DEVONIAN	TX	YOAKUM	1981	13220	24,484	1,388,687
65766333	8	NOLLEY	DEVONIAN	TX	ANDREWS	1967	12311	17,416	4,321,428
65967400	8	NORMAN	DEVONIAN	TX	GAINES	1961	12214	66,696	7,734,263
66373250	8A	O D C	DEVONIAN	TX	GAINES	1956	11993	11,656	2,812,852
74041100	8	RK	DEVONIAN	TX	MARTIN	1975	11815	525,717	21,538,949
79004250	8A	RUSSELL, NORTH	DEVONIAN	TX	GAINES	1948	11125	125,995	79,739,814
81913500	8A	SEAGRAVES	SILURO - DEVONIAN	TX	GAINES	1955	13028	0	4,944,608
81917666	8A	SEAGRAVES, S.	SILURO - DEVONIAN	TX	GAINES	1955	12997	15,519	1,783,158
82225040	8A	SEMINOLE	DEVONIAN	TX	GAINES	1977	11500	110,836	5,811,135
82229750	8A	SEMINOLE, NW.	DEVONIAN FB 2	TX	GAINES	1964	11456	10,604	1,508,906
82233200	8A	SEMINOLE, W.	DEVONIAN	TX	GAINES	1956	11136	7,588	1,271,248
82233400	8A	SEMINOLE, W.	DEVONIAN FB 2	TX	GAINES	1957	10554	0	1,783,937
82570200	8	SHAFTER LAKE	DEVONIAN	TX	ANDREWS	1947	9425	192,314	27,459,338
89038500	8A	TEX-SIN	DEVONIAN	TX	GAINES	1962	12285	84,781	7,998,812
91406500	8A	TRIPP	DEVONIAN	TX	GAINES	1964	12577	19,646	1,657,515
92548250	8	UNIVERSITY BLOCK 13	DEVONIAN	TX	ANDREWS	1960	8826	6,576	1,478,228
94748666	8A	WALKER	DEVONIAN	TX	COCHRAN	1967	11818	0	1,692,316
96202500	8A	WELLS	DEVONIAN	TX	DAWSON	1955	12083	102,137	8,760,790
96408166	8A	WESCOTT	DEV.	TX	GAINES	1964	12360	38,035	3,933,775
96487500	8A	WEST	DEVONIAN	TX	YOAKUM	1957	11058	75,184	23,898,463

above the Fusselman Formation and below the Woodford Shale therefore belong to the Silurian-age Wristen Group (fig. 3).

In New Mexico it is locally difficult to differentiate the Wristen (Fasken Formation) from the underlying Fusselman. Where distinguishable, the Wristen (Fasken Formation) thickens in a westerly direction across west Texas and into New Mexico (fig. 19). It reaches thicknesses of 1,400 ft (425 m) in the area of western Andrews County and southeastern Lea County (fig. 19).

Table 8, continued. Wristen Buildups and Platform Carbonate play (play 105).

RRC RESN	RRC	FLDNAME	RESNAME	STATE	COUNTY	DISCYR	DEPTHTOP	2000 PROD	CUMPROD
		ANDERSON RANCH	DEVONIAN	NM	LEA	1953	13374	6,311	8,732,227
		BAGLEY	SILURO-DEVONIAN	NM	LEA	1949	10950	115,910	28,461,902
		BRONCO	SILURO-DEVONIAN	NM	LEA	1955	11700	47,298	16,048,762
		BRONCO WEST	DEVONIAN	NM	LEA	1965	12170	6,347	1,420,225
		CAUDILL	DEVONIAN	NM	LEA	1954	13585	24,661	5,711,745
		CROSSROADS	SILURO-DEVONIAN	NM	LEA	1948	12115	59,787	43,440,653
		CROSSROADS EAST	DEVONIAN	NM	LEA	1956	12173	48,240	2,540,103
		CROSSROADS SOUTH	DEVONIAN	NM	LEA	1954	12250	33,601	3,272,563
		CROSSROADS WEST	DEVONIAN	NM	LEA	1959	12000	672	2,063,579
		DEAN	DEVONIAN	NM	LEA	1955	13600	172	3,034,645
		DENTON	DEVONIAN	NM	LEA	1949	11360	268,927	101,227,563
		DENTON SOUTH	DEVONIAN	NM	LEA	1955	13110	4,627	3,748,807
		ECHOLS	DEVONIAN	NM	LEA	1951	11500	0	4,622,000
		ECHOLS NORTH	DEVONIAN	NM	LEA	1952	12057	18,995	1,416,811
		FOWLER	DEVONIAN	NM	LEA	1955	7587	7,257	1,326,698
		GARRETT WEST	DEVONIAN	NM	LEA	1970	12850	13,930	3,115,656
		GLADIOLA	DEVONIAN	NM	LEA	1950	11859	42,531	52,841,901
		GLADIOLA SOUTHWEST	DEVONIAN	NM	LEA	1960	12304	9,052	4,435,681
		KING	DEVONIAN	NM	LEA	1956	12439	13,350	6,238,669
		KNOWLES	DEVONIAN	NM	LEA	1949	12570	21,013	4,941,623
		KNOWLES SOUTH	DEVONIAN	NM	LEA	1954	12140	95,498	9,712,376
		LANGLEY	DEVONIAN	NM	LEA	1979	12150	2,850	1,370,899
		LEA	DEVONIAN	NM	LEA	1960	3774	22,604	7,800,254
		LITTLE LUCKY LAKE	DEVONIAN	NM	CHAVES	1958	11050	6,774	1,826,075
		LOVINGTON	DEVONIAN	NM	LEA	1969	11570	14,997	1,735,773
		MCCORMACK SOUTH	SILURIAN	NM	LEA	1967	7100	58,516	1,015,681
		MEDICINE ROCK	DEVONIAN	NM	LEA	1961	12630	0	1,638,000
		MESCALERO	DEVONIAN	NM	LEA	1952	9850	19,533	5,832,949
		MOORE	DEVONIAN	NM	LEA	1952	10100	11,513	22,218,658
		RANGER LAKE WEST	DEVONIAN	NM	LEA	1967	12850	8,424	1,185,371
		SHOE BAR	DEVONIAN	NM	LEA	1953	12480	0	1,082,000
		SHOE BAR EAST	DEVONIAN	NM	LEA	1968	13013	10,132	1,944,953
		SHUGART	SILURO-DEVONIAN	NM	EDDY	1957	12362	4,805	1,114,333
		TEAGUE NORTHWEST	DEVONIAN	NM	LEA	1992	7450	48,909	1,001,274
		VACUUM MID	DEVONIAN	NM	LEA	1963	11644	5,183	1,766,983
		VACUUM SOUTH	DEVONIAN	NM	LEA	1958	11546	22,592	8,930,675
		Totals						**4,773,912**	**888,757,885**

Fasken Formation reservoirs are developed in two settings: (1) platform-margin buildup successions along the platform margin in central Andrews County and (2) shallow-water facies in the interior of the platform (Ruppel and Holtz, 1994). Reservoirs in both settings are mainly localized over structural traps. Platform-margin deposits are composed of skeletal wackestones to grainstones to boundstones (fig. 20), whereas inner-platform deposits are composed of mudstones to pellet and skeletal wackestones to grainstones (Ruppel and Holtz, 1994). Porosity in the buildup-related reservoirs is developed as primary intergranular porosity in flanking and capping grainstones and as leached vuggy porosity in boundstones and wackestones. Porosity in Fasken shallow-water carbonate reservoirs is associated with the formation of vugs, molds, and

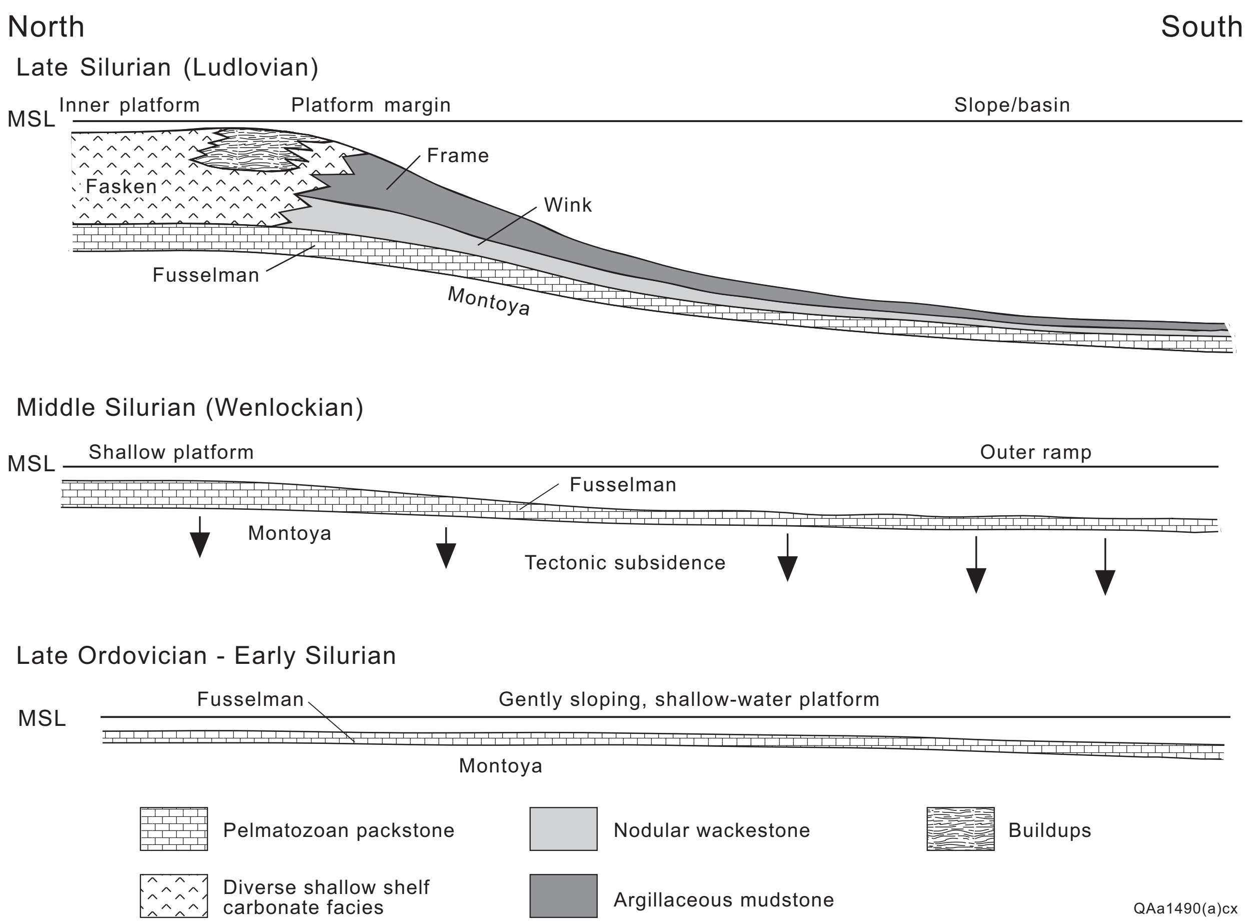

Figure 18. North-south cross sections illustrating the depositional history of the Silurian carbonate section in west Texas and New Mexico. From Ruppel and Holtz (1994). The Wristen Group is divided into the deepwater carbonates of the Wink and Frame Formations and the shallow-water platform carbonates of the Fasken Formation (Ruppel and Holtz, 1994). The Wristen platform margin trended east-west across southern Andrews and northern Midland Counties.

intercrystalline pores by dolomitization and leaching of skeletal fragments (Ruppel and Holtz, 1994).

Leaching and dolomitization apparently resulted from multiple exposure events associated with sea-level fall during and after Fasken deposition (Canter and others, 1992; Ruppel and Holtz, 1994). Karst features have been interpreted from cores in Fasken reservoirs at Emerald field in Yoakum County (Entzminger and Loucks, 1989), Buckwheat field in Howard

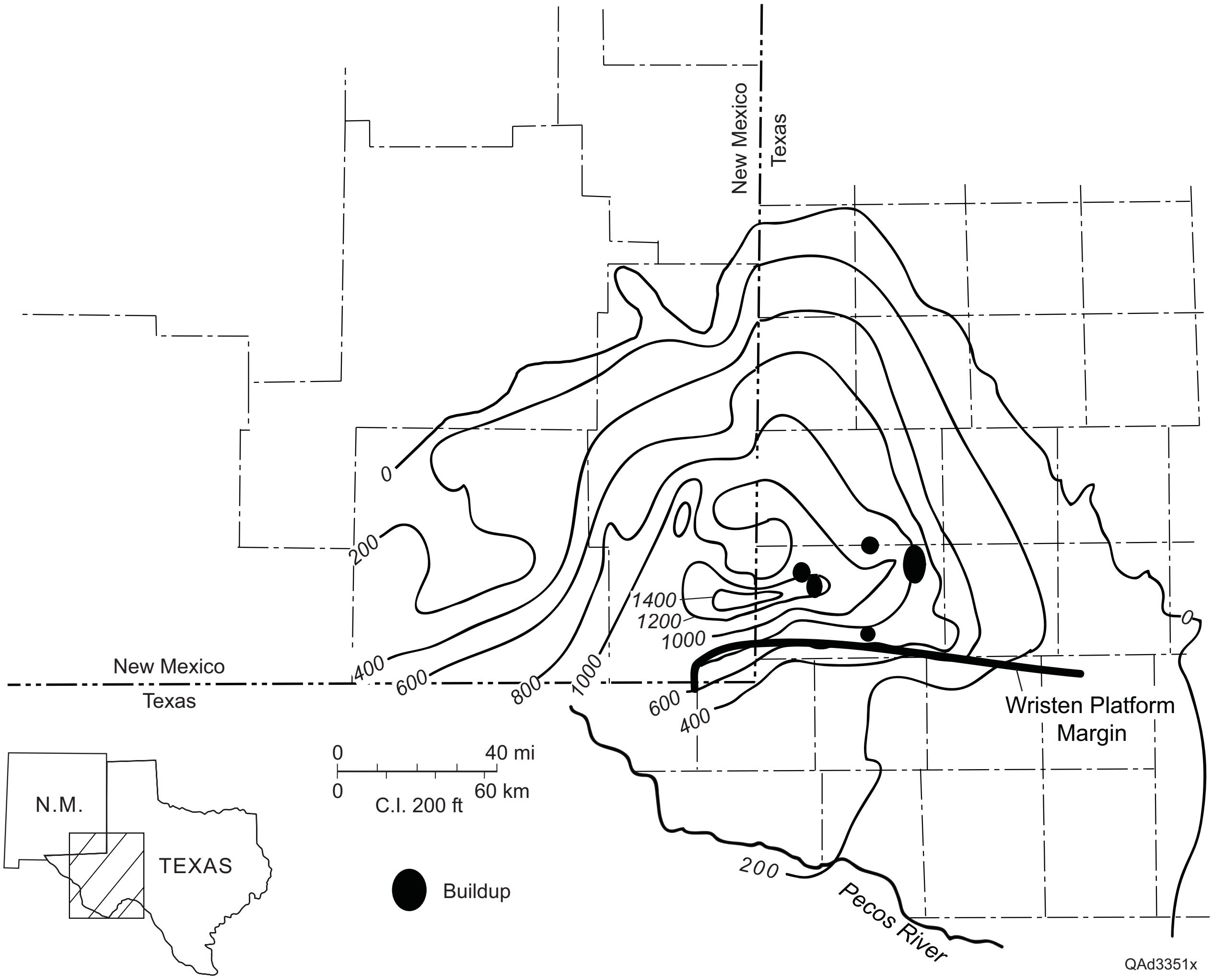

Figure 19. Thickness map of the Wristen Group in west Texas and New Mexico. The New Mexico part of the Wristen was added to the Wristen isopach map of Texas (Ruppel and Holtz, 1994) on the basis of biostratigraphy (Barrick and others, 1993; Barrick, 1995) and regional stratigraphy (Ruppel and Holtz, 1994; Baldonado and Broadhead, 2002, and unpublished).

County (Troschinetz, 1989), and Fullerton field in Andrews County. (Buckwheat field produces from both Fusselman and Wristen reservoirs and is assigned to the Fusselman play.) Karsting is probably associated with regional uplift and erosion of the North American craton during the Middle Devonian (Entzminger and Loucks, 1989; Ruppel and Holtz, 1994).

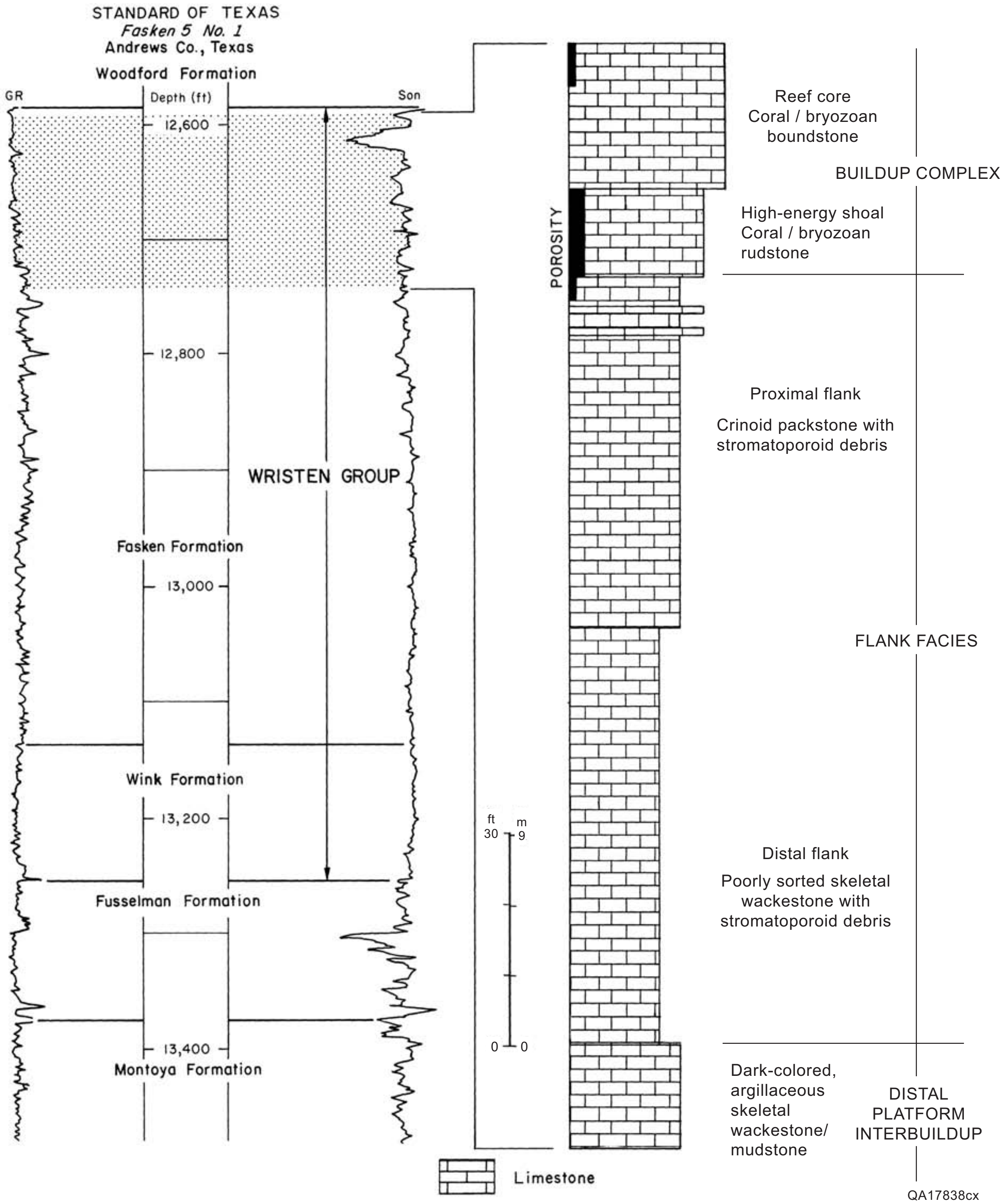

Figure 20. Stratigraphic section of the Fasken Formation (Wristen Group) in the Standard of Texas Fasken 5 No. 1 well. The Fasken section is an aggradational, upward-shallowing, platform-margin succession that is capped by a carbonate buildup. From Ruppel and Holtz (1994).

The overlying Woodford Shale acts as both source (Comer, 1991) and seal. Traps are dominantly structural. Reservoir net pay in the play ranges from 6 to 300 ft (2 to 90 m) and averages 57 ft (17 m). Porosity ranges from 3 to 14 percent and averages 7 percent (Ruppel and Holtz, 1994). Permeability ranges from 3 to 400 md (3 to 400 × 10^{-3} μm^2) and averages 45 md (45 × 10^{-3} μm^2). In general, production from individual reservoirs in this play peaks within a few years after discovery and then undergoes a sharp decline. Unlike many younger carbonate reservoirs in the Permian Basin, Wristen reservoirs typically have active water drives (Galloway and others, 1983).

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Devonian Plays

The Lower Devonian Thirtyone Formation (fig. 3) overlies the Silurian Wristen Group apparently conformably throughout the southern Midland Basin and southern Central Basin Platform. With the exception of local outliers, the Thirtyone is interpreted as having been entirely removed north of this area by Middle Devonian erosion (McGlasson, 1967; Canter and others, 1992; Ruppel and Holtz, 1994; Barrick, 1995). The Thirtyone Formation contains two end-member reservoir facies, (1) skeletal packstones and grainstones and (2) spiculitic chert (fig. 21). Carbonate packstones and grainstones were deposited as in-place accumulations on the Early Devonian shallow-water platform and as resedimented carbonate sands on the outer ramp to slope. Cherts accumulated in deeper water beyond the extent of carbonate deposition. Each of these facies, whose distribution is reciprocal, constitutes a distinct reservoir trend (Ruppel and Holtz, 1994). Thirtyone Formation carbonates are more abundant in the upper part of the formation and to the north, whereas Thirtyone cherts are most abundant in the lower part of the formation and in the south part of the subcrop (fig. 21).

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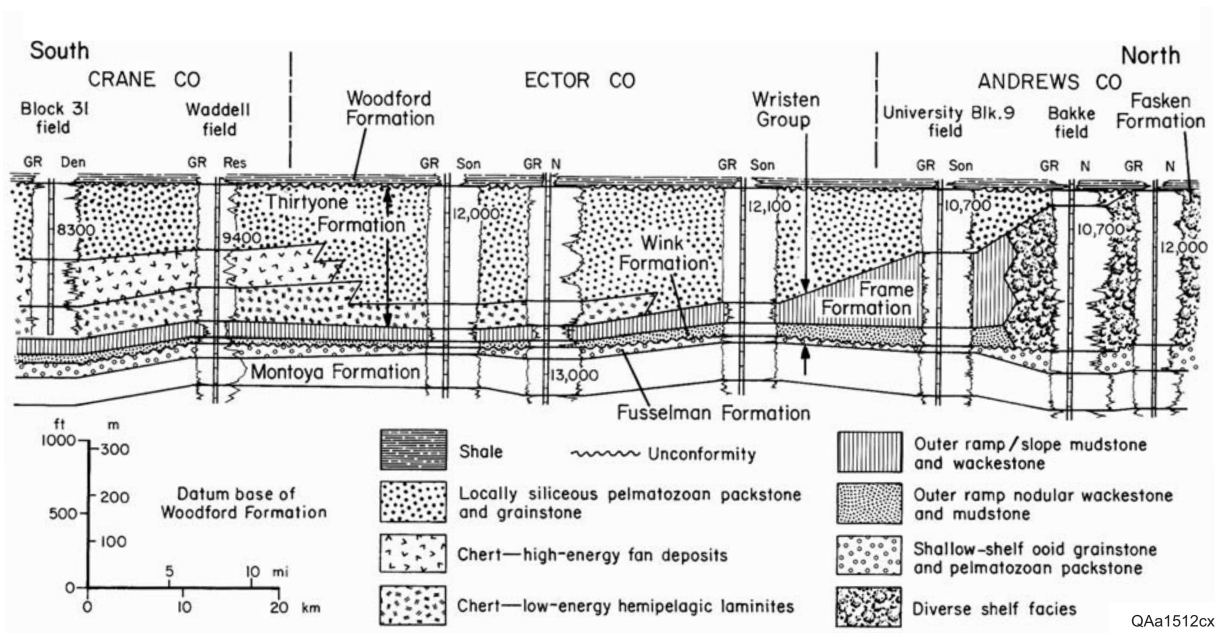

Figure 21. South-north dip cross section showing distribution of major Silurian and Devonian strata. From Ruppel and Holtz (1994). Cross section depicts the wedge-on-wedge relationship between the Wristen Group strata and overlying Thirtyone Formation strata. See Ruppel and Holtz (1994) for location of cross section.

Devonian Thirtyone Deepwater Chert (Play 106)

The Devonian Thirtyone Deepwater Chert play consists of 44 reservoirs that had produced >1 MMbbl (1.59×10^5 m^3) of oil through 2000; cumulative production from the play was 785.9 MMbbl (1.25×10^8 m^3) (table 9). All but one of the reservoirs in the play is in Texas, along the south part of the Central Basin Platform and adjacent areas (fig. 22). Thirtyone Deepwater Chert reservoirs are concentrated along the Thirtyone basin axis, where chert is

Table 9. Devonian Thirtyone Deepwater Chert play (play 106). 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
292203	8	ABELL	DEVONIAN	TX	CRANE	1953	5245	112,298	11,901,722
587332	7C	ADAMC	DEVONIAN	TX	UPTON	1953	10490	28,430	5,208,779
4184333	8	ATAPCO	DEVONIAN	TX	CRANE	1959	5520	63,160	1,398,972
5524664	8	BAR-MAR	DEV.	TX	CRANE	1965	5258	205,886	5,143,157
6671166	8	BEDFORD	DEVONIAN	TX	ANDREWS	1945	8777	271,459	19,358,362
9230142	8	BLOCK 11	DEVONIAN	TX	ANDREWS	1951	8230	71,365	11,110,212
9236333	8	BLOCK 11, SW.	DEVONIAN	TX	ANDREWS	1952	8160	8,153	5,113,708
9358450	8	BLOCK 31	DEVONIAN	TX	CRANE	1945	8812	576,450	223,850,169
20607001	8	CORDONA LAKE		TX	CRANE	1949	5470	450,129	32,578,669
20615500	8	CORDONA LAKE, WEST	DEV.	TX	CRANE	1965	5561	9,327	1,490,496
21577180	8	CRAWAR	DEVONIAN, NORTH	TX	CRANE	1958	6450	82,659	6,308,067
21907111	8	CROSSETT	DEVONIAN	TX	CRANE	1944	5440	404,815	25,568,056
21912333	8	CROSSETT, S.	DETRITAL	TX	CROCKETT	1965	4924	916,976	16,972,491
21912666	8	CROSSETT, S.	DEVONIAN	TX	CROCKETT	1956	5324	0	17,145,768
23543666	8	DAWSON	DEVONIAN	TX	CRANE	1955	5168	0	2,165,509
25188400	8	DOLLARHIDE	DEVONIAN	TX	ANDREWS	1955	8051	1,551,384	97,596,076
25189200	8	DOLLARHIDE, EAST	DEVONIAN	TX	ANDREWS	1949	10186	249,835	9,284,134
31768001	8	FLYING -W-		TX	WINKLER	1949	9660	16,890	1,944,700
32555666	7C	FRANCO	DEVONIAN	TX	UPTON	1964	10633	13,929	1,765,137
35652186	8	GOLDSMITH	DEVONIAN	TX	ECTOR	1948	7875	123,246	15,171,587
35654166	8	GOLDSMITH, N.	DEVONIAN	TX	ECTOR	1946	7900	23,752	9,021,147
38255174	8	HALLEY	DEVONIAN	TX	WINKLER	1956	9884	0	3,425,981
40296500	7C	HELUMA, EAST	DEVONIAN	TX	UPTON	1973	8740	39,768	4,563,131
40300500	7C	HELUMA, SE	DEVONIAN	TX	UPTON	1979	9024	28,200	1,613,983
49042250	8	KERMIT, SOUTH	DEVONIAN-OIL	TX	WINKLER	1957	8220	140	9,656,276
49129198	8	KEYSTONE	DEVONIAN	TX	WINKLER	1946	8040	6,597	15,403,476
49413200	7C	KING MOUNTAIN	DEVONIAN	TX	UPTON	1956	10459	21,950	1,870,050
59560300	7C	MCKAY CREEK	CABALLOS	TX	TERRELL	1979	6238	12,161	1,173,298
62417270	8	MONAHANS, NORTH	DEVONIAN	TX	WINKLER	1955	9447	1,963	6,347,324
68222080	8	P&P	DEVONIAN	TX	CRANE	1995	5508	188,795	1,375,704
70129348	8	PECOS VALLEY	DEVONIAN 5400	TX	PECOS	1953	5771	168,096	8,388,267
70129812	8	PECOS VALLEY	PERMIAN, LOWER	TX	PECOS	1956	5140	39,022	3,236,057
70279125	7C	PEGASUS	DEVONIAN	TX	UPTON	1952	12353	29,575	1,442,855
89408205	8	THISTLE	CABALLOS NOVACULITE	TX	PECOS	1984	2679	9,821	1,291,062
89690250	8	THREE BAR	DEVONIAN	TX	ANDREWS	1945	8385	126,428	41,023,054
91450333	8	TROPORO	DEVONIAN	TX	CRANE	1957	5404	61,872	5,576,672
91455500	8	TROPORO, N	DEVONIAN	TX	CRANE	1979	5555	20,556	1,261,495
91803200	8	TUNIS CREEK	DEVONIAN	TX	PECOS	1982	6835	103,474	3,607,730
88071174	8	TXL	DEVONIAN	TX	ECTOR	1944	8050	58,311	58,747,516
88071232	8	TXL	DEVONIAN-MAIN PAY	TX	ECTOR	1970	8075	29,758	2,465,157
92618125	8	UNIVERSITY WADDELL	DEVONIAN	TX	CRANE	1949	9040	529,063	70,267,302
96756200	8	WHEELER	DEVONIAN	TX	WINKLER	1945	8590	15,734	10,348,368
99275250	8	YARBROUGH & ALLEN	DEVONIAN	TX	ECTOR	1954	8505	45,369	3,569,192
		DOLLARHIDE	DEVONIAN	NM	LEA	1952	8167	69725	9,179,120
	Totals							**6,786,521**	**785,929,988**

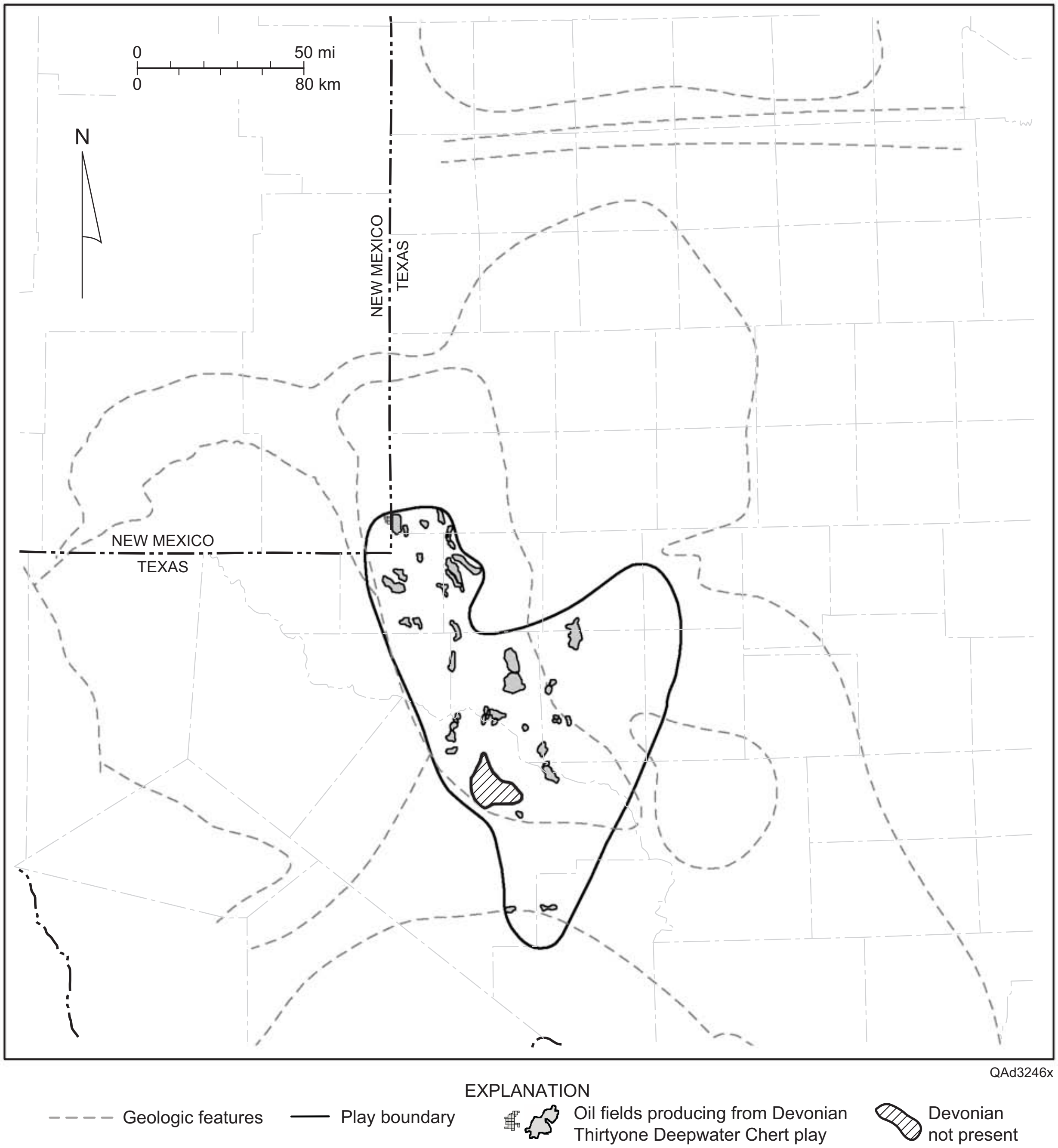

Figure 22. Play map for the Devonian Thirtyone Deepwater Chert play, showing location of reservoirs having >1 MMbbl cumulative production, the play boundary, and geologic features. See figure 1 for county names and figure 2 for identification of geologic features.

thickest (Ruppel and Holtz, 1994). The Devonian is missing on the Fort Stockton high in northern Pecos County (Ewing, 1990), so the play is not present in this area (fig. 22). Traps are anticlinal structures, or they were formed by erosional truncation (Tyler and others, 1991). The largest fields are associated with structural uplifts bounded by basement reverse faults that formed during the Pennsylvanian (Montgomery, 1998).

Thick-bedded laminated chert, commonly called “tripolitic chert,” is the most important reservoir facies in the Thirtyone Formation (Ruppel and Holtz, 1994). The chert is highly porous and contains varying amounts of carbonate. Burrowed chert facies have more variable porosity but are productive in some reservoirs (Saller and others, 2001). Thirtyone Formation chert strata accumulated in deepwater slope and basin settings by submarine gravity flow and hemipelagic sedimentation (Ruppel and Holtz, 1994).

Geologic interpretation of the Devonian Thirtyone Chert in West Texas was summarized in Saller and others (1991), Ruppel and Holtz (1994), Ruppel and Hovorka (1995a, b), Ruppel and Barnaby (2001), and Saller and others (2001). Reservoirs in the north part of the play (for example, Dollarhide and Three Bar in Andrews County) are developed in a continuous, porous, spiculitic chert interval at the base of the Thirtyone Formation (Ruppel and Barnaby, 2001) (figs. 23, 24). Chert in this setting was deposited on a gently sloping outer platform during regional transgression. Heterogeneity in these reservoirs is caused mainly by faulting, fracturing, and dissolution of carbonate along unconformities (Ruppel and Barnaby, 2001). Reservoirs in the south part of the play (for example, University Waddell and Block 31 in Crane County) produce from basin-center, submarine-fan cherts that exhibit more complex geometries and considerably more lateral and vertical heterogeneity than is observed to the north (Barnaby and others, 1998). Reservoirs are composed of thin, vertically stacked,

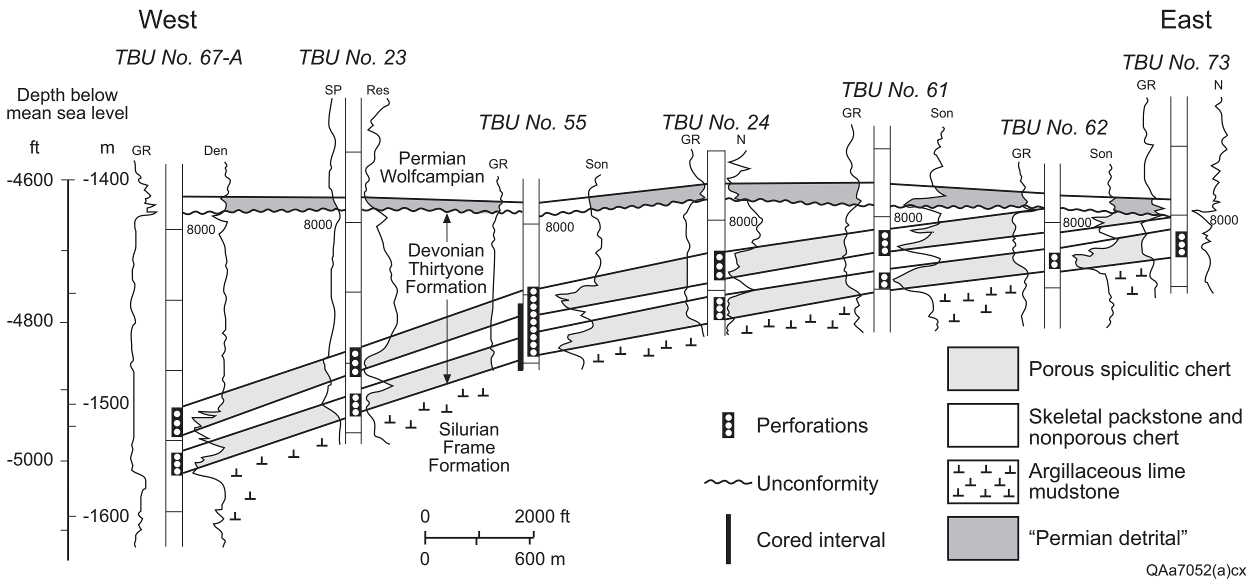

Figure 23. West-east cross section in Three Bar field, Andrews County, Texas. Cross section is perpendicular to the structural axis of the field and shows updip truncation of the reservoir pay zone beneath the sub-Permian unconformity. From Ruppel and Hovorka (1995); see that publication for location of cross section.

and laterally discontinuous cherts deposited as debris flows and turbidites (Ruppel and Barnaby, 2001).

Most of the porosity in the Thirtyone chert is moldic and intercrystalline (Tyler and others, 1991). Moldic pores formed by leaching of sponge spicules and carbonate allochems. Intercrystalline pores developed within the chert matrix. Micropores, which are <5 µm in diameter, make up at least 50 percent of the total porosity (Saller and others, 1991; Ruppel and Barnaby, 2001). Porosity and permeability generally decrease with increased carbonate content. Fractures in the brittle chert matrix are locally important in some reservoirs, such as Three Bar (Ruppel and Holtz, 1994).

In the area of this play, erosion during the Pennsylvanian removed Mississippian and earlier Pennsylvanian strata (Kosters and others, 1989); in most fields, Devonian reservoir

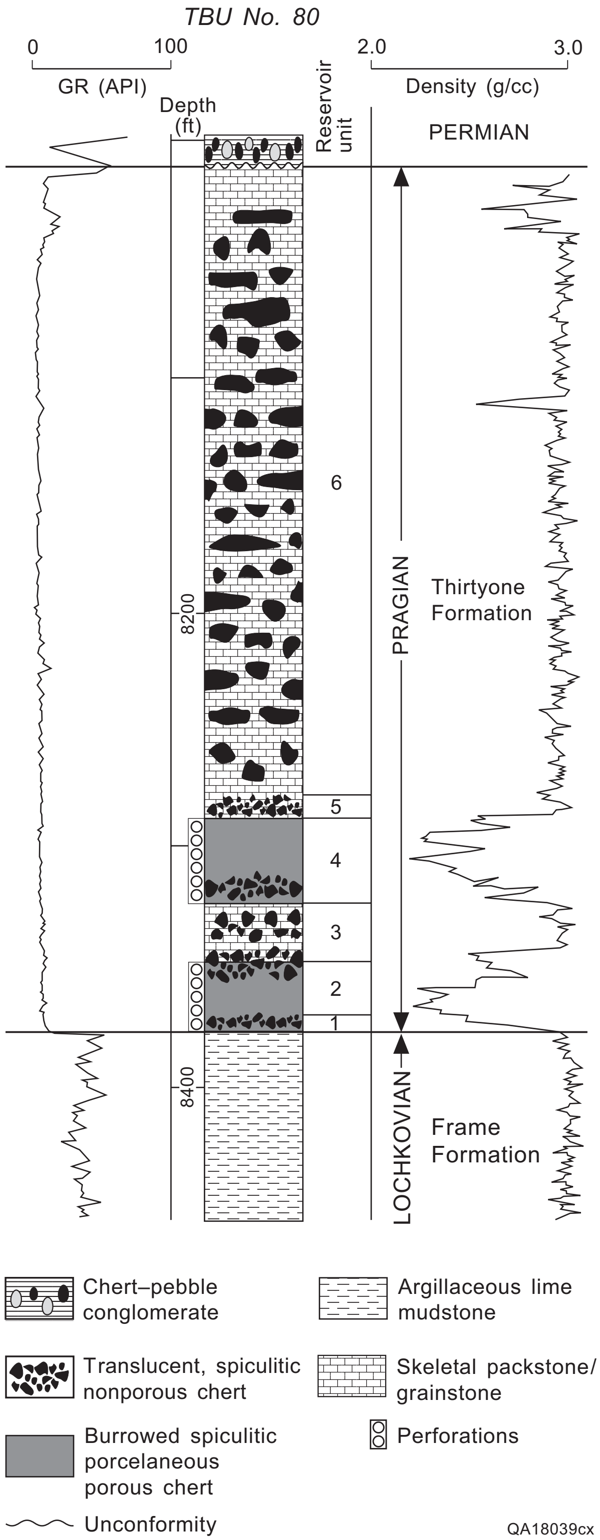

Figure 24. Typical stratigraphic succession and wireline-log signature of Thirtyone Formation in the Amoco 80 Three Bar Unit well, Three Bar field, Andrews County, Texas. From Ruppel and Hovorka (1995).

intervals are directly overlain by Permian strata. In some areas a zone of eroded and reworked chert conglomerate rests above the Devonian Thirtyone chert (fig. 23). This “Permian Detrital” zone is productive in Crossett, S. (Detrital), field (Richards, 1982). Although the reservoir zone is not in situ Devonian Thirtyone Chert, the Crossett, S. (Detrital), reservoir has been included in the Devonian Thirtyone Chert play.

Ruppel and Holtz (1994) estimated that approximately 700 MMbbl (1.11×10^8 m^3) of mobile oil remains in reservoirs of this play. Reservoirs in the Thirtyone Chert play have been the subject of a variety of enhanced-recovery techniques. North Cross Unit of Crossett Devonian field and South Cross Unit of Crossett South Devonian fields have undergone CO_2 floods (L. S. Melzer, personal communication, 2003). Dollarhide (Devonian), which had an estimated 146 MMbbl (2.32×10^7 m^3) of original oil in place (OOIP), has undergone secondary waterflooding and tertiary infill drilling and CO_2 injection (Saller and others, 1991, 2001). Different areas of the field have responded differently to various phases of recovery, but the overall field recovery was 13 percent of OOIP by primary recovery, 30 percent by the waterflood, 3.5 percent by infill drilling, and 11 percent by the CO_2 flood (Saller and others, 2001). Compartmentalization caused by faulting and facies changes had a minor effect during primary recovery but a more major influence on secondary and tertiary recovery (Saller and others, 2001). Infill drilling was most effective in areas having thicker zones of the heterogeneous burrowed chert facies and near the edges of reservoir compartments (Saller and others, 2001). Response to the CO_2 flood was better in areas having thicker zones of the homogeneous laminated, microporous chert facies (Saller and others, 2001).

Recovery at Three Bar (Devonian) field was 27 percent of OOIP during primary and secondary recovery. The lower recovery compared with that of Dollarhide is probably caused by greater reservoir heterogeneity and structural complexity at Three Bar (Ruppel and Hovorka, 1995a, b; Montgomery, 1998).

Block 31 (Devonian) is the largest reservoir in the play, having produced >223 MMbbl (3.55×10^7 m^3) through 2000. Ultimate recovery from this reservoir is estimated to be as high as 60 percent (Galloway and others, 1983). Good recovery probably results from the presence of thick intervals of the porous, thick-bedded, laminated chert facies (Ruppel and Holtz, 1994); early pressure maintenance; and infill drilling. The first miscible gas-injection, enhanced-oil-recovery project was initiated in the Block 31 Devonian reservoir in 1952 (Galloway and others, 1983; Ebanks, 1988). The high-pressure, lean-gas injection and infill-drilling programs carried out in this reservoir both increased recoverable reserves (Galloway and others, 1983).

Porosity in the Thirtyone chert reservoirs, which is highly variable because of variations in chert:carbonate ratio, ranges from 2 to 30 percent and averages 15 percent (Ruppel and Holtz, 1994). Matrix permeability is also variable but averages about 23 md (23×10^{-3} μm^2). Fracture permeability is critical in many of the reservoirs. Reservoir net pay in the play ranges from 15 to 170 ft (5 to 50 m) and averages 61 ft (19 m).

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Devonian Thirtyone Ramp Carbonate (Play 107)

The Devonian Thirtyone Ramp Carbonate is the smaller of the two plays that produce from the Thirtyone Formation (Ruppel and Holtz, 1994). The Thirtyone Ramp Carbonate play consists of 17 reservoirs that have produced >1 MMbbl (1.59×10^5 m^3) of oil through 2000; cumulative production from the play is 110.2 MMbbl (1.75×10^7 m^3) (table 10). Reservoirs in the play occur in the north part of the Thirtyone Formation area, in Andrews, Ector, and Midland Counties (fig. 25). Traps are simple and faulted anticlines (Galloway and others, 1983).

Carbonates of the Thirtyone Formation were deposited on a shallow-water carbonate platform that prograded basinward (south) during sea-level highstand (Ruppel and Holtz, 1994). The reservoirs in this play are made up of skeletal packstones and grainstones composed primarily of pelmatozoan debris (fig. 26). At the north end of the trend, the packstones were deposited in sand shoals and bars in a shallow-water setting. Farther south, the packstones appear to have been deposited by downslope gravity-flow processes in an outer-ramp to slope setting

Table 10. Devonian Thirtyone Ramp Carbonate play (play 107). 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
2727250	8	ANDREWS, N.	DEVONIAN	TX	ANDREWS	1960	10424	84,434	7,844,331
2730284	8	ANDREWS, SOUTH	DEVONIAN	TX	ANDREWS	1953	11075	5,759	10,316,428
4605222	8	AZALEA	DEVONIAN	TX	MIDLAND	1957	11520	35,158	1,714,524
5166333	8	BAKKE	DEVONIAN	TX	ANDREWS	1956	10500	59,408	17,106,630
9202166	8	BLOCK 9	DEVONIAN	TX	ANDREWS	1960	12540	3,612	1,540,950
12763333	8	BRYANT -G-	DEVONIAN	TX	MIDLAND	1979	12002	563,813	1,643,736
23907142	8	DEEP ROCK	DEVONIAN	TX	ANDREWS	1963	10063	18,460	1,713,689
25395166	8	DORA ROBERTS	DEVONIAN	TX	MIDLAND	1955	12010	16,055	2,528,808
28843111	8	EMBAR	DEVONIAN	TX	ANDREWS	1954	9346	10,846	1,335,402
28899166	8	EMMA	DEVONIAN	TX	ANDREWS	1954	10192	6,778	5,753,019
33176284	8	FUHRMAN-MASCHO	DEVONIAN	TX	ANDREWS	1956	10000	12,649	1,835,504
35652310	8	GOLDSMITH	FIGURE 5 DEVONIAN	TX	ECTOR	1956	7760	0	1,358,571
39176332	8	HARPER	DEVONIAN	TX	ECTOR	1962	10005	87,721	10,515,508
39969400	8	HEADLEE	DEVONIAN	TX	ECTOR	1953	11756	0	14,167,925
39971500	8	HEADLEE, N.	DEVONIAN	TX	ECTOR	1956	12210	49,323	6,195,590
91350100	8	TRIPLE-N	DEVONIAN	TX	ANDREWS	1957	10600	3,706	1,072,723
92534250	8	UNIVERSITY BLOCK 9	DEVONIAN	TX	ANDREWS	1954	10450	789,597	23,606,166
		Totals						**1,747,319**	**110,249,504**

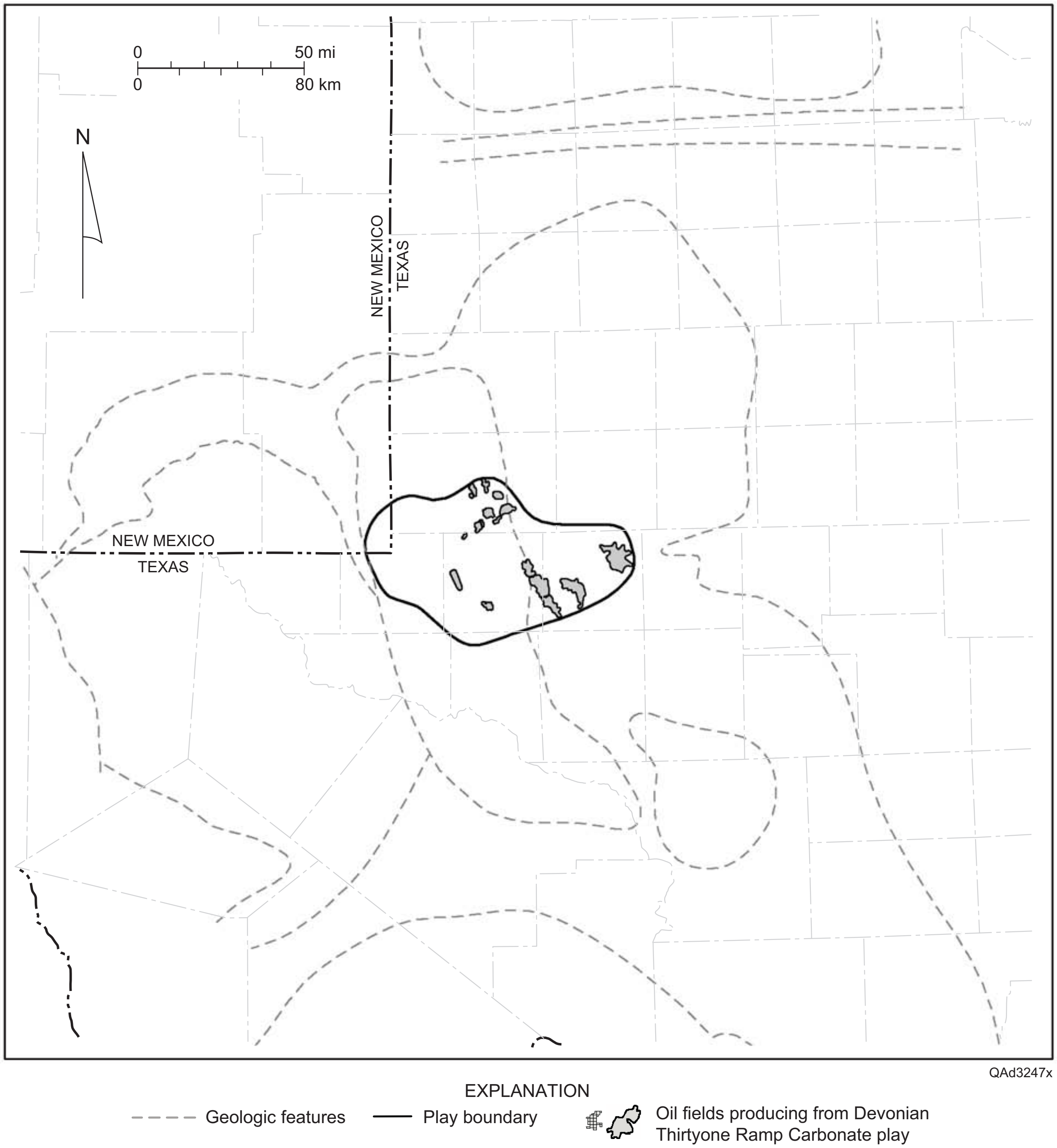

Figure 25. Play map for the Devonian Thirtyone Ramp Carbonate play, showing location of reservoirs having >1 MMbbl cumulative production, the play boundary, and geologic features. See figure 1 for county names and figure 2 for identification of geologic features.

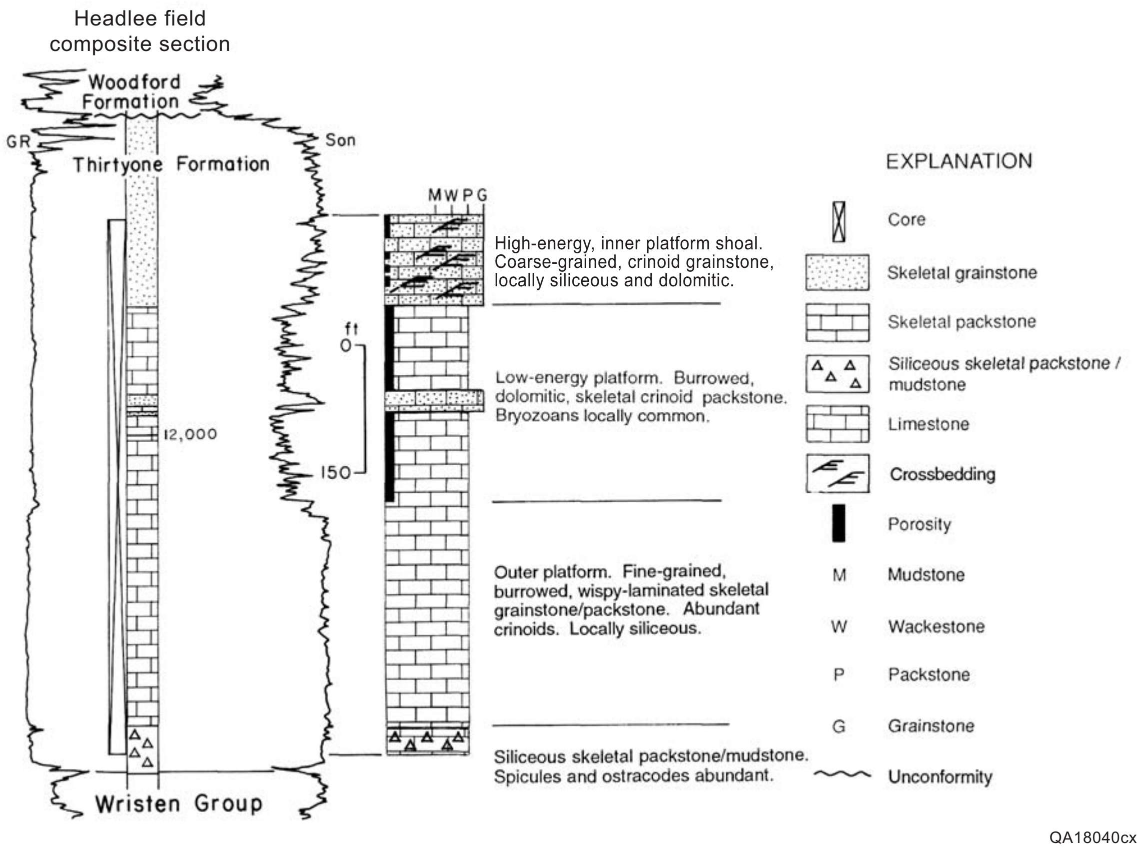

Figure 26. Stratigraphic section of the Thirtyone Formation in Headlee (Devonian) field, Ector County, Texas. From Ruppel and Holtz (1994). The Thirtyone Formation in this field is almost entirely carbonate, composed of an upward-shallowing succession.

(Tyler and others, 1991; Ruppel and Holtz, 1994). The Thirtyone carbonates are mostly limestone, but there are local areas of dolostone. The Thirtyone Formation in the Bryant -G- (Devonian) reservoir in Midland County, Texas, includes silicified skeletal packstones and grainstones (Wind, 1998).

Porosity developed generally as a result of leaching of carbonate mud in skeletal packstones, producing intergranular pore space (Ruppel and Holtz, 1994). Intercrystalline porosity is associated with dolomitization in some fields, such as Bakke, University Block 9, and South Andrews, and with development of karst horizons in Three Bar field (Ruppel and Holtz, 1994; Weiner and Heyer, 1999). In University Block 9 field, the best porosity was preserved in shelf packstones and wackestones because mud inhibited precipitation of pore-filling cement (Weiner and Heyer, 1999, 2000). Average porosity is 6 percent, but in some reservoirs more extensive leaching associated with dolomitization has produced intercrystalline pores and small vugs associated with higher porosity values.

Horizontal drilling increased production from the Thirtyone carbonate reservoir in University Block 9 field in Andrews County by >2,000 bbl/day (31.8 m^3/d) (Weiner and Heyer, 2000). Image logs, cores, and 3-D seismic data were used to identify reservoir compartments formed by faults. These data indicated that structure of the field is more complicated than was initially interpreted. In 1967 the field was mapped as an unfaulted dome (Galloway and others, 1983). More recently, modern 3-D seismic data were interpreted as indicating an arcuate, field-defining fault having reverse and strike-slip components and several antithetic normal and reverse faults (Weiner and Heyer, 1999). Horizontal reentries ranging from 1,000 to 1,700 ft (305 to 518 m) long were drilled to reach untapped compartments in the field. Some of the lateral reentries drilled out of old, depleted wells were recompleted in new compartments and produced >150 bbl/day (23.8 m^3/d).

Horizontal drilling—both reentry laterals and multilateral, newly drilled wells—also increased production of both gas and oil from the Bryant –G– (Devonian) reservoir (Burkett, 2002; Rowan and others, 2002). Laterals in the Bryant –G– (Devonian) ranged from 1,270 to 5,440 ft (387 to 1,658 m) long. The open-hole laterals were stimulated with acid conveyed by tubing (Rowan and others, 2002).

North Cross unit in Crossett Devonian field and South Cross unit in Crossett South Devonian field are undergoing CO_2 floods (L. S. Melzer, personal communication, 2003). The

CO_2 flood at North Cross unit was initiated as a secondary flood in 1972; production response was observed after 1 year, and fieldwide oil-production response occurred after 2 years (Kinder Morgan, 2004). Through 1994, the CO_2 flood had recovered 24 percent of OOIP, and residual oil saturation was reduced to 3 percent in the area swept by CO_2.

Reservoir net pay in the play ranges from 14 to 310 ft (4 to 94 m) and averages 80 ft (24 m). Porosity ranges from 3.5 to 9.5 and averages 6.4 percent; permeability ranges from 0.4 to 30 md (30×10^{-3} μm^2) and averages 1.5 md (1.5×10^{-3} μm^2) (Ruppel and Holtz, 1994).

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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**

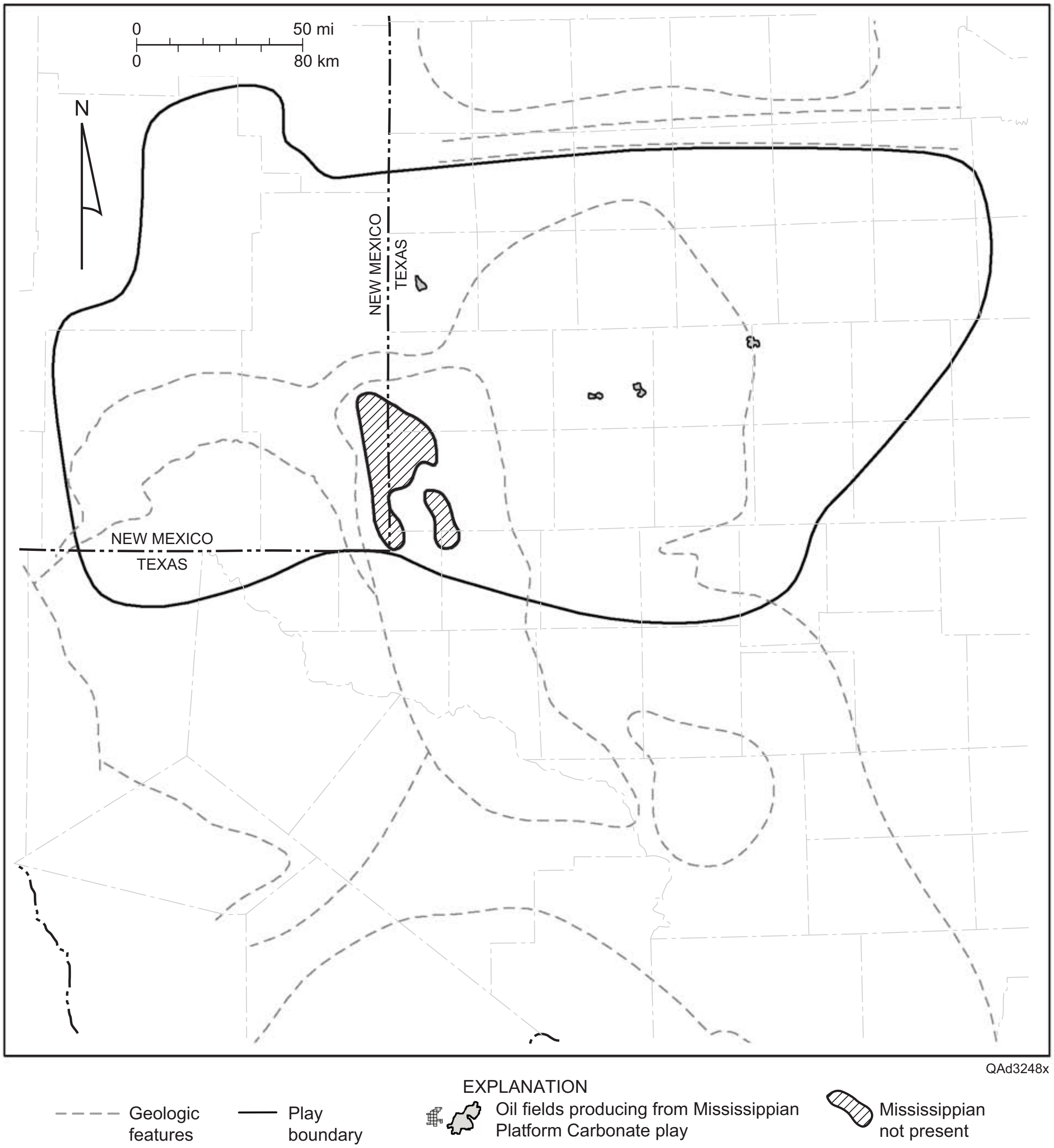

Figure 27. Play map for the Mississippian Platform Carbonate play, showing location of reservoirs having >1 MMbbl cumulative production, the play boundary, and geologic features. See figure 1 for county names and figure 2 for identification of geologic features.

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

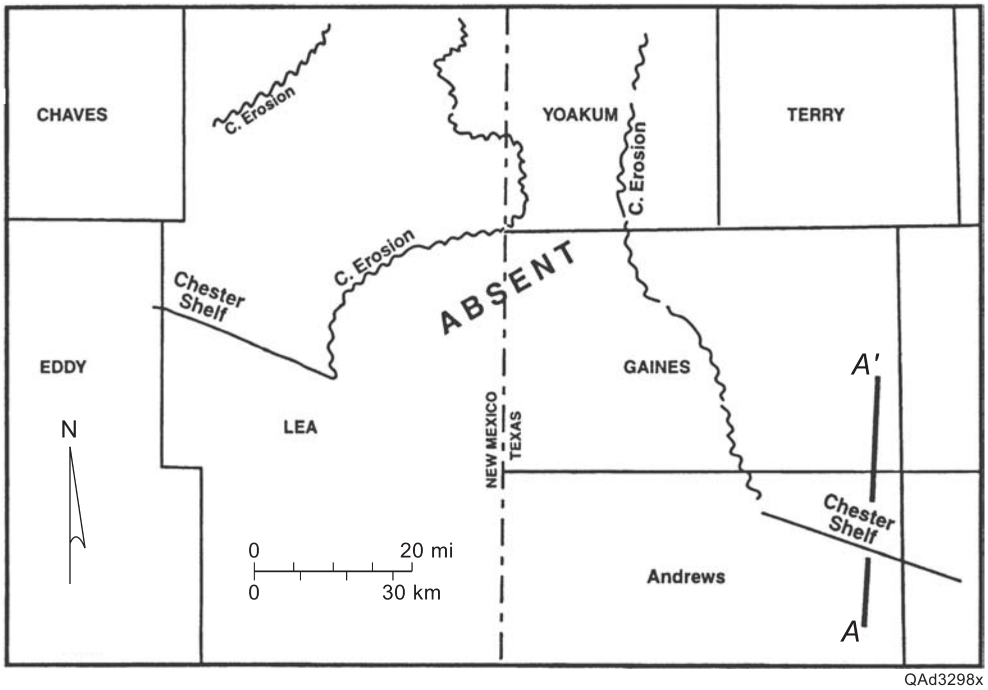

Figure 28. Map showing location of Chester limestone subcrop. From Hamilton and Asquith (2000). Upper Mississippian carbonates were deposited on the Chester platform while the Barnett Shale was deposited in the basin to the south. Cross section A-A´ shown in figure 29.

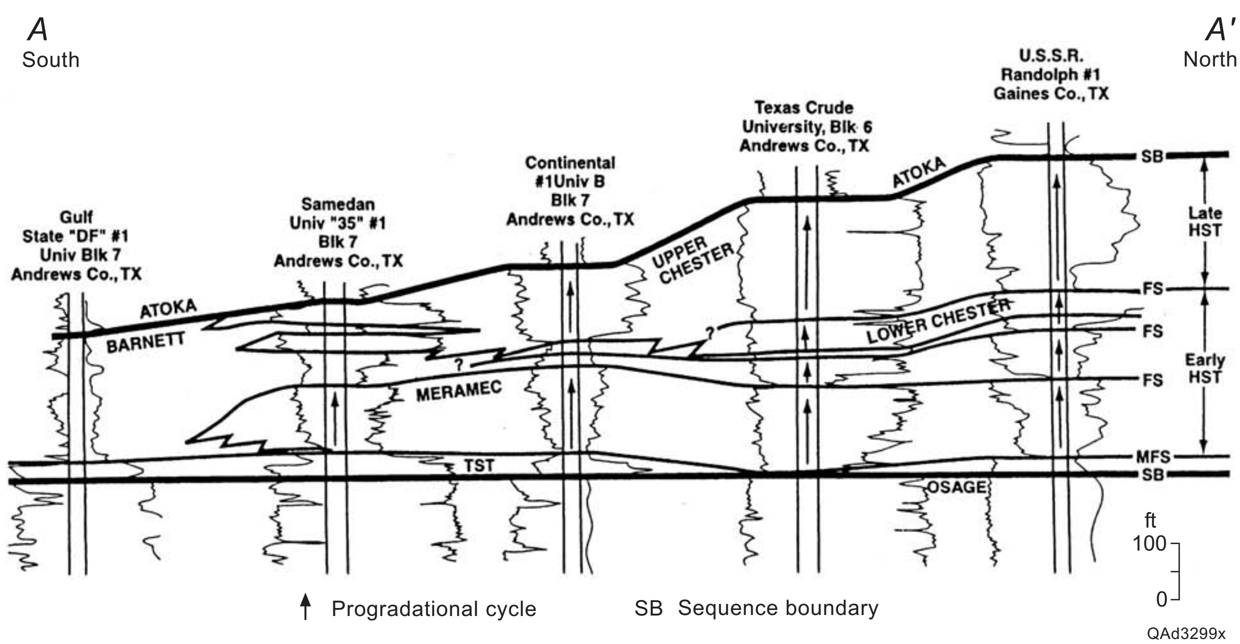

Figure 29. South-north cross section A-A´ of the upper Mississippian Meramec and Chester limestones. From Hamilton and Asquith (2000). Line of section shown in figure 28.

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 (5×10^{-3} μm^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 181×10^{-3} μm^2) and averages 40 md (40×10^{-3} μm^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**

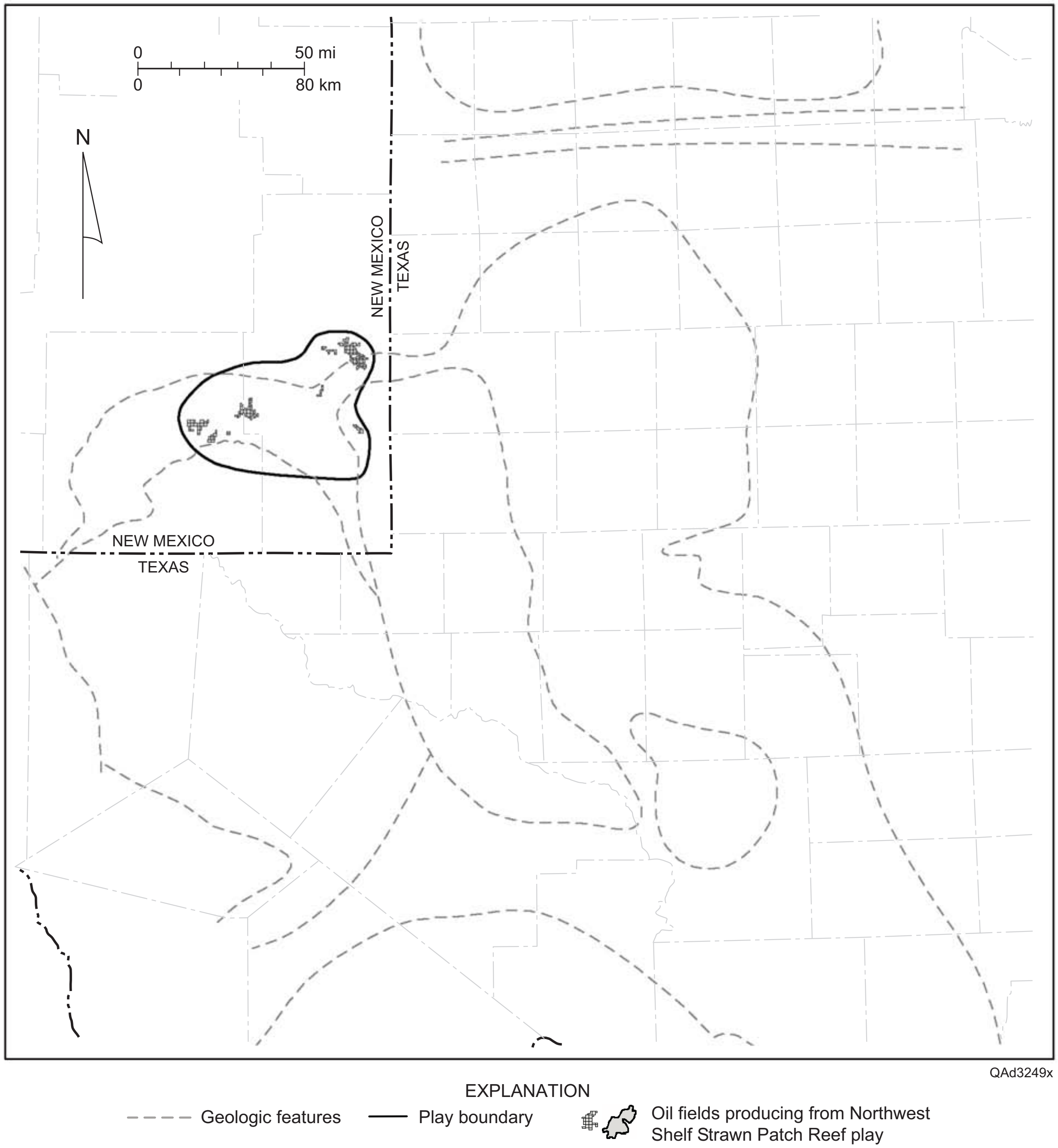

Figure 30. Play map for the Northwest Shelf Strawn Patch Reef play, showing location of reservoirs having >1 MMbbl cumulative production, the play boundary, and geologic features. See figure 1 for county names and figure 2 for identification of geologic features.

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).

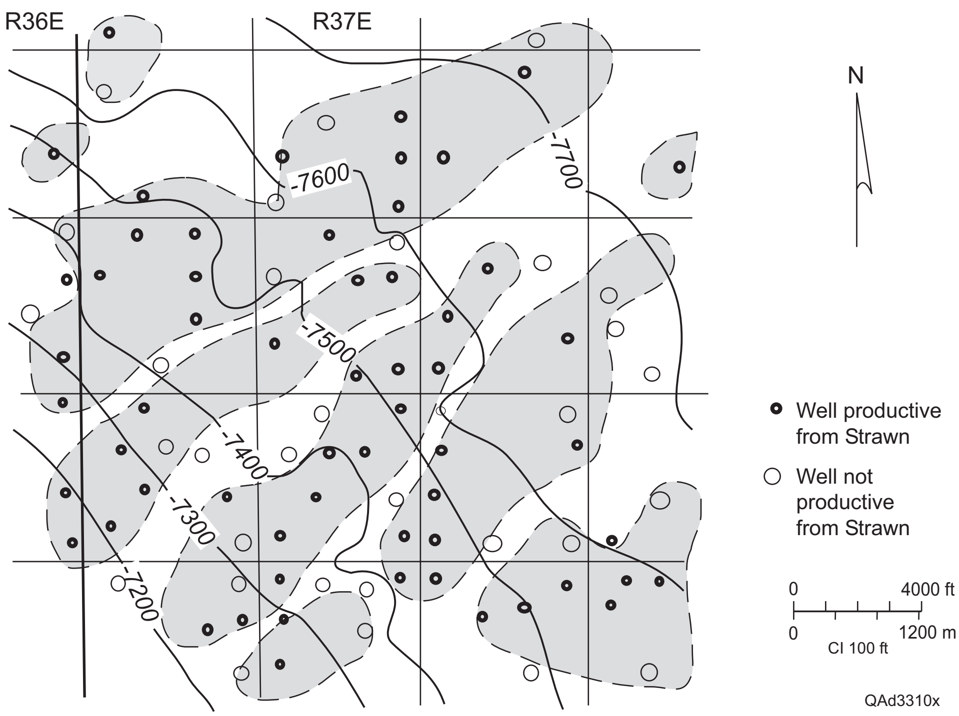

Figure 31. Map of Strawn structure and porosity at the Lovington Northeast reservoir. Shown is structure of the Strawn limestone. Contour interval is 50 ft. Shaded areas are where the Strawn has porosity ≥4 percent. Modified by Speer (1993) from Caughey (1988).

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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**

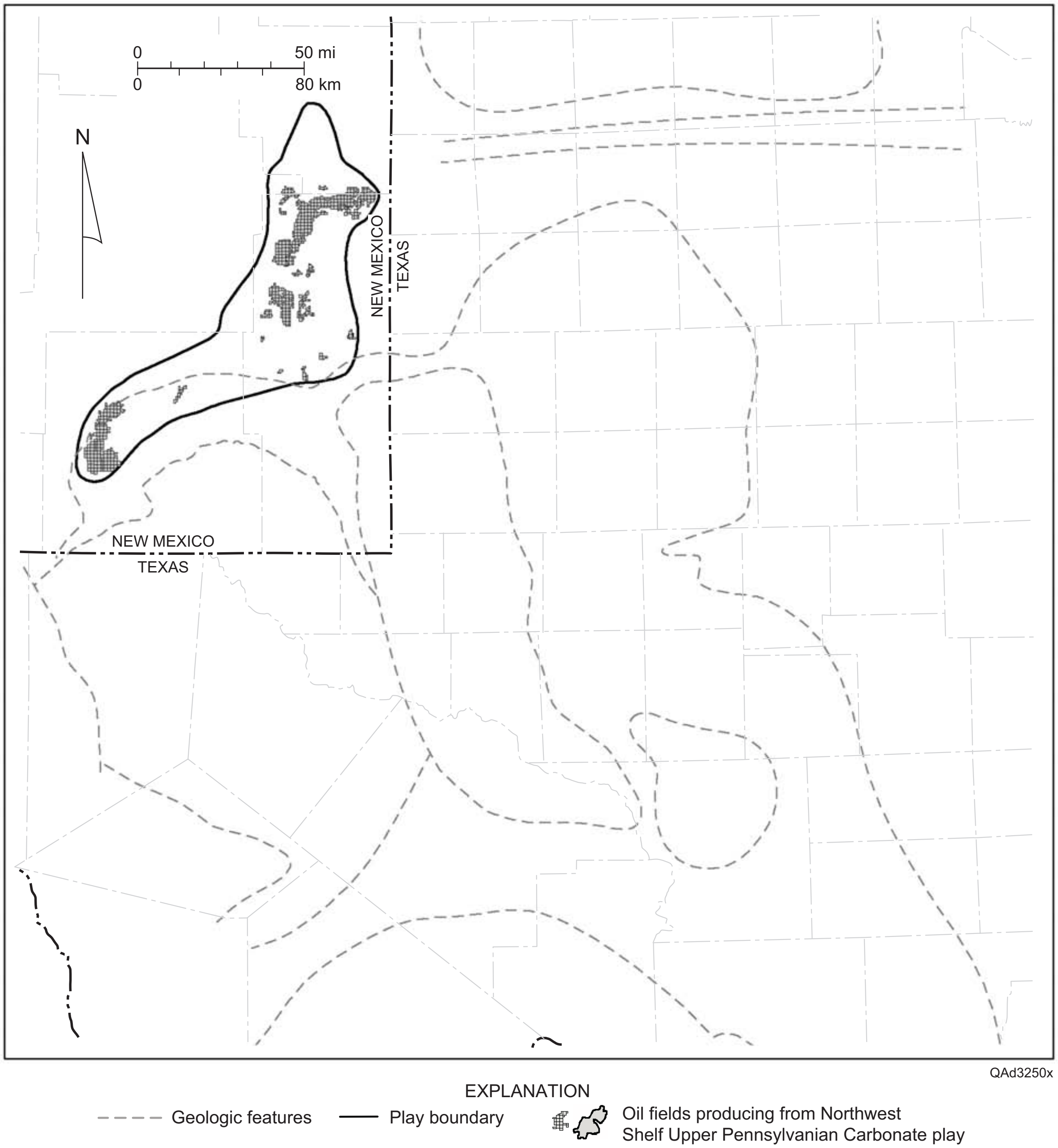

Figure 32. Play map for the Northwest Shelf Upper Pennsylvanian Carbonate play, showing location of reservoirs having >1 MMbbl cumulative production, the play boundary, and geologic features. See figure 1 for county names and figure 2 for identification of geologic features.

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

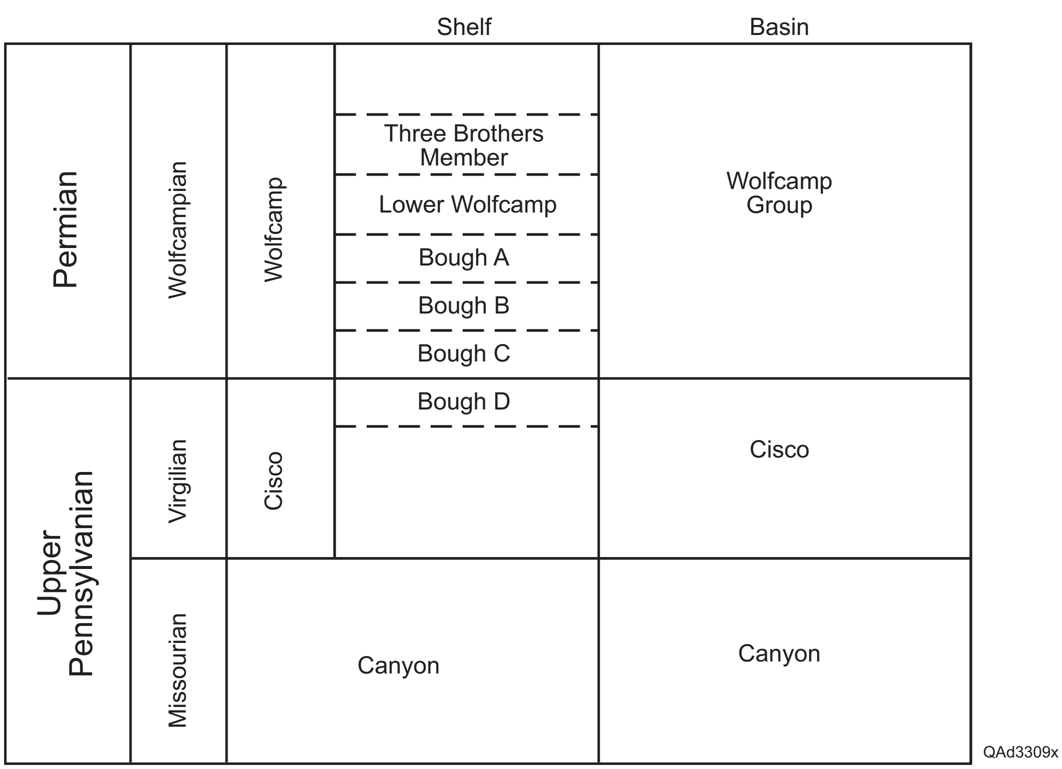

Figure 33. Stratigraphic column of Upper Pennsylvanian and Lower Permian strata, southeast New Mexico.

(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

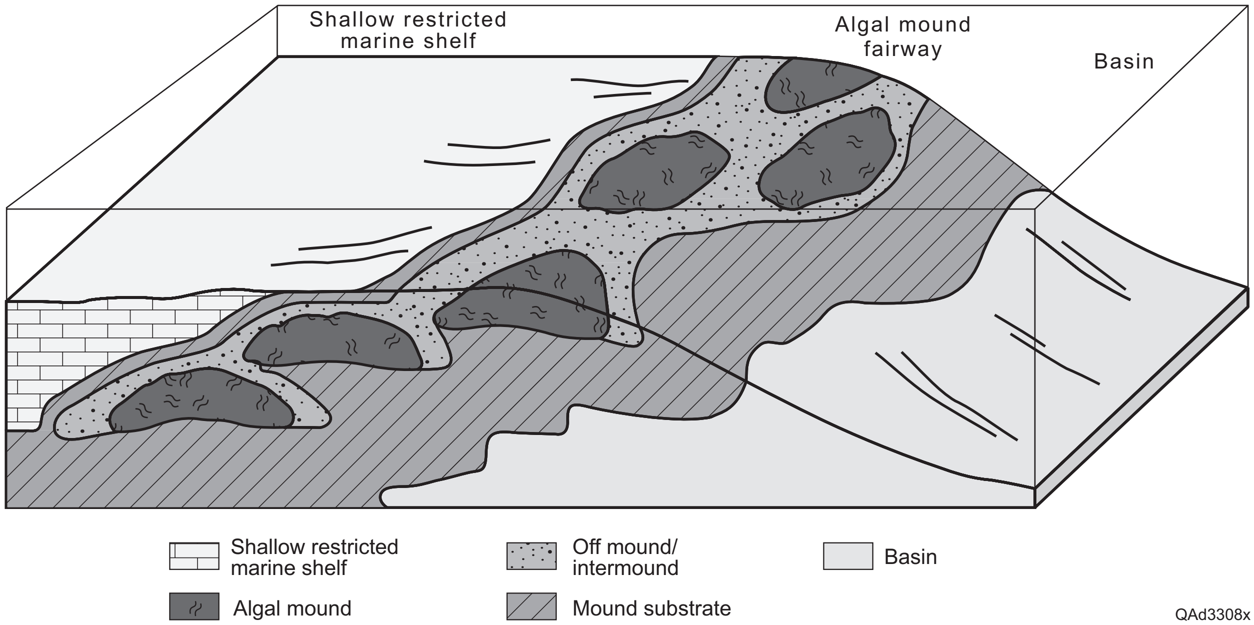

Figure 34. Depositional model for Upper Pennsylvanian algal-mound complex, South Dagger Draw reservoir. After Cox and others (1998).

(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

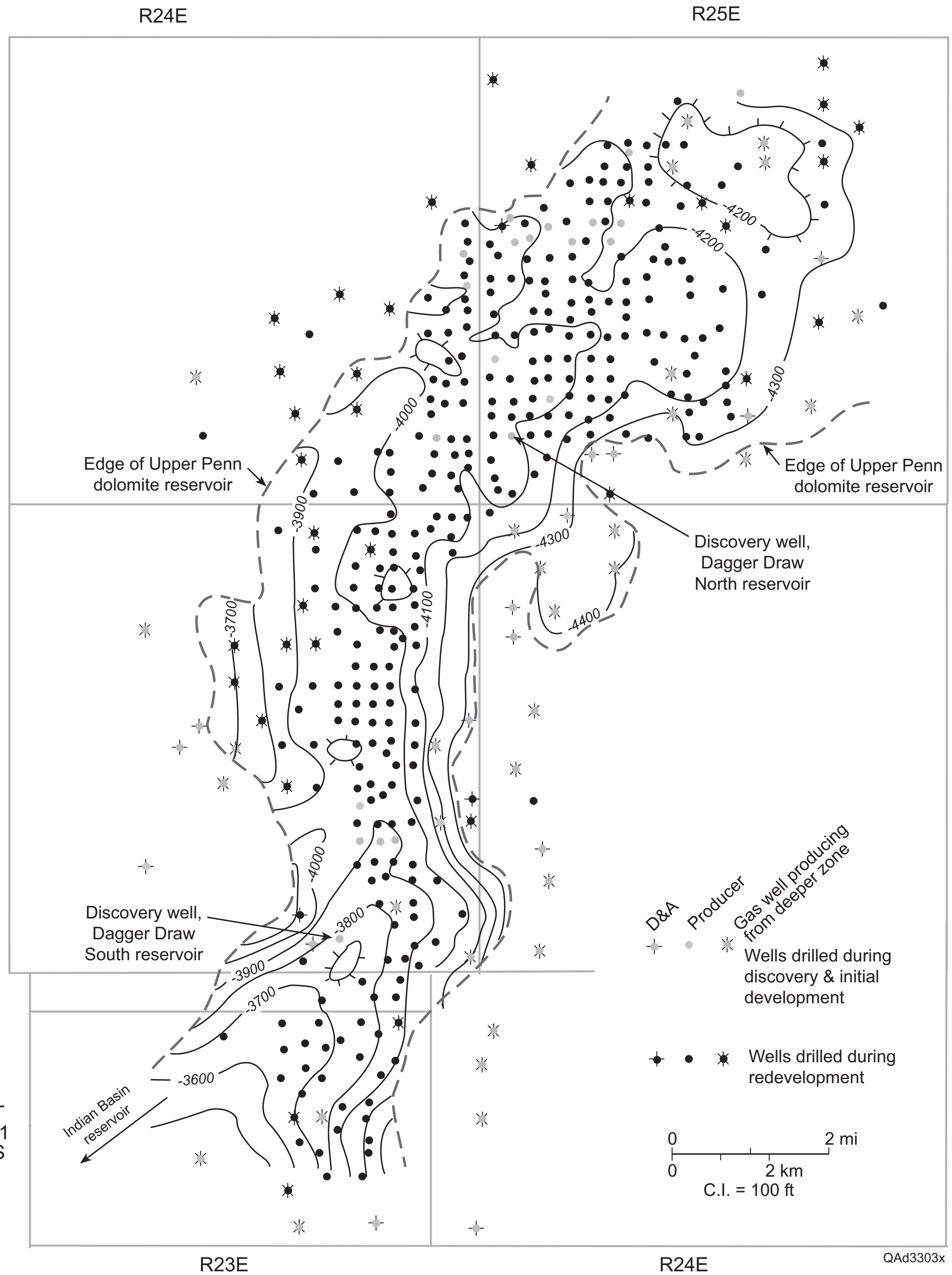

Figure 35. Structure-contour map on top of Upper Pennsylvanian dolostone reservoir and South Dagger Draw and North Dagger Draw reservoirs and time periods during which wells were drilled. After Broadhead (1999). Contours from Reddy (1995).

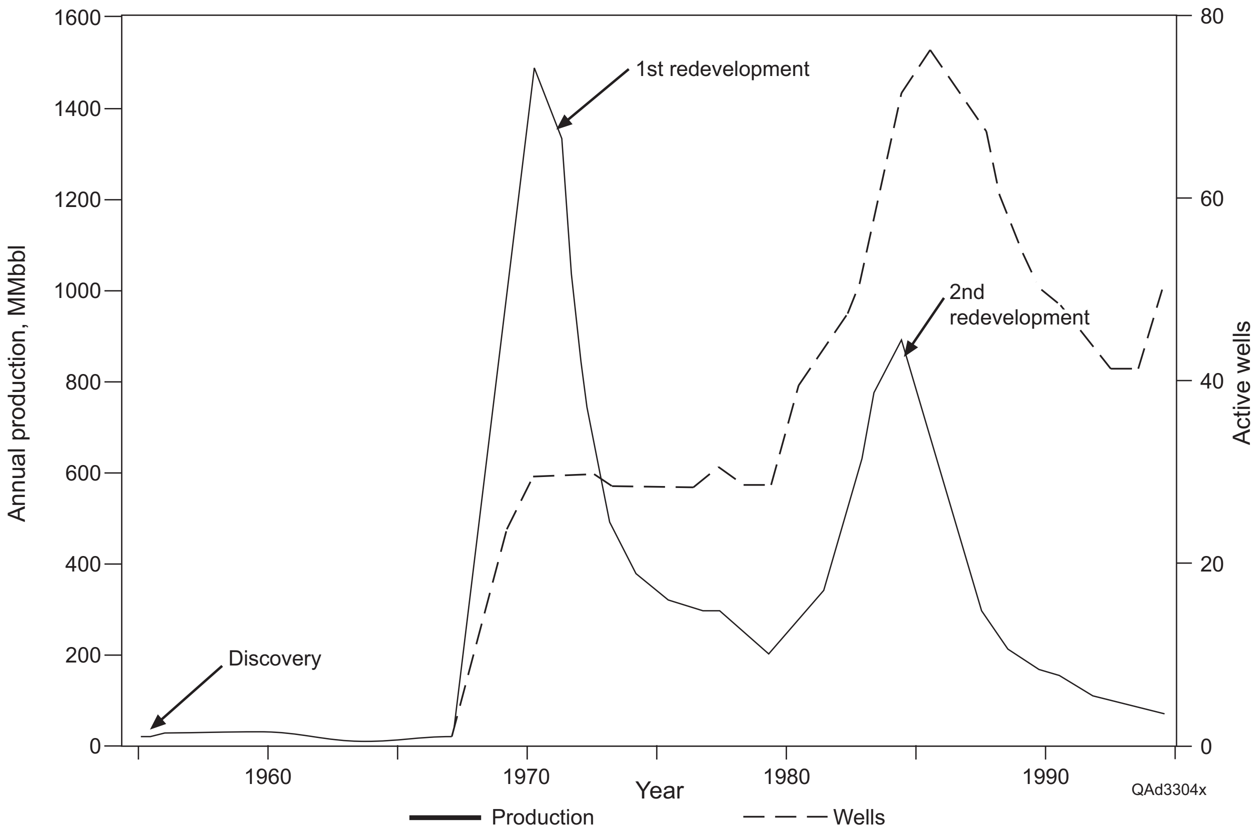

Figure 36. Historical annual oil production and number of productive wells active in any given year, Baum Upper Pennsylvanian reservoir. After Broadhead (1999).

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).

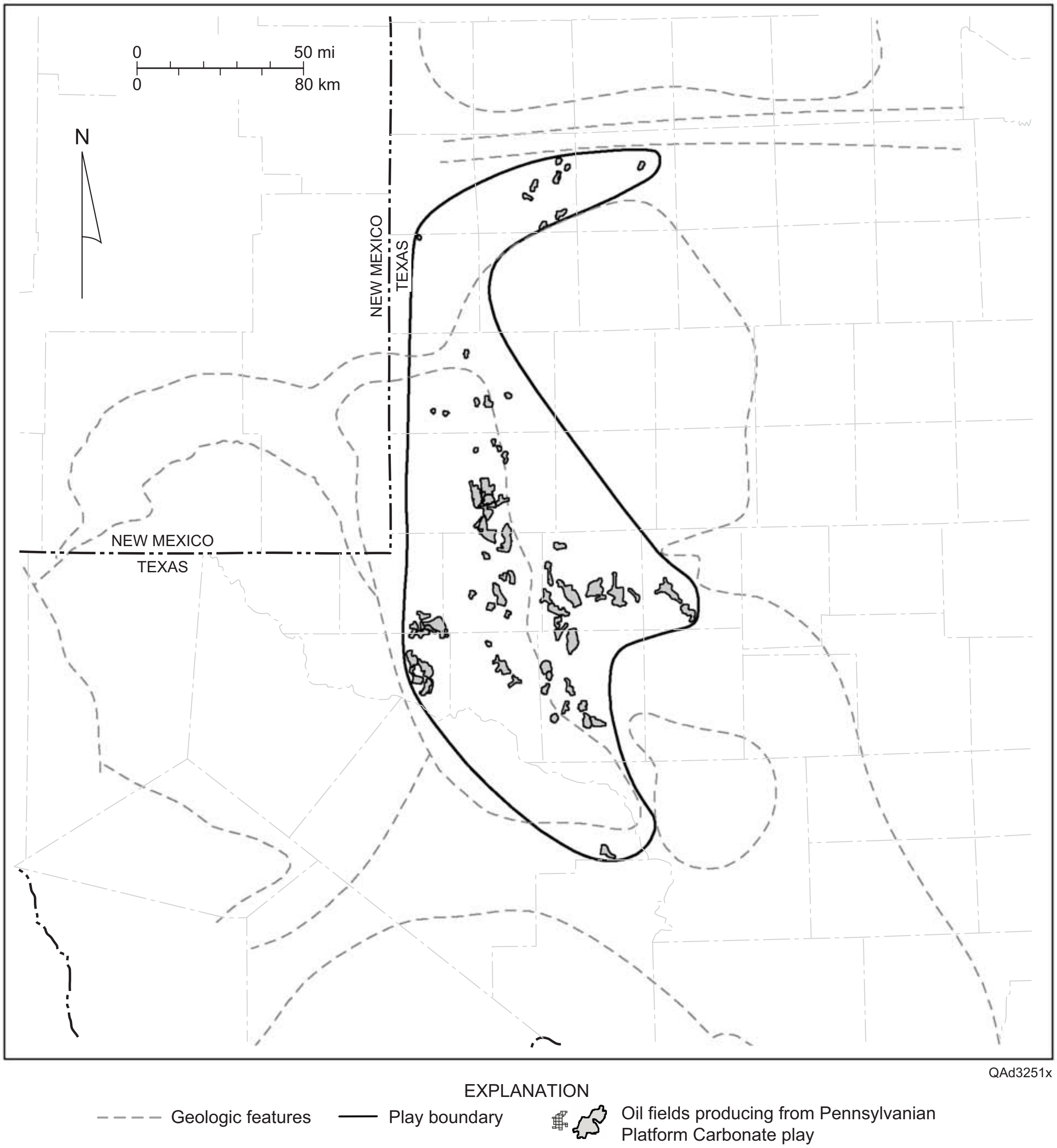

Figure 37. Play map for the Pennsylvanian Platform Carbonate play, showing location of reservoirs having >1 MMbbl cumulative production, the play boundary, and geologic features. See figure 1 for county names and figure 2 for identification of geologic features.

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	8587	100,645	22,978,851
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	1969	7907	22,107	4,489,708
9450200	7C	BLOCK 42	PENN	TX	UPTON	1956	9450	19,971	2,559,545
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	1983	10055	18,543	1,115,433
25395100	8	DORA ROBERTS	CONSOLIDATED	TX	MIDLAND	1995	10341	34,294	2,371,206
25585500	8A	DOSS	CANYON	TX	GAINES	1949	8850	0	1,712,794
28899747	8	EMMA	STRAWN	TX	ANDREWS	1958	9123	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	8088	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
93958100	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 (0.1×10^{-3} μm^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

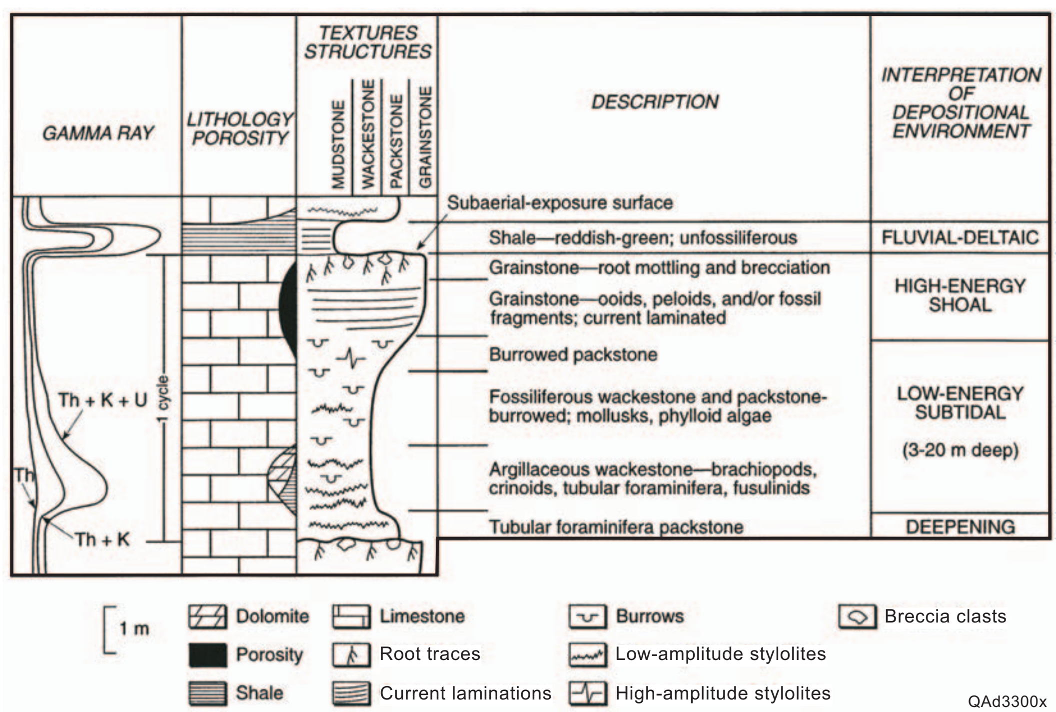

Figure 38. Idealized upward-shallowing cycle in Upper Pennsylvanian carbonates in the Southwest Andrews area. From Saller and others (1999b).

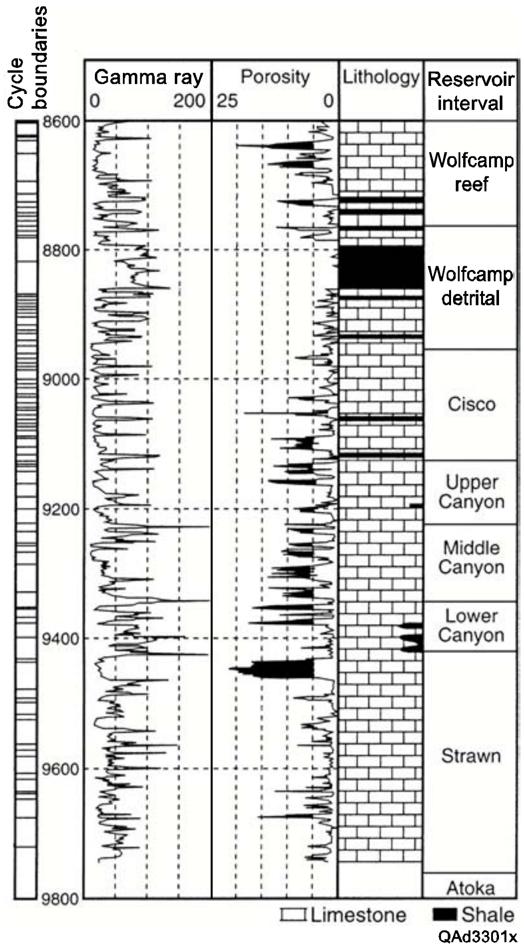

Figure 39. Core description and gamma-ray log through the producing interval in the X-1 well, Andrews field, Southwest Andrews area, Andrews County. After Saller and others (1999a), reprinted by permission of the AAPG, whose permission is required for further use. ©Copyright 1999. The American Association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

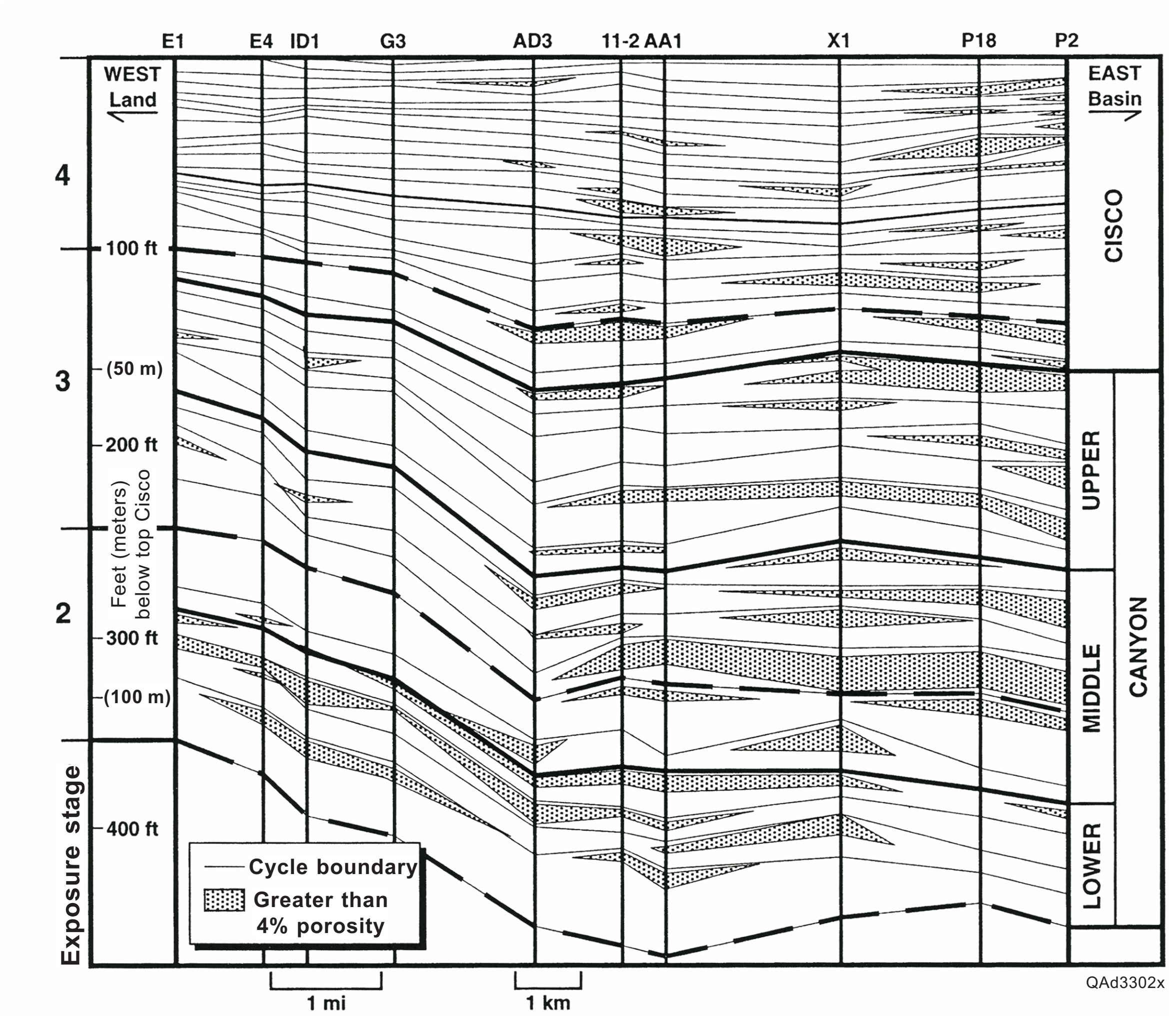

Figure 40. Stratigraphic cross section showing distribution of porous limestone in the Canyon and Cisco intervals in Deep Rock and Parker fields, southwest Andrews County. After Saller and others (1999a), reprinted by permission of the AAPG, whose permission is required for further use. ©Copyright 1999. 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 (66×10^{-3} μm^2) and ranges from 0.1 to 1,100 md (0.1 to $1{,}100 \times 10^{-3}$ μm^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	32,125	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	1,062,852
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**

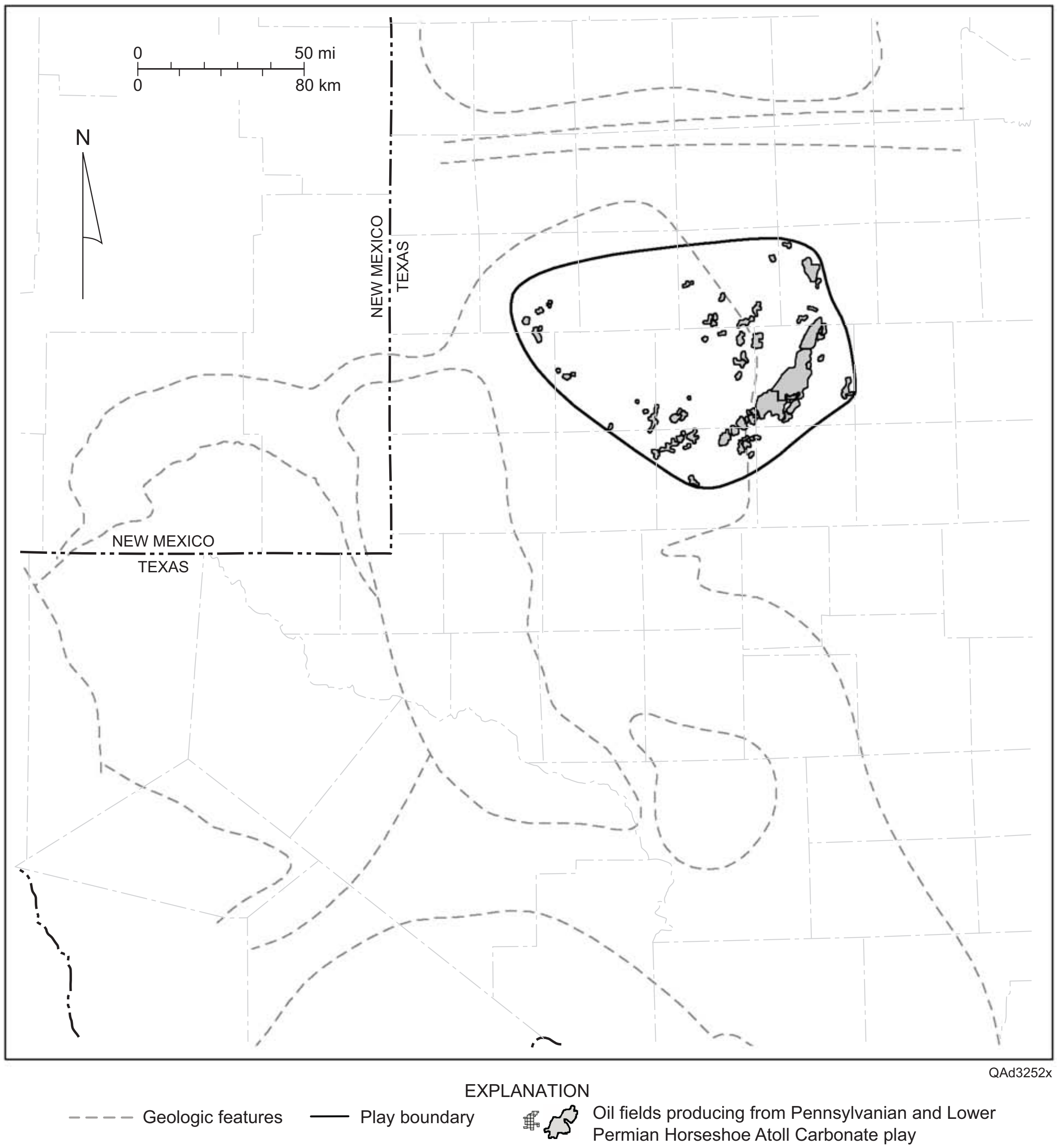

Figure 41. Play map for the Pennsylvanian and Lower Permian Horseshoe Atoll Carbonate play, showing location of reservoirs having >1 MMbbl cumulative production, the play boundary, and geologic features. See figure 1 for county names and figure 2 for identification of geologic features.

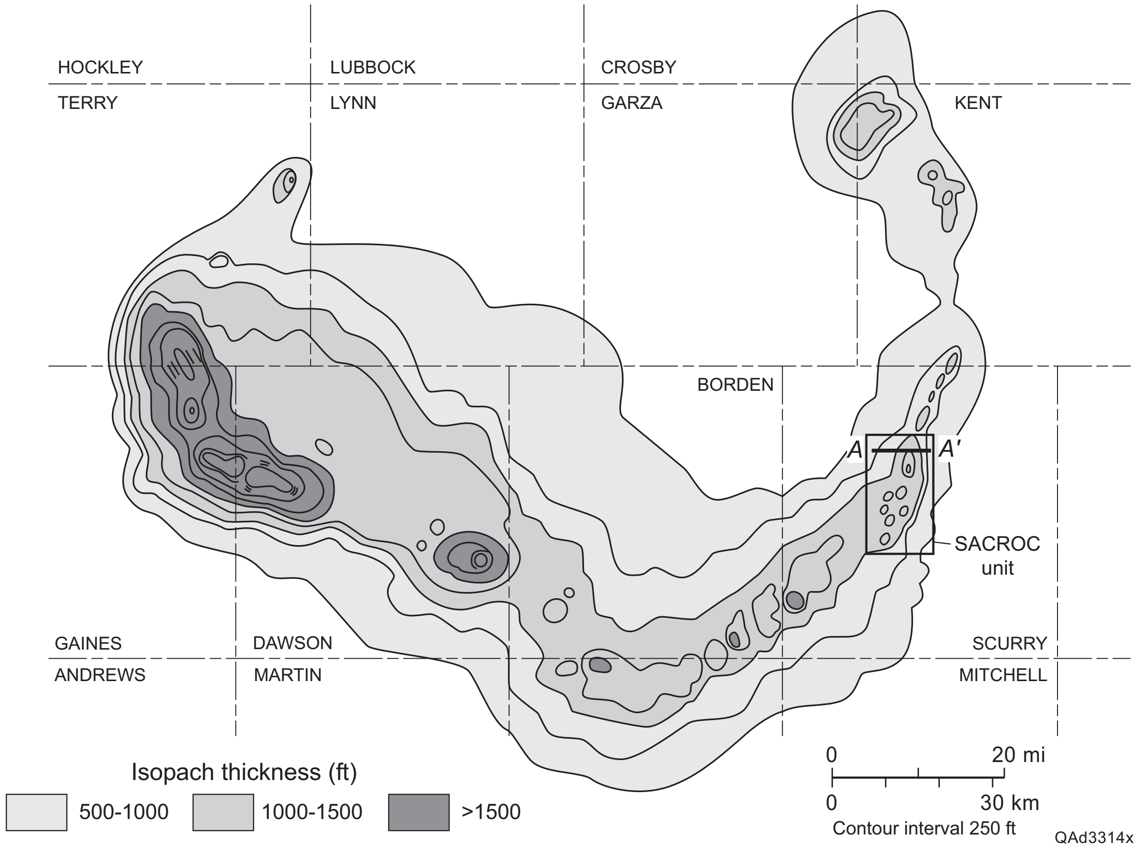

Figure 42. Isopach map of the Horseshoe Atoll carbonate. Modified from Galloway and others (1983); after Vest (1970). The thickest carbonate buildup is along the western margin, which is structurally lower, and where active atoll accretion continued into Early Permian time (Galloway and others, 1983).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

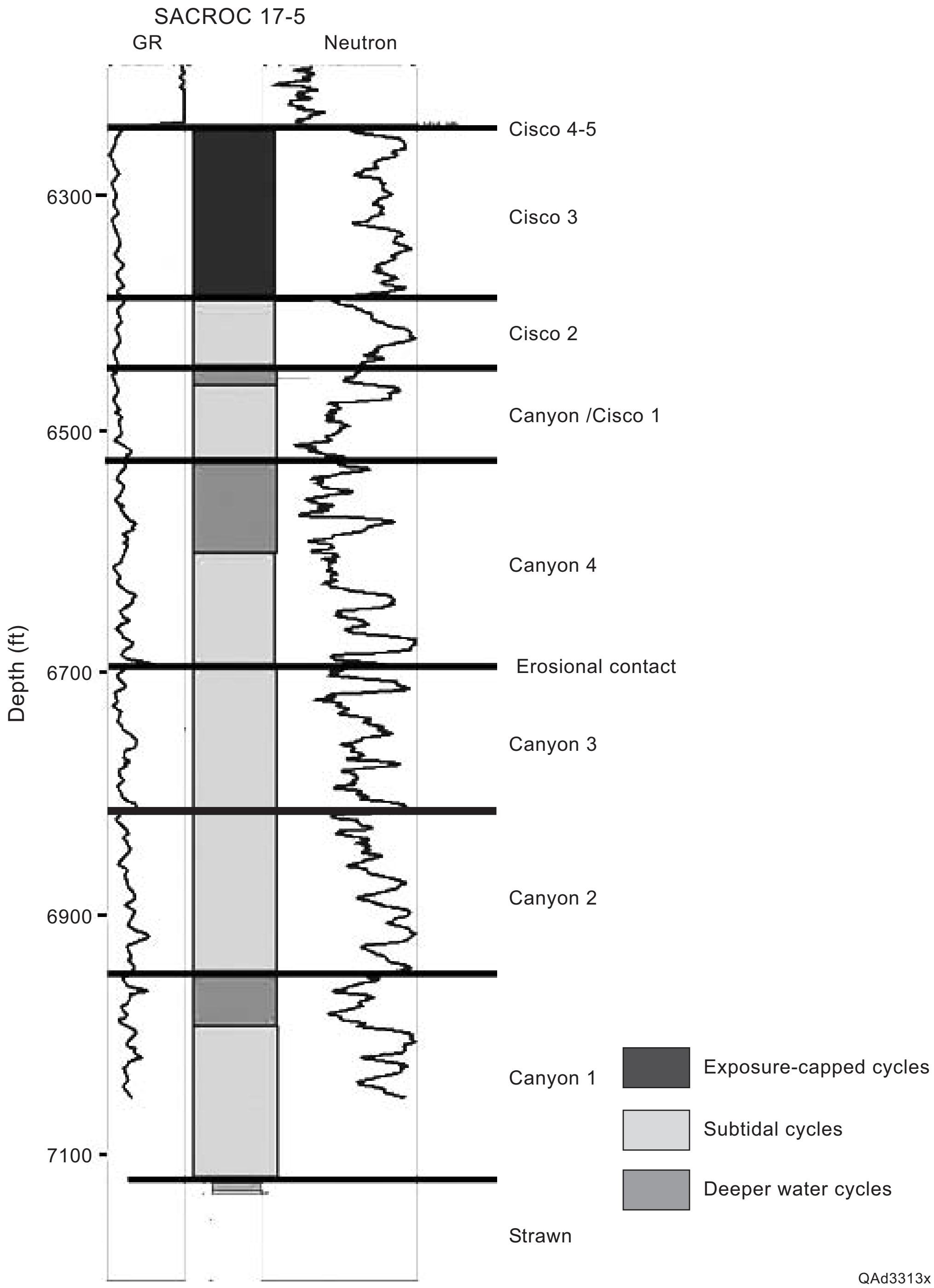

Figure 43. Typical log from the center of the Horseshoe Atoll in the SACROC unit showing high-frequency sequences.

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 × 10^{-3} μm^2) and averages 19 md (19 × 10^{-3} μm^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 × 10^8 m^3) of

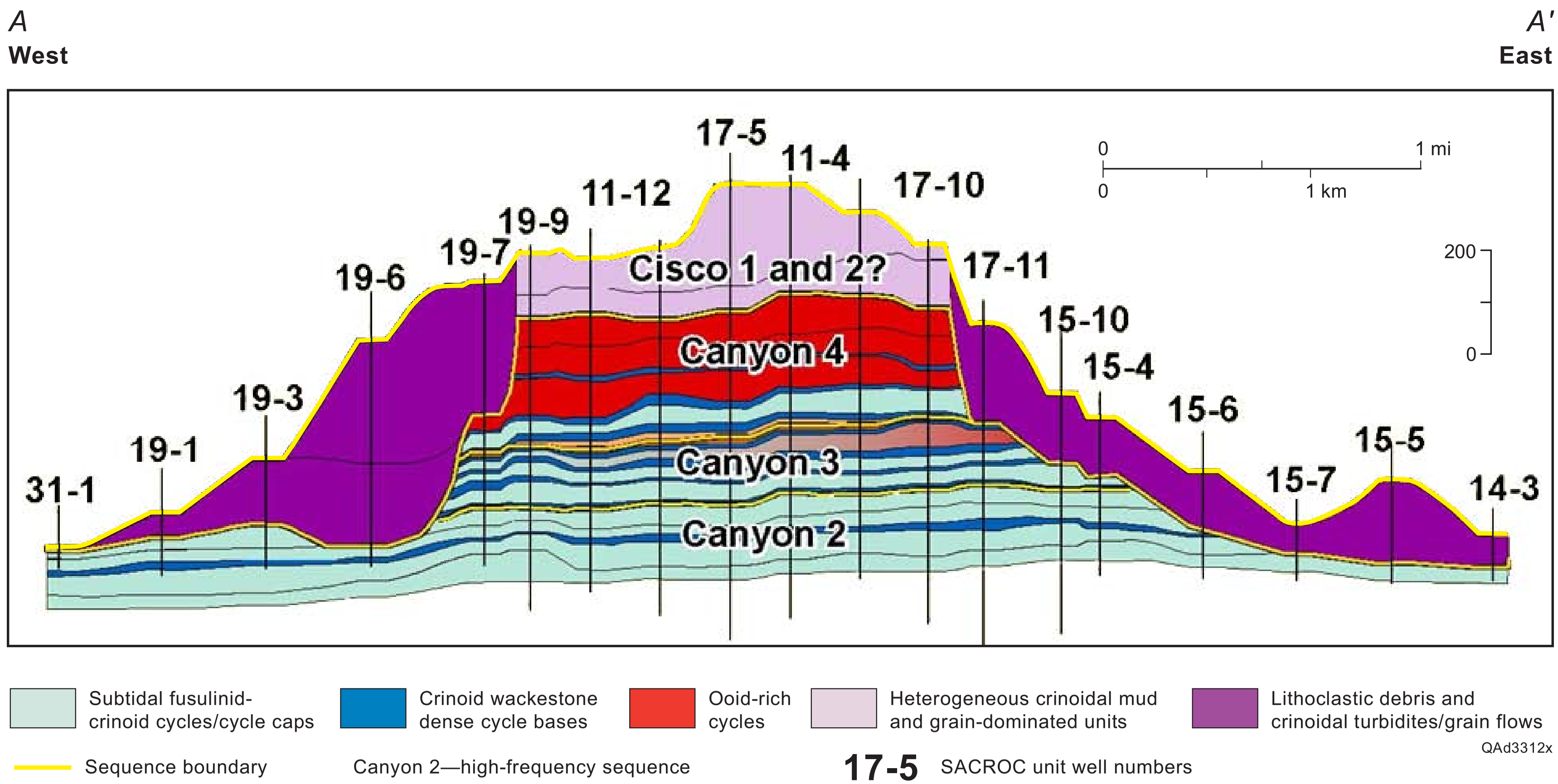

Figure 44. East-west cross section A-A´ of the north part of SACROC unit. Location of section shown in figure 42.

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	7019	24,266	2,298,589
9630400	7C	BLOODWORTH, NE.	5750 CANYON	TX	NOLAN	1967	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	20,406,213
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	1961	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	6180	12,056	15,359,584
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	67,116	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
69098166	7B	PARDUE	CANYON	TX	FISHER	1949	4415	10,899	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
79303666	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

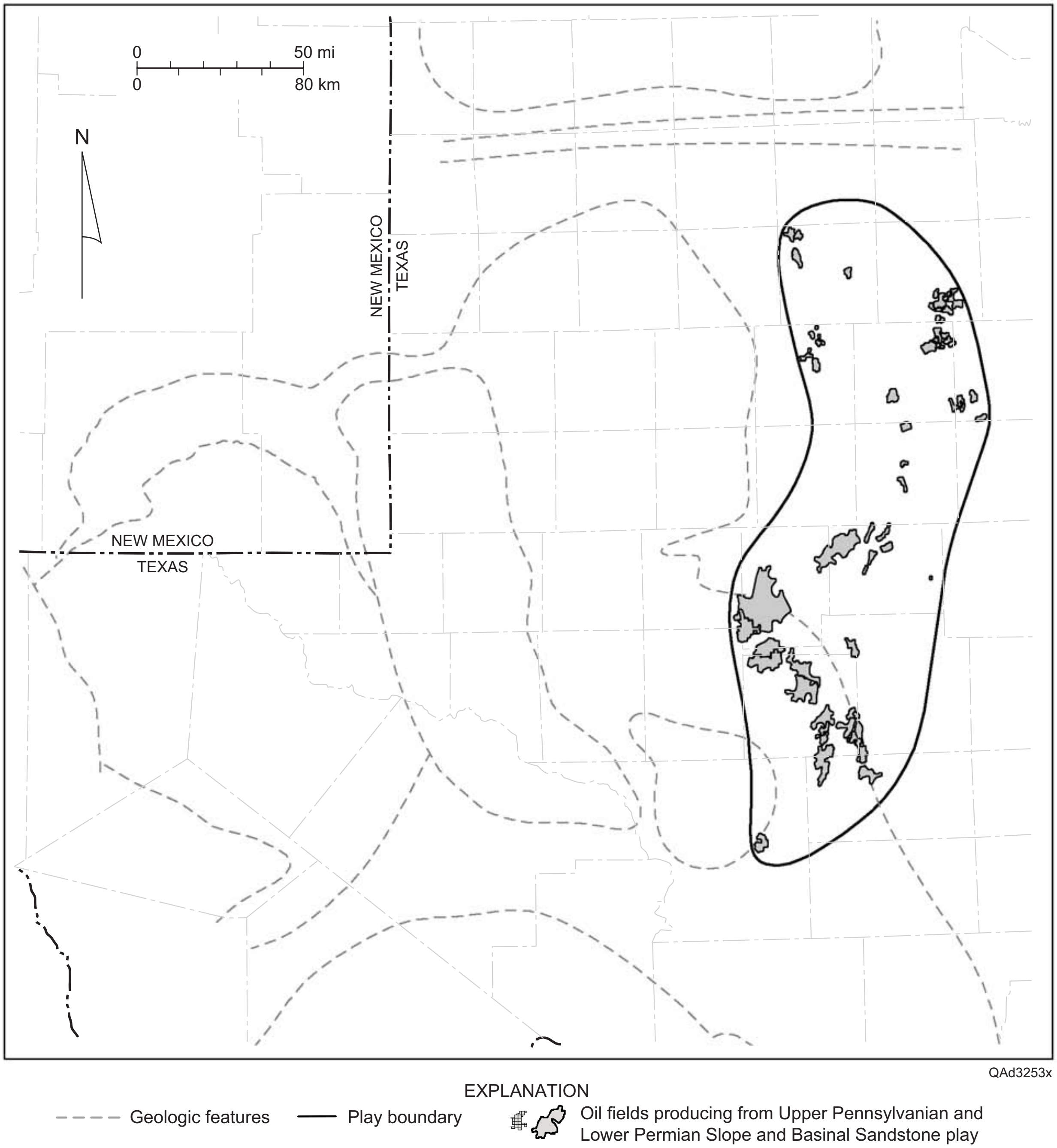

Figure 45. Play map for the Upper Pennsylvanian and Lower Permian Slope and Basinal Sandstone play, showing location of reservoirs having >1 MMbbl cumulative production, the play boundary, and geologic features. See figure 1 for county names and figure 2 for identification of geologic features.

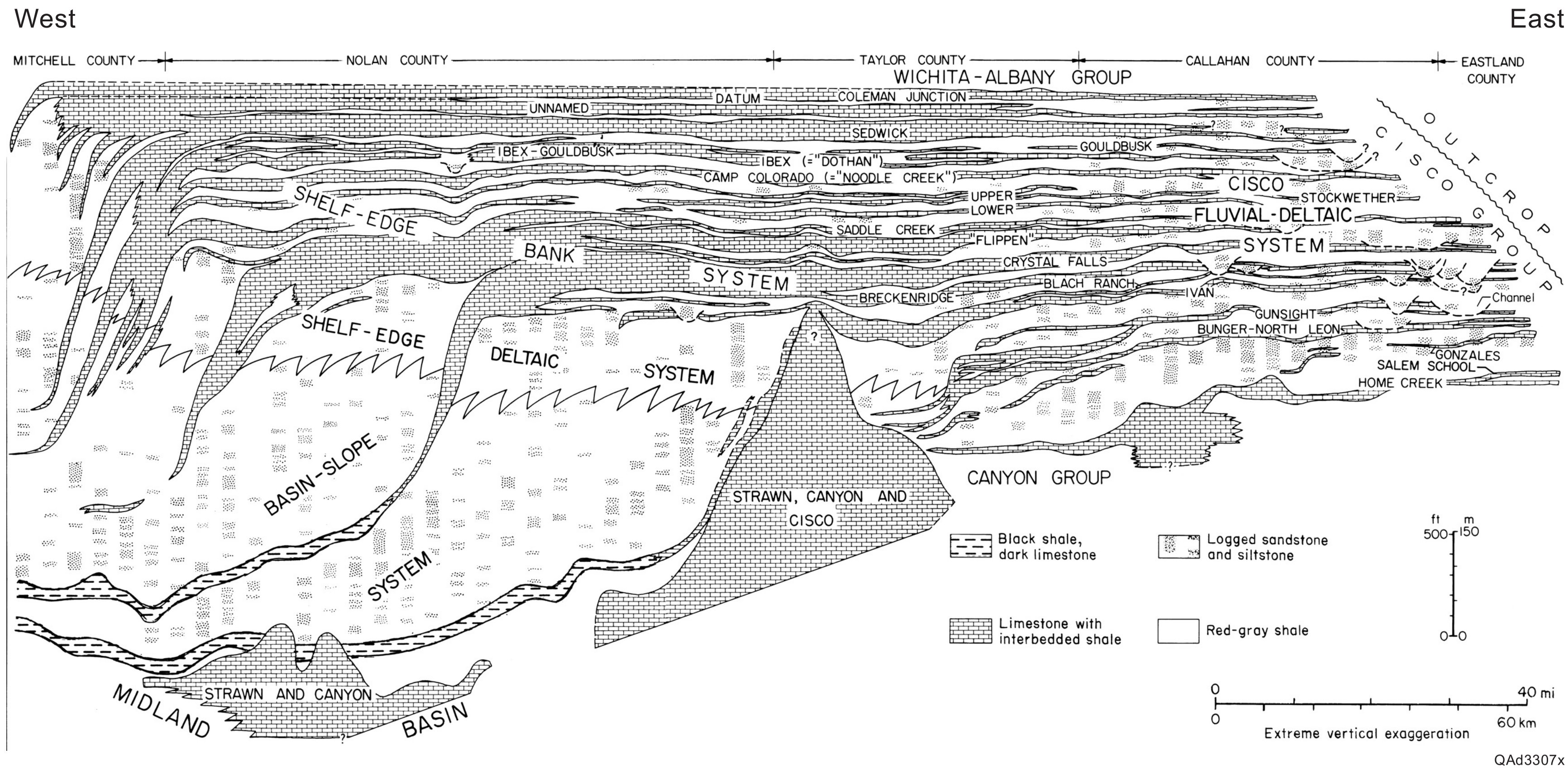

Figure 46. Generalized west-east dip cross section, Virgilian and Wolfcampian Series, from the Eastern Shelf in North-Central Texas into the Midland Basin. Horizontal scale approximate. From Brown and others (1990); modified from Brown (1969).

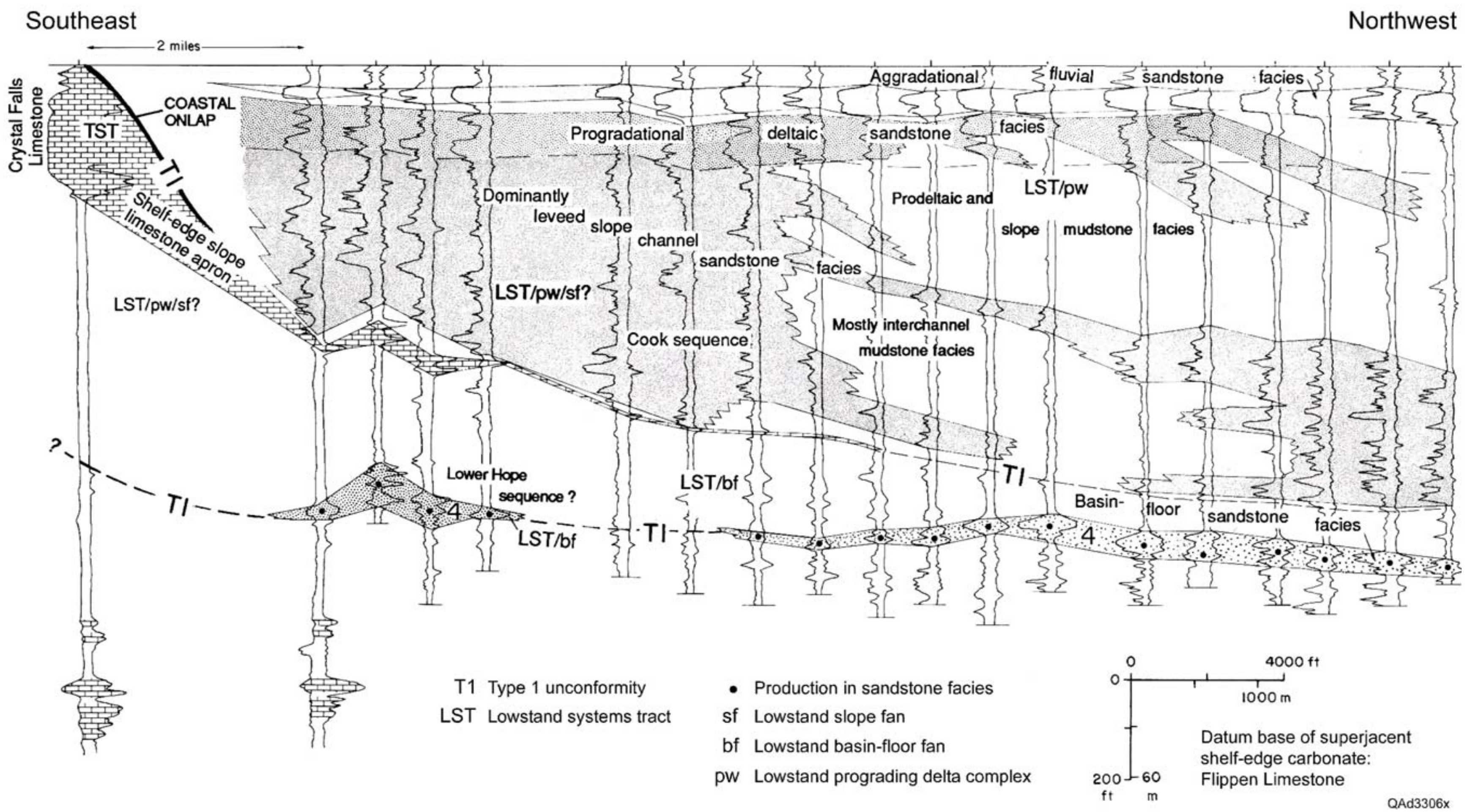

Figure 47. Southeast-northwest cross section of Lake Trammel, S., and Lake Trammel, W., fields, Nolan County, showing lowstand detached basin-floor submarine fans and lowstand slope-fan and prograding-delta complex. Modified from Brown and others (1990); based on original figure of Galloway and Brown (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 $\times 10^{-3}$ 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	1960	9200	495,459	22,699,269
22576666	8A	D. E. B.	WOLFCAMP, ZONE B	TX	GAINES	1960	9400	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
65766888	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**

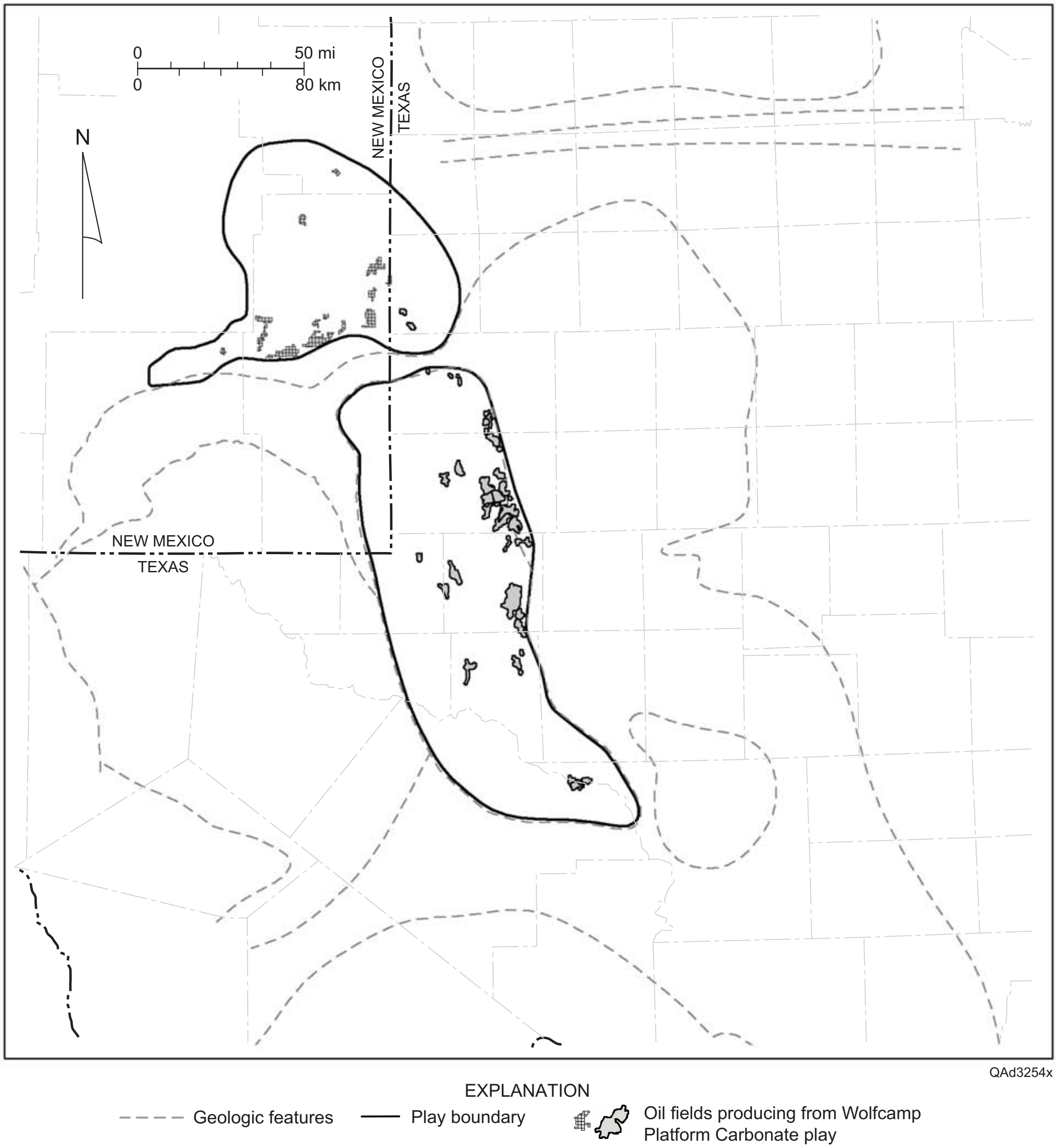

Figure 48. Play map for the Wolfcamp Platform Carbonate play, showing location of reservoirs having >1 MMbbl cumulative production, the play boundary, and geologic features. See figure 1 for county names and figure 2 for identification of geologic features.

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;

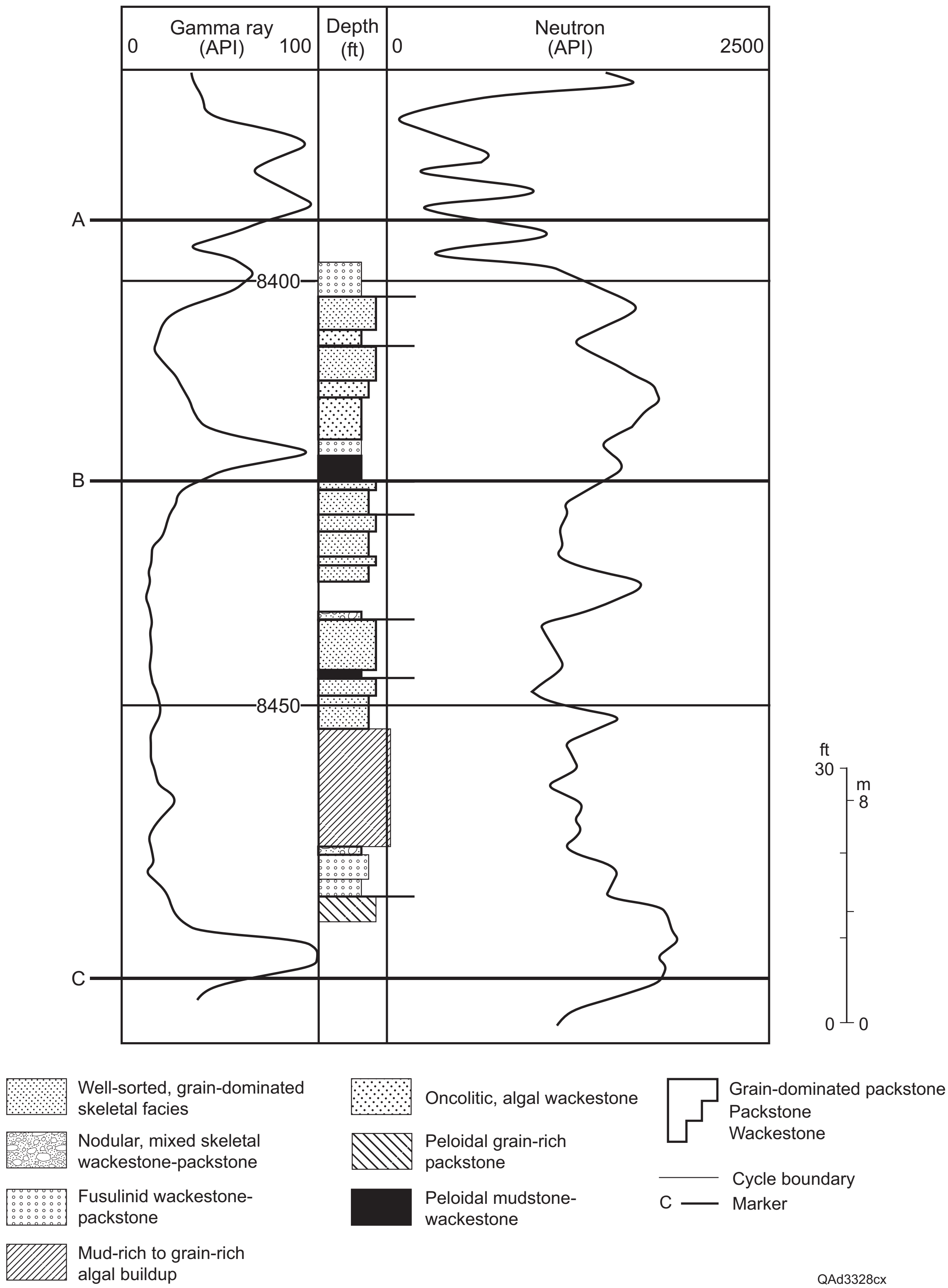

Figure 49. Typical vertical Wolfcamp facies succession in the Wolfcamp Platform Carbonate play. From Ruppel (2001). Core and log are from University Block 9 field, Andrews County, from the Shell 9A No. 1 well (Cross Timbers 11 SA No. 1 well). See Ruppel (2001) for location of well.

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

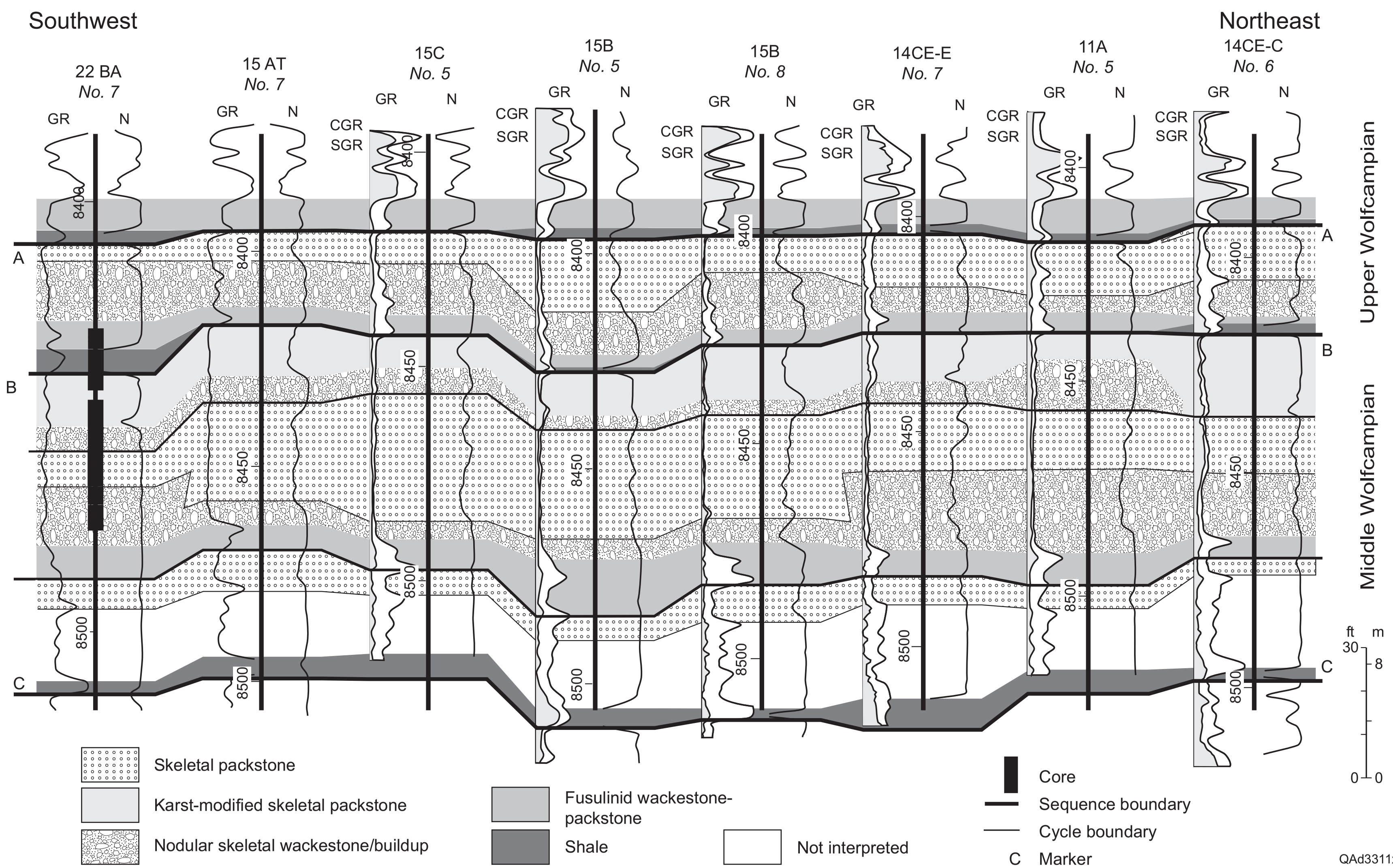

Figure 50. Southwest-northeast cross section of University Block 9 field, showing Wolfcamp stratigraphy, cycles, and facies as interpreted from core-calibrated image logs. From Ruppel (2001). See Ruppel (2001) for location of cross section.

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	60,515	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
21382875	8	COYANOSA	WOLFCAMP	TX	PECOS	1970	11614	2,768	6,299,774
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
42971664	8	HOWARD-GLASSCOCK	WOLFCAMP 7400	TX	HOWARD	1970	7441	76,590	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	79,498	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**

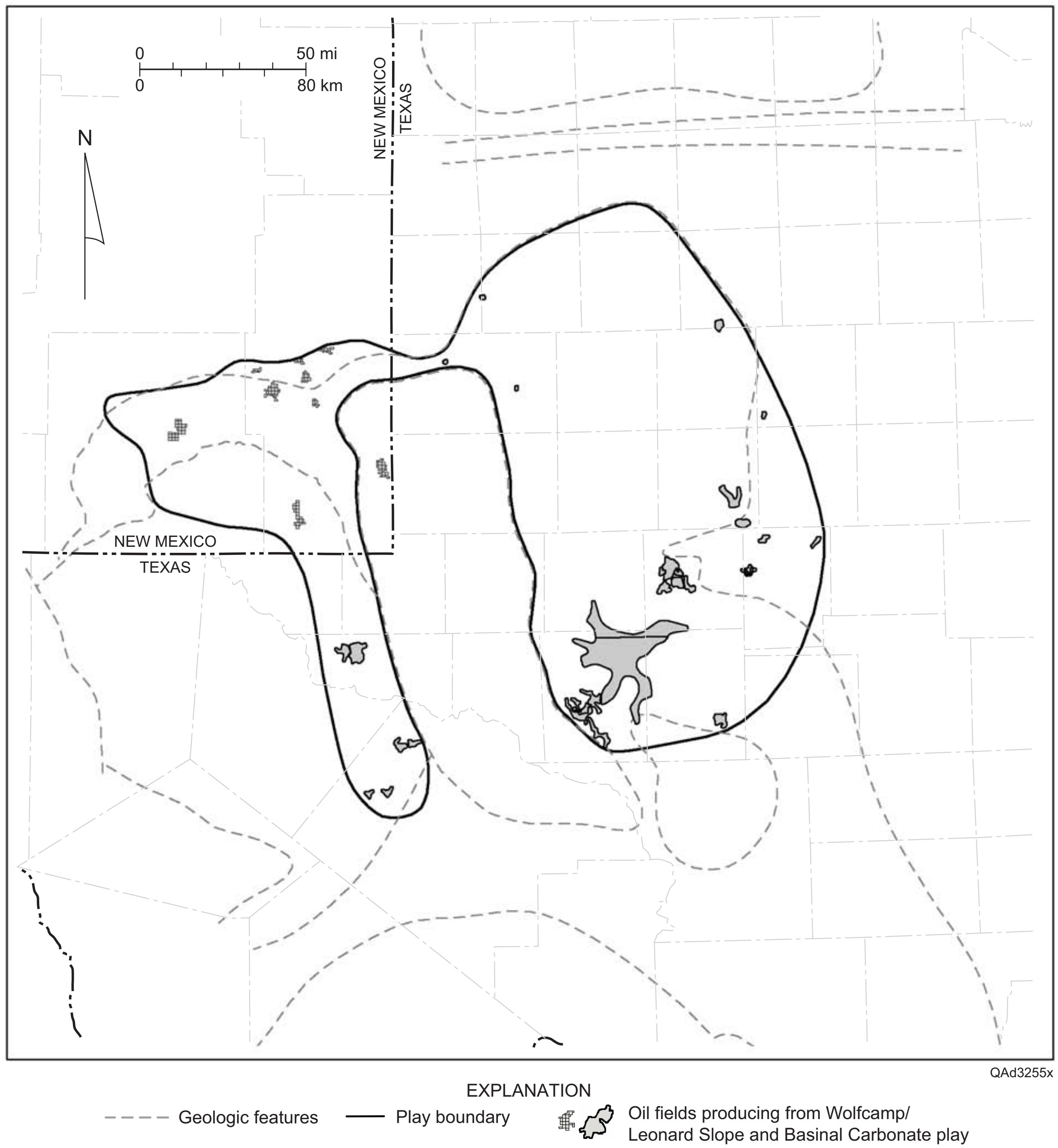

Figure 51. Play map for the Wolfcamp/Leonard Slope and Basinal Carbonate play, showing location of reservoirs having >1 MMbbl cumulative production, the play boundary, and geologic features. See figure 1 for county names and figure 2 for identification of geologic features.

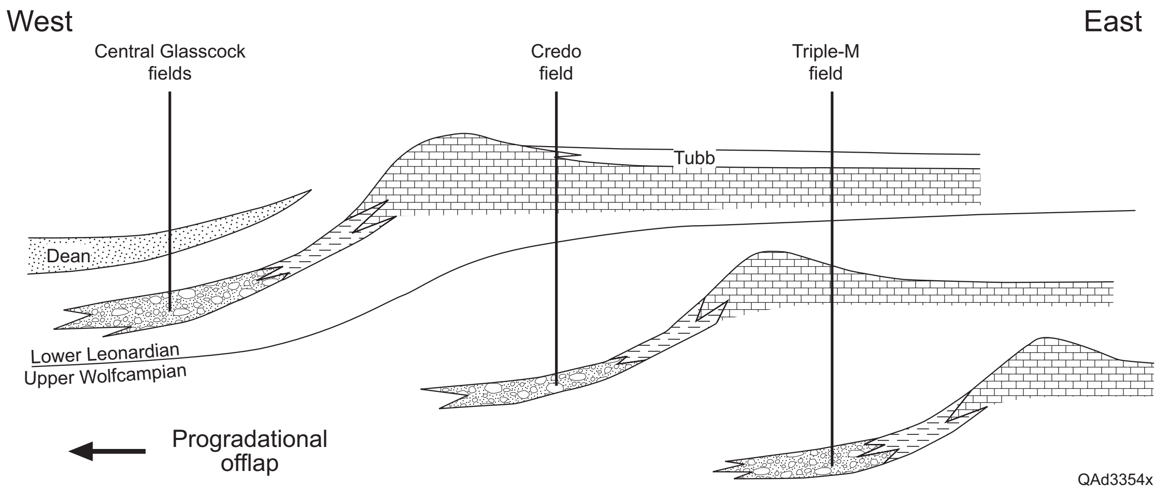

Figure 52. West-east cross section illustrating progradation of the Eastern Shelf margin and fields producing from Wolfcamp and Leonard periplatform carbonates in Glasscock and Sterling fields. From Mazzullo (1997).

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).

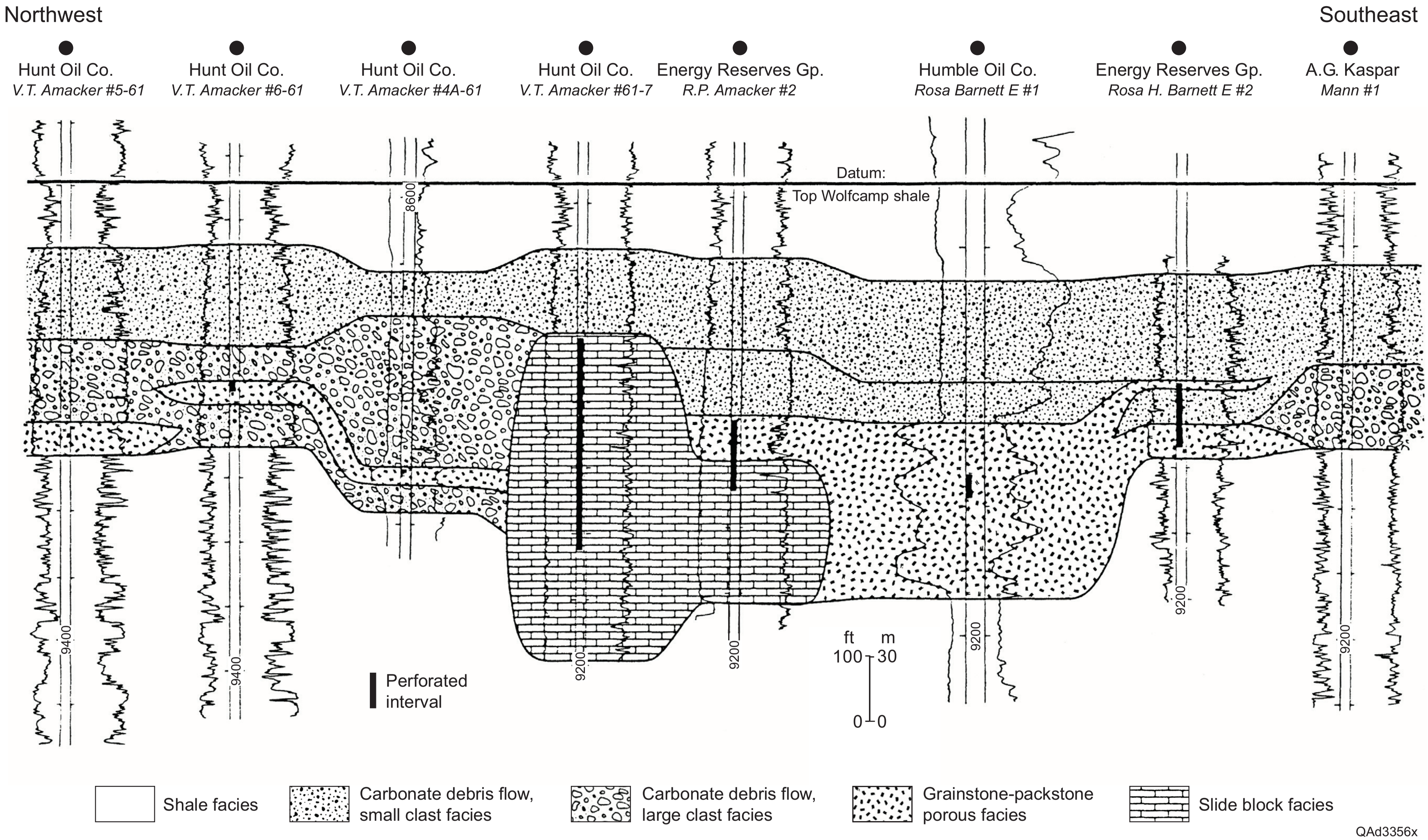

Figure 53. Northwest-southeast stratigraphic cross section showing producing zones in Amacker Tippett Wolfcamp field, Upton County. From Van Der Loop (1990). See Van Der Loop (1990) for location of cross section.

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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Abo Platform Carbonate (Play 116)

The Abo Platform Carbonate play includes 23 reservoirs in Texas and New Mexico that have produced >1 MMbbl (1.59×10^5 m^3) through 2000 (table 21). Total production from these reservoirs is 541.5 MMbbl (8.61×10^7 m^3). Reservoirs in the play are developed along the south margin of the Northwest Shelf and along the west margin of the Central Basin Platform (fig. 54). Deposition of the Abo at the beginning of the Leonard marks the transition from paleogeographically complex Upper Pennsylvanian-Wolfcampian isolated buildups to more organized shelf margin platforms (Kerans, 2000). Outcrop study of the Abo interval in Apache Canyon of the Sierra Diablo Mountains, west Texas, indicates that it is composed of six high-frequency sequences: three aggradational sequences making up the transgressive sequence set and three prograding clinoforms making up the highstand sequence set (Kerans, 2000; Kerans and others, 2000).

Table 21. Abo Platform Carbonate play (play 116). 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
8234002	8A	BILLY	ABO	TX	LAMB	1995	6674	119,876	1,168,302
12376666	8A	BROWN	WICHITA - ALBANY	TX	GAINES	1960	8004	20,255	4,550,006
49460500	8A	KINGDOM	ABO REEF	TX	TERRY	1970	8120	1,262,687	57,666,707
53411070	8A	LEVELLAND	ABO	TX	HOCKLEY	1976	7566	21,576	1,521,730
53411852	8A	LEVELLAND	WICHITA-ALBANY	TX	HOCKLEY	1965	7488	19,083	1,039,496
87157200	8A	SUNDOWN	ABO	TX	HOCKLEY	1978	7926	29,741	1,056,569
91621001	8A	TSTAR	ABO	TX	HOCKLEY	1996	8039	837,713	3,223,835
95397600	8A	WASSON	WICHITA ALBANY	TX	GAINES	1960	11038	99,477	11,639,560
95402333	8A	WASSON, S.	WICHITA - ALBANY	TX	GAINES	1962	7711	19,268	4,652,147
		BRUNSON SOUTH	ABO DRINKARD	NM	LEA	1988	6750	102,791	10,117,489
		BUCKEYE	ABO	NM	LEA	1965	8950	19,140	2,529,960
		CORBIN	ABO	NM	LEA	1959	8410	72,551	15,684,050
		DOUBLE A	LOWER ABO	NM	LEA	1964	9300	12,498	1,076,771
		DOUBLE A SOUTH	ABO	NM	LEA	1964	8900	24,923	1,970,186
		EMPIRE	ABO	NM	EDDY	1957	6014	45,511	225,140,765
		JACKSON	ABO	NM	EDDY	1961	6910	1,646	1,053,208
		LOVINGTON	ABO	NM	LEA	1951	8340	80,989	33,983,198
		MALJAMAR	ABO	NM	LEA	1959	8977	3,834	1,029,476
		MONUMENT	ABO	NM	LEA	1948	7180	1,291,446	7,139,437
		MONUMENT NORTH	ABO	NM	LEA	1977	7300	220,836	1,204,844
		VACUUM	ABO REEF	NM	LEA	1960	8650	366,857	91,163,873
		VACUUM NORTH	ABO	NM	LEA	1963	8500	1,298,837	52,981,986
		WANTZ	ABO	NM	LEA	1950	6560	134,048	9,866,088
	Totals							**6,105,583**	**541,459,683**

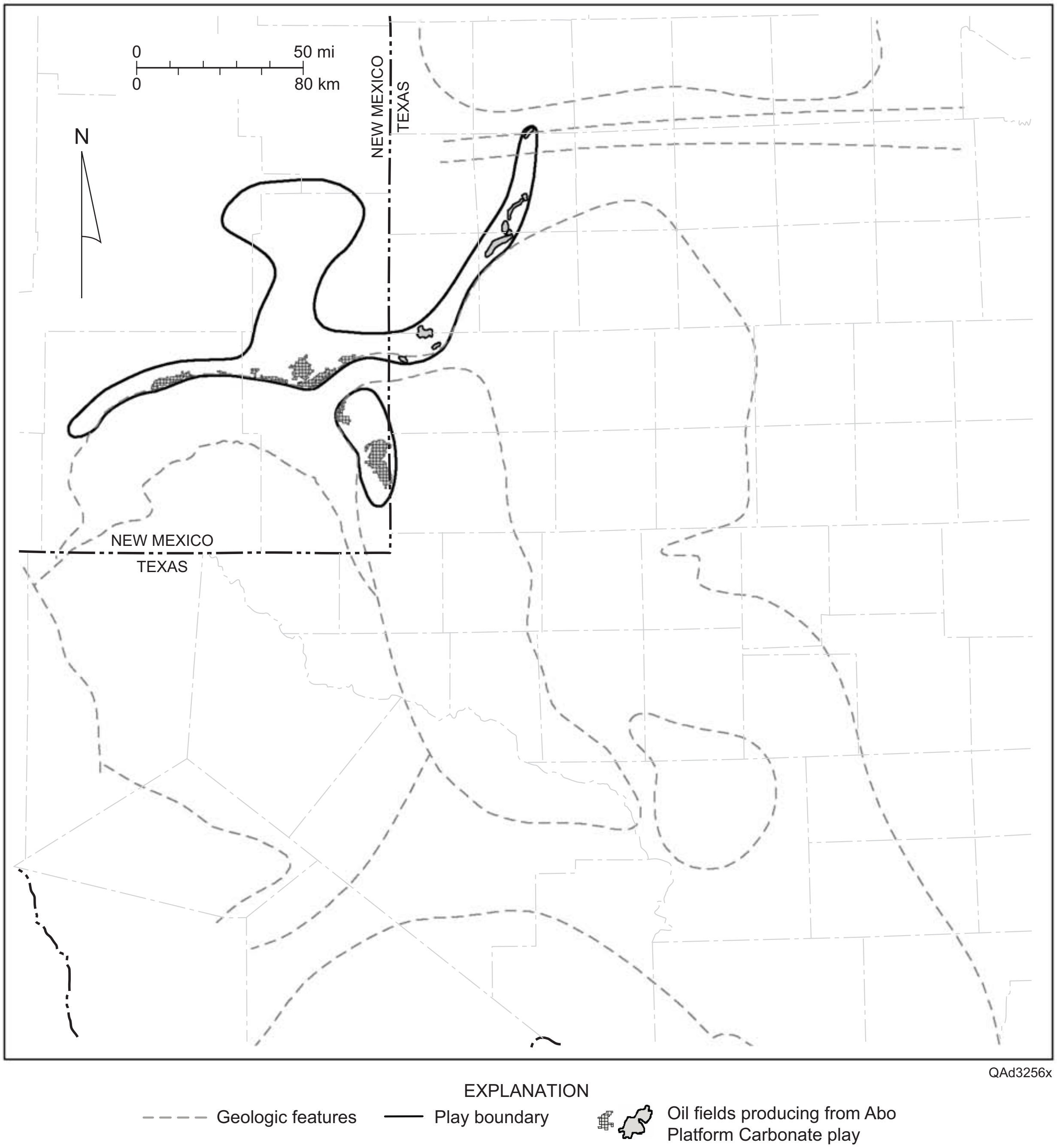

Figure 54. Play map for the Abo Platform Carbonate play, showing location of reservoirs having >1 MMbbl cumulative production, the play boundary, and geologic features. See figure 1 for county names and figure 2 for identification of geologic features.

The Abo is productive from shelf and shelf-margin facies on the Northwest Shelf and Central Basin Platform (fig. 54). Although commonly referred to as the Abo Reef Trend, Abo reservoirs do not represent organic reef facies (Mazzullo, 1982). Outcrop studies (Kerans and others, 2000) demonstrate that platform-margin Abo successions are dominated by grain-rich packstones and grainstones that have undergone significant karst-related diagenesis. Analysis of the Abo succession at Kingdom Abo field in Terry and Hockley Counties, Texas, has confirmed the importance of grain-rich skeletal carbonates and karst-related diagenesis in the subsurface (Kerans, 2000; Kerans and others, 2000). The facies model for Kingdom Abo field is of a strongly progradational highstand ramp having three main facies tracts: inner shelf, shelf crest/shelf margin, and slope (fig. 55a). The field produces from upper-slope fusulinid packstones and grainstones and shelf-crest peloidal grainstones of the highstand sequence set (Kerans, 2000; Kerans and others, 2000). True reefal boundstone is only sparsely developed. The narrow shelf-parallel sweet spot of Abo production is interpreted to be a combination of maximum grainstone thickness and paleokarst overprint (Kerans, 2000; Kerans and others, 2000).

The dominant frequency of 3-D seismic data at reservoir depths is commonly too low to define Abo clinoform stratigraphy (Zeng and Kerans, 2003). High-frequency seismic data (>70 Hz) follow thinner, time-bounded, clinoform depositional elements (time-stratigraphic units) in the Abo, but low-frequency seismic data tend to image thicker, low-angle lithofacies units (time-transgressive units) (fig. 55b) (Zeng and Kerans, 2003).

At Kingdom (Abo) and Kingdom, North (Abo), fields, the average porosity is 6.5 percent and average permeability is 9 md (9×10^{-3} μm^2); pay cutoffs are 4 percent porosity and 1 md (1×10^{-3} μm^2) permeability (Party and others, 1998).

The Abo Platform Carbonate play extends into New Mexico along the southern edge of the Northwest Shelf and on the northwest margin of the Central Basin Platform (fig. 54). In

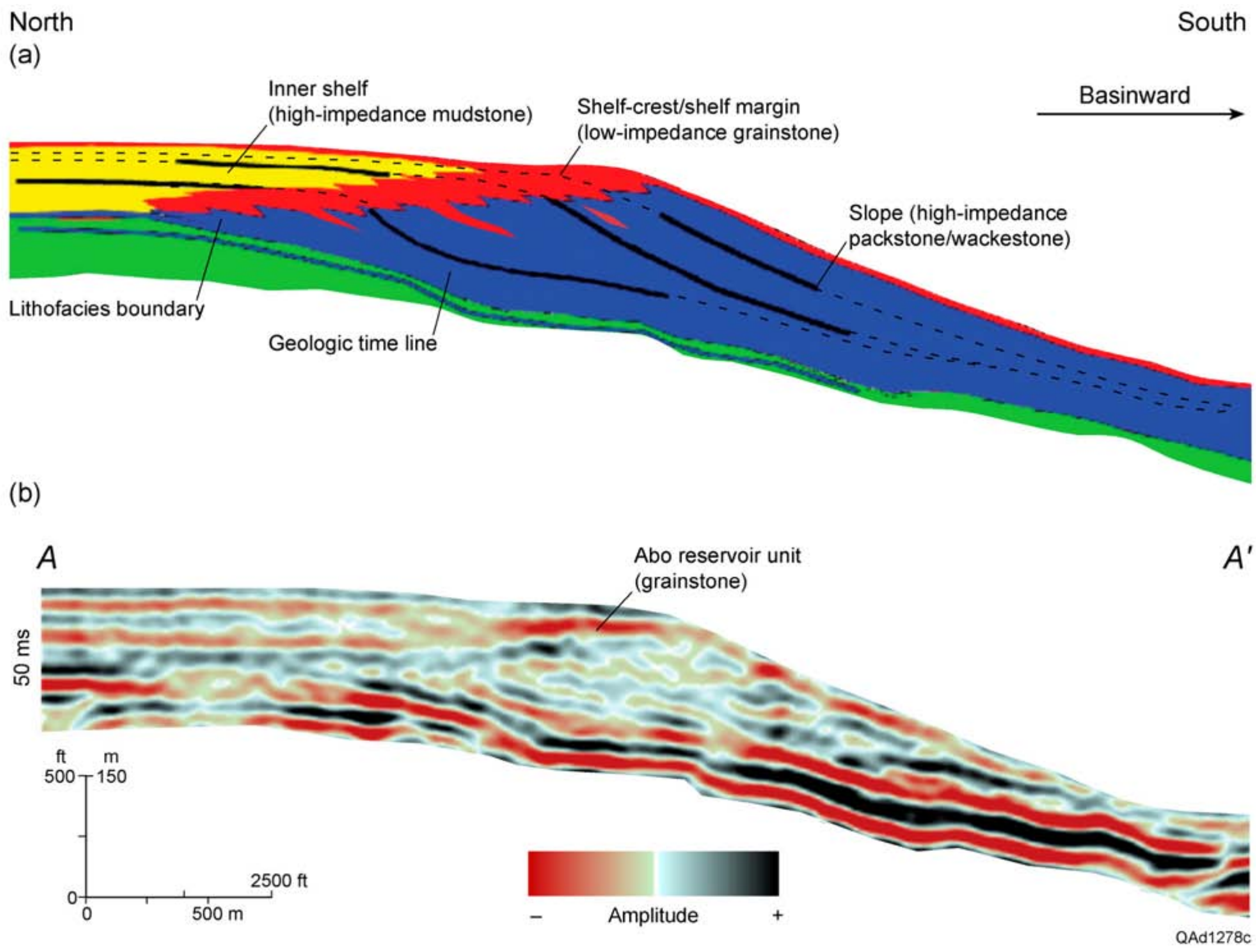

Figure 55. (a) Depositional model of the progradational Abo sequence. Time-stratigraphic units comprise clinoform deposits that consist of inner shelf, shelf-crest/shelf-margin, and slope facies. Three time-transgressive lithostratigraphic units (inner shelf mudstone, shelf-crest/shelf-margin grainstone, and slope wackestone) develop when the system progrades basinward. Lithostratigraphic units dip landward and cross geologic time lines. (b) A seismic line from a multichannel, migrated, P-wave 3-D data volume in Kingdom Abo field shows a slightly landward dipping seismic reflection event that corresponds to the time-transgressive, shelf-crest/shelf-margin grainstone lithofacies. See Zeng and Kerans (2000) for location of seismic section. After Zeng and Kerans (2000), reprinted by permission of the AAPG, whose permission is required for further use. ©Copyright 2003. The American Association of Petroleum Geologists. All rights reserved.

New Mexico, the play is divided into two subplays. The Abo Platform Margin Carbonate subplay consists of reservoirs deposited at the shelf edge, and the Abo Carbonate Shelf subplay consists of reservoirs that are found north of the shelf margin. There are 62 known, discovered reservoirs in the New Mexico part of the Abo Platform Carbonate play, 14 of which have produced >1 MMbbl (1.59×10^5 m^3) (fig. 54; table 21). Cumulative production from those 14 New Mexico reservoirs was 455 MMbbl (7.23×10^7 m^3) as of 2000. During the 1970's, production in the play was dominated by the Empire Abo reservoir and as this important reservoir began to decline in the late 1970's, production from the play in New Mexico went into decline. Abo production in New Mexico increased during the latter half of the 1990's as production in the Monument reservoir increased as a result of additional drilling.

The Abo trend is localized along the preexisting 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 Abo trend is delineated in younger, shallower strata by a drape of the overlying sediments, which forms the Artesia-Vacuum Arch (Kelley, 1971).

Reef reservoirs in the Abo Platform Margin Carbonate subplay are white to light-gray, finely to coarsely crystalline dolostones (LeMay, 1960, 1972; Snyder, 1962). Pervasive dolomitization has obliterated depositional sedimentary structures and textures in the New Mexico reservoirs. Pay thickness exceeds 700 ft (210 m) in parts of the Empire Abo reservoir but is less than 100 ft (30 m) in most of the other reservoirs. Porosity is vugular, intercrystalline, and fracture. Porosity and permeability are irregularly distributed, and fluid communication within reservoirs is poor (LeMay, 1960, 1972). As a result, small gas pockets are present within structurally low areas of a reservoir.

Traps in the shelf-margin reservoirs are predominantly stratigraphic (LeMay 1960, 1972). The vertical seal is formed by green siliciclastic shales and interbedded finely crystalline dolostones of the shelf facies that has prograded southward over the shelf-margin facies.

East-west limits of the reservoirs are defined by gentle structural or morphologic plunge of the reservoir facies under the oil-water contact or by occlusion of porosity by anhydrite cement on the shelfward side (LeMay 1960, 1972). Southern limits of the Abo reservoirs are delineated by transition to nonporous, black, argillaceous lime mudstones and fine-grained sandstones of the basinal Bone Spring Formation (fig. 56). Dark-colored rocks of the Bone Spring are organic rich and are the probable source rocks for oil in the shelf-edge carbonate reservoirs.

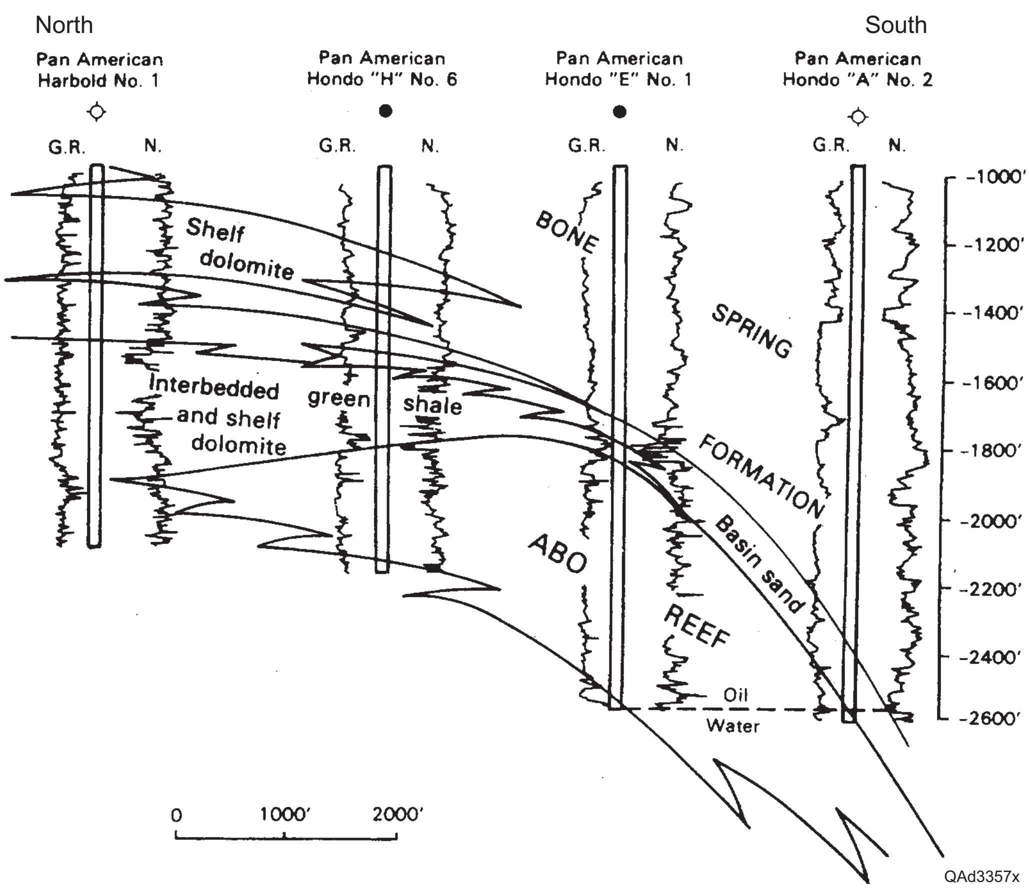

Figure 56. North-south structural cross section of the Empire Abo reservoir showing relationship of porous Abo reef to Abo backreef facies and basinal Bone Spring Formation. Vertical scale is in feet below sea level. From LeMay (1960). See LeMay (1960) for location of cross section.

Reservoirs in the Abo Carbonate Shelf subplay are dolostones that were deposited on an evaporitic restricted marine shelf. Although poorly documented, traps appear to be formed by broad, low-relief anticlines. Porous zones appear to have relatively good continuity within defined reservoirs. Overall, however, porosity and permeability are unevenly distributed within Abo carbonates on the Northwest Shelf. Reservoirs are generally smaller and have smaller reserves in the Abo Carbonate Shelf subplay than reservoirs in the Abo Platform Margin Carbonate subplay. Only one reservoir in the Abo Carbonate Shelf subplay, Vacuum North, has produced >1 MMbbl (1.59×10^5 m^3), although there are several other reservoirs that should exceed the 1 MMbbl (1.59×10^5 m^3) level during the next decade.

The primary drive mechanism for Abo carbonate reservoirs is primary gas-cap expansion supplemented by solution-gas drive. Best reservoir practices include perforating the pay well below the gas-oil contact in order to prevent coning of the gas cap into the perforated interval, thereby conserving reservoir energy (Hueni and Schuessler, 1993). Unitization of the field may be implemented in order to initiate gas reinjection so that loss of reservoir energy and, therefore, production rates may be stabilized.

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Leonard Restricted Platform Carbonate (Play 117)

The Leonard Restricted Platform Carbonate play consists of 183 reservoirs that had produced >1 MMbbl (1.59×10^5 m^3) of oil through 2000; cumulative production from the play was 3,295 MMbbl (5.24×10^8 m^3) (table 22). Reservoirs of Leonardian age on the Central Basin Platform, Northwest Shelf, and Eastern Shelf are included in this play (fig. 57), with the exception of Abo reservoirs on the Northwest Shelf. The Leonard Restricted Platform Carbonate play includes rocks assigned to the Wichita (also known as the Wichita/Albany or Abo), Clear Fork, Tubb, Yeso, Glorieta (also known as the San Angelo), and locally to the Holt (fig. 3). With the exception of the Holt, lower San Andres rocks in the uppermost Leonardian are not included in this play. The Clear Fork Group in Texas is separated into lower and upper Clear Fork units by the Tubb Formation, a zone of silty carbonate. The top of the Clear Fork is separated from the overlying San Andres Formation by the Glorieta silty carbonate. The entire interval is productive, but the lower Clear Fork has had the greatest amount of production (Montgomery, 1998).

Mazzullo (1982) and Mazzullo and Reid (1989) summarized large-scale stratigraphy and depositional systems of the lower Leonard in the Midland Basin. The Leonardian stratigraphic section is ~2,500 to 3,000 ft (~760 to 915 m) thick, and reservoirs are typically developed at depths between 5,600 and 7,800 ft (1,700 and 2,400 m) (Tyler and others, 1991). Leonardian reservoirs contained an estimated 14.5 Bbbl (2.31×10^9 m^3) of original oil in place (Holtz and others, 1992), approximately 15 percent of the total resource in the Permian Basin, but recovery efficiencies are the lowest among carbonate reservoirs in the Permian Basin (Ruppel and others, 2000).

Table 22. Leonard Restricted Platform Carbonate play (play 117). 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	SUBPLAY
292058	8	ABELL	CLEAR FORK	TX	PECOS	1950	3555	11,400	1,043,523	
292580	8	ABELL	PERMIAN 3800	TX	PECOS	1949	3800	5,495	1,000,919	
292500	8	ABELL	PERMIAN-GENERAL	TX	CRANE	1975	4200	49,449	1,658,580	
1406001	8A	ALEX		TX	TERRY	1945	5150	54,445	1,623,604	
3172500	8A	ANTON	CLEAR FORK, LOWER	TX	HOCKLEY	1959	6502	24,778	1,045,786	
3180001	8A	ANTON, WEST		TX	HOCKLEY	1950	6655	46,493	2,517,174	
3194001	8A	ANTON-IRISH		TX	HALE	1944	5348	3,466,252	200,803,233	
3644568	8	ARMER	TUBB	TX	CRANE	1955	4865	15,168	1,441,098	
4279500	7C	ATKINSON, W.	SAN ANGELO	TX	TOM GREEN	1965	816	55,327	2,311,838	
5524830	8	BAR-MAR	TUBB	TX	CRANE	1965	3962	13,153	1,022,337	
6378284	8	BAYVIEW	GLORIETA	TX	CRANE	1961	3008	3,671	2,595,807	
6385500	8	BAYVIEW, W.	GLORIETA	TX	CRANE	1965	3023	5,725	1,026,923	
9250001	8	BLOCK 12		TX	ANDREWS	1946	7170	24,318	3,003,421	
8944750	8	BLOCK A-28	WICHITA-ALBANY	TX	ANDREWS	1964	7463	21,924	1,690,793	
8958400	8	BLOCK A-34	GLORIETA	TX	ANDREWS	1955	5910	136,778	3,112,350	
8962500	8	BLOCK A-34, NORTHWEST	GLORIETA	TX	ANDREWS	1955	5914	16,864	1,402,909	
11082333	8	BOYDELL, S.	CLEAR FORK, LO.	TX	ANDREWS	1967	7089	132,105	2,325,116	
12118500	8A	BROADVIEW, WEST	CLEAR FORK	TX	LUBBOCK	1960	5565	155,447	3,389,002	
12230333	8	BROOKLAW	CLEAR FORK, LOWER	TX	PECOS	1969	3460	16,172	2,195,374	
12376001	8A	BROWN		TX	GAINES	1948	6030	12,203	5,380,103	
12448200	8	BROWN & THORP	CLEAR FORK	TX	PECOS	1951	3028	24,560	6,882,219	
12449800	8	BROWN & THORP, EAST	TUBB	TX	PECOS	1965	3125	84,867	2,681,183	
14200800	8	C-BAR	TUBB	TX	CRANE	1957	5320	19,076	2,622,880	
19541001	8	COLEMAN RANCH		TX	MITCHELL	1946	2560	231,378	10,496,867	
19543500	8	COLEMAN RANCH, N.	CLEAR FORK	TX	MITCHELL	1953	3050	68,512	4,051,150	
20609666	8	CORDONA LAKE, NORTH	TUBB 4500	TX	CRANE	1966	4546	1,927	1,061,583	
21577450	8	CRAWAR	GLORIETA	TX	WARD	1954	4040	51,440	1,285,530	
21907555	8	CROSSETT	3000 CLEAR FORK	TX	CRANE	1952	2960	38,765	3,022,275	
23907568	8	DEEP ROCK	GLORIETA 5950	TX	ANDREWS	1954	5700	307,694	13,186,510	
24562284	8A	DIAMOND -M-	CLEAR FORK	TX	SCURRY	1940	3170	341,882	9,832,055	
25188200	8	DOLLARHIDE	CLEAR FORK	TX	ANDREWS	1949	6545	755,549	47,270,501	
25544001	8A	DORWARD		TX	GARZA	1950	2456	269,535	26,776,688	
27664500	8A	EDMISSON	CLEAR FORK	TX	LUBBOCK	1957	5143	436,211	14,122,508	
27668500	8A	EDMISSON, N.W.	CLEAR FORK	TX	LUBBOCK	1979	5446	224,312	2,958,886	
28843888	8	EMBAR	5600	TX	ANDREWS	1955	5606	23,398	6,368,089	
28843666	8	EMBAR	PERMIAN	TX	ANDREWS	1942	6280	30,050	6,779,777	
28961568	8	EMPEROR	HOLT	TX	WINKLER	1946	4765	117,711	9,475,152	
28963500	8	EMPEROR, EAST	CLEAR FORK, LO.	TX	WINKLER	1962	6097	11,227	1,131,119	
31222300	8A	FLANAGAN	CLEARFORK, CONS.	TX	GAINES	1949	7142	848,550	34,993,943	
31893333	8A	FORBES	GLORIETA	TX	CROSBY	1955	3605	434,735	8,897,397	
33158250	8	FUHRMAN	GLORIETA	TX	ANDREWS	1950	5612	189,906	11,248,689	
33230001	8	FULLERTON		TX	ANDREWS	1941	7300	3,170,615	309,506,748	
34113125	8A	GARZA	GLORIETA	TX	GARZA	1956	3758	3,514	1,449,452	
34113160	8A	GARZA	GLORIETA, S. DEEP	TX	GARZA	1985	3692	33,230	4,388,968	
34742450	8A	GIEBEL	CFA	TX	GAINES	1998	7670	51,489	1,507,141	
35652868	8	GOLDSMITH	5600	TX	ECTOR	1947	5600	1,147,401	240,096,410	
35652062	8	GOLDSMITH	CLEAR FORK	TX	ECTOR	1946	6300	1,906,142	93,193,807	
35653333	8	GOLDSMITH, EAST	GLORIETA	TX	ECTOR	1955	5136	6,782	1,360,016	
35659125	8	GOLDSMITH, W.	CLEAR FORK, UP.	TX	ECTOR	1956	5640	42,287	9,675,776	
37695500	8A	H & L	GLORIETA	TX	GARZA	1967	3397	25,087	2,838,452	
38255116	8	HALLEY	CLEAR FORK	TX	WINKLER	1961	5162	36,697	2,881,280	
38255406	8	HALLEY	GLORIETA	TX	WINKLER	1957	5006	27,169	4,333,697	
38455500	8A	HAMILTON	CLEARFORK	TX	HOCKLEY	1980	6459	56,904	1,207,473	
39176690	8	HARPER	GLORIETA	TX	ECTOR	1988	5500	52,206	1,118,476	
39242001	8A	HARRIS		TX	GAINES	1949	5965	1,039,986	77,544,178	
41769001	8A	HOBBS, EAST		TX	GAINES	1949	6390	18,953	1,623,627	
42499500	8A	HOOPLE	CLEAR FORK	TX	LUBBOCK	1976	4432	429,394	14,531,548	
42971166	8	HOWARD GLASSCOCK	CLEAR FORK,MI	TX	HOWARD	1970	3705	155,631	6,808,390	
42971332	8	HOWARD-GLASSCOCK	GLORIETA	TX	HOWARD	1925	3200	603,262	39,431,415	
43731333	8A	HUNTLEY	GLORIETA	TX	GARZA	1954	3966	31,002	7,649,424	
44148500	8	IATAN, EAST HOWARD		TX	HOWARD	1926	2700	1,837,814	168,656,507	
44245500	8A	IDALOU, NORTH	CLEARFORK, LO	TX	LUBBOCK	1979	5650	80,698	2,252,994	
45680500	8	JANELLE, SE.	TUBB	TX	WARD	1962	5344	74,002	4,843,708	
46134500	8A	JENKINS, NORTH	CLEAR FORK	TX	GAINES	1954	7148	147,180	2,690,500	
47007380	8	JOHNSON	GLORIETA	TX	ECTOR	1973	5452	77,950	8,122,905	
47267608	8	JORDAN	TUBB	TX	ECTOR	1948	5250	6,226	3,416,506	
48583664	8A	KELLY SNYDER	CLEAR FORK, LOWER	TX	SCURRY	1956	3320	4,561	1,227,148	
49043333	8	KERMIT, SE.	TUBB	TX	WINKLER	1965	6211	12,037	1,012,432	
49099500	7C	KETCHUM MT.	CLEAR FORK	TX	IRION	1955	4548	295,594	9,226,117	
49129066	8	KEYSTONE	CLEAR FORK	TX	WINKLER	1958	5739	53,239	5,291,790	
49129396	8	KEYSTONE	HOLT	TX	WINKLER	1943	4800	515,675	44,955,406	
49133001	8	KEYSTONE, SOUTH		TX	WINKLER	1958	6470	30,539	3,276,871	
52624900	8	LEA	TUBB	TX	CRANE	1955	4448	19,898	1,842,206	
52872001	8A	LEE HARRISON		TX	LUBBOCK	1941	4870	268,977	15,622,248	
52916500	8A	LEEPER	GLORIETA	TX	TERRY	1958	5896	447,007	14,672,329	
53759333	8A	LINKER	CLEAR FORK	TX	HOCKLEY	1961	7162	112,546	1,953,860	
55953250	8	LYLES	CLEAR FORK	TX	CRANE	1970	3170	18,836	2,423,992	

Table 22, continued. Leonard Restricted Platform Carbonate play (play 117).

RRC RESN	RRC	FLDNAME	RESNAME	STATE	COUNTY	DISCYR	DEPTHTOP	2000 PROD	CUMPROD	SUBPLAY
57774275	8	MARTIN	CONSOLIDATED	TX	ANDREWS	2000	7490	463,407	8,977,662	
57774664	8	MARTIN	TUBB	TX	ANDREWS	1955	6260	50,355	2,115,646	
59563333	8	MCKEE	CLEAR FORK, LOWER	TX	CRANE	1950	4050	5,720	1,078,221	
60698664	7C	MERTZON	SAN ANGELO	TX	IRION	1955	1648	6,811	3,430,892	
60873426	8	METZ	GLORIETTA	TX	ECTOR	1959	4426	21,951	1,802,537	
62079500	8A	MIRIAM	GLORIETA 4740	TX	LYNN	1966	4867	13,720	1,145,553	
62415083	8	MONAHANS	CLEAR FORK	TX	WARD	1945	4750	216,894	19,445,953	
62417110	8	MONAHANS, NORTH	CLEARFORK	TX	WINKLER	1987	5610	80,297	1,146,607	
64890750	8	NELSON	WICHITA	TX	ANDREWS	1948	7160	3,776	2,354,254	
65567300	8	NIX	CLEARFORK	TX	ANDREWS	1989	7036	64,986	2,269,877	
65572001	8	NIX, SOUTH		TX	ANDREWS	1954	7386	34,829	3,279,283	
67899001	8A	OWNBY		TX	YOAKUM	1941	5350	341,910	19,365,908	
67899400	8A	OWNBY	CLEAR FORK, UPPER	TX	YOAKUM	1959	6592	663,398	22,886,861	
69351166	8	PAROCHIAL-BADE	CLEAR FORK	TX	STERLING	1954	2211	47,566	4,764,467	
70537924	8	PENWELL	4500	TX	ECTOR	1948	4410	0	2,805,483	
70537066	8	PENWELL	CLEAR FORK	TX	ECTOR	1953	4996	31,481	1,878,499	
70537462	8	PENWELL	GLORIETA	TX	ECTOR	1953	4420	24,417	7,345,775	
68101500	8A	P. H. D.	GLORIETA	TX	GARZA	1955	4296	54,844	2,535,850	
72552500	8A	POST	GLORIETA	TX	GARZA	1950	2700	193,539	15,161,894	
72995001	8A	PRENTICE		TX	YOAKUM	1951	5940	68,854	48,873,597	
72995498	8A	PRENTICE	6700	TX	YOAKUM	1950	6700	2,294,110	150,194,889	
72995166	8A	PRENTICE	CLEAR FORK, LOWER	TX	YOAKUM	1955	8130	52,878	3,778,472	
74450300	7C	RAMON	LEONARD	TX	SCHLEICHER	1980	2617	150,855	1,177,882	
76093666	8A	REVILO	GLORIETA	TX	SCURRY	1955	2624	60,635	13,908,430	
76707001	8A	RILEY, NORTH		TX	GAINES	1947	6930	1,280,855	44,651,363	
77247600	8	ROBERDEAU	CLEAR FORK, UPPER	TX	CRANE	1963	3000	5,823	2,149,749	
77252111	8	ROBERDEAU, S.	CLEAR FORK LOWER	TX	CRANE	1965	3330	10,302	1,184,878	
77252888	8	ROBERDEAU, S.	TUBB	TX	CRANE	1967	3321	18,149	2,161,929	
77318666	8A	ROBERTSON, N.	CLEAR FORK 7100	TX	GAINES	1956	7114	3,949,386	176,656,655	
77622550	7C	ROCK PEN	CLEAR FORK	TX	IRION	1988	3840	34,272	1,181,195	
77643333	8A	ROCKER -A-	CLEAR FORK	TX	GARZA	1958	3236	19,900	1,269,266	
77643666	8A	ROCKER -A-	GLORIETA	TX	GARZA	1955	3082	59,510	4,308,818	
78168500	8A	ROPES, E.	CLEAR FORK	TX	HOCKLEY	1964	6036	35,196	3,017,622	
78936600	8	RUNNING W	TUBB	TX	CRANE	1962	4340	3,844	1,197,246	
78938500	8	RUNNING W, N.	HOLT	TX	CRANE	1964	4008	12,606	1,093,983	
79002166	8A	RUSSELL	CLEARFORK 7000	TX	GAINES	1943	7300	389,816	63,297,892	
79002332	8A	RUSSELL	GLORIETA 6100	TX	GAINES	1942	6100	95,004	9,018,065	
79004750	8A	RUSSELL, NORTH	6600	TX	GAINES	1957	6736	89,005	2,412,699	
80473620	8	SAND HILLS	SAN ANGELO, UPPER	TX	CRANE	1963	3618	20,568	3,375,873	
80473682	8	SAND HILLS	TUBB	TX	CRANE	1930	4500	912,916	102,067,768	
82225284	8A	SEMINOLE	SAN ANGELO	TX	GAINES	1947	6536	104,349	8,777,639	
82233600	8A	SEMINOLE, W.	LEONARD	TX	GAINES	1956	8742	0	1,473,334	
82570100	8	SHAFTER LAKE	CLEAR FORK	TX	ANDREWS	1948	6910	438,894	10,252,003	
82710166	8A	SHARON RIDGE	CLEAR FORK	TX	SCURRY	1950	2994	824,804	40,352,615	
83991400	8A	SLAUGHTER	CLEAR FORK 7190	TX	HOCKLEY	1966	7332	203,399	2,696,681	
84257333	8	SMITH	CLEAR FORK	TX	ANDREWS	1950	7340	48,817	1,213,636	
84345001	8A	SMYER		TX	HOCKLEY	1944	5980	562,854	48,419,531	
84469001	8	SNYDER		TX	HOWARD	1937	2800	553,905	43,595,719	
86175500	8A	STINNETT, SE.	CLEAR FORK	TX	LUBBOCK	1963	4585	100,717	2,749,554	
86252400	8A	STOCKYARD	CLEARFORK, UPPER	TX	GAINES	1991	6480	226,342	1,976,951	
87143500	8	SUN VALLEY	TUBB, LOWER	TX	PECOS	1969	3272	22,151	1,874,552	
87145500	8	SUN VALLEY, N.	TUBB, LOWER	TX	PECOS	1969	3363	13,236	1,261,965	
89010700	8A	TEX-MEX, SE.	WICHITA ALBANY	TX	GAINES	1983	7498	213,664	5,335,900	
89024333	8A	TEX-PAC	CLEAR FORK	TX	GAINES	1956	8290	3,113	1,886,905	
90188001	7C	TIPPETT		TX	CROCKETT	1947	6100	1,897	3,627,887	
90188415	7C	TIPPETT	LEONARD, LOWER	TX	CROCKETT	1962	5067	49,749	4,979,264	
91903333	8	TURNER-GREGORY	CLEAR FORK	TX	MITCHELL	1955	2668	152,698	10,555,530	
88071696	8	TXL	TUBB	TX	ECTOR	1950	6158	1,321,643	56,553,202	
92450001	8	UNION		TX	ANDREWS	1943	7459	25,373	16,655,594	
93234500	8A	VAREL	GLORIETA	TX	SCURRY	1955	2680	9,478	1,559,599	
93852750	8	VINCENT	CLEAR FORK, LOWER	TX	HOWARD	1977	4410	11,131	3,111,060	
95152475	8	WARD-ESTES, N.	WICHITA - ALBANY	TX	WARD	1995	6581	207,473	1,247,410	
95245500	8A	WARHORSE	CLEARFORK, UP.	TX	TERRY	1975	6801	31,639	3,346,790	
95431001	8A	WASSON 72		TX	YOAKUM	1940	7200	3,095,164	109,696,671	
95400333	8A	WASSON, NE.	CLEAR FORK	TX	YOAKUM	1954	7800	651,891	20,763,808	
96166333	8	WELLAW	CLEAR FORK, LO.	TX	PECOS	1967	3094	0	1,181,678	
96373400	8	WENTZ	CLEAR FORK	TX	PECOS	1953	2415	54,010	5,045,383	
96563001	8	WESTBROOK		TX	MITCHELL	1921	3100	1,086,214	106,699,704	
96565500	8	WESTBROOK, EAST	CLEAR FORK	TX	MITCHELL	1975	3166	48,233	2,233,993	
97057500	8A	WHITHARRAL	CLEAR FORK, LO.	TX	HOCKLEY	1971	6938	90,782	3,909,654	
94432500	8A	WTG	GLORIETA	TX	GARZA	1979	3232	70,399	2,712,643	
99070200	8	WYNNE	CLEAR FORK, UP.	TX	CRANE	1972	3090	8,058	1,435,782	

Table 22, continued. Leonard Restricted Platform Carbonate play (play 117).

RRC RESN	RRC	FLDNAME	RESNAME	STATE	COUNTY	DISCYR	DEPTHTOP	2000 PROD	CUMPROD	SUBPLAY
		ATOKA	GLORIETA YESO	NM	EDDY	1983	2660	124,457	4,031,176	UPPER YESO
		BLINEBRY O & G	BLINEBRY	NM	LEA	1945	5600	727,220	41,171,199	BLINEBRY
		DOLLARHIDE	TUBB DRINKARD	NM	LEA	1951	6616	441,314	24,207,673	DRINKARD
		DRINKARD	DRINKARD	NM	LEA	1944	6500	330,675	74,707,203	DRINKARD
		EUNICE NORTH O & G	BLINEBRY TUBB DRINKARD	NM	LEA	1987	5700	741,238	24,720,888	BLINEBRY
		FOWLER	UPPER YESO	NM	LEA	1950	5705	33,803	4,923,367	UPPER YESO
		HOBBS	DRINKARD	NM	LEA	1952	6880	23,413	3,091,100	DRINKARD
		HOBBS	UPPER BLINEBRY	NM	LEA	1968	5870	56,680	6,402,273	BLINEBRY
		HOUSE	DRINKARD	NM	LEA	1949	6980	23,377	1,678,305	DRINKARD
		JUSTIS	BLINEBRY	NM	LEA	1958	5000	100,203	9,680,025	BLINEBRY
		JUSTIS	BLINEBRY TUBB DRINKARD	NM	LEA	1992	5720	320,279	30,206,714	TUBB
		JUSTIS	TUBB DRINKARD	NM	LEA	1959	5837	90,980	3,869,009	DRINKARD
		KNOWLES WEST	DRINKARD	NM	LEA	1975	8236	17,108	2,185,907	DRINKARD
		LOVINGTON	PADDOCK	NM	LEA	1952	6150	158,011	17,571,938	UPPER YESO
		MALJAMAR	PADDOCK	NM	EDDY	1951	5300	31,848	1,299,622	UPPER YESO
		MONUMENT	BLINEBRY	NM	LEA	1948	5660	65,875	10,134,918	BLINEBRY
		MONUMENT	PADDOCK	NM	LEA	1948	5190	121,460	10,547,574	UPPER YESO
		MONUMENT	TUBB	NM	LEA	1959	6400	153,027	5,109,750	TUBB
		NADINE WEST	PADDOCK BLINEBRY	NM	LEA	1980	6008	160,227	3,477,154	BLINEBRY
		OIL CENTER	BLINEBRY	NM	LEA	1962	5907	47,294	8,244,514	BLINEBRY
		PADDOCK	PADDOCK	NM	LEA	1945	5170	217,867	30,191,406	UPPER YESO
		PADDOCK SOUTH	PADDOCK	NM	LEA	1957	5100	8,397	2,816,108	UPPER YESO
		PENASCO DRAW	SAN ANDRES YESO	NM	EDDY	1982	2250	22,130	2,284,403	UPPER YESO
		SKAGGS	DRINKARD	NM	LEA	1953	6850	44,835	2,986,271	DRINKARD
		SKAGGS	GLORIETA	NM	LEA	1958	5250	10,421	1,895,880	UPPER YESO
		TEAGUE	BLINEBRY	NM	LEA	1967	5400	371,846	6,373,727	BLINEBRY
		TUBB OIL & GAS	TUBB	NM	LEA	1979	6000	54,651	7,131,218	TUBB
		VACUUM	BLINEBRY	NM	LEA	1963	6600	31,646	2,323,848	BLINEBRY
		VACUUM	DRINKARD	NM	LEA	1962	7600	255,689	4,363,153	DRINKARD
		VACUUM	GLORIETA	NM	LEA	1963	6100	1,130,709	73,520,926	UPPER YESO
		WARREN	TUBB	NM	LEA	1958	6500	15,848	1,525,346	TUBB
		WARREN OIL & GAS	BLINEBRY TUBB	NM	LEA	1957	5900	207,046	5,407,698	BLINEBRY
		WEIR	BLINEBRY	NM	LEA	1961	5700	34,399	1,786,126	BLINEBRY
		WEIR EAST	BLINEBRY	NM	LEA	1962	5800	19,540	1,010,761	BLINEBRY
	Totals							**49,928,957**	**3,297,197,998**	

The sequence-scale architecture of Leonardian rocks in the Permian Basin has been documented from integrated outcrop and subsurface studies by Fitchen and others (1995). Ruppel and others (2000) described the high-frequency sequence- and cycle-architecture of the lower Clear Fork, Tubb, and upper Clear Fork in outcrops of the Sierra Diablo Mountains, west Texas.

Leonardian rocks on the Central Basin Platform and Northwest and Eastern Shelves were deposited in restricted, low-energy depositional conditions that occurred on a shallow-water carbonate platform (fig. 58). Leonardian rocks are dominated by cyclic alternations of peritidal, tidal-flat deposits and shallow-water, subtidal rocks (Presley, 1987; Ruppel, 1992; Ruppel and

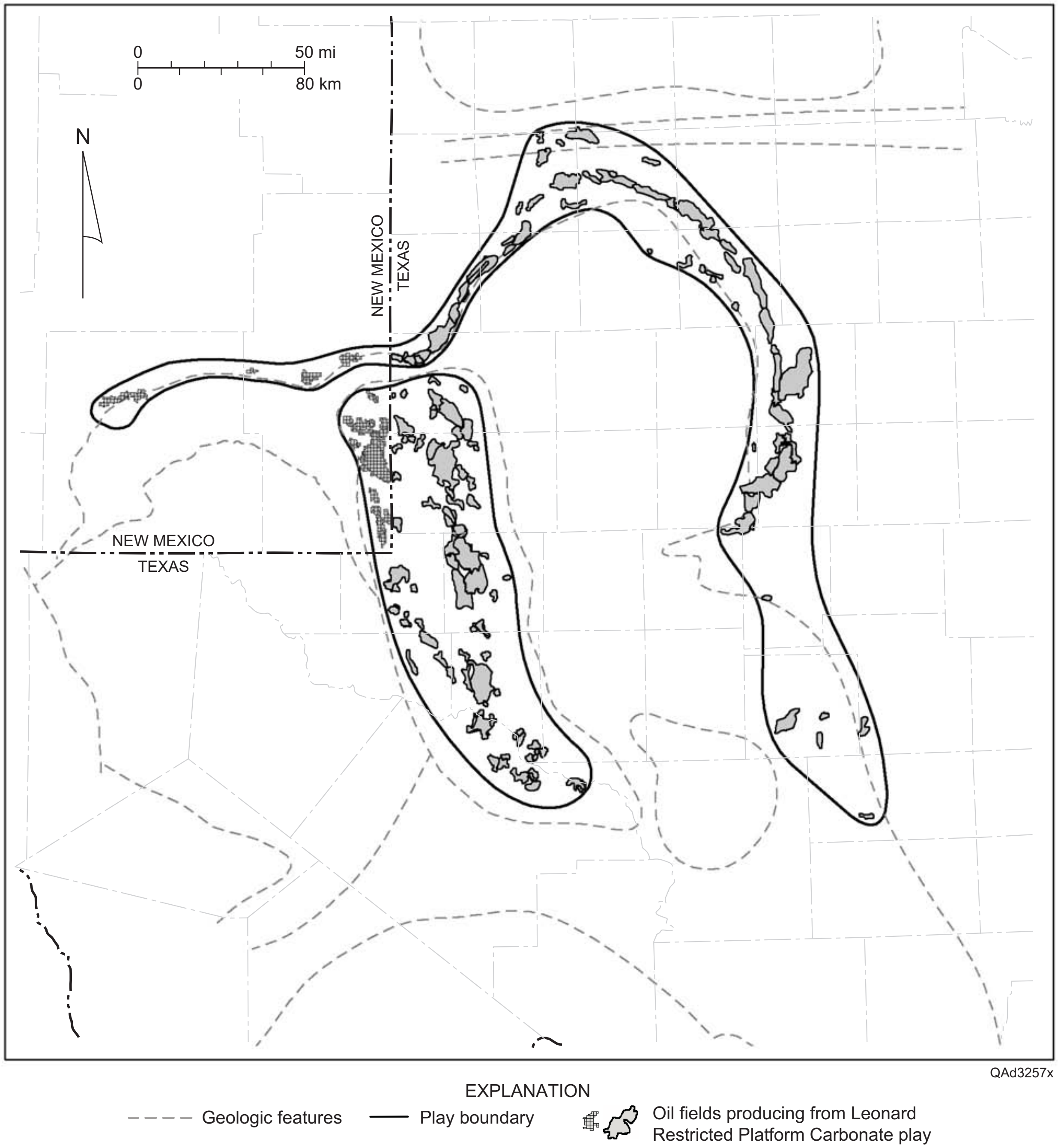

Figure 57. Play map for the Leonard Restricted Platform Carbonate play, showing location of reservoirs having >1 MMbbl cumulative production, the play boundary, and geologic features. See figure 1 for county names and figure 2 for identification of geologic features.

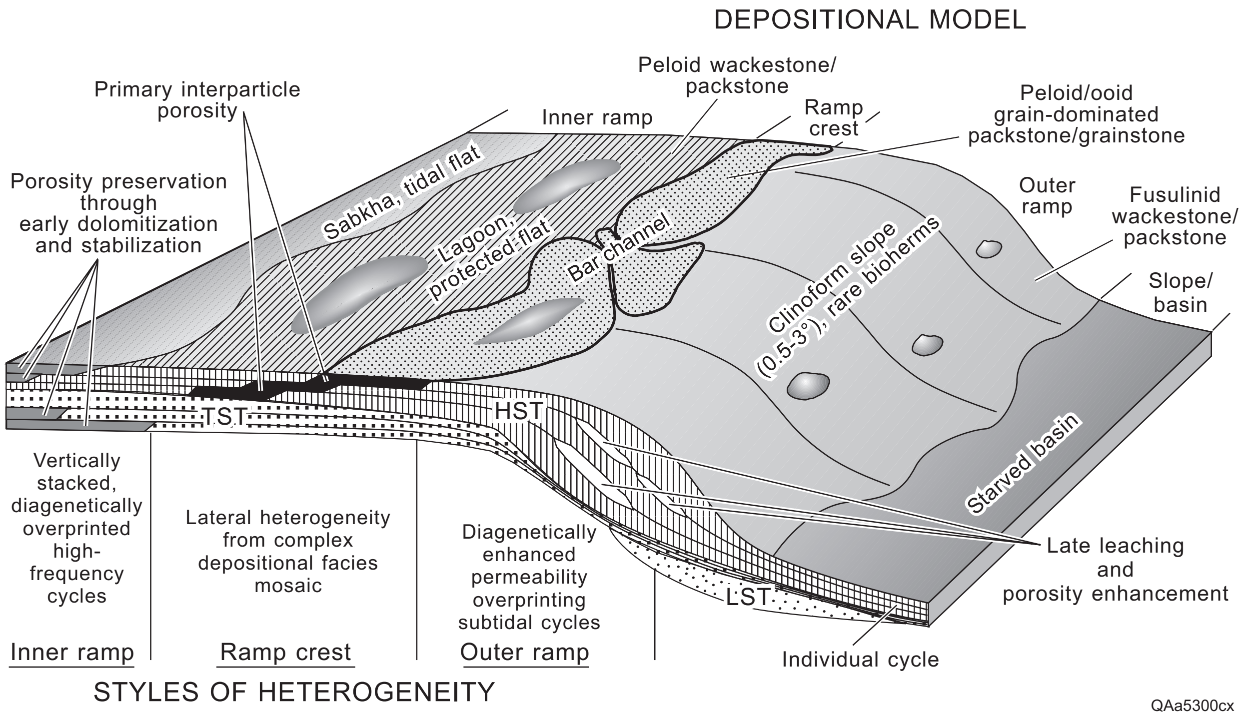

Figure 58. Depositional model for middle Permian carbonate platform deposits in the Permian Basin. From Kerans and Ruppel (1994).

others, 1995; Atchley and others, 1999). The Tubb and Glorieta are composed dominantly of siliciclastic-rich tidal-flat deposits (Ruppel, 2002). High-frequency cycles, averaging ~3 to 6 ft (~1 to 2 m) in thickness, are composed of (1) basal, mud-rich, subtidal rocks; (2) overlying, grain-dominated, subtidal rocks; and (3) cycle-capping, tidal-flat rocks (Ruppel, 1992, 2002; Ruppel and others, 2000). Cycle sets, 20 to 40 ft (6 to 12 m) in thickness, are defined by stacking of high-frequency cycles. These cycle sets, plus local variations in paleotopography, controlled the development of depositional and diagenetic fabrics (Atchley and others, 1999; Ruppel, 2002). Although early diagenesis apparently preserved porosity at cycle tops, petrophysical properties are dominantly related to depositional facies (Ruppel, 2002). Tidal-flat deposits have high porosity but low permeability because their pore structure is dominated by fenestral vugs. The best reservoir quality occurs in grain-dominated, dolomitized, subtidal rocks having high porosity and relatively high permeability and oil saturation associated with intergranular and intercrystalline pores (Atchley and others, 1999; Ruppel, 2002; Jones and others, 2003).

Stratigraphically controlled petrophysical variability in the South Wasson Clear Fork reservoir (Wasson 72) in Yoakum County produces flow-unit-scale layering that results in highly stratified reservoir behavior (Jennings and others, 2002). South Wasson Clear Fork is undergoing the only CO_2 flood currently being conducted in a Clear Fork reservoir in the Permian Basin. The CO_2 flood, initiated in 1986 in the early stages of the waterflood, uses a 2:1 WAG injection ratio (Kinder Morgan, 2004).

A reservoir-characterization study of Fullerton Clear Fork field (fig. 59), Andrews County, developed techniques to improve the resolution and predictability of key reservoir properties for construction of more accurate reservoir models. The integration of cycle-stratigraphic (Ruppel, 2003), rock-fabric (Jones and others, 2003), and 3-D seismic data (Zeng and others, 2003) provided a robust basis for distributing reservoir rock and fluid properties (Wang and others, 2003). A cycle-stratigraphic framework for the lower Clear Fork, Wichita, and Abo reservoir intervals at Fullerton field was constructed by integrating information from outcrop analogs in the Sierra Diablo Mountains of west Texas (Ruppel and others, 2000) with >1,500 ft (>5,000 m) of core from the field (figs. 59, 60).

To create a high-resolution permeability model of Fullerton field, core samples were assigned to a petrophysical class on the basis of fabric, pore type, lithology, and crystal size, and then class-specific transforms were used to calculate permeability from wireline-log porosity (Jones and others, 2003). Stratigraphically keyed vertical changes in petrophysical class were mapped throughout a study area within the field, and calculated permeabilities were used to populate a 3-D model that incorporates stratigraphic architecture, rock-fabric data, and

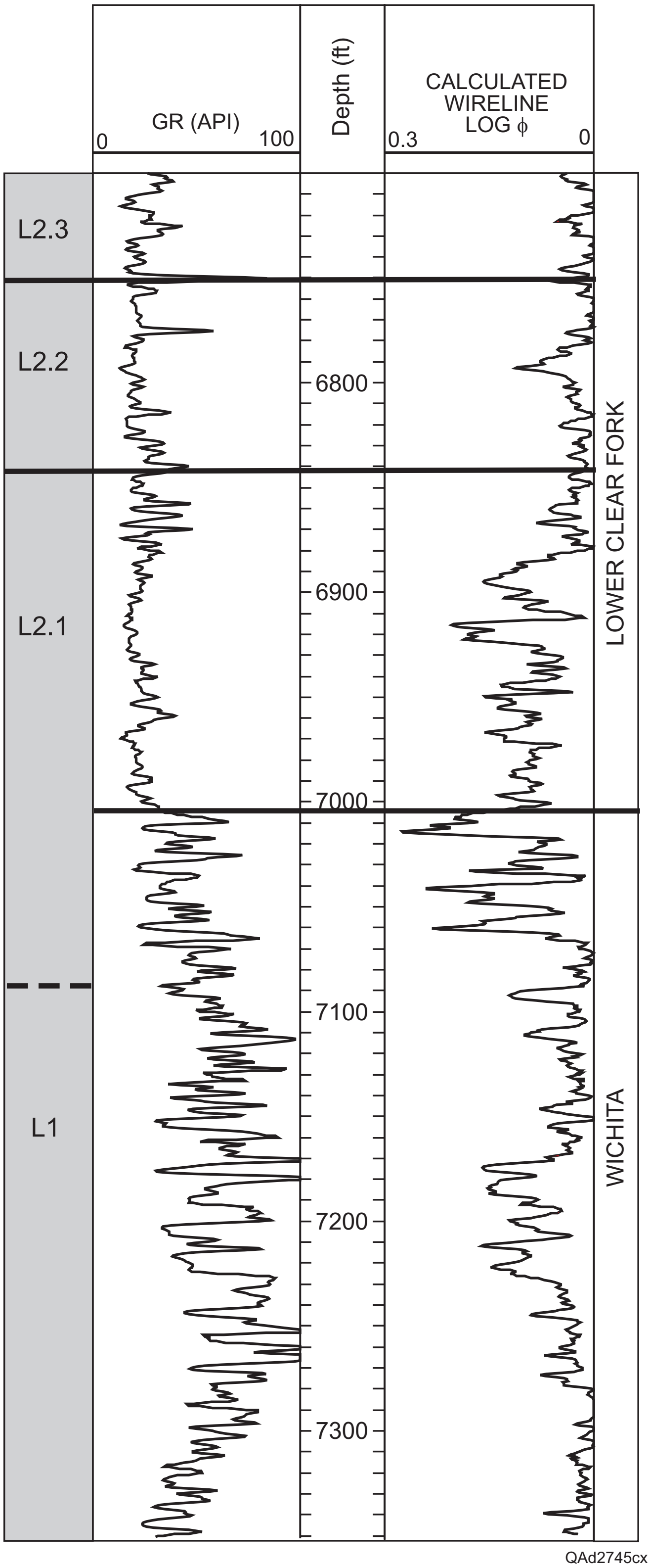

Figure 59. Typical log from Fullerton Clear Fork reservoir, from the Fullerton Clearfork Unit 5927 well. From Jones and others (2003). L1=Leonardian sequence 1; L2.1, L2.2, and L2.3 are Leonardian high-frequency sequences.

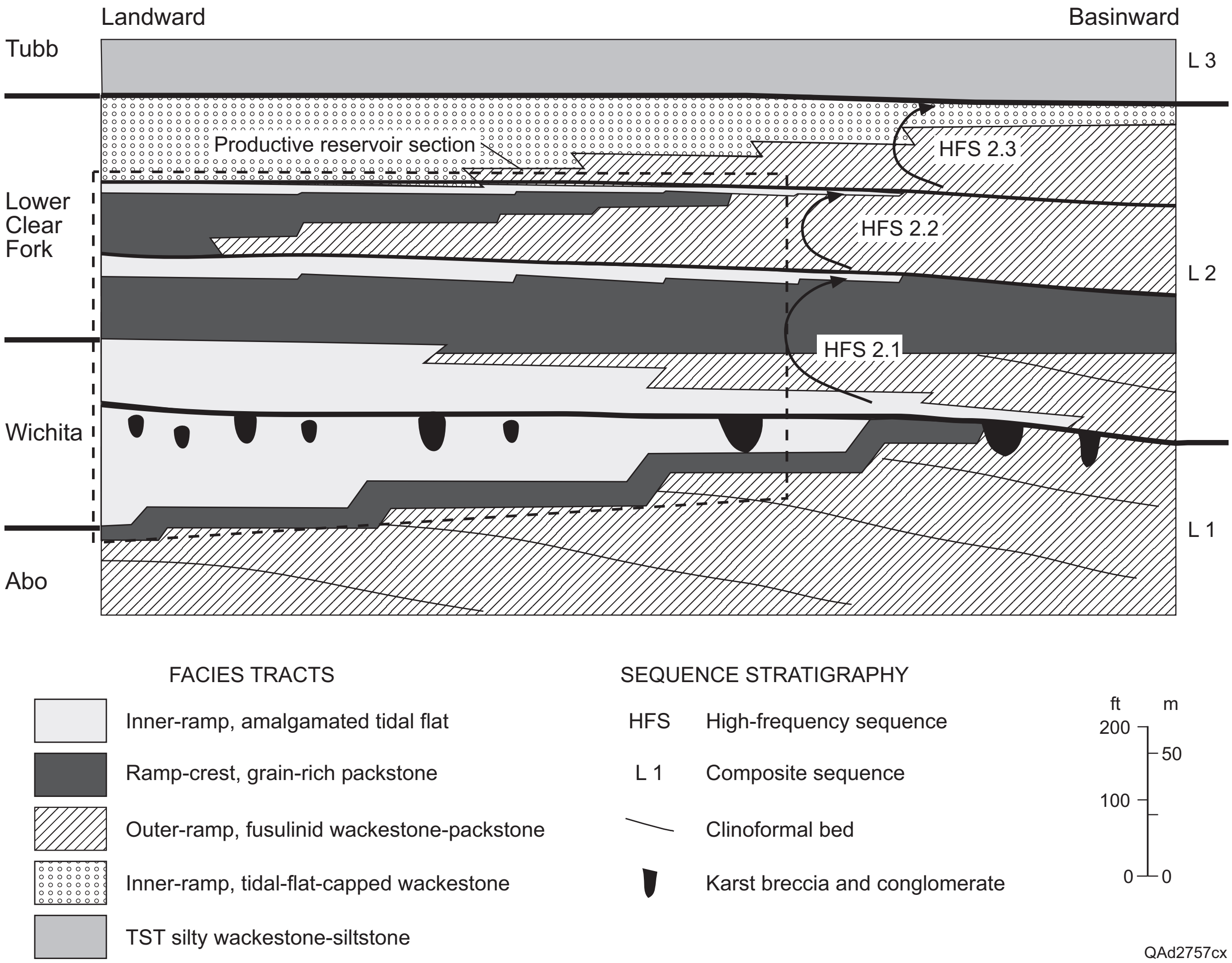

Figure 60. Sequence stratigraphic model of the Clear Fork reservoir succession at Fullerton field, Andrews County, Texas. From Ruppel (2003).

petrophysical data. Porosity, permeability, and water saturation were modeled deterministically using a 2,000-ft (610-m) search radius. In general, the lowermost sequence of the lower Clear Fork has the best porosity and permeability. The estimated OOIP for the study area calculated from this model is 185 MMbbl (2.94×10^7 m^3). Because only 40 MMbbl (6.36×10^6 m^3) has been produced to date from this area, 145 MMbbl (2.31×10^7 m^3), or about 80 percent of the OOIP, probably remains. Results of reservoir characterization have been used to target future infill drilling and possible enhanced oil recovery (EOR) by CO_2 flood.

Reservoir characterization and flow modeling of the North Robertson Unit in Gaines County identified infill drilling targets by locating areas having (1) good reservoir quality in porous grainstone facies; (2) better flow capacity, as indicated by permeability-thickness; and (3) substantial remaining mobile oil (Montgomery, 1998; Montgomery and others, 1998; Nevans and others, 1999). New injector and producer wells were drilled using a line-drive pattern to lower costs, optimize injectivity and pressure support, and improve sweep (Nevans and others, 1999). Incremental production was increased by ~900 bbl/d (~143 m^3/d), and then leveled out at 450 to 500 bbl/d (32 to 36 bbl/d/well) [71.5 m^3/d to 79.5 m^3/d (5.1 to 5.7 m^3/d/well)] (Montgomery and others, 1998). The mud log, used with a porosity and resistivity log, was determined to be an effective, low-cost tool for identifying pay zones (Nevans and others, 1999).

Most of the fields in the play produce from large asymmetric anticlines developed over basement structures (Montgomery, 1998). Reservoir net pay in the play ranges widely, from 5 to 360 feet (Holtz and others, 1992; Montgomery, 1998). Porosity ranges from 3 to 23 percent and averages 11.0 percent; permeability ranges from 0.2 to 30 md (0.2 to 30×10^{-3} μm^2) and averages 5 md (5×10^{-3} μm^2) (Holtz and others, 1992).

Reservoirs of the Leonard Restricted Platform Carbonate play in New Mexico lie on the Central Basin Platform and along a curvilinear trend near the south margin of the Northwest Shelf (fig. 57). There are 102 known, discovered Leonard platform reservoirs in New Mexico, and 34 reservoirs have produced >1 MMbbl (1.59×10^5 m^3) (fig. 57; table 22). Most of these reservoirs are productive from platform dolostones and limestones, but some are productive from sandstones.

The Leonard Restricted Platform Carbonate play in New Mexico is productive from reservoirs in the Drinkard, Tubb, Blinebry, and Paddock Members of the Yeso Formation and in the Glorieta Formation (fig. 3). In the New Mexico part of the play, four subplays are recognized: (1) Drinkard, (2) Tubb, (3) Blinebry, and (4) upper Yeso (table 23). Maps of the four subplays are included in pdf format on the CD that accompanies this report, in addition to a pdf map that shows all reservoirs together on one map.

Production from the four subplays is mostly from stacked reservoirs on the Central Basin Platform. On the Northwest Shelf, however, the lower reservoirs (Drinkard, Tubb, Blinebry) are productive from only the east part of the play trend. Production from the upper Yeso reservoirs (Paddock and Glorieta) stretches from the New Mexico–Texas border westward into central Eddy County. The upper Yeso subplay is the most productive of the four Leonard subplays in New Mexico, as well as having the largest geographic extent (table 23). The stratigraphic distinction between the Paddock Member of the Yeso Formation and the Glorieta Formation is imprecise; many reservoirs correlated as Glorieta are actually Paddock (for example, the Vacuum Glorieta reservoir; Martin and Hickey, 2002).

Most reservoirs in the Leonard Restricted Platform Carbonate play in New Mexico are marine limestones and dolostones deposited on a restricted carbonate-dominated platform.

Table 23. The four New Mexico subplays of the Leonard Restricted Platform Carbonate play.

Subplay	**Principal productive stratigraphic units**	**Number of reservoirs with cumulative production of >1 MMbbl oil**	**Cumulative oil production from reservoirs with >1 MMbbl oil (MMbbl)**
Upper Yeso	Glorieta Formation Paddock Member of Yeso Formation	10	149
Blinebry	Blinebry Member of Yeso Formation	12	121
Tubb	Tubb Member of Yeso Formation	4	44
Drinkard	Drinkard Member of Yeso Formation	8	117

Carbonate reservoirs dominate the Drinkard, Blinebry, and Paddock sections. Fine-grained dolomitic sandstone reservoirs are dominant in some areas in the Tubb and Glorieta sections, but dolostone reservoirs are dominant elsewhere in the Tubb and Glorieta. Percentage of sandstone increases westward within the Glorieta, and sandstone reservoirs dominate the Glorieta section in the westernmost part of the play (Broadhead, 1993).

Drinkard reservoirs are productive from carbonates deposited in a variety of shelf and shelf-edge environments. On the Northwest Shelf, reservoir character in the Drinkard Member is related to the location of the underlying Abo reef trend (Martin and others, 1999; see play 116, Abo Platform Carbonate for a description of the Abo reef trend). In reservoirs located shoreward of the underlying Abo platform margin carbonate trend (for example, Vacuum Drinkard), reservoir facies are formed by patch reefs and associated grainstones. Reservoirs located basinward of the Abo trend (for example, Knowles West) are formed by foreslope oolite shoals. In the Justis Tubb Drinkard reservoir on the Central Basin Platform, the best-quality reservoir rocks are grain-dominated limestones; dolomitized grainstones are less porous and permeable (Hoffman, 2002).

Traps are generally formed by low-relief anticlines (fig. 61). A single structure may trap oil and gas in multiple pay zones. Depths to productive reservoirs range from 2,250 to 8,200 ft (690 to 2,500 m). In some reservoirs, facies variations can create porosity pinch-outs on anticlinal noses (fig. 62), as well as unevenness in reservoir quality across a structure, resulting in a stratigraphic component to trapping and production and internal compartmentalization of the reservoirs. Depositional variation within Leonardian stratal units influences the distribution of reservoir facies across an oil accumulation; grainstones, which are the primary productive facies

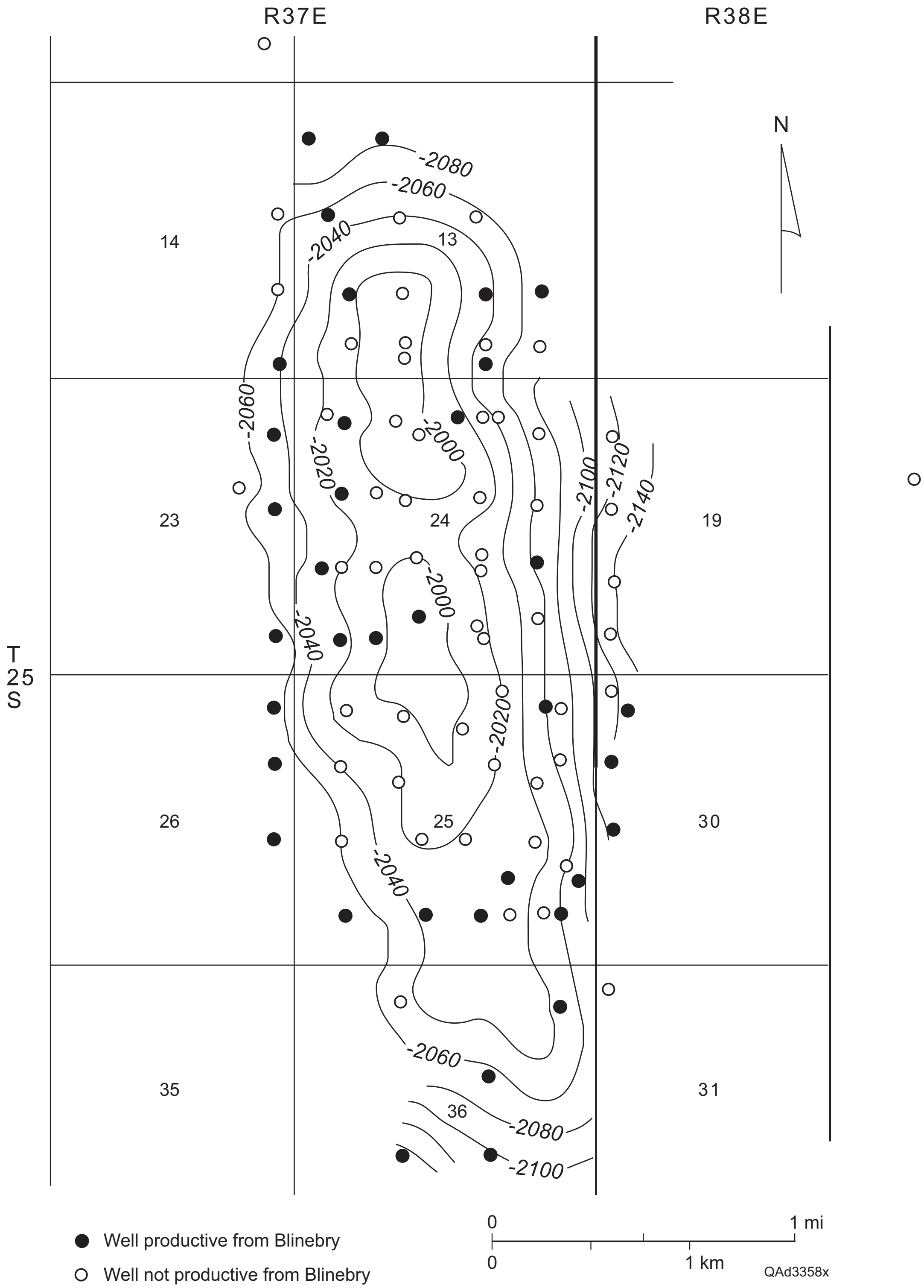

Figure 61. Structure contour map on top of Blinebry Member, Yeso Formation, Justis Blinebry reservoir. Datum is sea level. Contour interval equals 20 ft. After Marshall and Foltz (1960).

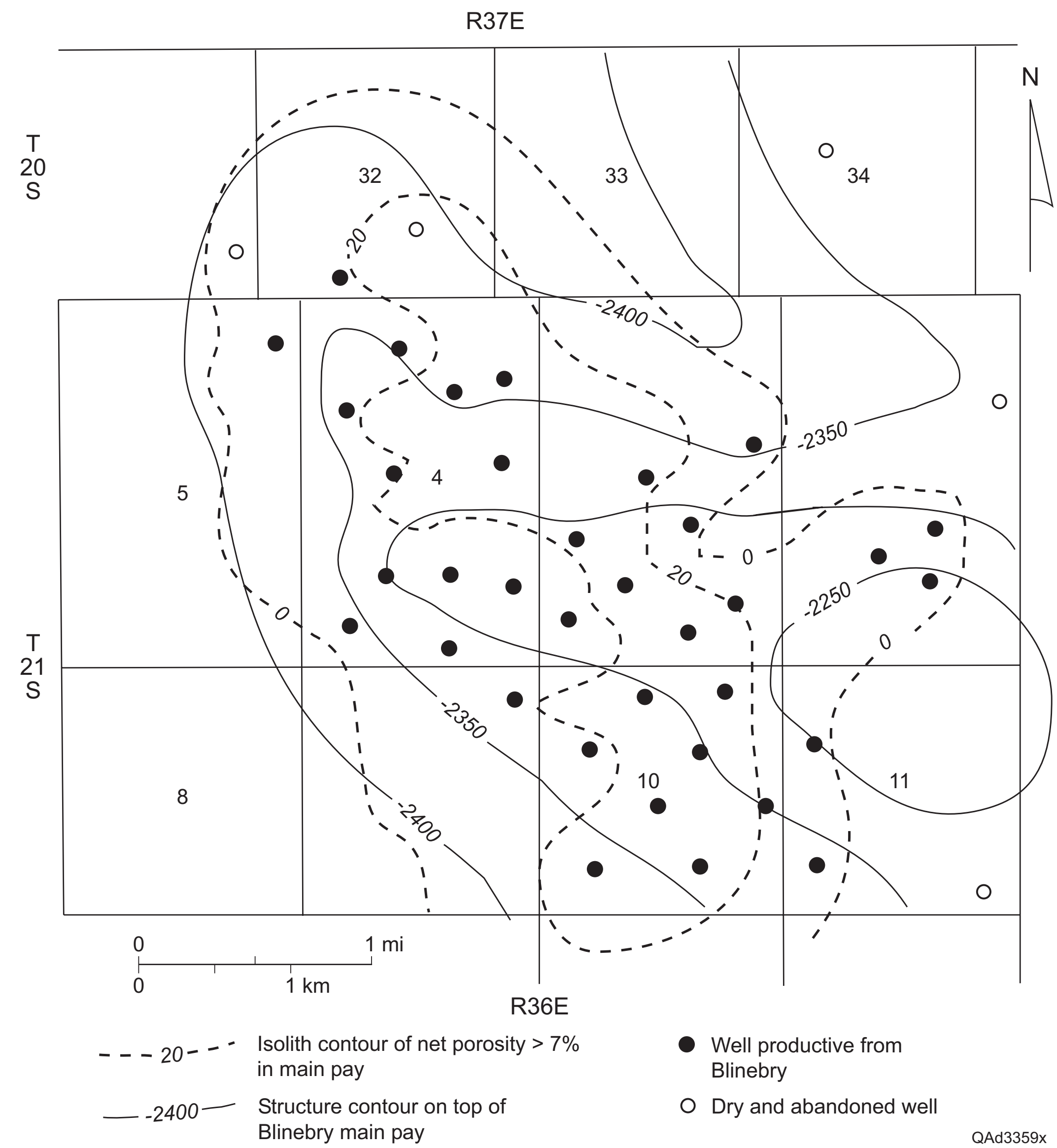

Figure 62. Structure contour map on top of the main Blinebry pay and isolith map of porosity >7 percent, Oil Center Blinebry reservoir. Datum is sea level. After Kincheloe and David (1977).

in many reservoirs, are not evenly distributed across an oil field but instead are concentrated in an oolite barrier facies, at least in the Paddock Member (fig. 63).

Many Leonard carbonate reservoirs are densely fractured. Natural fractures do not occur in all strata within a reservoir but may, instead, be confined to only a few stratigraphic intervals

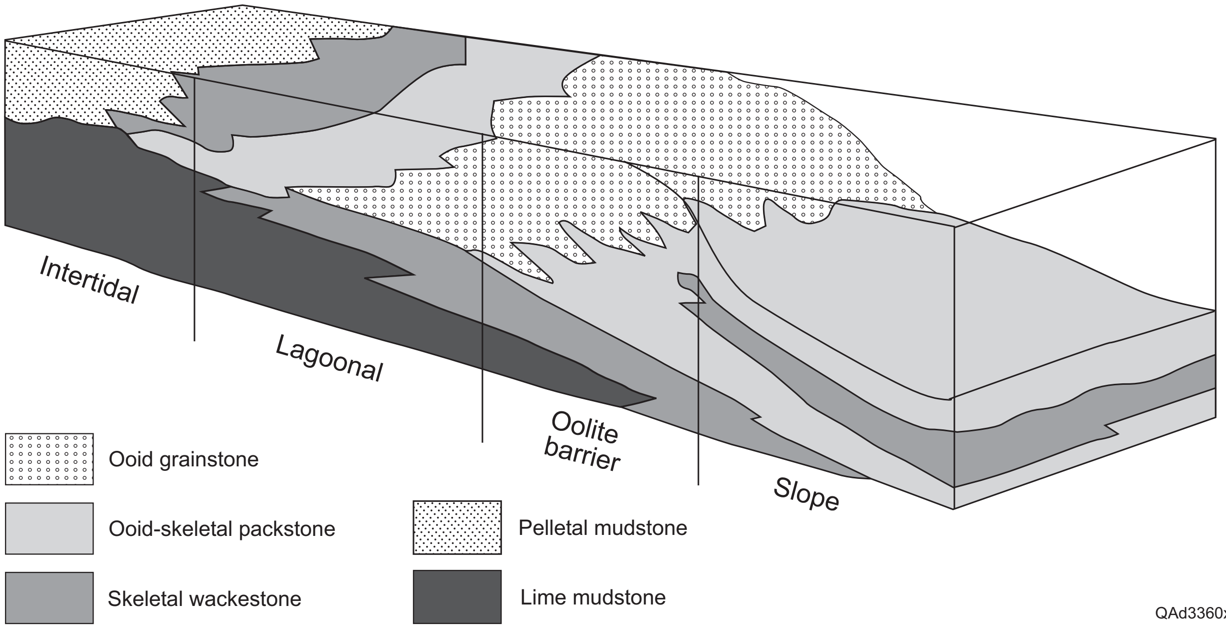

Figure 63. Block diagram of depositional environments in the Paddock Member of the Yeso Formation, Vacuum Glorieta reservoir. After Burnham (1991).

(Martin and Hickey, 2002). Therefore, waterflooding of reservoirs in enhanced recovery operations has often resulted in premature water breakthrough in fractured zones and has left significant volumes of oil unflooded and unrecovered in the nonfractured zones. Methods for optimizing recovery via waterflooding include the drilling of lateral wells in unfractured intervals (Martin and Hickey, 2002). The lateral boreholes are used for both production and water injection. In the Vacuum Glorieta West unit of the Vacuum Glorieta reservoir, horizontal laterals drilled into porous but unfractured reservoir zones are expected to result in increased incremental production of 2.6 MMbbl (4.13×10^5 m^3) (fig. 64; Martin and Hickey, 2002).

Anhydrite-filled fractures are characteristic of some Leonard carbonate reservoirs (Burnham, 1991). When present, they may compartmentalize the reservoir horizontally and,

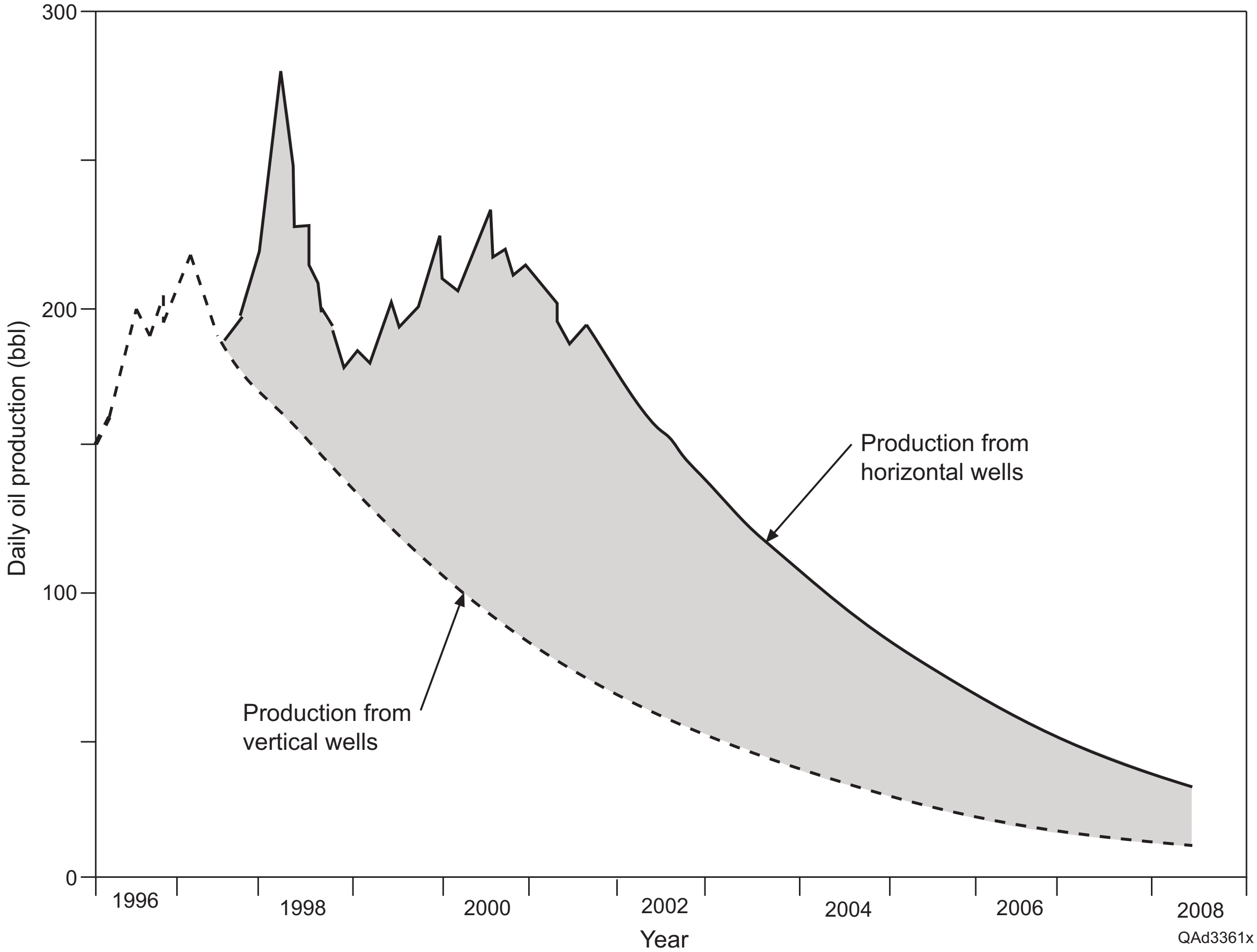

Figure 64. Daily oil production from Vacuum Glorieta West unit showing estimated incremental production that will be derived from the drilling of horizontal wells. From Martin and Hickey (2002).

as a result, be responsible for less than optimal production from standard spacing and patterns of vertical wells.

In the Dollarhide Drinkard reservoir, high-frequency sea-level fluctuations combined with deposition on an uneven paleotopographic surface resulted in a complex reservoir system composed of interbedded, landward- and seaward-stepping cycles; this architecture has given the reservoir a high degree of internal heterogeneity and compartmentalization (Fitchen and others, 1995; Ruppel and others, 1995; Johnson and others, 1997). Complex patterns of dolomitization controlled by depositional relations to intertidal and subtidal settings have also added heterogeneity to the reservoir. Texaco applied a sinusoidal horizontal drilling technique to optimize production (Johnson and others, 1997). This sinusoidal drilling resulted in a well that has been drilled laterally 2,000 ft (610 m) and has traversed 150 ft (46 m) of vertical section in the reservoir. The reservoir was treated with HCl before completion. The result was substantially increased initial production rates, which increased from 8 bbl/d (1.3 m^3/d) with original vertical completions to 70 bbl/d (11.1 m^3/d) from the lateral sinusoidal leg. Presumably the horizontal sinusoidal well either tapped isolated reservoir compartments that were not productive with the vertical wells or penetrated low-permeability portions of the reservoir that were not in adequate communication with the vertical well bore.

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Bone Spring Basinal Sandstone and Carbonate (Play 118)

Reservoirs of the Bone Spring Basinal Sandstone and Carbonate play lie within the north part of the Delaware Basin in New Mexico and stretch southward from the slope at the base of the Abo shelf edge toward the New Mexico–Texas border (fig. 65). There are 132 known, discovered reservoirs in this play, 16 of which have produced >1 MMbbl (1.59×10^5 m^3) (table 24). Cumulative production from these 16 reservoirs was 71 MMbbl (1.13×10^7 m^3) as of 2000. The Bone Spring Formation is Leonardian in age (fig. 3). Production from this play increased in the 1980's as several new reservoirs were discovered and subsequently declined during the middle and late 1990's as the newer reservoirs started to deplete. During 2000 total production from the play began to increase as a result of additional drilling and increased production in the Shugart North reservoir.

Reservoirs were deposited in a basinal setting seaward of the Abo shelf edge (fig. 66; see play 116). Production has been obtained from carbonate debris flows in the first, second, and third Bone Spring carbonates, as well as fine-grained sandstones in the first, second, and third

Table 24. Bone Spring Basinal Sandstone and Carbonate play (play 118).

RRC RESN	RRC	FLDNAME	RESNAME	STATE	COUNTY	DISCYR	DEPTHTOP	2000 PROD	CUMPROD
		AIRSTRIP	BONE SPRING	NM	LEA	1979	9329	13,176	2,427,057
		AIRSTRIP NORTH	BONE SPRING	NM	LEA	1986	9600	15,057	1,322,012
		EK	BONE SPRING	NM	LEA	1975	9450	37,524	1,883,915
		LEA	BONE SPRING	NM	LEA	1960	9480	25,700	3,341,316
		MESCALERO ESCARPE	BONE SPRING	NM	LEA	1984	8660	218,935	8,416,490
		MIDWAY	ABO	NM	LEA	1963	8850	8,689	2,877,582
		OLD MILLMAN RANCH	BONE SPRING	NM	EDDY	1991	6140	61,396	1,211,918
		QUAIL RIDGE	BONE SPRING	NM	LEA	1962	9315	8,501	1,718,885
		QUERECHO PLAINS	UPPER BONE SPRING	NM	LEA	1959	8538	76,542	2,370,677
		RED HILLS	BONE SPRING	NM	LEA	1992	12200	526,931	5,631,750
		RED TANK	BONE SPRING	NM	LEA	1992	8820	73,218	1,068,622
		SCHARB	BONE SPRING	NM	LEA	1963	10152	46,958	14,101,640
		SHUGART NORTH	BONE SPRING	NM	EDDY	1986	7680	1,005,857	8,808,302
		TAMANO	BONE SPRING	NM	EDDY	1985	8100	28,307	2,733,675
		TEAS	BONE SPRING	NM	LEA	1963	9300	56,336	1,150,363
		YOUNG NORTH	BONE SPRING	NM	LEA	1980	8416	252,027	11,639,256
		Totals						**2,455,154**	**70,703,460**

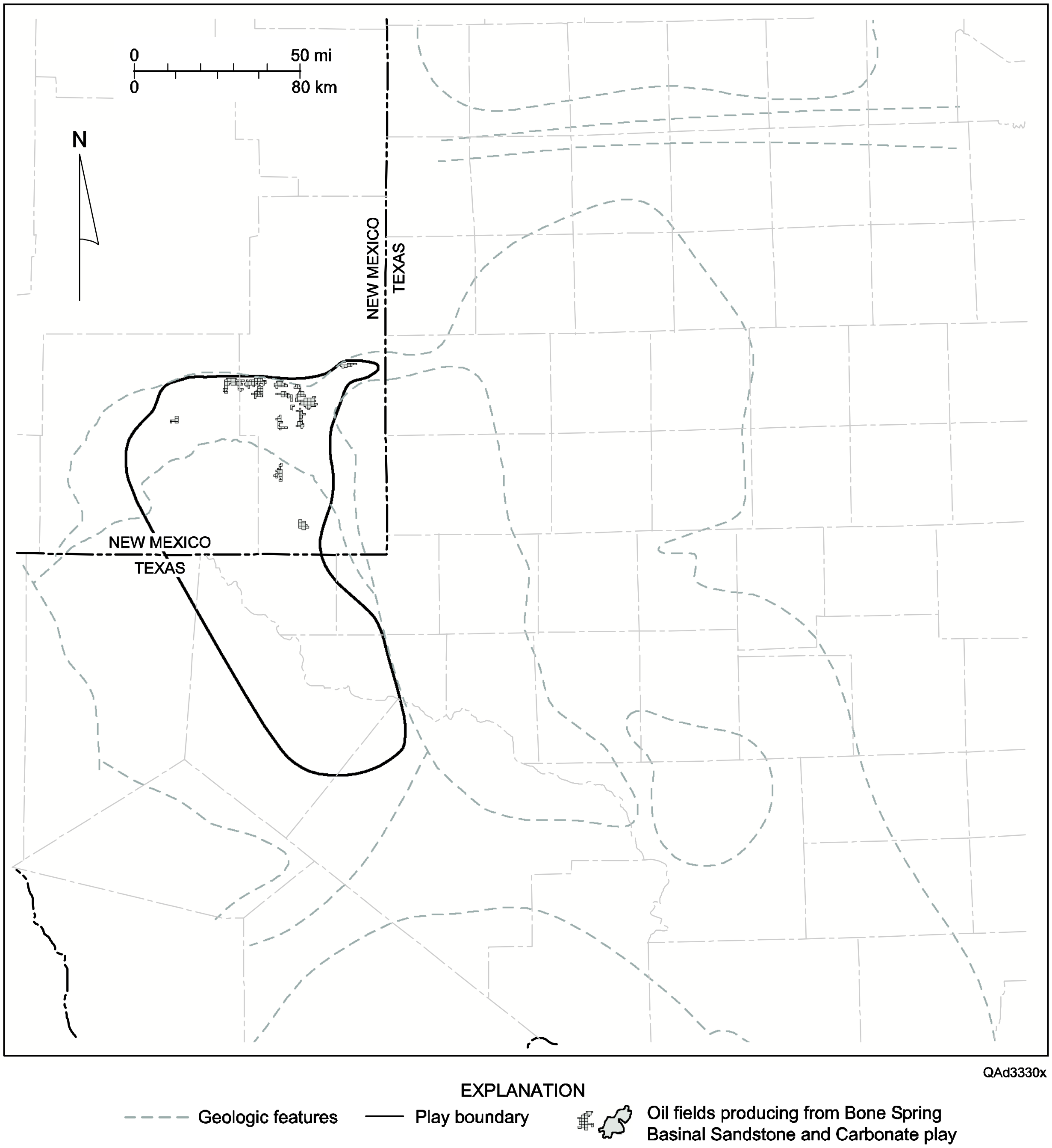

Figure 65. Play map for the Bone Spring Basinal Sandstone and Carbonate play, showing location of reservoirs having >1 MMbbl cumulative production, the play boundary, and geologic features. See figure 1 for county names and figure 2 for identification of geologic features.

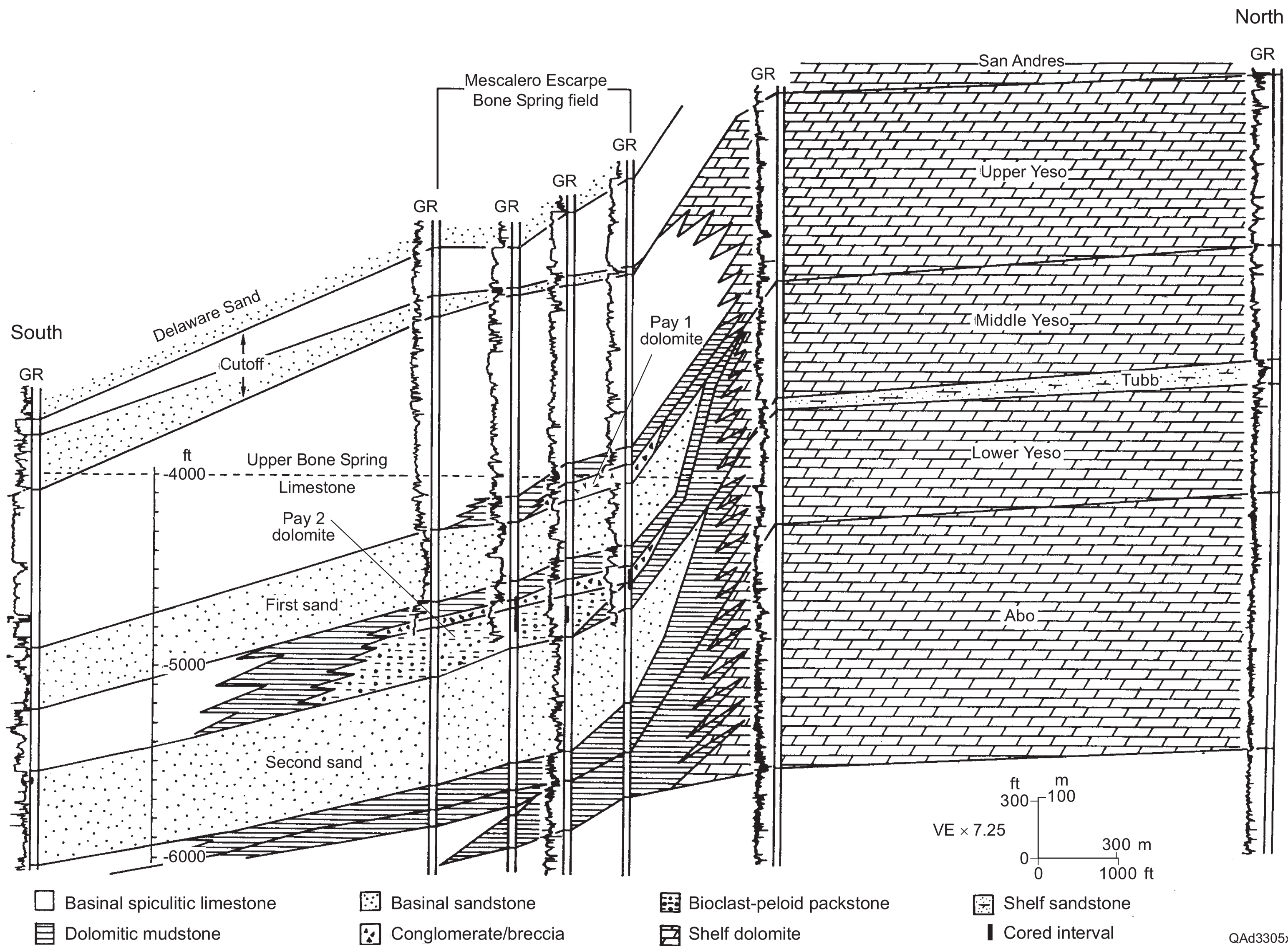

Figure 66. South-north cross section of Mescalero Escarpe reservoir showing southward depositional dip and transition from shelf facies of the Abo and Yeso Formations in the north to basinal carbonate and sandstone facies of the Bone Spring Formation in the south. After Saller and others (1989). See Saller and others (1989) for location of cross section.

Bone Spring sandstones (fig. 3) (Wiggins and Harris, 1985; Gawloski, 1987; Mazzullo and Reid, 1987; Saller and others, 1989; Montgomery, 1997; Downing and Mazzullo, 2000).

Carbonate debris flows form the primary Bone Spring reservoirs in the northernmost Delaware Basin and constitute the Bone Spring Carbonate subplay. These debris flows are located at the toe of slope of the Abo and Yeso shelf edge and were derived from carbonate detritus at the Abo and Yeso shelf margins. The reservoirs 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 and others, 1989), open fractures in dolopackstones have enhanced permeability. Traps are stratigraphic or combination structural-stratigraphic, with porous reservoirs contained in channels that pinch out depositionally updip as they rise onto the submarine slope to the north.

Siliciclastic turbidites have widespread distribution in the first, second, and third Bone Spring sandstones. The Bone Spring sandstone reservoirs constitute the Bone Spring Sandstone subplay. These turbidites consist of fine-grained sandstones cemented by dolomite and authigenic clays (Gawloski, 1987; Saller and others, 1989). They appear to have been deposited in a channel and fan system at the base of slope and on the basin plain (Montgomery, 1997; Pearson, 1999). Most reservoirs appear to be present in well-defined channels. Bone Spring sandstones are the primary reservoirs in fields more than 5 miles south of the shelf margin. Traps are stratigraphic or combination structural-stratigraphic, with porous reservoirs confined in channels that pinch out depositionally updip as they rise onto the submarine slope to the north. Recent drilling has extended the Bone Spring Sandstone subplay south into the Texas part of the Delaware Basin.

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Spraberry/Dean Submarine-Fan Sandstone (Play 119)

The Spraberry/Dean Submarine-Fan Sandstone play has produced 1,287 MMbbl (2.05×10^8 m^3) of oil from 40 reservoirs located along a north-south-oriented trend in the center of the Midland Basin (table 25, fig. 67). The play is estimated to have contained more than 10 Bbbl (1.59×10^9 m^3) of original oil in place (Tyler and others, 1984). Recovery efficiency of only 8 to 10 percent in Spraberry fields is typical after nearly 50 years of production, including waterflooding in some areas (Montgomery and others, 2000).

The Leonardian Spraberry and Dean sandstones (fig. 3) are similar in lithology and are made up of (1) very fine grained sandstone and coarse siltstone; (2) carbonate beds, sandy limestone, and minor sandstone; and (3) terrigenous shale (Handford, 1981; Guevara, 1988; Tyler and Gholston, 1988; Tyler and others, 1997). The Spraberry Trend Area Clear Fork reservoir, which produces from deepwater carbonate deposits, is assigned to the Wolfcamp/Leonard Slope and Basinal Carbonate play (115). The Spraberry and Dean were deposited as large basin-floor submarine-fan systems that were fed by turbidity currents and debris flows (Handford, 1981). Most of the production from this fine-grained, mud-rich, submarine-fan complex is from very fine grained sandstone and coarse siltstone units in the Spraberry at depths of 6,800 to 8,000 ft (2,075 to 2,440 m). The Spraberry has been divided into lower, middle, and upper intervals, and most production comes from thick (10 to 50 ft [3 to 15 m]), upward-coarsening sandstones in the upper and lower Spraberry (figs. 68, 69) (Guevara, 1988; Tyler and Gholston, 1988; Tyler and others, 1997). Regional updip pinch-out of Spraberry sandstones along the east margin of the Midland Basin (fig. 69) creates stratigraphic traps.

Matrix porosity ranges from 5 to 18 percent and permeability from 0.05 to 3 md (0.05 to 3×10^{-3} μm^2) (Montgomery and others, 2000). Low permeability results from the fine grain size, Play 25. Spraberry/Dean Submarine-Fan Sandstone play (play 119). 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
448200	8A	ACKERLY	DEAN SAND	TX	DAWSON	1954	8172	786,965	49,582,865
450900	8A	ACKERLY, NORTH	SPRABERRY	TX	DAWSON	1977	7739	149,571	2,936,419
702750	8A	ADCOCK	SPRABERRY	TX	DAWSON	1972	7556	23,587	1,268,187
7109875	7C	BENEDUM	SPRABERRY	TX	UPTON	1947	7593	65,313	24,699,962
11751200	8	BREEDLOVE	SPRABERRY	TX	MARTIN	1962	8350	50,272	2,400,927
11752666	8	BREEDLOVE, EAST	SPRABERRY	TX	MARTIN	1962	8180	37,477	2,347,842
11756500	8	BREEDLOVE, SOUTH	SPRABERRY	TX	MARTIN	1962	8084	60,512	3,979,507
12060500	8A	BRITT	SPRABERRY	TX	DAWSON	1957	7396	10,986	1,095,217
14627333	8A	CAIN	SPRABERRY	TX	GARZA	1959	4916	2,511	1,370,936
18790700	8A	CLAYTON RANCH, N.	SPRABERRY	TX	BORDEN	1985	5738	312,709	2,273,366
20482001	7C	COPE		TX	STERLING	1951	6031	51,018	12,672,984
21090500	8A	COULTER	SPRABERRY	TX	GARZA	1979	5296	50,131	1,184,144
27451500	8A	ECHOLS	SPRABERRY	TX	DAWSON	1984	8277	21,438	1,375,136
30559166	8A	FELKEN	SPRABERRY	TX	DAWSON	1955	7490	143,770	5,863,624
31236666	7C	FLAT ROCK	SPRABERRY	TX	UPTON	1951	7245	1,338	1,781,814
34961750	8A	GIN	SPRABERRY	TX	DAWSON	1965	8068	403,213	6,412,068
34970500	8A	GIN, NORTH	8000	TX	DAWSON	1975	8029	106,246	3,602,421
43878600	8	HUTEX	DEAN	TX	ANDREWS	1959	9595	6,935	2,273,165
46564750	8A	JO-MILL	SPRABERRY	TX	BORDEN	1954	7105	2,534,834	108,593,322
49113750	8A	KEY	SPRABERRY, UPPER	TX	DAWSON	1963	6978	2,474	1,040,170
49125500	8A	KEY WEST	SPRABERRY	TX	DAWSON	1982	7680	24,178	1,404,146
51152500	8	LACAFF	DEAN	TX	MARTIN	1969	9490	48,406	8,111,254
51742666	8A	LAMESA, WEST	SPRABERRY	TX	DAWSON	1960	7999	176,360	2,640,850
56082500	8	M.A.K.	SPRABERRY	TX	MARTIN	1963	8501	29,274	1,995,628
69233664	8	PARKS	SPRABERRY	TX	MIDLAND	1957	7770	249,123	7,815,355
69570500	8A	PATRICIA, WEST	SPRABERRY	TX	DAWSON	1962	8370	15,017	1,228,314
70279750	7C	PEGASUS	SPRABERRY	TX	UPTON	1952	8255	235,746	16,174,394
71260500	8A	PHIL WRIGHT	SPRABERRY	TX	DAWSON	1982	7832	127,586	3,699,781
76043500	8A	REO	JO MILL, LOWER	TX	BORDEN	1980	7350	175,859	3,638,537
84258500	8A	SMITH	SPRABERRY	TX	DAWSON	1950	7940	15,446	1,541,626
85279200	7C	SPRABERRY	TREND AREA	TX	GLASSCOCK	1952	6785	5,564,574	433,832,105
85280300	8	SPRABERRY	TREND AREA	TX	MIDLAND	1952	8000	14,978,687	489,365,061
85280500	8	SPRABERRY	TREND AREA DEAN-WLFCP	TX	GLASSCOCK	1966	9022	0	10,704,270
85282001	8A	SPRABERRY, DEEP		TX	DAWSON	1949	6420	82,106	11,213,033
85282500	8A	SPRABERRY, DEEP	SPRABERRY, LO.	TX	DAWSON	1957	7592	357,449	13,701,528
85292450	8A	SPRABERRY, W.	DEEP, SPRABERRY	TX	DAWSON	1988	7018	248,525	13,023,206
87073333	8	SULPHUR DRAW	DEAN 8790	TX	MARTIN	1966	9442	132,277	13,147,477
88977284	8A	TEX-HAMON	DEAN	TX	DAWSON	1967	9555	68,015	6,356,866
89201500	7C	TEXON, W.	SPRABERRY	TX	REAGAN	1964	6923	0	2,924,301
96068666	8A	WELCH, SE.	SPRABERRY	TX	DAWSON	1952	7690	226,355	7,826,429
		Totals						**27,576,283**	**1,287,098,237**

quartz and dolomite cement, and authigenic pore-bridging chlorite and illite (Montgomery and others, 2000). The best reservoir zones (7 to 18 percent porosity and 0.3 to 3 md [0.3 to 3 × 10^{-3} μm^2] permeability) occur in stacked, 1- to 3-ft-thick (0.3- to 1-m) beds of massive siltstones and very fine grained sandstones (Schechter and McDonald, 1999; Montgomery and others, 2000).

Horizontal cores show that Spraberry sandstones contain two systems of natural fractures, one having vertical fracture sets striking north-northeast and east-northeast and the other having northeast-striking vertical fractures; fracture spacing and orientation are localized areally and

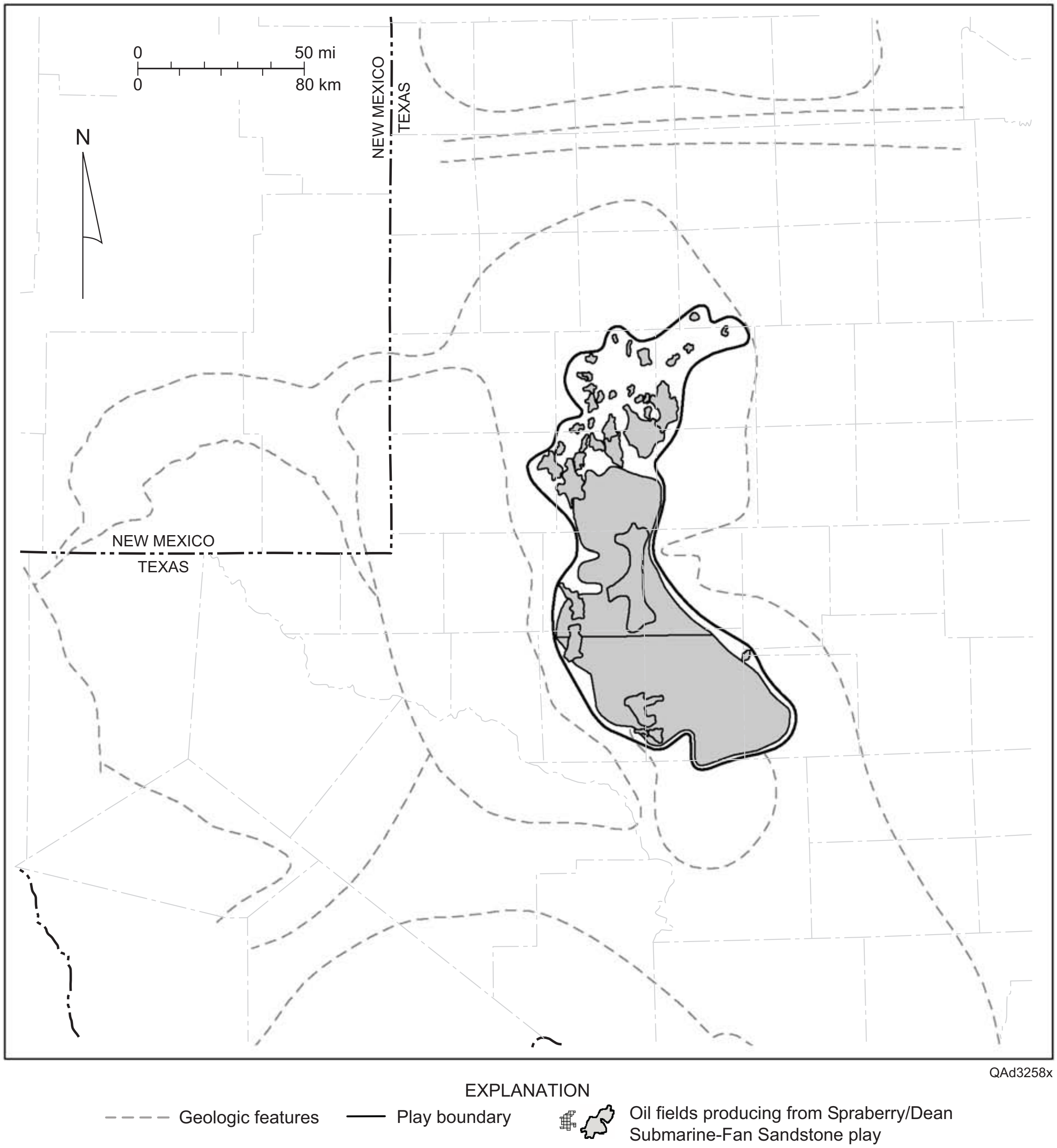

Fig. 67. Play map for the Spraberry/Dean Submarine-Fan Sandstone play, showing location of reservoirs having >1 MMbbl cumulative production, the play boundary, and geologic features. See figure 1 for county names and figure 2 for identification of geologic features.

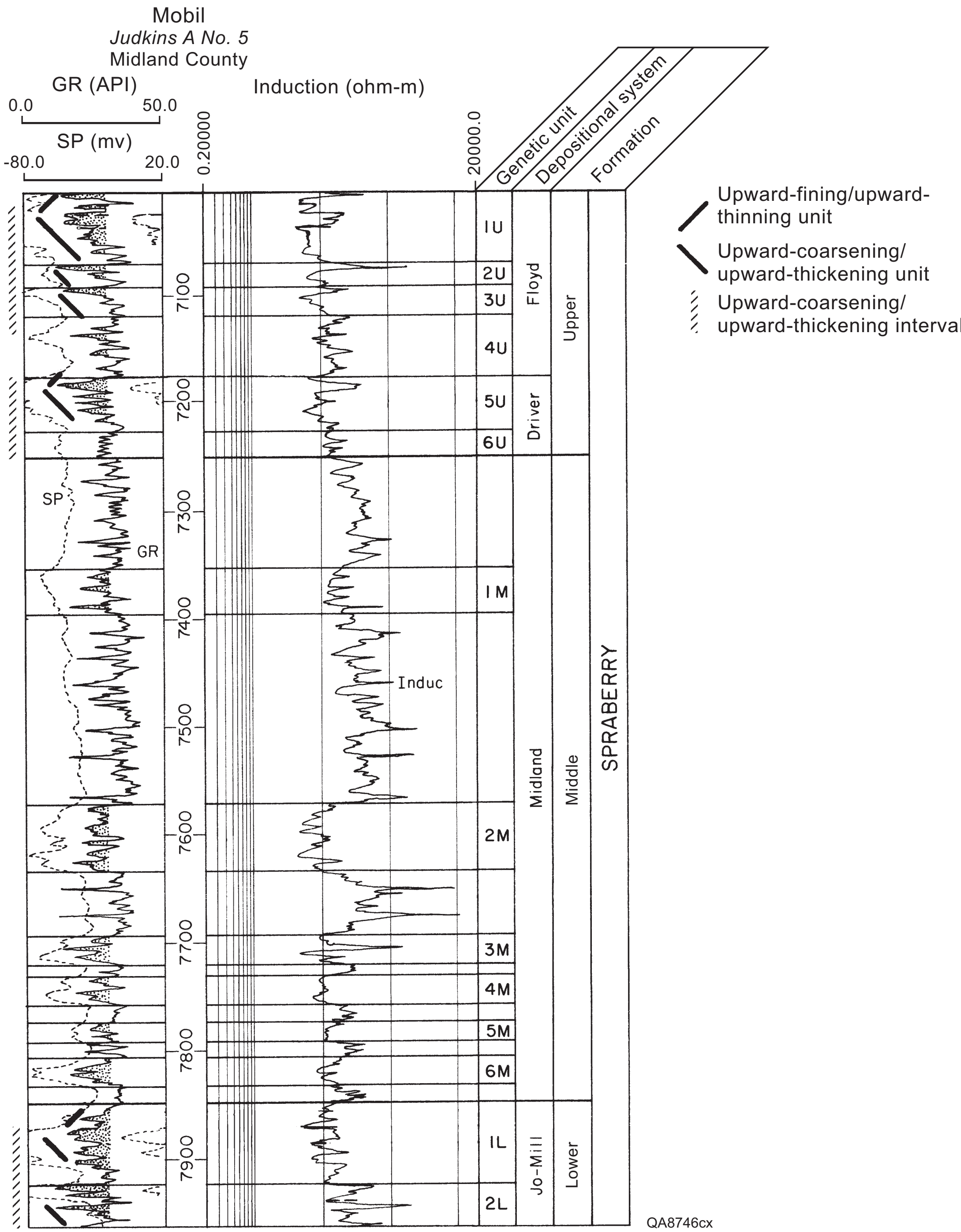

Figure 68. Type log of the Spraberry Formation in the central Spraberry Trend, showing several scales of division of the formation and principal vertical trends. From Tyler and others (1997).

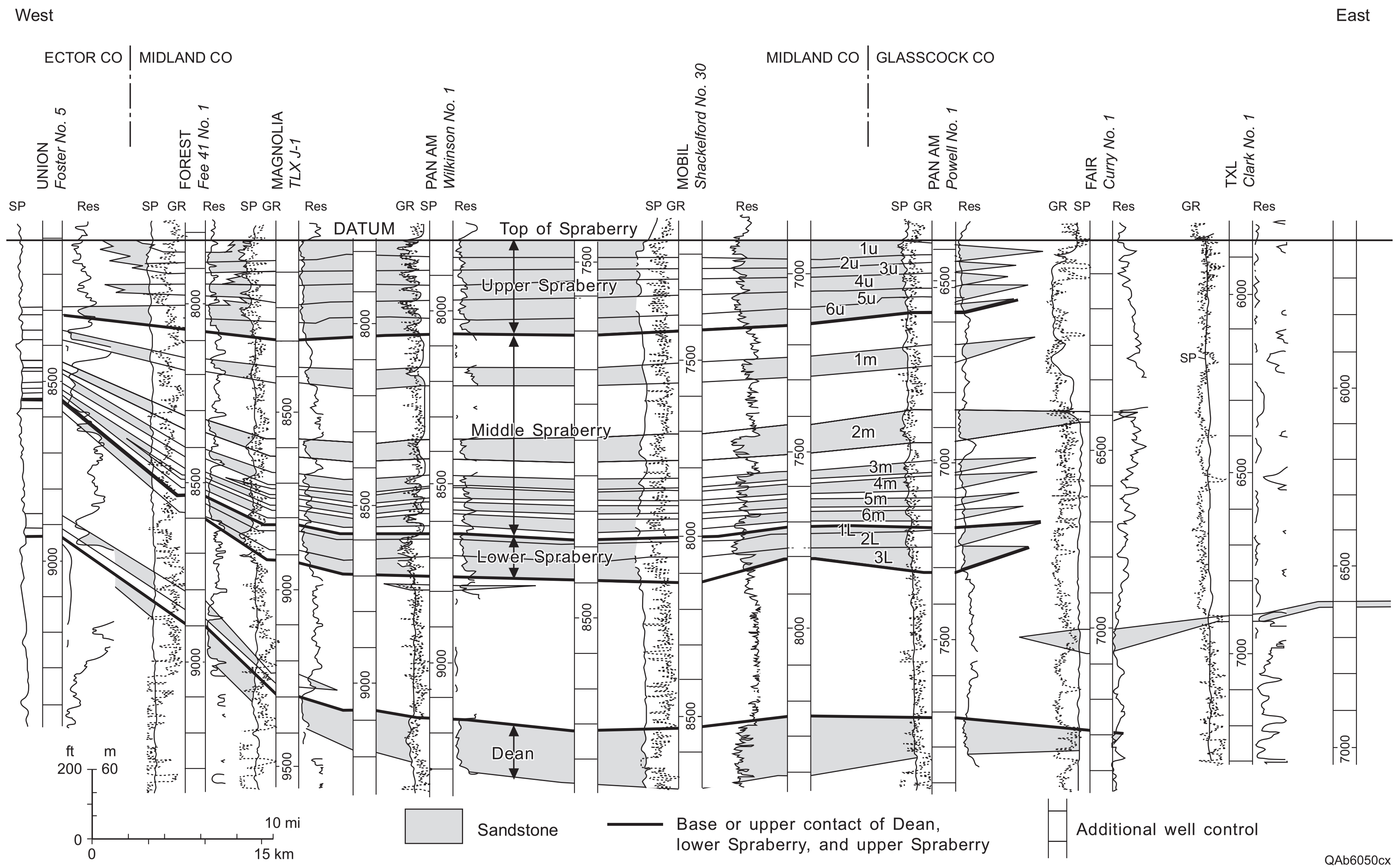

Figure 69. West-east Spraberry strike section in the distal parts of the Midland Basin. From Tyler and others (1997). Lateral continuity of sandstone intervals is greater than in the proximal areas of the basin. See Tyler and others (1997) for location of cross section.

lithologically (Lorenz, 1997; Montgomery and others, 2000; Lorenz and others, 2002). The natural fracture system causes high rates of initial production, but the matrix contains most of the oil (>95 percent) and controls long-term recovery (Montgomery and others, 2000). After early fracture depletion, recovery from Spraberry sandstones is controlled by displacement of matrix oil by water imbibition (Schechter and Guo, 1998; Montgomery and others, 2000). Pay zones are best identified as having shale volume of <15 percent and effective porosity of >7 percent (Banik and Schechter, 1996; Schechter and Banik, 1997).

Waterflooding had not been considered an effective recovery technique in the Spraberry, but a recent pilot waterflood in Spraberry Trend Area O'Daniel unit in Midland County indicates that it can be successful (Schechter and others, 2001; Schechter, 2002; Schechter and others, 2002). Low-rate water injection led to a significant increase in oil production in wells located along the primary northeast fracture orientation from the injection wells. Daily oil production increased by 20 to 30 bbl (3.2 to 4.8 m^3) in each of seven on-trend wells. Total oil production in the pilot area increased from 200 bbl/d (31.8 m^3/d) to 400 bbl/d (63.6 m^3/d) after 1.5 years of water injection, yielding >75,000 bbl (>1.19×10^4 m^3) of incremental oil from an area that had previously been waterflooded (Schechter and others, 2002).

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Upper Permian (Guadalupian) Plays

Thirteen oil plays in the Permian Basin are defined in the Upper Permian Guadalupian Series (table 1). San Andres reservoirs are divided into four plays—San Andres Platform Carbonate, Northwest Shelf San Andres Platform Carbonate, Eastern Shelf San Andres Platform Carbonate, and San Andres Karst-Modified Platform Carbonate. The San Andres Platform Carbonate play and the San Andres Karst-Modified Platform Carbonate play were defined by Tyler and others (1991). In the oil atlas, the reservoirs in these two plays made up part of three plays—Yates Area, San Andres/Grayburg (North Central Basin Platform), and San Andres/Grayburg (South Central Basin Platform) (Galloway and others, 1983).

The four Grayburg plays in Texas (Grayburg Platform Carbonate, Grayburg High-Energy Platform Carbonate—Ozona Arch, Grayburg Platform Mixed Clastic/Carbonate, and San Andres/Grayburg Lowstand Carbonate) contain reservoirs that partly composed the San Andres/Grayburg (North Central Basin Platform), and San Andres/Grayburg (South Central Basin Platform) plays of Galloway and others (1983). Two San Andres and Grayburg plays occur in New Mexico: (1) Upper San Andres and Grayburg Platform Mixed—Artesia Vacuum Trend and (2) Upper San Andres and Grayburg Platform Mixed—Central Basin Platform Trend.

The three Upper Permian sandstone plays—Queen Tidal-Flat Sandstone, Artesia Platform Sandstone, and Delaware Mountain Group Basinal Sandstone—are similar to the plays in the *Atlas of Major Texas Oil Reservoirs*, except that the Artesia Platform Sandstone represents only part of the Permian Sandstone and Carbonate play of Galloway and others (1983).

The carbonates and evaporites of the San Andres and Grayburg Platform Carbonate plays were deposited on a shallow-water shelf that surrounded the Midland Basin during the early Guadalupian. Depositional environments varied from open-marine complexes along the shelf margin to restricted subtidal complexes and arid tidal flats toward the interior of the platform (Tyler and others, 1991). Through time the entire facies tract prograded basinward, so that the older San Andres shelf edge exists platformward of the younger Grayburg shelf edge. As a result, San Andres reservoirs lie generally platformward of the trend of the younger Grayburg reservoirs. Oil in Upper Permian (Guadalupian) rocks occurs mainly at the boundary between updip evaporites and associated shelf dolomites and clean sandstones and siltstones (Ward and others, 1986).

Significant insight into San Andres reservoirs of the Permian Basin has been developed through studies of the San Andres in outcrop in the Guadalupe Mountains (Lucia and others, 1991, 1992; Kerans and others, 1992, 1994; Hovorka and others, 1993; Grant and others, 1994; Kerans and Fitchen, 1995; Jennings, 2000). Well-exposed outcrops allow the study of lateral relationships in geologic and petrophysical structure in these shallow-water platform carbonates.

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Northwest Shelf San Andres Platform Carbonate (Play 120)

Reservoirs in San Andres platform carbonates on the Northwest Shelf of the Midland Basin (fig. 70) have a cumulative production of 3,969.3 MMbbl (6.31×10^8 m^3) from 38 reservoirs (table 26), making the Northwest Shelf San Andres Platform Carbonate play the play with the highest oil production in the Permian Basin (table 2). Reservoirs produce from the lower and middle San Andres Formation. Leonard reservoirs were included in this play in the *Atlas of Major Texas Oil Reservoirs* (Galloway and others, 1983), but those reservoirs have been combined into the Leonard Restricted Platform Carbonate play in this portfolio. Reservoirs in

Table 26. Northwest Shelf San Andres Platform Carbonate play (play 120). 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
10406500	8A	BONANZA	SAN ANDRES	TX	COCHRAN	1980	4893	28,022	2,070,837
11308001	8A	BRAHANEY		TX	YOAKUM	1945	5301	1,018,218	54,223,283
12961500	8A	BUCKSHOT	4950	TX	COCHRAN	1956	5010	61,081	11,816,602
22660500	8A	D-L-S	SAN ANDRES	TX	HOCKLEY	1971	5161	99,377	13,371,869
34438500	8A	GEORGE ALLEN	SAN ANDRES	TX	GAINES	1956	4934	12,271	1,255,323
39717500	8A	HAVEMEYER	SAN ANDRES	TX	GAINES	1977	5488	48,744	1,175,130
44313666	8A	ILLUSION LAKE	SAN ANDRES	TX	LAMB	1957	4116	2,023	2,274,312
51812001	8A	LANDON		TX	YOAKUM	1945	5100	46,344	7,100,093
53411001	8A	LEVELLAND		TX	COCHRAN	1945	4927	10,354,230	642,609,421
54098500	8A	LITTLEFIELD	SAN ANDRES	TX	LAMB	1953	4030	1,650	4,806,609
66373750	8A	O D C	SAN ANDRES	TX	GAINES	1956	5450	74,384	4,775,959
67905500	8A	OWNBY, WEST	SAN ANDRES	TX	YOAKUM	1953	5307	86,331	1,518,031
72995470	8A	PRENTICE	5100	TX	YOAKUM	1974	5240	23,390	1,877,441
72999500	8A	PRENTICE, NW.	SAN ANDRES	TX	YOAKUM	1969	5164	54,585	3,740,591
75552500	8A	REEVES	SAN ANDRES	TX	YOAKUM	1957	5544	700,856	33,359,158
79007500	8A	RUSSELL, S.	SAN ANDRES	TX	GAINES	1964	4859	51,318	2,395,124
79393750	8A	SABLE	SAN ANDRES	TX	YOAKUM	1957	5258	144,755	10,835,456
83991001	8A	SLAUGHTER		TX	COCHRAN	1937	5000	13,968,403	1,207,424,888
95397001	8A	WASSON		TX	YOAKUM	1937	4900	22,893,551	1,840,501,580
94215500	8A	WBD	SAN ANDRES	TX	YOAKUM	1969	5288	9,718	1,056,403
96187333	8A	WELLMAN, SW.	SAN ANDRES	TX	TERRY	1966	5509	41,568	2,982,644
96188333	8A	WELLMAN, W.	SAN ANDRES	TX	TERRY	1966	5583	110,422	2,607,101
96487001	8A	WEST		TX	YOAKUM	1938	5100	22,410	2,668,047
99343001	8A	YELLOWHOUSE		TX	HOCKLEY	1944	4463	199,052	15,574,053
99347500	8A	YELLOWHOUSE, S.	SAN ANDRES	TX	HOCKLEY	1957	4705	95,037	2,457,147
		BLUITT	SAN ANDRES	NM	ROOSEVELT	1963	4500	2,385	2,498,864
		CATO	SAN ANDRES	NM	CHAVES	1966	3414	11,912	16,254,326
		CHAVEROO	SAN ANDRES	NM	CHAVES & RO	1965	4184	66,509	24,500,761
		DIABLO	SAN ANDRES	NM	CHAVES	1963	2000	45,487	1,332,827
		FLYING M	SAN ANDRES	NM	LEA	1964	4400	128,934	11,164,009
		MESCALERO	SAN ANDRES	NM	LEA	1962	4063	40,787	6,949,075
		MILNESAND	SAN ANDRES	NM	ROOSEVELT	1958	4554	50,916	12,034,011
		SAWYER	SAN ANDRES	NM	LEA	1947	5000	21,181	1,664,257
		SAWYER WEST	SAN ANDRES	NM	LEA	1969	4950	34,277	4,244,060
		TODD	LOWER SAN ANDRES	NM	ROOSEVELT	1965	4440	7,608	2,952,336
		TOM TOM	SAN ANDRES	NM	CHAVES	1967	3914	21,292	3,539,296
		TOMAHAWK	SAN ANDRES	NM	CHAVES & RO	1977	4144	17,556	2,339,193
		TWIN LAKES	SAN ANDRES	NM	CHAVES	1965	2600	70,286	5,306,383
	Totals							**50,666,870**	**3,969,256,500**

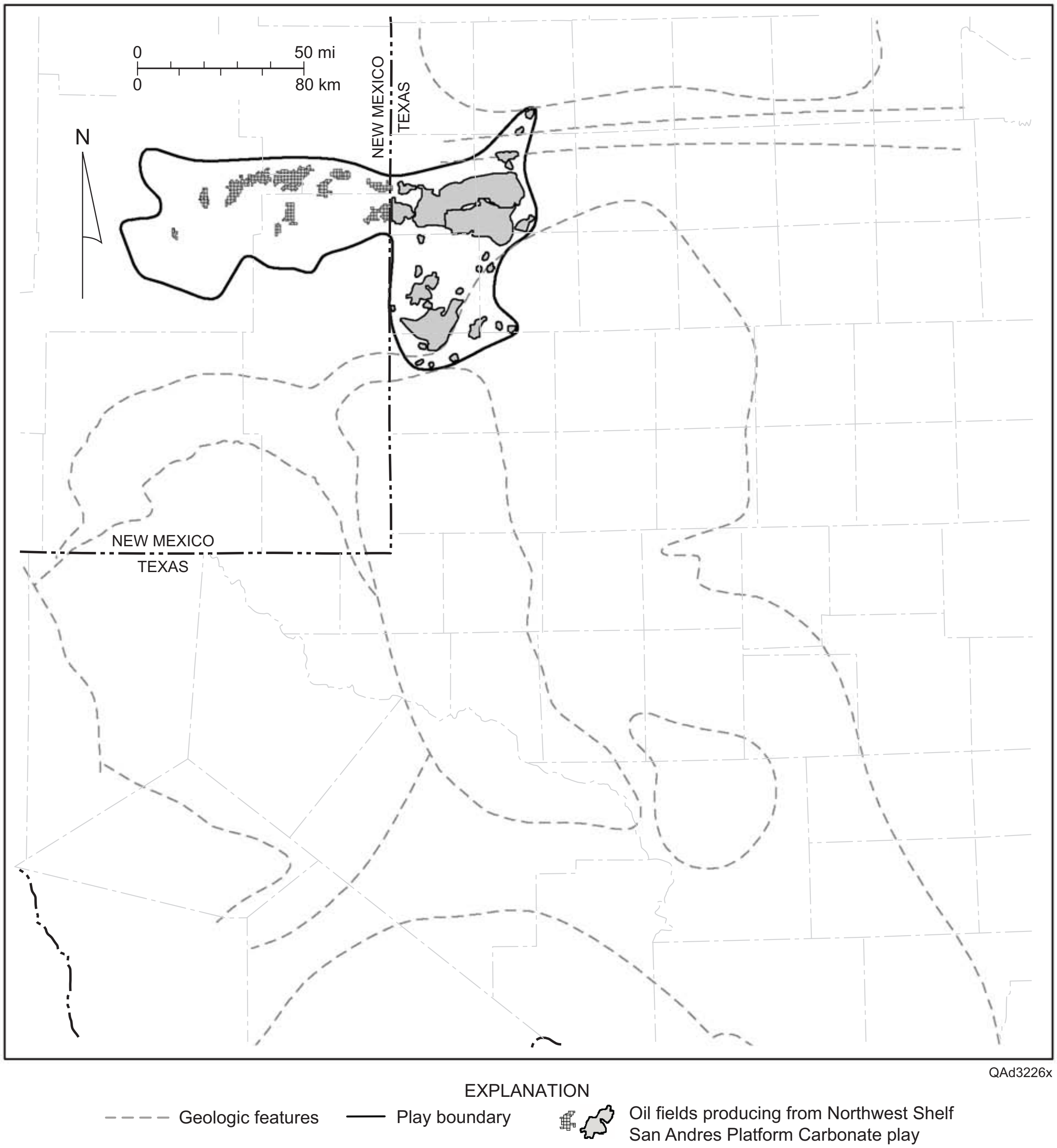

Figure 70. Play map for the Northwest Shelf San Andres Platform Carbonate play, showing location of reservoirs having >1 MMbbl cumulative production, the play boundary, and geologic features. See figure 1 for county names and figure 2 for identification of geologic features.

this play are formed by both structural and combined structural/stratigraphic traps (Gratton and LeMay, 1969; Cowan and Harris, 1986; Ward and others, 1986). The largest fields, such as Wasson, Levelland, and Slaughter, apparently result from both structural drape over the buried Abo trend on the southeast and stratigraphic facies changes to the northwest (Galloway and others, 1983). The oil-water contact at Wasson field and at other fields on the Northwest Shelf tilts to the northeast because of hydrodynamic flow in the San Andres (Mathis, 1986; Brown, 2001).

The San Andres on the Northwest Shelf represents a regressive series of cyclic deposits that prograded southward across a broad, low-relief, shallow-water shelf. Porous zones are offset basinward and occur in increasingly younger strata southward (Ramondetta, 1982a, b; Ward and others, 1986). The lower San Andres on the Northwest Shelf is composed, from bottom to top, of (1) open-marine, subtidal limestone; (2) restricted-marine, subtidal dolostones that form the reservoir facies; (3) intertidal and supratidal dolostones, and (4) salina and sabkha anhydrites (Cowan and Harris, 1986). Porosity in the reservoir facies is mostly intercrystalline and moldic. Porosity occurs in multiple zones formed in several upward-shallowing cycles. The base of each succession is formed by porous, subtidal, restricted-shelf carbonates that terminate upward in tight, intertidal and supratidal dolomite and anhydrite (Cowan and Harris, 1986; Mathis, 1986; Ward and others, 1986; Ebanks, 1990; Bent, 1992). Four major cycles, and, therefore, four distinct porosity zones, are found in the lower San Andres (Gratton and LeMay, 1969; Elliot and Warren, 1989), although some workers have identified five cycles (Pitt and Scott, 1981) or even as many as eight cycles (Cowan and Harris, 1986).

Wasson San Andres is the largest reservoir in the Permian Basin, having produced 1,840.5 MMbbl (2.93×10^8 m^3) through 2000; estimated OOIP was 4 Bbbl (6.36×10^8 m^3)

(Mathis, 1986). Wasson field is located about 40 miles landward of the shelf margin (Ramondetta, 1982a, b; Mathis, 1986). Production from Wasson San Andres occurs from near the middle of the San Andres Formation in two zones, the lower Main Pay zone and the upper First Porosity zone (fig. 71) (Mathis, 1986). The Main Pay produces from dolomitized, open-marine packstones and wackestones; the less-productive First Porosity zone produces from poorer-quality, shallower-water restricted marine and intertidal rocks (fig. 72). Main Pay subtidal pelletal packstones in the Denver unit have porosity of 15 to 20 percent and permeability from

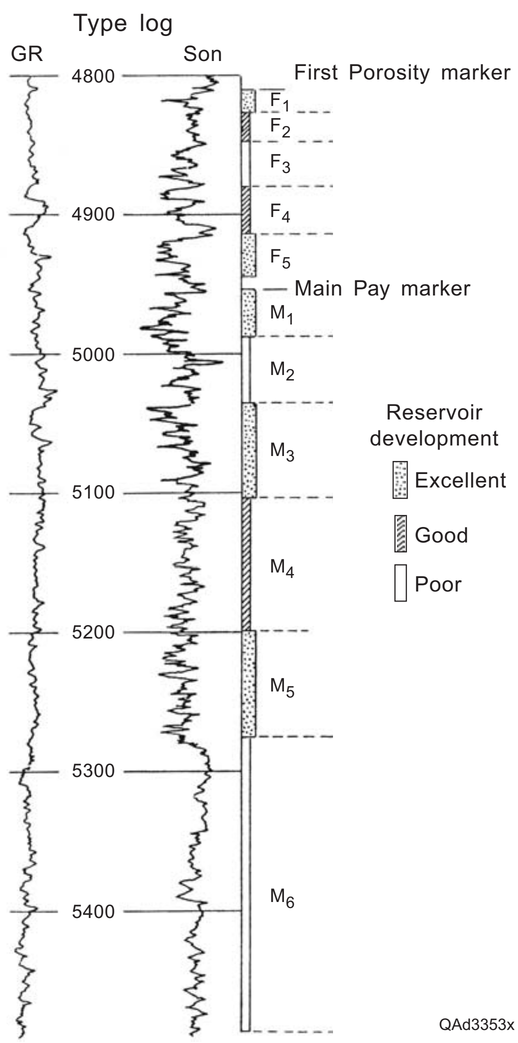

Figure 71. Type log for Denver unit in Wasson San Andres field. From Mathis (1986).

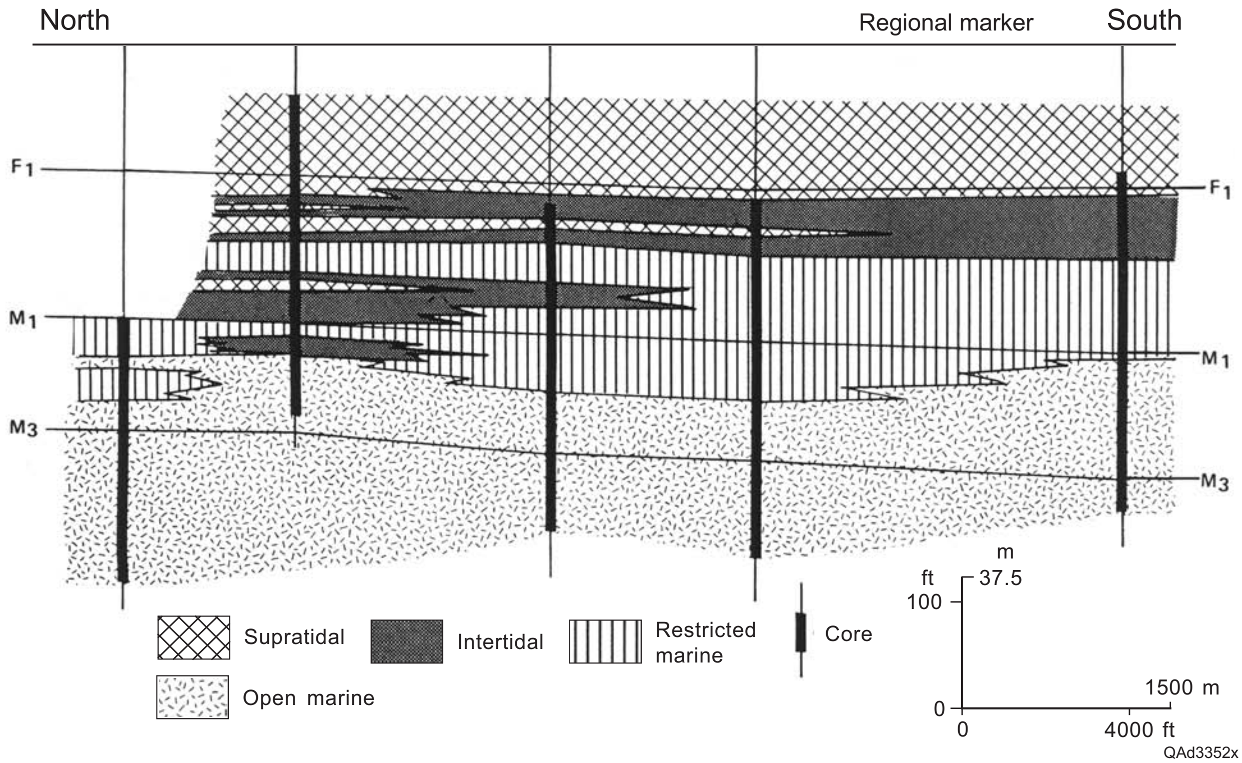

Figure 72. North-south cross section showing the distribution of depositional facies and correlation markers across Denver unit, Wasson San Andres field. From Mathis (1986). See figure 71 for definition of correlation markers.

10 to 50 md (10 to 50 × 10^{-3} μm^2), whereas Main Pay moldic wackestones have porosity as high as 10 percent but permeability of <1 md (<1 × 10^{-3} μm^2) (Mathis, 1986). In the Roberts unit, a permeability cutoff of ≥0.3 md (≥0.3 × 10^{-3} μm^2) was used, corresponding to a porosity cutoff of 6 percent (Bent, 1992). Both pay and nonpay zones have good lateral continuity; nonreservoir zones are apparently impermeable barriers to vertical fluid flow. Overlying dense dolomudstone and anhydrite form the seal.

Wasson San Andres field was divided into seven units when waterflooding began in the 1960’s. Primary recovery by solution-gas drive in the Denver unit was about 16 percent of OOIP, and waterflooding recovered an additional 22 percent of OOIP (Mathis, 1986). Several units within Wasson San Andres field are undergoing tertiary CO_2 floods (Bent, 1992).

The Willard unit at Wasson field produces from open-marine, skeletal-peloidal wackestone and packstone (Brown, 2002; Loucks and others, 2002). The highest reservoir quality and most continuous reservoirs are in the dolomitized, inner-ramp restricted lagoon and moderate-energy shoal facies (Loucks and others, 2002). Porosity in these facies is 8.5 percent and geometric mean permeability is 1 to 2 md ($1–2 \times 10^{-3}$ μm^2).

Levelland and Slaughter fields are located ~85 mi (~135 km) north of the San Andres shelf-margin position (Ramondetta, 1982a, b). Production is from the lower San Andres, below the Pi Marker radioactive siltstone that separates the upper and lower San Andres (Dulaney and Hadik, 1990). The northward pinch-out of porous dolomite into nonporous facies, in combination with subtle structural nosing and hydrodynamics, forms the trap at Levelland and Slaughter fields (Elliot and Walker, 1989). Most production is from subtidal marine facies (Dulaney and Hadik, 1990; Ebanks, 1990). Anhydrite fills the larger vuggy and moldic pores, so fluid flow is controlled by smaller intercrystalline pores in subtidal dolomudstones and dolowackestones (Chuber and Pusey, 1969; Ebanks, 1990). A cutoff of 0.1 md (0.1×10^{-3} μm^2), corresponding to 5 percent porosity, was used to define reservoir rock (Dulaney and Hadik, 1990). In the Mallet Lease of Slaughter field, the subtidal facies has average permeability of <10 md. Some parts of the intertidal facies have permeability of 2 to 3 md ($2–3 \times 10^{-3}$ μm^2), but the rest of the intertidal facies and all of the supratidal facies have permeability <1 md ($<1 \times 10^{-3}$ μm^2) (Ebanks, 1990).

The East Mallet unit in Slaughter field has been under a CO_2 miscible flood since 1989, after undergoing primary production from 1941 through 1966 and secondary waterflooding from 1966 until 1989 (Drozd and Gould, 1991). Injection wells are in a northwest-oriented line-drive pattern, with 19-acre well spacing. CO_2 injection alternates with water injection in 4-month cycles. Porosity in the two productive zones averages 9 to 11 percent, and permeability averages 2 to 4 md (2 to 4 × 10^{-3} μm^2) (Drozd and Gould, 1991). Other units in Levelland and Slaughter fields are also undergoing CO_2 floods (L. S. Melzer, Personal Communication, 2003).

The C. S. Dean “A” unit in Slaughter field underwent secondary recovery by waterflooding developed on 80-acre, 5-spot patterns. Infill drilling was later done in part of the unit on 20-acre spacing (Watson, 1992).

In New Mexico, the Northwest Shelf San Andres Platform Carbonate play is located in northern Lea, southern Roosevelt, and eastern Chaves Counties (fig. 70). Traps are stratigraphic or combination structural-stratigraphic (Gratton and LeMay, 1969; Yedlosky and McNeal, 1969; Keller, 1992). Porosity zones pinch out updip to the north and northwest where porosity is occluded by anhydrite cement. Combination traps where zero porosity lines are draped across generally south plunging structural noses form the Cato, Chaveroo, and Milnesand reservoirs. The cyclicity of the regressive sequences has led to vertical stacking of porosity zones. In some places, zero-porosity lines in multiple zones are nearly coincident, resulting in production from two or more hydraulically isolated porosity zones within a single reservoir. Evaporite-cemented underseals in some reservoirs prevented oil from secondary migration in structures that were tilted subsequent to entrapment (Keller, 1992), resulting in a tilted base-of-oil.

Some of the San Andres reservoirs are cut by wrench faults of probable Tertiary age (Scott, 1995). At Cato and Tom Tom, faulting is thought to have enhanced low matrix permeability (Scott, 1995). It is therefore likely that permeability varies as a function of proximity to the faults that cut the reservoir.

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Eastern Shelf San Andres Platform Carbonate (Play 121)

The 24 reservoirs in the Eastern Shelf San Andres Platform Carbonate play have produced 706.9 MMbbl (1.12×10^8 m^3) of oil (table 27). The play, located on the Eastern Shelf of the Midland Basin (fig. 73), produces from dolomites and sandstones of the Upper Permian Guadalupian (Yates, Seven Rivers, Queen, Grayburg/San Andres) Series (fig. 3). Leonard reservoirs were included in this play in the *Atlas of Major Texas Oil Reservoirs* (Galloway and others, 1983), but those reservoirs have been combined into the Leonard Restricted Platform Carbonate play (117) in this portfolio. Simple anticlines form the traps within this section of multiple porous dolomite and sandstone reservoirs (Galloway and others, 1983). There is also a stratigraphic component to the trapping caused by the loss of porosity and permeability updip to the east, resulting from porosity occlusion by evaporites (Ward and others, 1986).

Table 27. Eastern Shelf San Andres Platform Carbonate play (play 121). 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
13047001	8A	BUENOS		TX	GARZA	1949	3397	28,989	1,834,059
18593666	8	CLARK	SAN ANDRES	TX	STERLING	1949	890	58,468	1,568,965
19346426	8A	COGDELL	SAN ANDRES	TX	KENT	1951	1475	13,455	1,455,502
20553500	8A	CORAZON	SAN ANDRES	TX	SCURRY	1953	2139	86,512	5,457,029
34113001	8A	GARZA		TX	GARZA	1926	2900	1,365,884	116,170,788
34113425	8A	GARZA	SAN ANDRES, DEEP	TX	GARZA	1985	3465	260,431	9,648,491
37356666	8A	GUINN	SAN ANDRES	TX	LYNN	1961	4031	12,836	1,875,859
40752500	8	HERRELL, EAST	QUEEN SAND	TX	STERLING	1953	1454	98,148	4,793,966
42971001	8	HOWARD GLASSCOCK		TX	HOWARD	1925	1500	2,741,620	403,182,614
43731666	8A	HUNTLEY	3400	TX	GARZA	1954	3387	397,269	16,691,235
43732500	8A	HUNTLEY, EAST	SAN ANDRES	TX	GARZA	1956	3138	145,244	8,883,820
44147500	8	IATAN	SAN ANDRES	TX	MITCHELL	1957	2364	28,431	2,350,479
44149001	8	IATAN, NORTH		TX	HOWARD	1943	2908	31,551	3,791,827
59304250	8	MCDOWELL	SAN ANDRES	TX	GLASSCOCK	1964	2341	9,867	2,526,387
62711001	8	MOORE		TX	HOWARD	1937	3200	160,062	15,258,997
69351498	8	PAROCHIAL-BADE	QUEEN SAND	TX	STERLING	1951	1103	8,791	2,031,854
68101001	8A	P. H. D.		TX	GARZA	1944	3565	211,704	10,800,728
77643001	8A	ROCKER -A-		TX	GARZA	1950	2422	83,503	7,180,789
77647333	8A	ROCKER -A-, NW.	SAN ANDRES	TX	GARZA	1959	2772	97,187	2,248,354
82710498	8A	SHARON RIDGE	1700	TX	SCURRY	1923	1759	618,179	66,480,174
87173100	8A	SUNILAND		TX	LYNN	1978	3803	76,245	9,769,796
89732500	8A	THREE WAY	SAN ANDRES	TX	GARZA	1958	3493	26,924	2,192,455
93233333	8	VAREL	SAN ANDRES	TX	HOWARD	1955	3080	15,313	6,542,943
95445666	7C	WATER VALLEY	SAN ANDRES	TX	TOM GREEN	1948	1035	37,224	4,159,900
		Totals						**6,613,837**	**706,897,011**

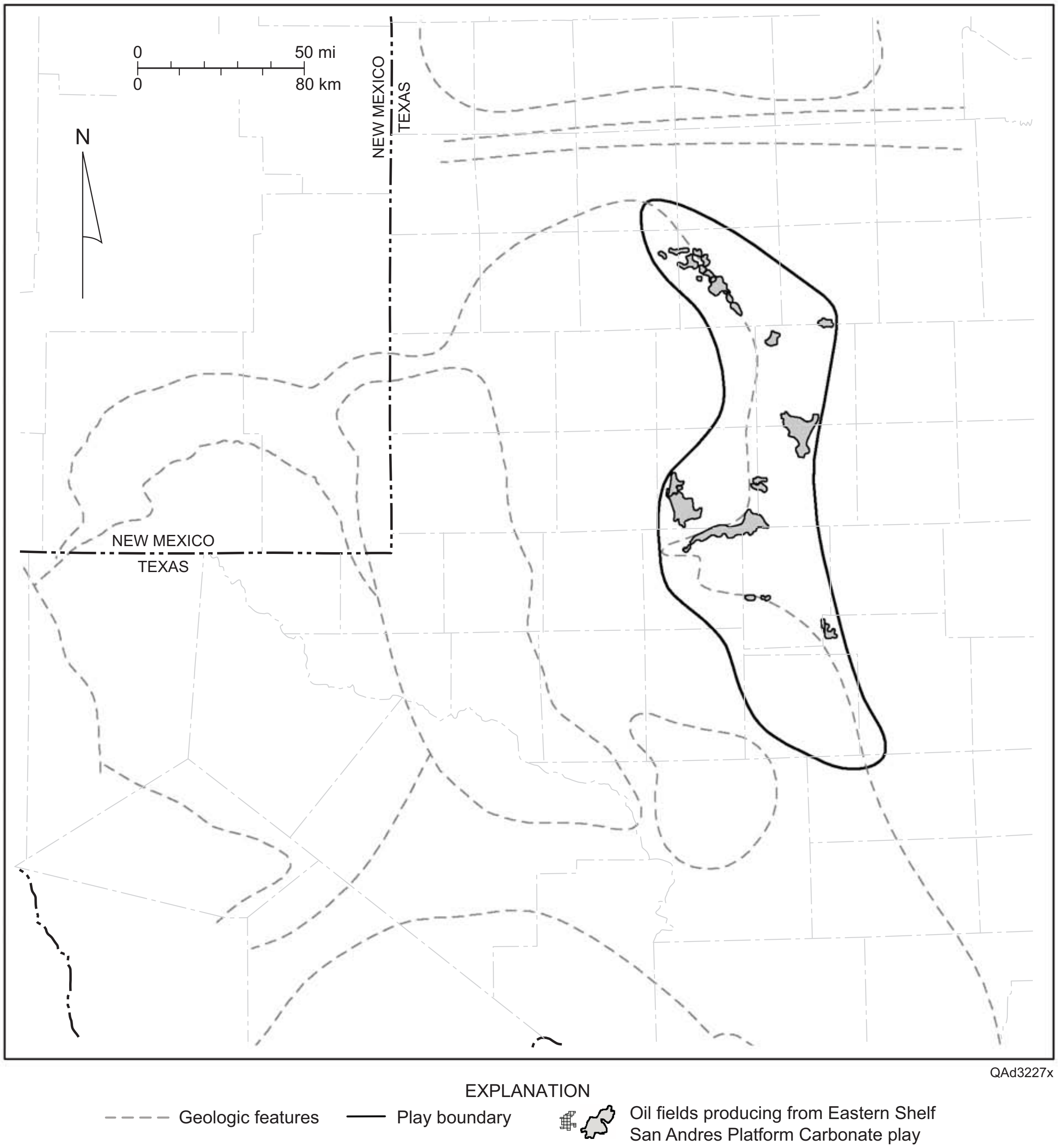

Figure 73. Play map for the Eastern Shelf San Andres Platform Carbonate play, showing location of reservoirs having >1 MMbbl cumulative production, the play boundary, and geologic features. See figure 1 for county names and figure 2 for identification of geologic features.

The Permian section on the Eastern Shelf is composed of dolomite, anhydrite, sandstone and siltstone (red beds), and halite (Galloway and others, 1983). The Eastern Shelf prograded westward into the Midland Basin during the Permian (Van Siclen, 1958; Brown and others, 1990), and carbonate deposition ended on the Eastern Shelf during the middle Guadalupian (Ward and others, 1986). Upper Guadalupian rocks are composed of cyclic deposits of sandstone, anhydrite, and halite.

Howard Glasscock, the largest field in the play, produced 403.2 MMbbl (6.41×10^7 m^3) through 2000. Production in Howard Glasscock field comes from the Yates, Seven Rivers, Queen, Grayburg/San Andres, and Glorieta intervals (fig. 74). Until 1969, production from the Leonardian Glorieta interval was reported as part of Howard Glasscock field, but since that date Glorieta production has been reported separately by the Railroad Commission of Texas as Howard-Glasscock Glorieta. The San Andres/Grayburg interval at Howard Glasscock field is a prograding sequence from open marine to supratidal carbonates that are pervasively dolomitized (White, 1984). The dominant reservoir facies is dolomudstone, with scattered areas of oolitic grainstone in the field (Mooney, 1982; White, 1984). Porosity is composed of intercrystalline pores and vugs that are occluded partly by anhydrite (Martin and others, 1997). Average porosity is 10.5 percent and average permeability is 5 md (5×10^{-3} μm^2) (Mooney, 1982).

The Yates, Seven Rivers, and Queen Formations at Howard Glasscock field produce from fine- to coarse-grained quartz sandstones interbedded with red shale and anhydrite (Mooney, 1982) Average porosity in the Yates sandstone is 23 percent and average permeability is 200 md (200×10^{-3} μm^2) (Mooney, 1982). The Seven Rivers and Queen sandstones have average porosity of 19 to 20 percent and average permeability of 11 to 34 md (11 to 34×10^{-3} μm^2). The Queen sandstones on the Eastern Shelf were deposited primarily by

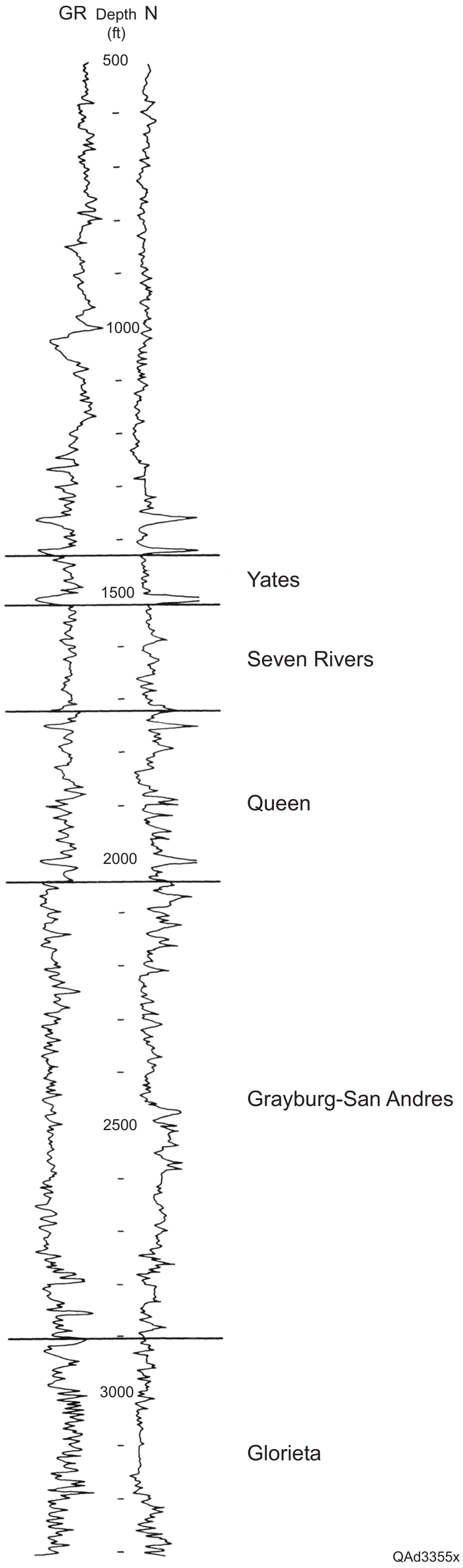

Figure 74. Typical gamma-ray–neutron log through the Permian section in Howard Glasscock field. From Galloway and others (1983).

fluvial processes in ephemeral stream (wadi) and wadi-fan environments; eolian deposition occurred in isolated areas (Slone and Mazzullo, 2000).

Pilot waterflooding of Howard-Glasscock field began in 1964, and in the 1970's an extensive coring program was conducted to aid in log interpretation, geologic mapping, and injection-well planning (Wilson and Hensel, 1978). The Glorieta, Clear Fork, San Andres, Queen, and Seven Rivers Formations are being waterflooded in Howard Glasscock field on 10-acre patterns with multiple-zone well completions (Miller and others, 1998). Bypassed pay potential in this mature, waterflooded field was identified by characterizing petrophysical flow units (Martin and others, 1997).

Tiltmeter mapping in the Howard Glasscock East unit determined that hydraulic fracturing was occurring under normal waterflood injection conditions in the San Andres carbonates and Seven Rivers and Queen sandstones (Griffin and others, 2000). Average fracture azimuths of the created vertical fractures were approximately east-west. Proper pattern alignment to maximize sweep efficiency on the basis of fracture orientation is to have injectors and producers lined up in an east-west direction (Griffin and others, 2000).

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San Andres Karst-Modified Platform Carbonate (Play 122)

The six reservoirs in the San Andres Karst-Modified Platform Carbonate play have produced 1,567.1 MMbbl (2.49×10^8 m^3) of oil (table 28) from the structurally high southern end of the Central Basin Platform (fig. 75). Most of the production has come from Yates field (1,381 MMbbl [(2.20×10^8 m^3]), which occurs on the structural crest and had original oil in place of 4,000 MMbbl (6.36×10^8 m^3) (Galloway and others, 1983; Tyler and others, 1991). The Toborg reservoir produces from shallow Lower Cretaceous Trinity sandstones associated with Yates field.

Post-Guadalupian structural tilting caused northward dip of the Central Basin Platform, but thinning by onlap in the Grayburg and Seven Rivers Formations supports the interpretation that this part of the platform was also a relatively positive feature during the Guadalupian (Tyler and others, 1991). Localized San Andres karst development along the south margin of the Central Basin Platform in Yates (Craig, 1988, 1990), Taylor-Link West (Kerans and Parsley, 1986; Tyler and others, 1991; Lucia and others, 1992), and McCamey (Guiseppe and Trentham, 1999) fields provides further evidence that this area was a positive feature during the Guadalupian (Tyler and others, 1991).

Table 28. San Andres Karst-Modified Platform Carbonate play (play 122).

RRC RESN	RRC	FLDNAME	RESNAME	STATE	COUNTY	DISCYR	DEPTHTOP	2000 PROD	CUMPROD
21766001	7C	CROCKETT		TX	CROCKETT	1938	1571	21,883	4,762,786
58840001	7C	MCCAMEY		TX	UPTON	1925	2100	117,862	135,137,987
77841333	7C	RODMAN-NOEL	GRAYBURG	TX	UPTON	1953	1745	1,091	1,143,800
88567700	8	TAYLOR LINK W.	SAN ANDRES	TX	PECOS	1984	1800	75,010	1,640,304
90286001	8	TOBORG		TX	PECOS	1929	500	126,482	43,045,830
99295001	8	YATES		TX	PECOS	1926	1500	11,117,801	1,381,373,107
		Totals						**11,460,129**	**1,567,103,814**

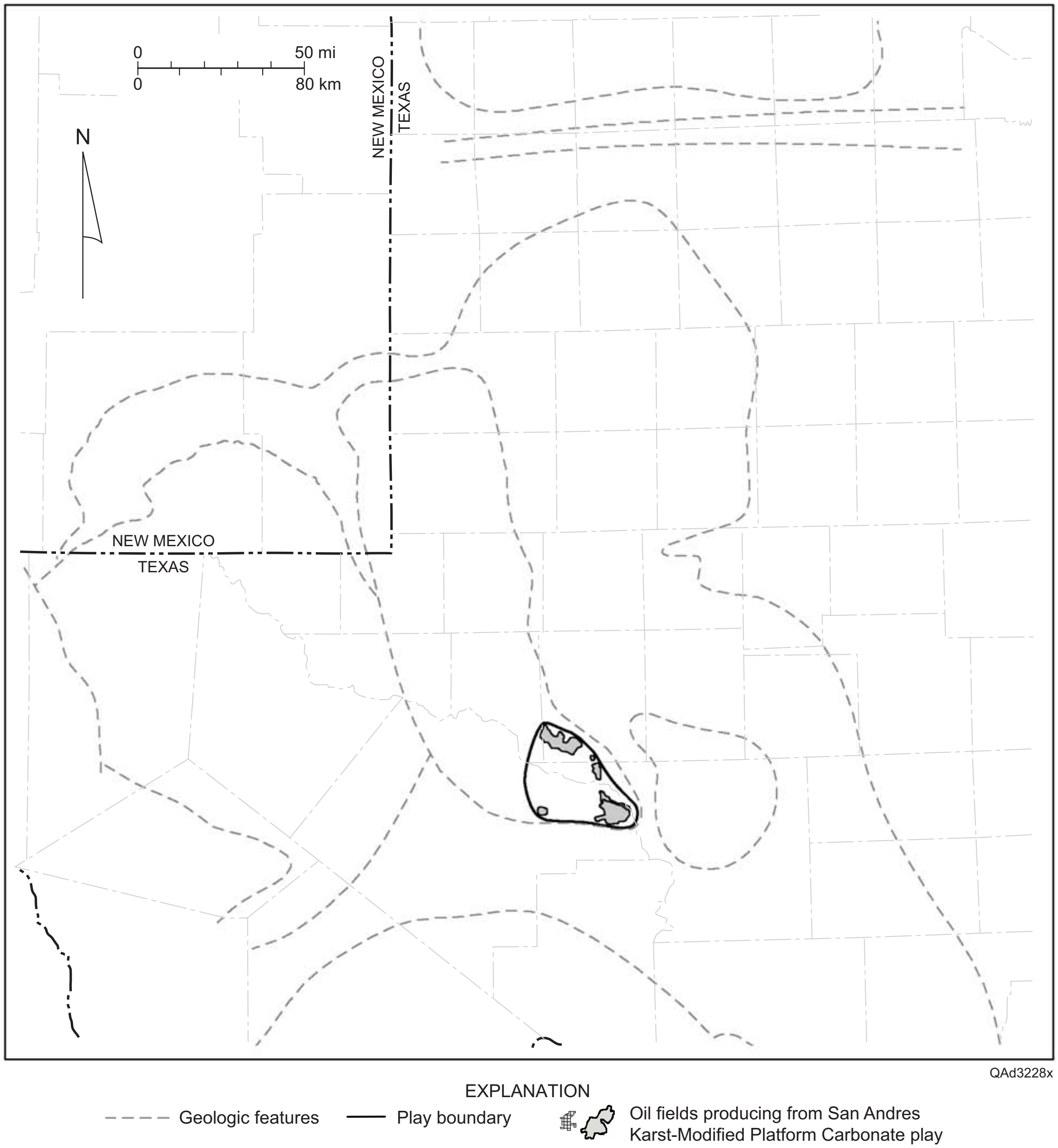

Figure 75. Play map for the San Andres Karst-Modified Platform Carbonate play, showing location of reservoirs having >1 MMbbl cumulative production, the play boundary, and geologic features. See figure 1 for county names and figure 2 for identification of geologic features.

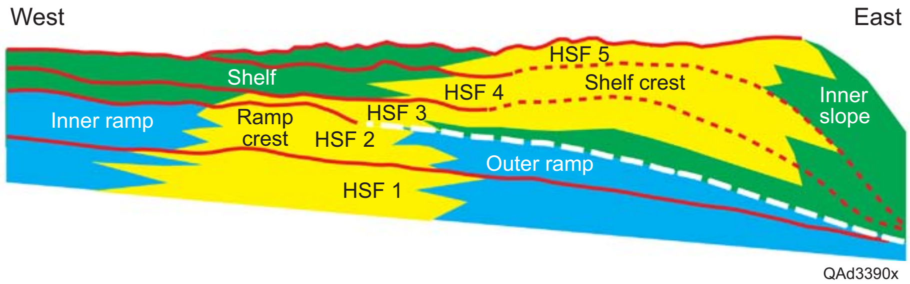

Figure 76. Sequence stratigraphy and facies tracts of Yates field illustrated on a west-east cross section. After Tinker (2000), reprinted by permission of the AAPG, whose permission is required for further use. ©Copyright 2000. The American Association of Petroleum Geologists. All rights reserved. The transgressive systems tract is composed of high-frequency sequences (HFS) 1-2, and the highstand systems tract is composed of HFS 3-5. The shelf-crest facies (yellow) shifted basinward significantly between HFS 2 and HFS 3. See Tinker (2000) for location of seismic section.

The main reservoirs in the play are dolomites of the San Andres Formation, which are characterized by thick accumulations of reservoir-quality grainstones at the top of an upward-shallowing sequence, reflecting the higher-energy depositional setting of the shelf margin facing the Sheffield Channel (Tyler and others, 1991) (fig. 2). The general facies tract is composed of middle-shelf lagoons, shelf-crest (ramp-crest) subtidal shoals/eolian dunes, and slope (outer-ramp) subtidal environments (Tinker, 1996) (fig. 76). San Andres reservoirs in Yates field are mostly moldic to sucrosic packstones and grainstones deposited in aggrading and prograding shallow subtidal and shoal-island environments (fig. 77) (Tinker and Mruk, 1995). The productive shelf-crest facies are located in the central and east part of the field (fig. 76). Dolomite reservoir zones have average porosity of 15 percent and average matrix permeability of 100 md ($100 \times 10^{-3}\ \mu m^2$) (Snell and Close, 1999). Clastics in the Seven Rivers, Queen, and Grayburg Formations are also productive in Yates field. Clastic reservoir facies include tabular, shallow subtidal siltstones and sandstones in the Grayburg and Queen Formations and sandstones

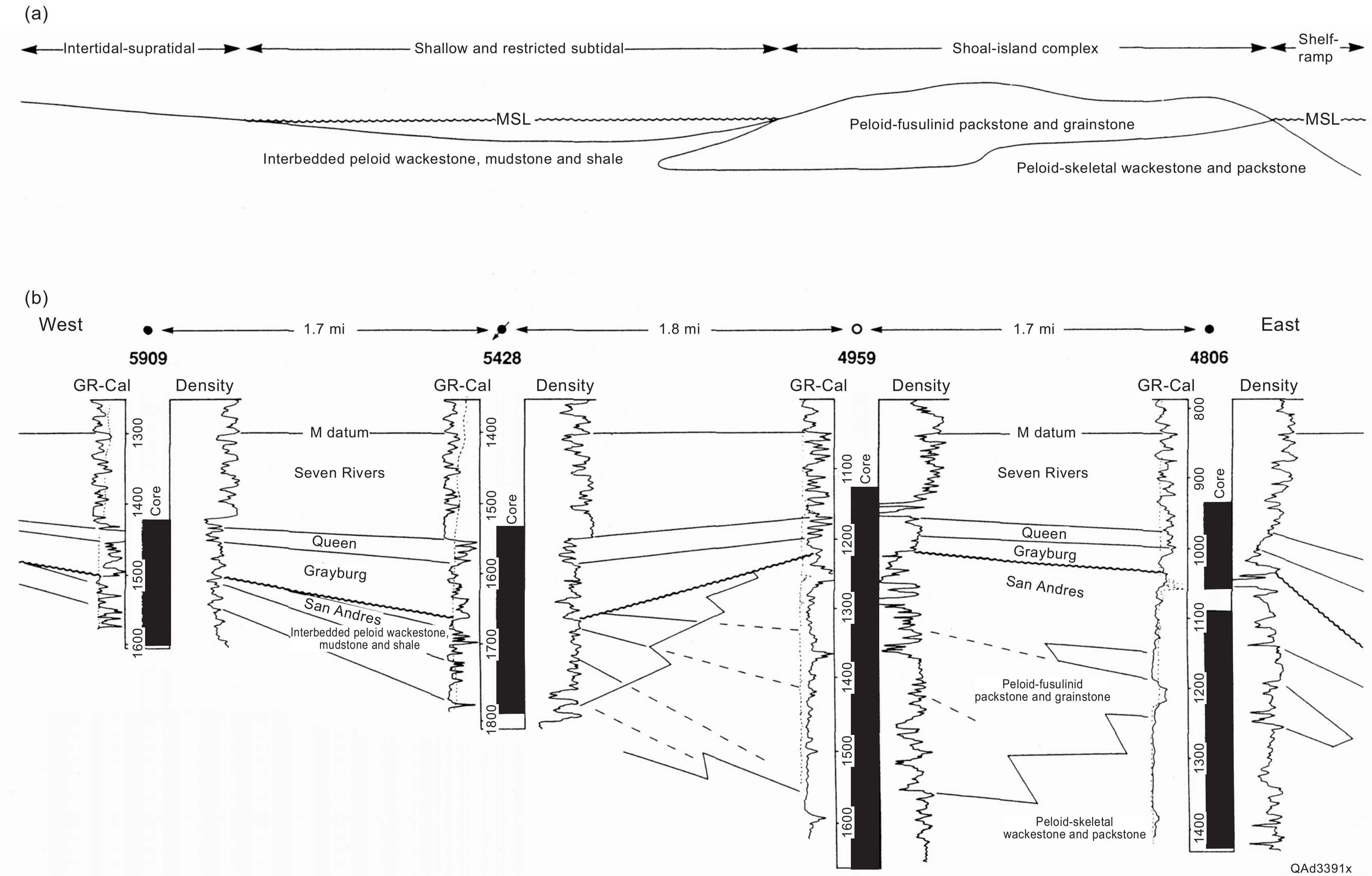

Figure 77. West-east cross section of Yates field showing (a) depositional setting and (b) log responses for major lithofacies and projected time-stratigraphic framework (dashed lines). From Tinker and Mruk (1995). See Tinker and Mruk (1995) for location of cross section.

deposited in a beach-dune-bar complex in the lower Seven Rivers Formation (Tinker and Mruk, 1995). The evaporite-dominated Seven Rivers Formation forms the reservoir seal.

Porosity in Yates field occurs as interparticle pores, fractures, and open caves. Permeability was greatly increased by open caves and solution-enlarged joints that developed by karstification during multiple subaerial exposure events in the San Andres (Craig and others, 1986; Craig, 1988, 1990; Tinker and others, 1995). The most significant cave formation occurred during exposure following San Andres deposition. Early development of a regional fracture system provided conduits for solution enlargement during karstification and formation of vuggy and cavernous pores along joints (Tinker and others, 1995). Open caverns in Yates field contributed to bit drops and flow rates in many wells of >10,000 bbl/d (>1.59×10^3 m^3) to as high as 200,000 bbl/d (3.18×10^4 m^3) during early field development (Tinker and others, 1995). Fracture permeability exceeds 1 darcy (Snell and Close, 1999).

Development history of Yates field was summarized by LaPointe and others (1998), Golder Associates (1999), Snell and Close (1999), and Campanella and others (2000). Before 1976, Yates field was operated under primary depletion. The field was unitized in 1976, when a gas-injection pressure-maintenance program was instituted to slow water invasion into the oil-producing part of the reservoir and conserve reservoir energy. The gas-injection program allowed greater use of efficient gas-cap gravity drainage. Waterflooding began on the western flanks of the field in 1979, and a polymer flood of the oil column was initiated in additional areas of the west side from 1983 through 1986. From late 1985 until 1991, CO_2 was injected in the north, east, and crestal areas of the field.

A 3-D reservoir model of Yates field was developed to support reservoir management (Tinker and Mruk, 1995; Tinker, 1996). By lowering the gas-oil and water-oil contacts, a fieldwide co-production project was initiated in late 1992 to dewater reservoir areas containing oil bypassed by water encroachment. Methods used were (1) high-volume water withdrawals and (2) gas-cap inflation by increasing reservoir pressure using methane and nitrogen injection. Co-production reversed aquifer encroachment by removing water from the fracture network and allowing the oil to flow from the matrix into the fracture system. Co-production also resulted in gravity drainage within the expanded gas cap.

Fracture models have supported Yates field development since 1992 (LaPointe and others, 1998; Golder Associates, 1999). Wells in the field produce matrix fluids through the extensive natural fracture network. Fracture models were used to identify areas where the fracture network is best developed and thus take advantage of the natural drainage system by maximizing withdrawals from high-rate, high-efficiency wells in these areas. In 1993 and 1994 more than 30 new short-radius horizontal wells were drilled and almost 400 wells were shut in while a stable total daily oil production rate was maintained.

A steam pilot project began in 1998 to improve vertical gravity drainage using a patented process called Thermally Assisted Gravity Segregation (TAGS) (Wadleigh, 1996). Steam was injected into the fractured secondary gas cap to heat oil, reduce viscosity, and improve gravity drainage from dolomite matrix toward conductive fractures (Snell and Close, 1999). Oil mobilized by steam injection drains vertically to the oil column and then laterally via fractures to producing wells.

Taylor Link field is another karst-modified ramp-crest grainstone reservoir (fig. 78) in which karstification influences fluid flow and production. Poor waterflood performance—high produced-water volumes and low oil cut—is probably caused by injected water flowing through a system of karst-related fractures, microbreccias, and large vugs in this dual-porosity system

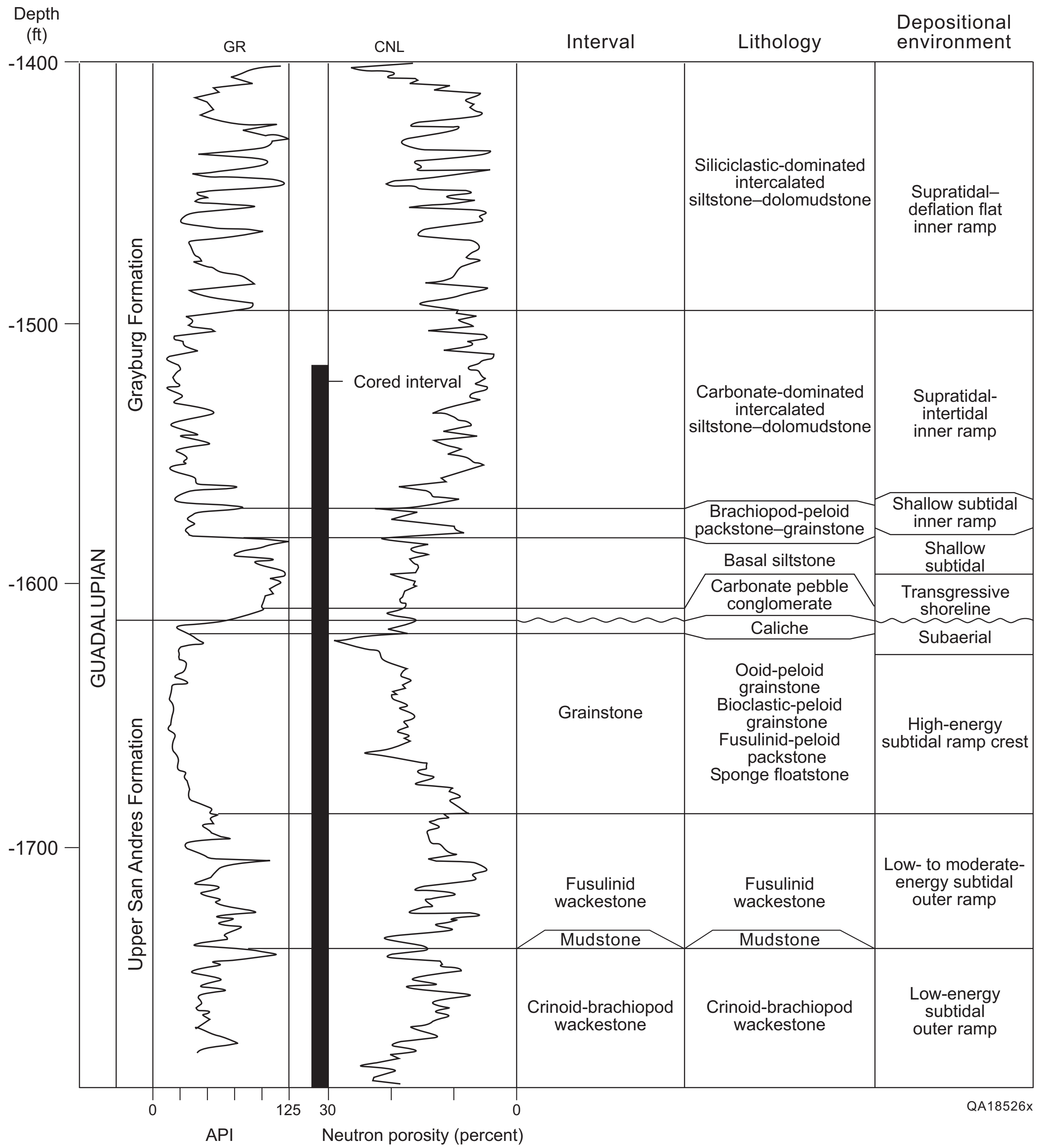

Figure 78. Typical gamma-ray/neutron log and characteristic lithologies and depositional environments for the upper San Andres and Grayburg Formations at Taylor-Link West field. From Lucia and others (1992).

(Tyler and others, 1991; Lucia and others, 1992). When the water injection rate was increased, oil production decreased because more water flowed through fractured wackestones and less through the oil-saturated ooid-grainstone facies (Tyler and others, 1991). Concentrating the waterflood in the ooid grainstones should increase oil recovery.

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San Andres Platform Carbonate (Play 123)

The San Andres Platform Carbonate play has produced 2,151.3 MMbbl (3.42×10^8 m^3) of oil from 52 reservoirs (table 29), making it the fourth-largest play in the Permian Basin (table 2). The carbonates of the San Andres Platform Carbonate play were deposited on the shallow-water Central Basin Platform (fig. 79) during the early Guadalupian. Depositional environments varied from open-marine complexes along the platform margin to restricted subtidal complexes and arid tidal flats toward the interior of the platform (Tyler and others, 1991). The sequence hierarchy and facies architecture of the San Andres Formation in the Permian Basin have been documented from outcrop studies by Kerans and others (1994) and Kerans and Fitchen (1995). Geologic and engineering characteristics of many of the reservoirs in this play are summarized in two volumes of papers edited by Bebout and Harris (1986, 1990).

The upper San Andres reservoirs in this play are developed in thick (~300 ft [~90 m]), dolomitized, subtidal parts of upward-shoaling cycles (Ruppel and Cander, 1988; Garber and Harris, 1990; Major and others, 1990; Tyler and others, 1991) (fig. 80). The lower two-thirds of each cycle is made up of a thick section of subtidal facies composed of dolomitized skeletal wackestone to pellet grainstone; fusulinids and other normal-marine fossils are abundant (figs. 81, 82). The pellet grainstones are poorly sorted and burrowed, indicating relatively low-energy deposition. Overlying the subtidal section is a thin zone of locally distributed shallow-water subtidal to intertidal pellet, skeletal, and ooid grainstones (fig. 83). These grainstones are well sorted and locally laminated and crossbedded, indicating relative high-energy deposition. Capping the cycle is a supratidal sequence consisting of interbedded mudstone, siliciclastic siltstone, and pisolite facies that form the reservoir seal.

Table 29. San Andres Platform Carbonate play (play 123). 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
8618375	8A	BLACKWATCH	SAN ANDRES	TX	GAINES	1995	4624	289,940	1,324,791
8958500	8	BLOCK A-34	SAN ANDRES	TX	ANDREWS	1979	4676	16,529	1,120,760
10821500	8	BOURLAND	SAN ANDRES	TX	ECTOR	1952	4352	6,208	1,125,033
15724500	8A	CARM-ANN	SAN ANDRES	TX	GAINES	1979	4779	40,031	1,307,285
14200400	8	C-BAR	SAN ANDRES	TX	CRANE	1949	3520	106,116	20,386,507
21289400	8	COWDEN, NORTH	CLEAR FORK	TX	ECTOR	1970	5239	187,810	5,850,903
21289600	8	COWDEN, NORTH	DEEP	TX	ECTOR	1939	5170	890,410	69,141,846
25347750	8	DONNELLY	HOLT	TX	ECTOR	1950	5275	25,315	1,710,117
25347875	8	DONNELLY	SAN ANDRES	TX	ECTOR	1950	4305	16,856	8,423,063
28899001	8	EMMA		TX	ANDREWS	1939	4300	29,427	20,813,110
28899415	8	EMMA	GLORIETA	TX	ANDREWS	1953	5405	77,925	3,630,701
33230500	8	FULLERTON	SAN ANDRES	TX	ANDREWS	1945	4785	2,263,344	39,796,567
33473250	8A	G-M-K	SAN ANDRES	TX	GAINES	1957	5598	348,872	15,599,746
33477500	8A	G-M-K, SOUTH	SAN ANDRES	TX	GAINES	1963	5450	383,957	16,777,664
35652001	8	GOLDSMITH		TX	ECTOR	1935	4300	650,195	357,953,213
35652558	8	GOLDSMITH	HOLT	TX	ECTOR	1952	5106	10,859	2,298,769
35653666	8	GOLDSMITH, EAST	HOLT	TX	ECTOR	1954	4988	13,515	8,214,446
35653888	8	GOLDSMITH, EAST	SAN ANDRES	TX	ECTOR	1962	4224	4,172	9,088,613
35654664	8	GOLDSMITH, N.	SAN ANDRES, CON.	TX	ECTOR	1964	4500	242,053	22,178,175
35659625	8	GOLDSMITH, W.	SAN ANDRES	TX	ECTOR	1956	4280	34,462	6,843,367
38686500	8A	HANFORD	SAN ANDRES	TX	GAINES	1977	5421	199,866	11,999,935
39176001	8	HARPER		TX	ECTOR	1933	4300	281,997	50,261,732
42401400	8A	HOMANN	SAN ANDRES	TX	GAINES	1977	5328	50,334	2,058,353
37821900	8	H. S. A.	SAN ANDRES	TX	WARD	1979	4485	297,120	1,491,427
46132500	8A	JENKINS	SAN ANDRES	TX	GAINES	1950	4543	149,200	3,162,188
47007400	8	JOHNSON	HOLT	TX	ECTOR	1973	5303	151,214	12,446,922
47267001	8	JORDAN		TX	CRANE	1937	3700	396,670	90,771,561
49129594	8	KEYSTONE	SAN ANDRES	TX	WINKLER	1960	4465	179,306	4,308,999
49138100	8	KEYSTONE, SW.	SAN ANDRES	TX	WINKLER	1981	4446	32,957	1,306,447
52497333	8	LAWSON	SAN ANDRES	TX	ECTOR	1950	4320	39,262	16,068,261
52624800	8	LEA	SAN ANDRES	TX	CRANE	1955	3075	81,383	10,167,344
54116500	8	LITTMAN	SAN ANDRES	TX	ANDREWS	1951	4313	10,140	1,390,768
57774581	8	MARTIN	SAN ANDRES	TX	ANDREWS	1945	4300	531	2,920,470
60137001	8	MEANS		TX	ANDREWS	1934	4400	3,879,160	232,243,704
69193426	8	PARKER	GRAYBURG, SAN ANDRES	TX	ANDREWS	1935	4800	82,719	4,322,184
70537001	8	PENWELL		TX	ECTOR	1926	3800	1,075,359	100,075,474
77316852	8A	ROBERTSON	SAN ANDRES	TX	GAINES	1952	4700	7,244	2,221,921
77318900	8A	ROBERTSON, N.	SAN ANDRES	TX	GAINES	1976	4704	529,810	5,011,781
80473248	8	SAND HILLS	JUDKINS	TX	CRANE	1960	3000	149,953	12,616,500
80473310	8	SAND HILLS	MCKNIGHT	TX	CRANE	1944	3420	623,821	128,500,389
80481001	8	SAND HILLS, WEST		TX	CRANE	1943	3883	34,616	2,899,960
82225142	8A	SEMINOLE	SAN ANDRES	TX	GAINES	1936	5032	10,074,235	602,619,981
82226500	8A	SEMINOLE, EAST	SAN ANDRES	TX	GAINES	1959	5450	225,895	10,892,763
82228800	8A	SEMINOLE, NE.	SAN ANDRES	TX	GAINES	1986	5427	222,003	1,897,871
82231500	8A	SEMINOLE, SE.	SAN ANDRES	TX	GAINES	1964	5310	30,980	3,007,614
82233001	8A	SEMINOLE, WEST		TX	GAINES	1948	5042	289,706	47,466,149
82570500	8	SHAFTER LAKE	SAN ANDRES	TX	ANDREWS	1953	4482	528,064	49,810,814
82572666	8	SHAFTER LAKE, N.	SAN ANDRES	TX	ANDREWS	1952	4559	2,914	1,231,741
83977500	8	SLATOR	SAN ANDRES	TX	ECTOR	1957	4172	5,925	2,416,337
89715400	8A	THREE-O-THREE	SAN ANDRES	TX	GAINES	1991	5538	95,489	1,244,903
88071580	8	TXL	SAN ANDRES	TX	ECTOR	1952	4380	88,578	12,508,307
94482001	8	WADDELL		TX	CRANE	1927	3500	966,371	108,369,174
		Totals						**26,420,818**	**2,151,296,650**

Early, pervasive dolomitization preserved much of the primary porosity in these San Andres reservoirs (Ruppel and Cander, 1988; Leary and Vogt, 1990). As a result, porosity distribution is controlled mainly by variations in original depositional texture and fabric. Some porosity was later occluded by anhydrite. Anhydrite forms 20 to 30 percent of the whole rock in the San Andres Formation at Emma field, where it occurs as nodules, cement, fossil

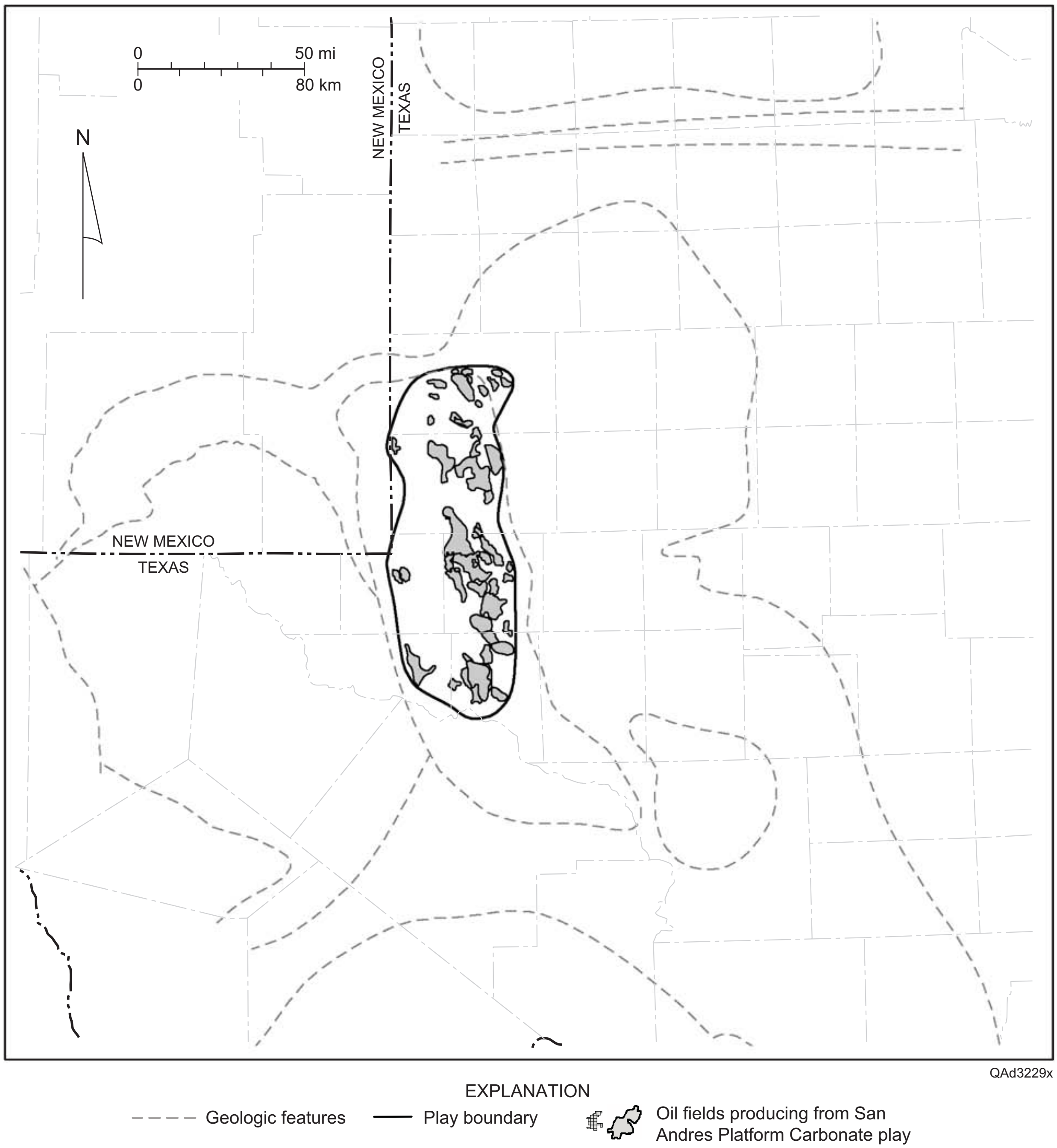

Figure 79. Play map for the San Andres Platform Carbonate play, showing location of reservoirs having >1 MMbbl cumulative production, the play boundary, and geologic features. See figure 1 for county names and figure 2 for identification of geologic features.

Emma San Andres reservoir

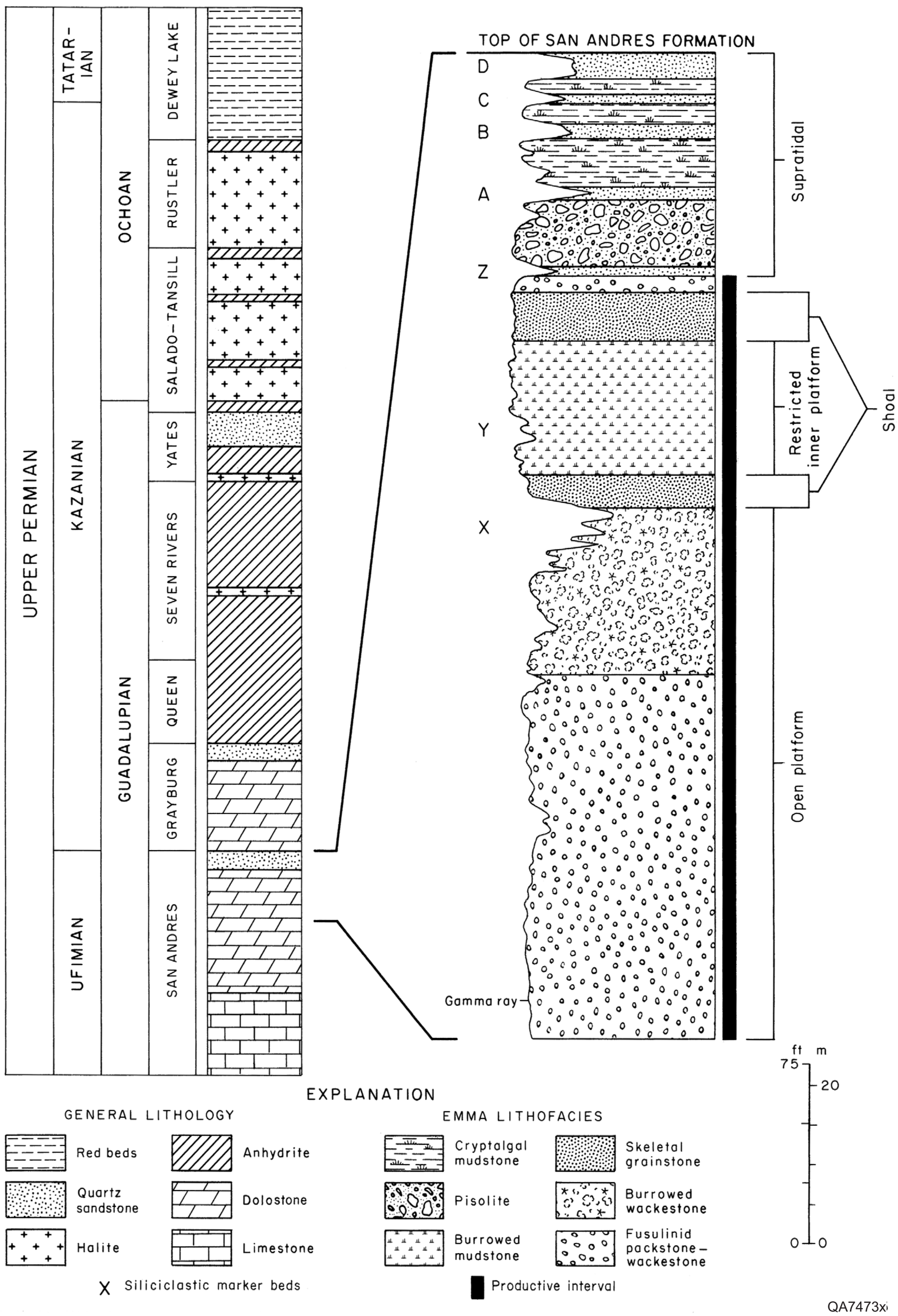

Figure 80. General Upper Permian stratigraphy and upper San Andres facies in the Emma field area, Andrews County. From Ruppel and Cander (1988).

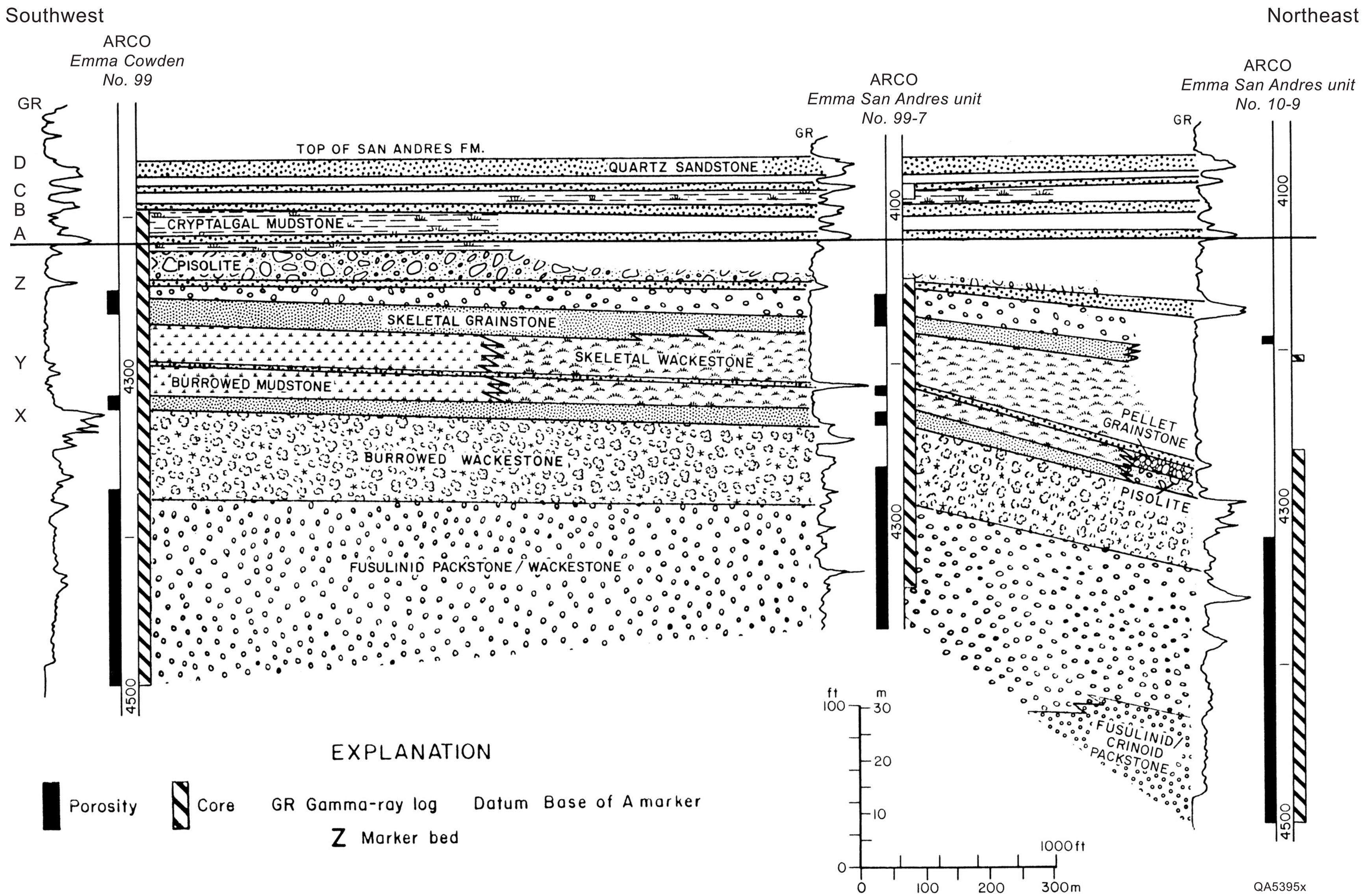

Figure 81. Southwest-northeast stratigraphic cross section of Emma field showing lateral and vertical extent of various lithofacies. From Ruppel and Cander (1988). See Ruppel and Cander (1988) for location of cross section.

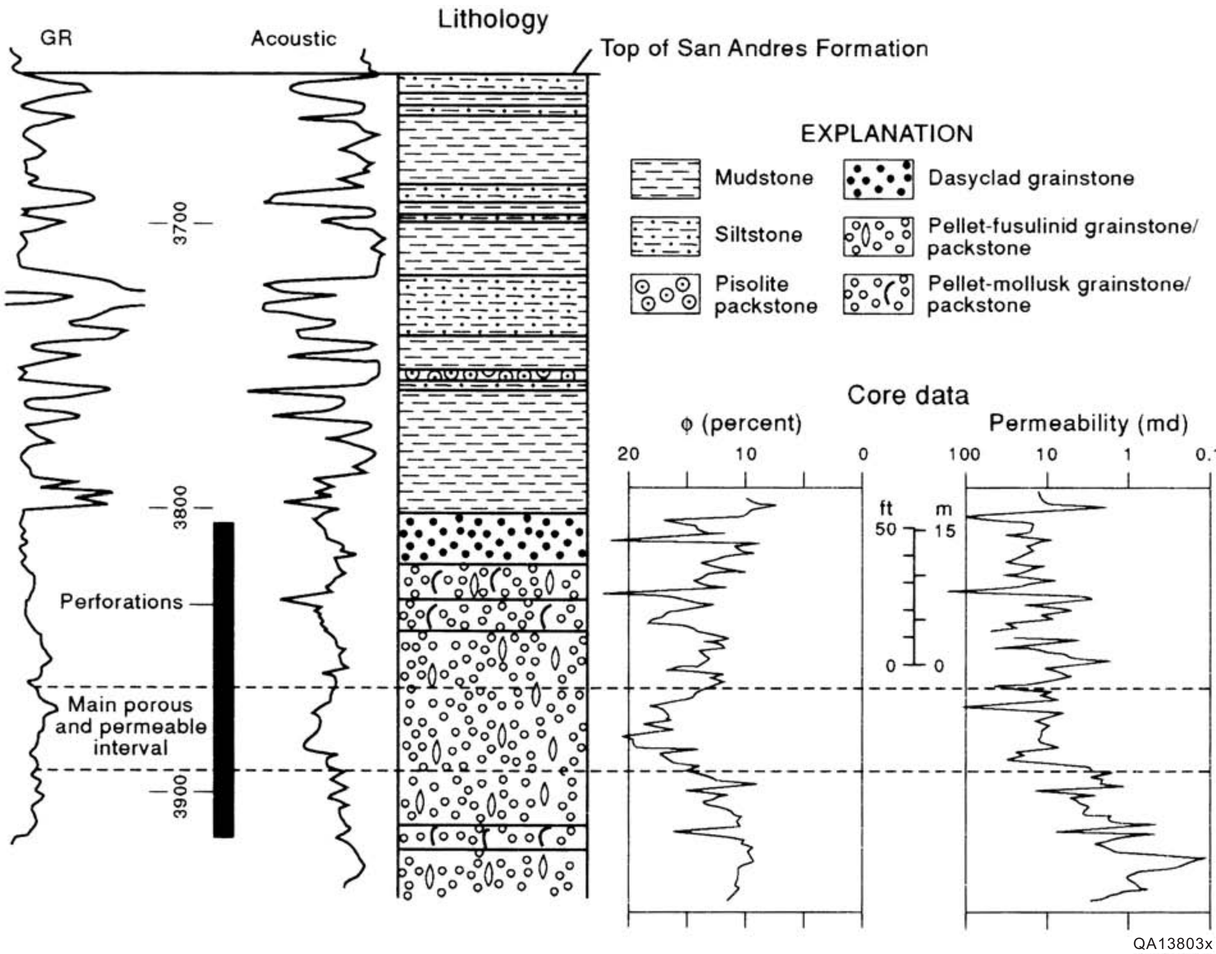

Figure 82. Log/core correlations for the EPSAU No. 207 well in East Penwell San Andres unit (EPSAU), Penwell field, Ector County. From Major and others (1990). Facies are described from core, and porosity and permeability are from whole-core analyses.

mold fillings, and fracture fillings (Ruppel and Cander, 1988). Minor anhydrite leaching locally increased reservoir porosity.

Production from the Emma San Andres reservoir is primarily from open-platform fusulinid packstone/wackestone facies and restricted inner-platform (shoal) skeletal grainstone facies (figs. 81, 84) (Ruppel and Cander, 1988). Porosity in the fusulinid packstone/wackestone facies at Emma field averages 8.7 percent, and permeability averages 1.4 md (1.4×10^{-3} μm^2). In the skeletal grainstone facies, porosities of 10 to 15 percent and permeabilities of 10 to 100 md

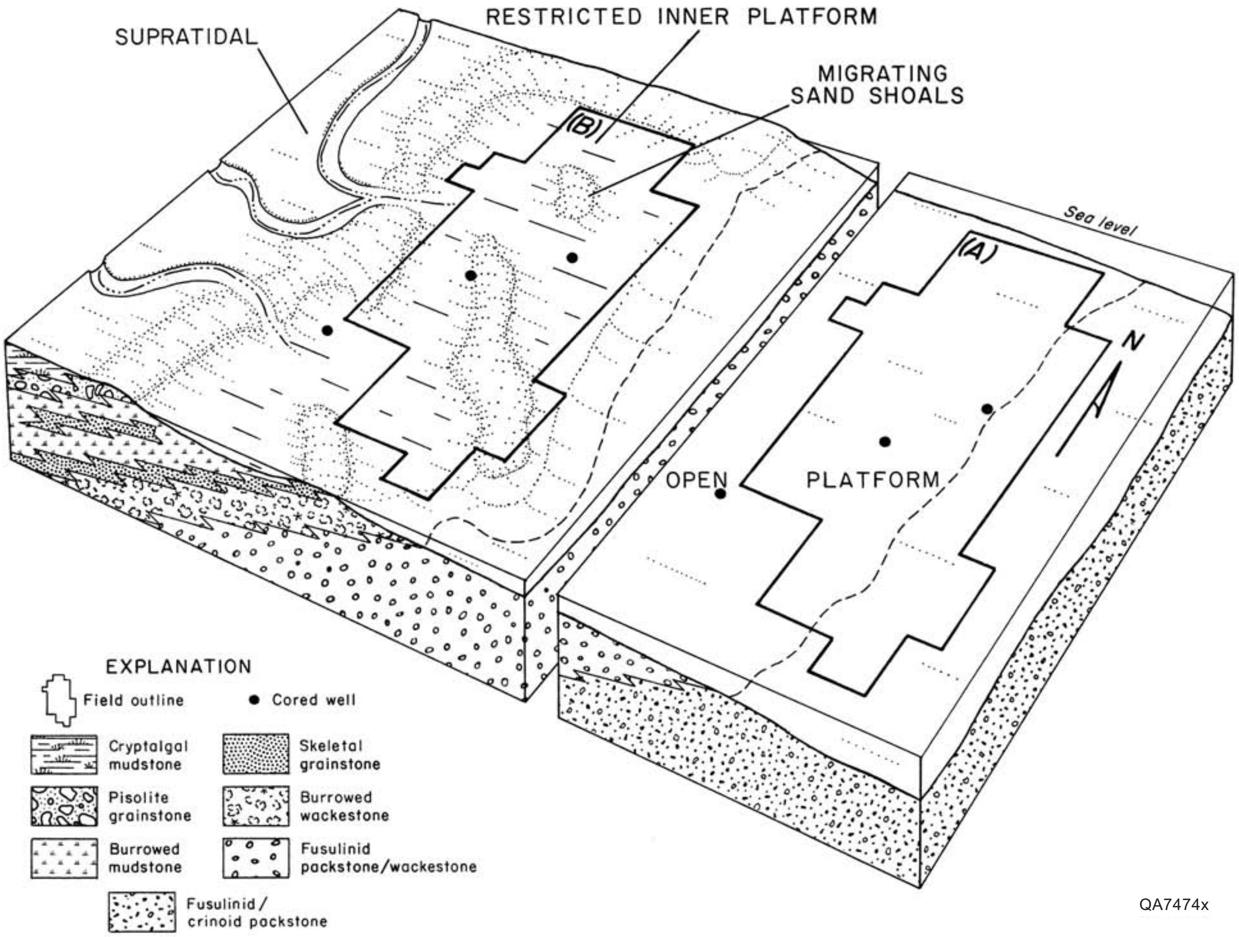

Figure 83. Paleoenvironmental reconstruction of Emma field area during late San Andres time. From Ruppel and Cander (1988). (A) When the lower part of the reservoir sequence was deposited, the area was characterized by deposition of subtidal, open-platform sediments on a gently east sloping carbonate ramp. (B) The upper part of the section was deposited in peritidal to supratidal conditions during a generally upward shallowing trend.

(10 to 100 $\times$ 10^{-3} μm^2) are common (Ruppel and Cander, 1988). At West Seminole field, the San Andres reservoir produces from oolitic and peloidal grainstones and fusulinid packstone/grainstones (Caldwell and Harpole, 1986). The reservoir facies are interbedded with low-permeability fusulinid wackestones in which porosity has been filled by anhydrite.

Reservoirs in this play produce from low-relief anticlines. Trapping results from lateral and vertical facies changes from porous and permeable subtidal dolostones of the reservoir to

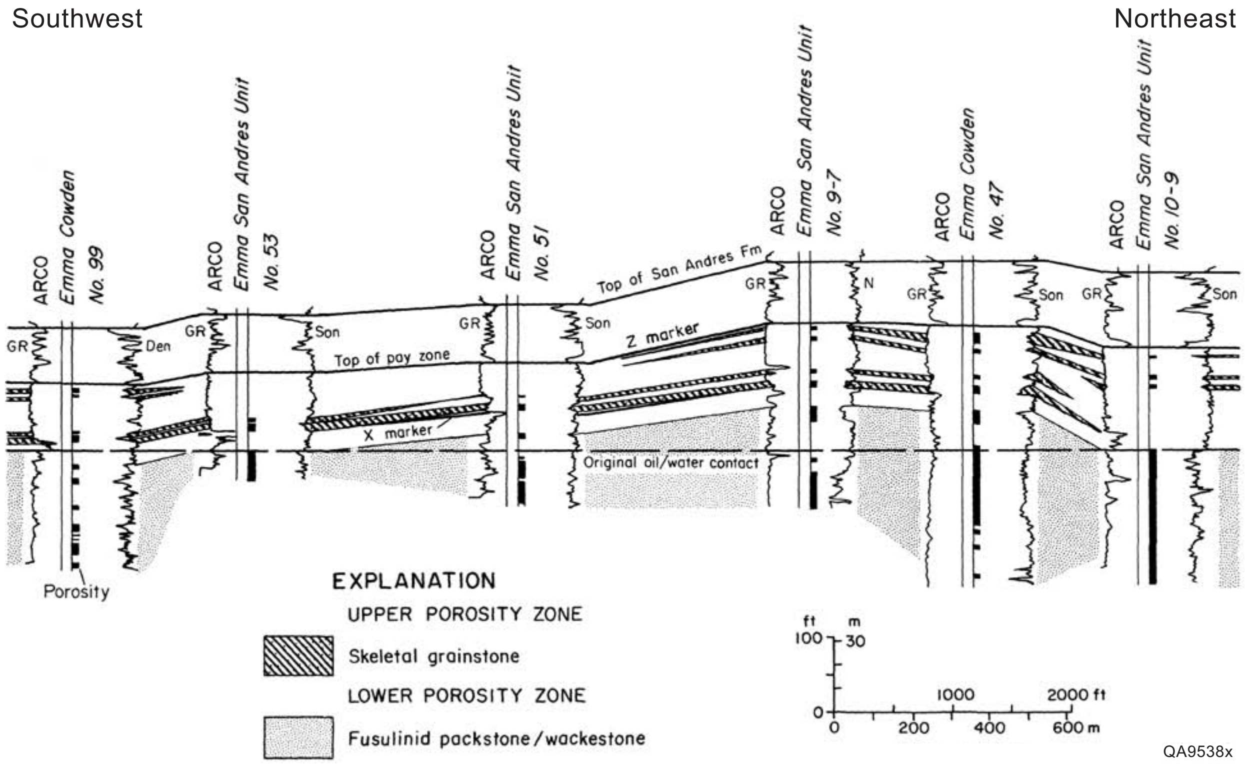

Figure 84. Southwest-northeast cross section showing distribution of skeletal grainstone and fusulinid packstone/wackestone reservoir facies across Emma field. From Ruppel and Cander (1988). Grainstone beds are laterally discontinuous. See Ruppel and Cander (1988) for location of cross section.

low-porosity and low-permeability intertidal and supratidal dolostones and anhydrite (Tyler and others, 1991). Natural fractures may be an important component of heterogeneity in these reservoirs. Productivity at Keystone field is interpreted as being dependent on fracture permeability (Major and Holtz, 1997). Horizontal wells drilled perpendicular to the direction of open natural fractures (northeast-southwest in Keystone field) could maximize primary recovery.

Penwell San Andres reservoir in Ector County (fig. 79) produces mainly from the subtidal pellet grainstone/packstone facies (fig. 82), which has well-preserved interparticle porosity (Major and others, 1990). Late diagenetic dissolution of anhydrite and dolomite in this facies increased porosity and improved reservoir quality (Siemers and others, 1995). The presence of gypsum in the San Andres Formation complicates both log interpretation and core analysis in this and other San Andres reservoirs (Bebout and others, 1987; Major and others, 1990). The acoustic log is the most reliable wireline tool for determining porosity (Major and others, 1990; Holtz and Major, 2004). Samples for core analysis should be processed at low temperature to avoid driving off bound water in gypsum during core cleaning (Major and others, 1990).

West Jordan unit of Jordan field, in Crane and Ector Counties (fig. 79), produces from compartmentalized shoal facies that formed on slight paleotopographic highs (French and Hinterlong, 2000). The reservoir produces from an asymmetric anticline formed by drape and compaction of San Andres deposits over Pennsylvanian-age structures. A permeability model of West Jordan unit, constructed using the method of Lucia (1995, 1999), incorporates the flow properties characteristic of rock-fabric pore types (French and Hinterlong, 2000). The geometries of the reservoir shoal facies were well defined by net-pay maps computed using a 0.5-md ($0.5 \times 10^{-3}\ \mu m^2$) permeability cutoff, and the model closely matches cumulative production.

The Means reservoir in Andrews County (fig. 79) produces from both the San Andres and Grayburg Formations, but the upper 300 ft (90 m) of the San Andres is the most productive interval (Bartel and Broomhall, 1986). Reservoir characterization was conducted prior to initiation of a CO_2 flood (George and Stiles, 1986). Core analyses were used to determine a porosity cutoff of 3 percent, equivalent to permeability of 0.1 md ($0.1 \times 10^{-3}\ \mu m^2$) (George and Stiles, 1986). A CO_2 flood consisting of 172 inverted 9-spot patterns on 10-acre spacing began at Means San Andres unit (MSAU) of Means field in 1983 (Bartel and Broomhall, 1986; Magruder and others, 1990). Production from the unit was 15,500 bbl/d ($2.46 \times 10^3\ m^3/d$) by December 1985, after having dropped below 9,000 bbl/d ($1.43 \times 10^3\ m^3/d$) prior to initiation of

CO_2 injection (George and Stiles, 1986). By 1999 MSAU had 476 active wells, and average production from the unit was 10,500 bbl/d (1.67×10^3 m^3/d) (Price and others, 2000). An operational challenge at MSAU is the narrow operating-pressure window between minimum miscibility pressure of 1,850 to 2,300 psi (12.8 to 15.9 Mpa) and formation parting pressure 2,700 to 2,800 psi (18.6 to 19.3 Mpa) (George and Stiles, 1986; Magruder and others, 1990).

Seminole field in Gaines County (fig. 79) produces from an atoll-like mound of aggradationally stacked carbonate developed above a Pennsylvanian-age structure (Lucia and others, 1995; Wang and others, 1996, 1998a, b, c). Seismic data suggest that Seminole is one of several isolated platforms built during the early San Andres that became joined with the rest of the San Andres platform during progradation of the upper San Andres (Lucia and others, 1995). Productive intervals are in the upper San Andres and the upper part of the lower San Andres. Main reservoir facies are fusulinid dolowackestone, fusulinid-peloid grain-dominated dolopackstone, and coated-grain dolograinstone (Sonnenfeld and others, 2001). Reservoir properties are controlled by facies, both through original porosity distribution and later dolomitization. Facies distribution is related to paleohighs trending NNE. Facies maps demonstrate paleostructural control starting with crestal and ending with peripheral concentrations of grain-dominated reservoir facies (Sonnenfeld and others, 2003).

Simulation of Seminole San Andres field indicates that high-frequency cycles and rock-fabric units are the two critical scales for modeling these shallow-water carbonate ramp reservoirs (Lucia and others, 1995; Wang and others, 1998a, b, c). Description of rock-fabric facies stacked within high-frequency cycles provided a framework for constructing geologic and reservoir models (fig. 85). Discrete petrophysical functions were fit to rock-fabric units, and fluid flow and recovery efficiency were estimated using petrophysical properties of rock-fabric flow

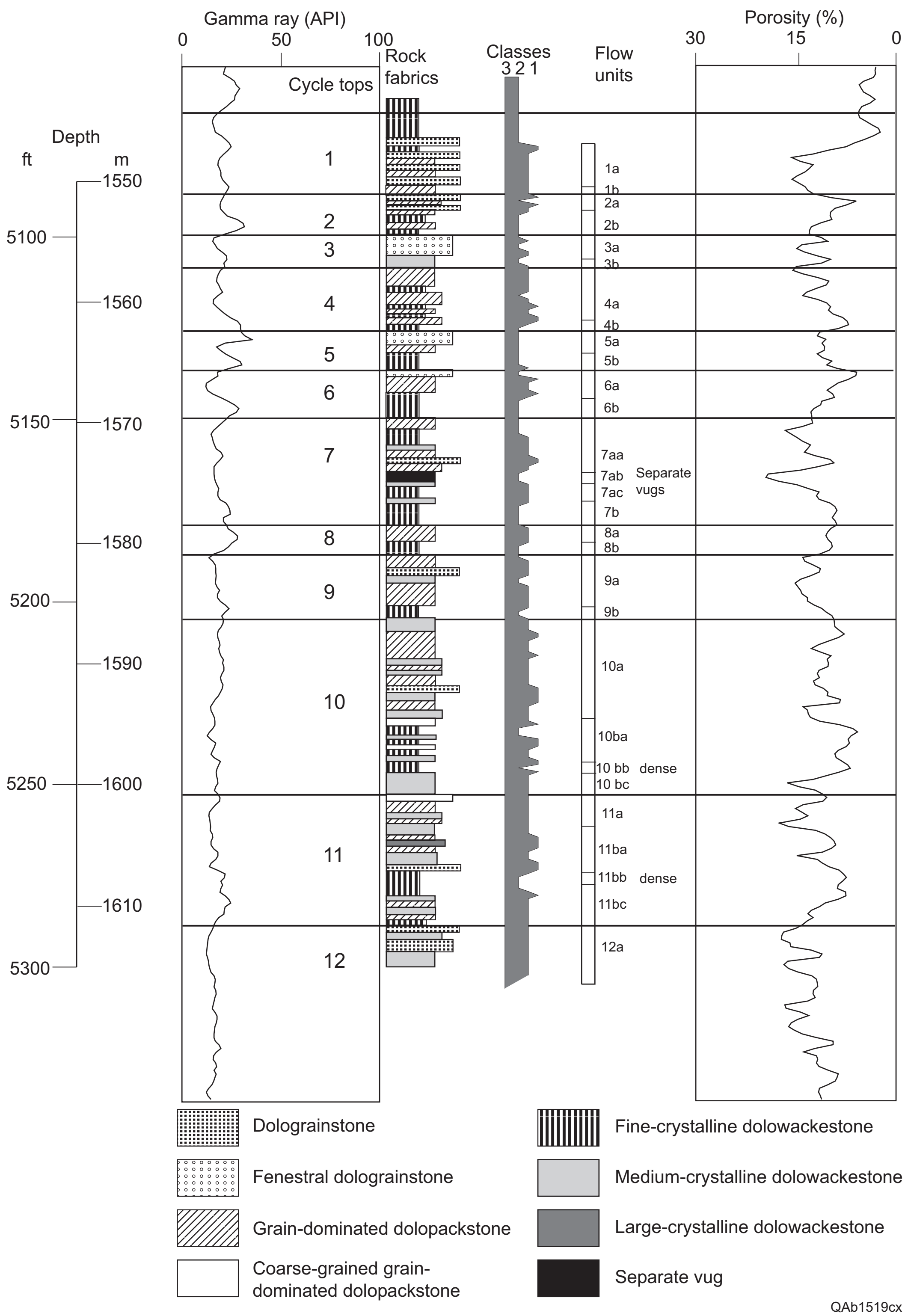

Figure 85. High-frequency cycles and rock-fabric facies in the Amerada Hess SSAU No. 2505 well, Seminole field, Gaines County. From Wang and others (1996).

units. Simulation results showed that critical factors affecting recovery efficiency are stacking patterns of rock-fabric flow units, the ratio of vertical permeability to horizontal permeability (k_{vh}), and dense mudstone distribution (Wang and others, 1998a). CO_2 flooding of Seminole San Andres unit began in 1985. Core, log, seismic, and production data were integrated into an 8-million-cell full-field model of Seminole San Andres unit to enhance reservoir management and estimate remaining reserves (Zahm and others, 2002; Sonnenfeld and others, 2003).

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Upper San Andres and Grayburg Platform Mixed—Central Basin Platform Trend (Play 124)

The Upper San Andres and Grayburg Platform Mixed—Central Basin Platform Trend play is located in New Mexico on the northwest part of the Central Basin Platform in Lea County, with some smaller reservoirs (<1 MMbbl [1.59×10^5 m^3]) cumulative oil production) located off the northwest flank of the Central Basin Platform within the Delaware Basin (fig. 86). Eight reservoirs have produced >1 MMbbl (1.59×10^5 m^3) (table 30). Cumulative production from these eight reservoirs was 809 MMbbl through 2000. Production is commingled from mixed dolostones and clastics of the upper San Andres Formation and the Grayburg Formation. The play has been in decline over the last 30 years. An upturn in production during the middle to late 1980's was caused by implementation of several large pressure-maintenance projects within the Hobbs Grayburg San Andres reservoir.

Reservoirs of the upper San Andres Formation and Grayburg Formation are high-energy dolograinstones from shoal environments and shallow-marine dolomitic sandstones (Garber and Harris, 1986; Lindsay, 1991). Facies are probably similar to better-studied Texas reservoirs that

Table 30. Upper San Andres and Grayburg Platform Mixed—Central Basin Platform Trend play (play 124).

RRC RESN	RRC	FLDNAME	RESNAME	STATE	COUNTY	DISCYR	DEPTHTOP	2000 PROD	CUMPROD
		ARROWHEAD	GRAYBURG	NM	LEA	1957	6500	315,369	32,921,348
		CARTER SOUTH	GRAYBURG SAN ANDRES	NM	LEA	1955	5150	20,772	2,369,529
		EUNICE MONUMENT	GRAYBURG SAN ANDRES	NM	LEA	1929	3950	2,385,325	392,454,534
		EUNICE SOUTH	GRAYBURG SAN ANDRES	NM	LEA	1969	3910	30,771	1,613,611
		HOBBS	GRAYBURG SAN ANDRES	NM	LEA	1928	4000	2,672,316	340,970,244
		HOBBS EAST	GRAYBURG SAN ANDRES	NM	LEA	1951	4449	143,422	5,894,293
		PENROSE	SKELLY GRAYBURG	NM	LEA	1936	3435	141,074	21,616,809
		SKAGGS	GRAYBURG	NM	LEA	1937	3608	81,311	11,117,325
		Totals						**5,790,360**	**808,957,693**

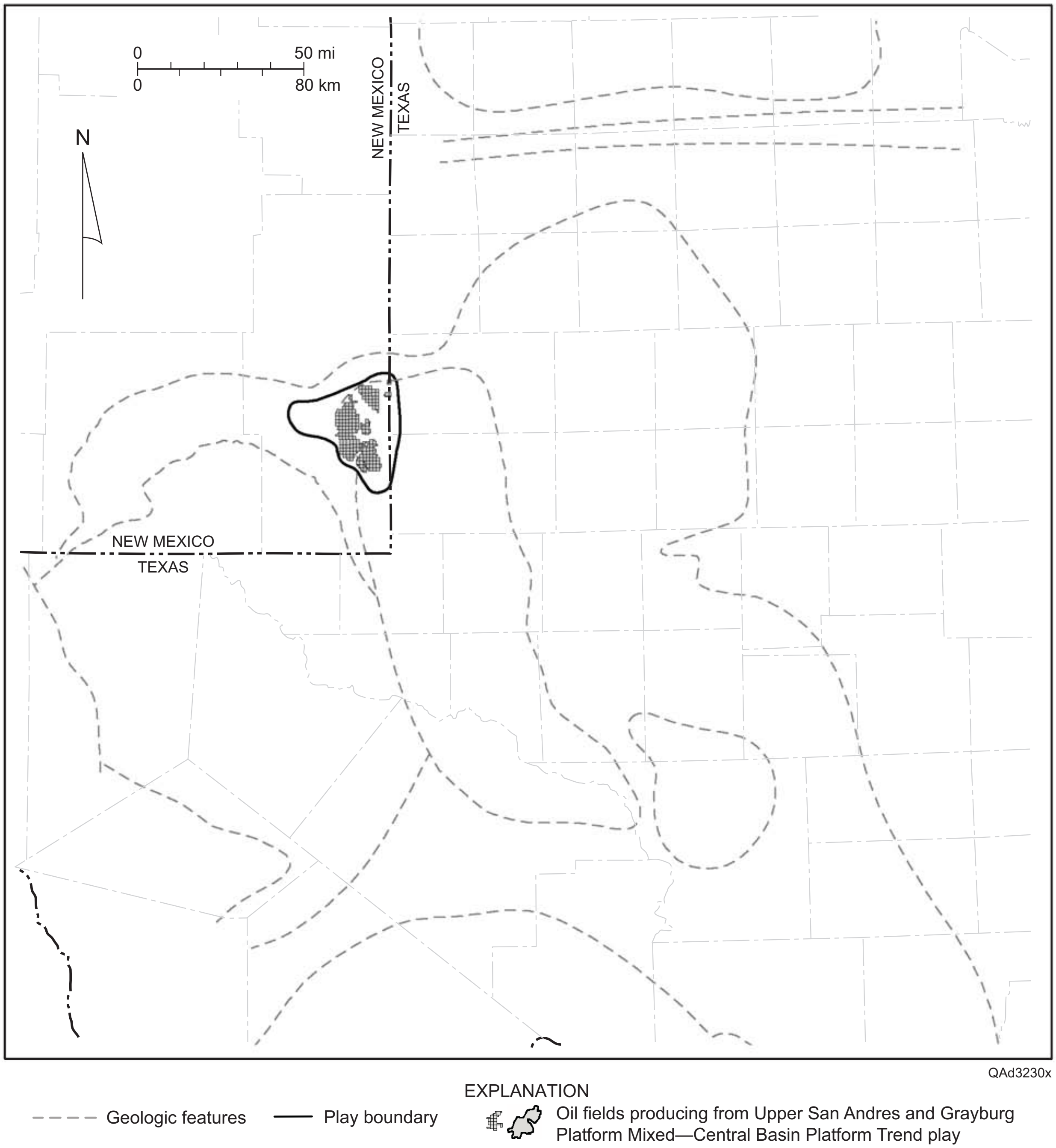

Figure 86. Play map for the Upper San Andres and Grayburg Platform Mixed—Central Basin Platform Trend play, showing location of reservoirs having >1 MMbbl cumulative production, the play boundary, and geologic features. See figure 1 for county names and figure 2 for identification of geologic features.

include environments fluctuating between supratidal through platform margin, with wackestone through boundstone textures (Galloway and others, 1983). Porosity is generally best developed in platform-margin grainstone facies, but lower energy facies have locally developed secondary porosity (Galloway and others, 1983). Traps are formed mainly by gentle, north-south-trending anticlines.

The Eunice Monument reservoir is a combination trap formed by anticlinal closure on the west, north, and south but is stratigraphic to the east where porous dolograinstones of a high-energy shoal complex and subtidal dolomitic sandstones are sealed updip by a back-shoal facies consisting of impermeable dolomitic sandstones, dolostones, and evaporites (Lindsay, 1991). Vertical seals are formed by impermeable evaporitic facies of the upper Grayburg and lower Queen Formations. Reservoirs are typically heterogeneous, and reservoir quality and distribution can vary across a single trap-forming structure (Galloway and others, 1983).

San Andres production from the Hobbs reservoir is from the uppermost part of the San Andres, which shows evidence of karst modification—solution-widened fractures, large vugs, and small pockets of breccia. High well-test permeability suggests that permeability in the field is strongly influenced by a large interconnected pore system. The Hobbs reservoir had a longer primary production history than most San Andres fields.

Dominant production mechanisms in the play are water and solution-gas drive. Waterflooding and pressure maintenance have been successfully implemented in many of the reservoirs in this play and have resulted in substantial increases in recovery.

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Upper San Andres and Grayburg Platform Mixed—Artesia Vacuum Trend (Play 125)

Reservoirs of the Upper San Andres and Grayburg Platform Mixed—Artesia Vacuum Trend play extend in an east-west direction from the city of Artesia to Hobbs in Eddy and Lea Counties, New Mexico (fig. 87). The play contains 13 reservoirs with >1 MMbbl (1.59×10^5 m^3) cumulative oil production. Cumulative production from these 13 reservoirs was 796 MMbbl (1.27×10^8 m^3) as of 2000 (table 31). Production in most reservoirs is commingled from the San Andres and Grayburg Formations. This is a mature play, especially within the highly productive San Andres carbonates. Production from the play reached a modern peak of >18 MMbbl/yr (2.86×10^6 m^3/yr) in the 1980's, mostly as a result of waterflooding of the Vacuum reservoir (fig. 88). Recent development of lower permeability Grayburg sandstones in the Grayburg Jackson reservoir during the mid-1990's has been successful to the point of reversing production decline (fig. 89) and is a major focus of current and future development.

The upper San Andres Formation is composed of restricted, backreef dolowackestones, dolopackstones, and dolograinstones (Ward and others, 1986; Purves, 1990). Reservoir facies lie between the Guadalupian (Goat Seep) shelf margin to the south and tight evaporites and dolomites of inner-shelf and lagoonal environments to the north. The overlying

Table 31. Upper San Andres and Grayburg Platform Mixed—Artesia Vacuum Trend play (play 125).

RRC RESN	RRC	FLDNAME	RESNAME	STATE	COUNTY	DISCYR	DEPTHTOP	2000 PROD	CUMPROD
		ARTESIA	QUEEN GRAYBURG SAN ANDRES	NM	EDDY	1923	2190	470,624	32,271,228
		ATOKA	SAN ANDRES	NM	EDDY	1950	1680	108,733	6,999,883
		EAGLE CREEK	SAN ANDRES	NM	EDDY	1959	1292	41,554	4,321,284
		GRAYBURG JACKSON	SEVEN RIVERS QUEEN GRAYBURG S	NM	EDDY & LEA	1929	2700	3,432,424	128,043,260
		HENSHAW WEST	GRAYBURG	NM	EDDY	1956	2870	5,605	5,024,733
		LOCO HILLS	QUEEN GRAYBURG SAN ANDRES	NM	EDDY	1949	2600	103,747	48,282,690
		LOVINGTON	GRAYBURG SAN ANDRES	NM	LEA	1986	4700	66,016	14,689,351
		LOVINGTON WEST	UPPER SAN ANDRES	NM	LEA	1990	4700	72,879	13,021,692
		MALJAMAR	GRAYBURG SAN ANDRES	NM	EDDY & LEA	1939	4050	1,003,045	158,141,214
		RED LAKE	QUEEN GRAYBURG SAN ANDRES	NM	EDDY	1934	1945	577,383	12,719,172
		SQUARE LAKE	GRAYBURG SAN ANDRES	NM	EDDY	1941	3040	109,812	28,338,035
		SQUARE LAKE NORTH	QUEEN GRAYBURG SAN ANDRES	NM	EDDY	1987	3300	9,376	2,690,235
		VACUUM	GRAYBURG SAN ANDRES	NM	LEA	1929	4500	5,391,799	341,873,609
		Totals						**11,392,997**	**796,416,386**

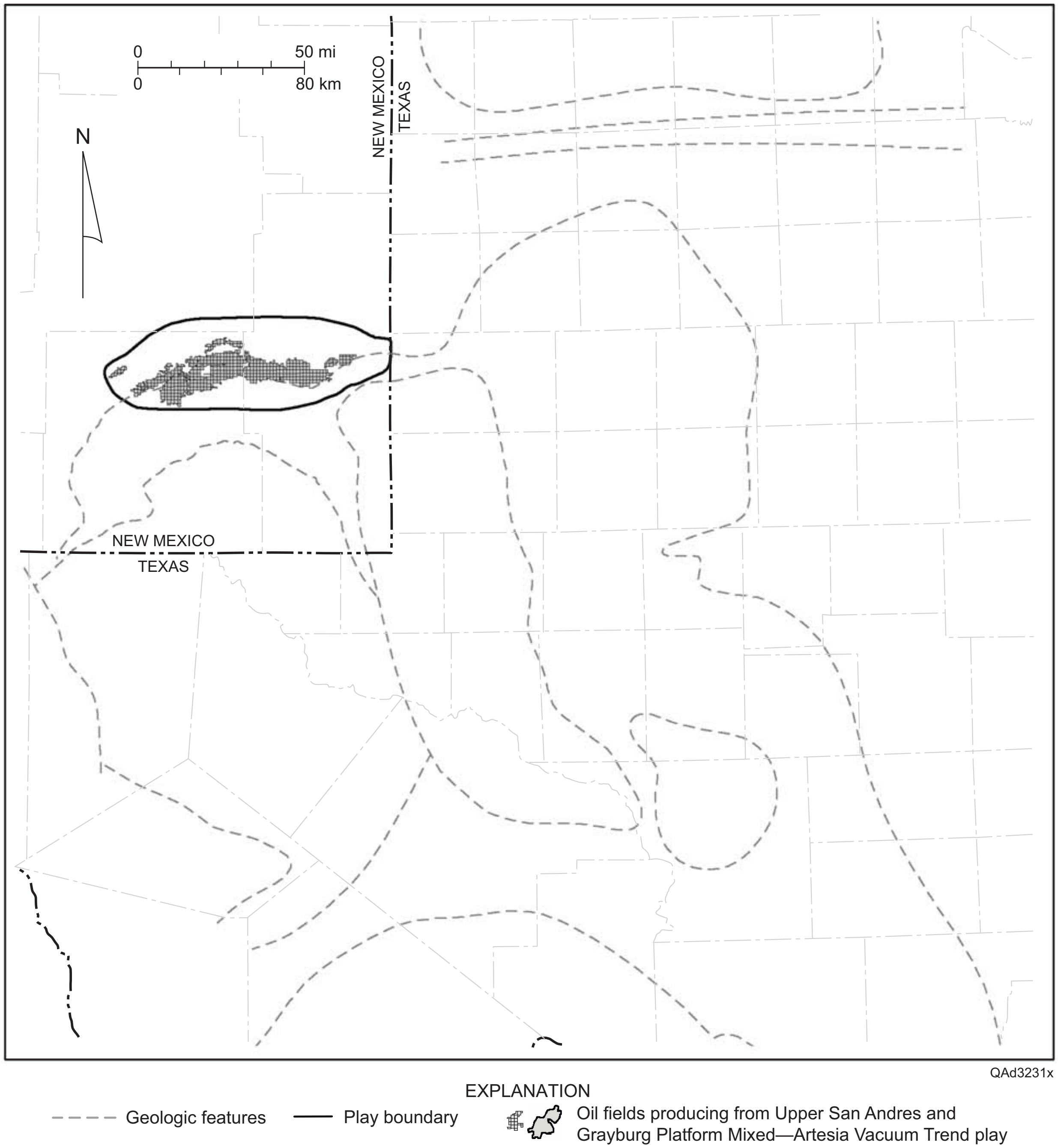

Figure 87. Play map for the Upper San Andres and Grayburg Platform Mixed—Artesia Vacuum Trend play, showing location of reservoirs having >1 MMbbl cumulative production, the play boundary, and geologic features. See figure 1 for county names and figure 2 for identification of geologic features.

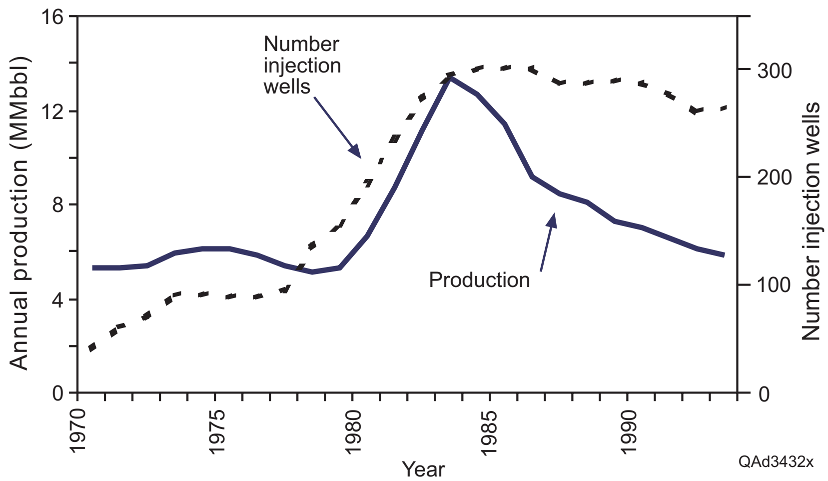

Figure 88. Annual oil production and number of injection wells in the Vacuum Grayburg San Andres reservoir from 1970 through 1993, showing the relationship between injection wells used for enhanced oil recovery and oil production. Most injection wells were used for water injection; after several years, a minor number of water injection wells were converted to polymer injection.

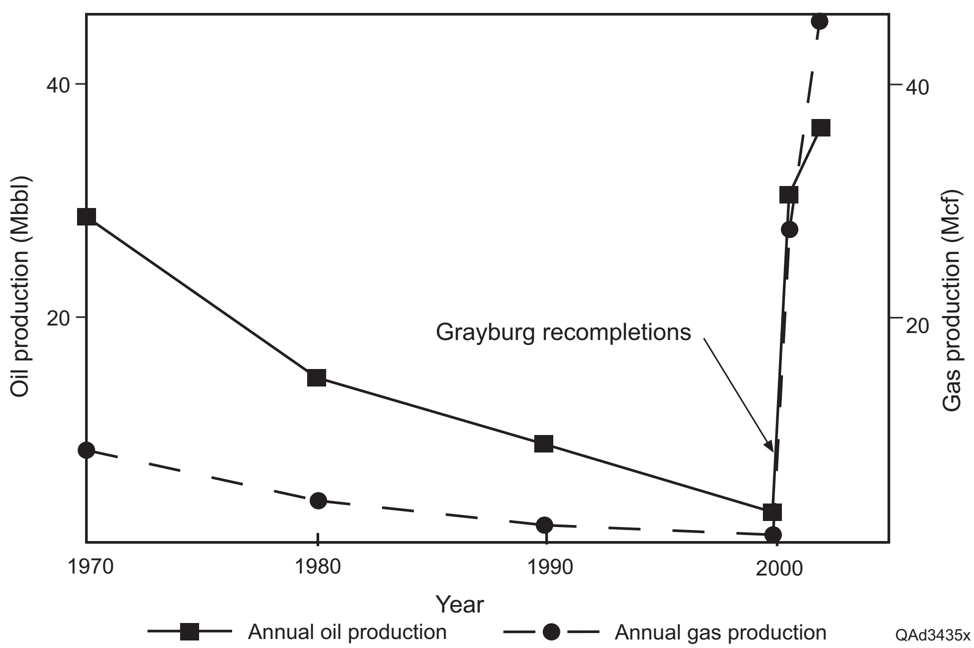

Figure 89. Annual combined oil and gas production for three wells in the Grayburg-Jackson reservoir, Upper San Andres and Grayburg Platform Mixed—Artesia Vacuum Trend play. These wells originally produced from San Andres zones and were in gradual decline, but production was revitalized when they were recompleted in Grayburg pay.

Grayburg Formation contains interbeds of dolomite, sandstone, and evaporites. Production in the San Andres is obtained principally from dolostones, and production in the Grayburg is obtained largely from sandstones.

Reservoirs in this play lie along the Artesia-Vacuum Arch, a shallow east-west-trending structure that overlies the deeper, older Abo shelf edge reef trend and Bone Spring flexure (Broadhead, 1993). The position of a reservoir with respect to the axis of the Artesia-Vacuum Arch dictates whether the Grayburg Formation or the upper part of the San Andres Formation is more productive. Those reservoirs located along the crest (for example, Maljamar, Vacuum, Grayburg-Jackson) are structurally high enough for the Grayburg and upper San Andres Formations to be in the oil zone, whereas on the flanks of the structure the San Andres is wet, and only the overlying Grayburg is in the regional oil leg. Exact location of some reservoirs is influenced by local structures that may be oriented at an angle to the regional shelf edge (see Purves, 1990). Traps are combination structural and stratigraphic, with the Artesia-Vacuum Arch providing the structural element. Updip (northerly) porosity pinch-outs into tight evaporitic lagoonal facies create the stratigraphic trapping component (Ward and others, 1986). The regional vertical seal is formed by impermeable strata within the overlying upper Grayburg and Queen Formations. Solution-gas drive is the primary production mechanism.

The San Andres Formation of the Northwest Shelf is composed of numerous high-frequency, upward-shoaling, carbonate depositional cycles (Purves, 1986; Handford and others, 1996; Modica and Dorobek, 1996; Stoudt and Raines, 2001; Pranter and others, 2004). Cycles consist of permeable subtidal carbonates that are capped by low-permeability peritidal carbonates that vertically compartmentalize the reservoir. Reservoir zones in the San Andres exhibit lateral as well as vertical variation in permeability (Hinrichs and others, 1986).

The Grayburg Formation consists of interbedded sandstones, siltstones, and dolomitic carbonates (fig. 90) (Handford and others, 1996; Modica and Dorobek, 1996). The sandstones, deposited in coastal, sabkha, sandflat, and eolian environments (fig. 91), are the principal reservoirs. The carbonates are subtidal deposits that are generally impermeable. Pores are commonly plugged by anhydrite.

The Vacuum reservoir exhibits complex internal vertical and horizontal segmentation of flow units. As described earlier, the reservoir is vertically compartmentalized by upward-shoaling carbonate cycles. It is divided into horizontal compartments by numerous high-angle, low-displacement faults (Pranter and others, 2004). Although vertical throw of the faults is <25 ft (<8 m) in most cases, it is sufficient to isolate thin, permeable beds across the faults, which act as horizontal seals. In addition, significant karsting and development of dissolution features, caves, and solution-collapse structures are associated with intraformational sequence boundaries, especially at the prominent sequence boundary that separates the upper part of the San Andres from the lower part of the San Andres (Stoudt and Raines, 2001; Pranter and others, 2004). Although karst development may have enhanced porosity and permeability in some San Andres reservoirs (for example, see Hovorka and others, 1993), karst pore systems at Vacuum are filled with impermeable sandstone, collapsed carbonates, or evaporites and act to further compartmentalize the reservoir both vertically and horizontally (Stoudt and Raines, 2001; Pranter and others, 2004). Similarly, destruction of karst-related porosity by anhydrite cementation has been described in the Maljamar reservoir of this play (Modica and Dorobek, 1996). The complex horizontal and vertical compartmentalization of flow units that formed as a result of cyclic deposition of permeable and impermeable facies, faults, and destruction of karst-derived porosity by sand and evaporite plugging and solution collapse makes

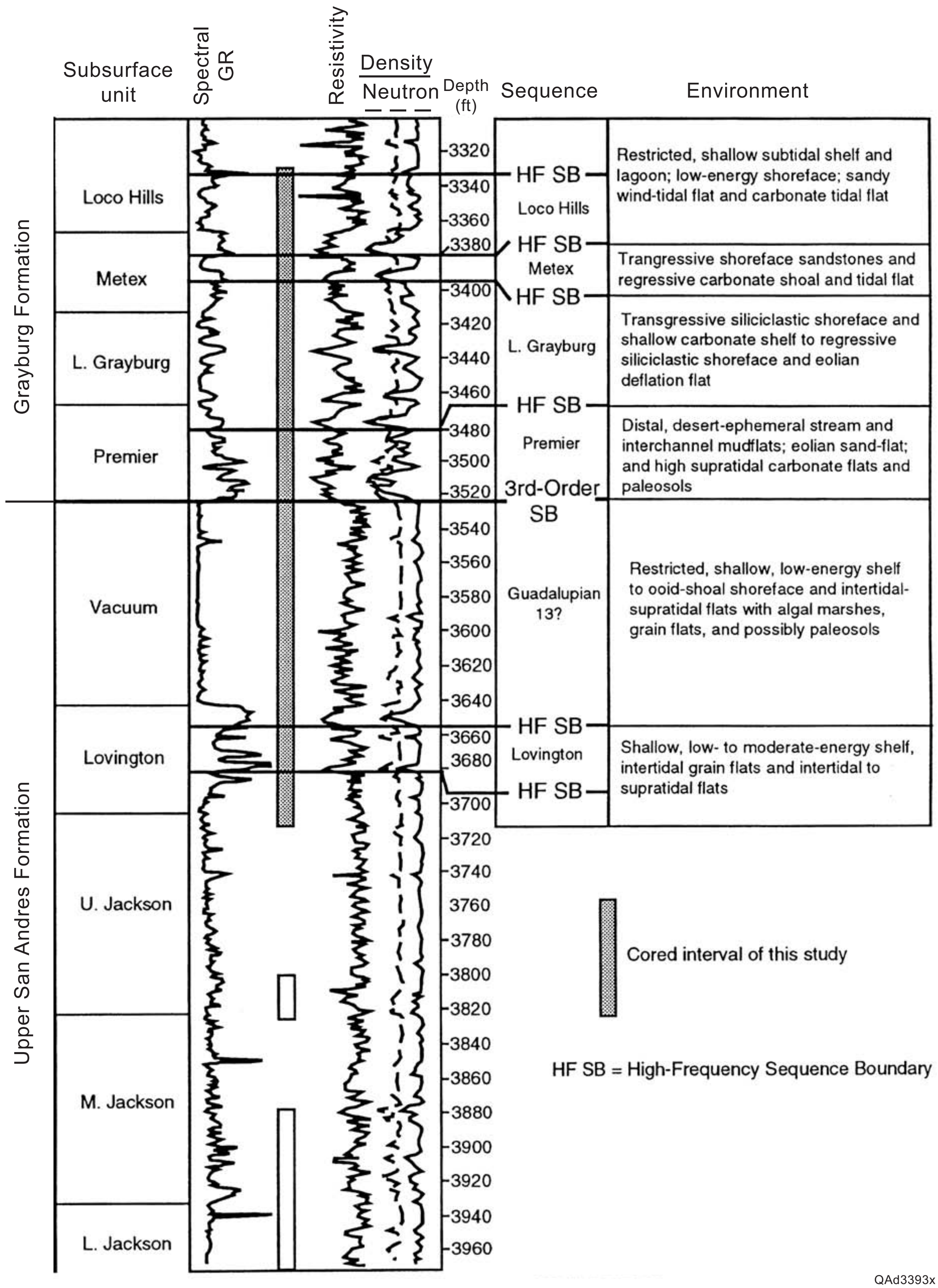

Figure 90. Stratigraphic column for the H. E. West "A" No. 22 well in Jackson-Grayburg field on the Northwest Shelf, Eddy County. From Handford and others (1996).

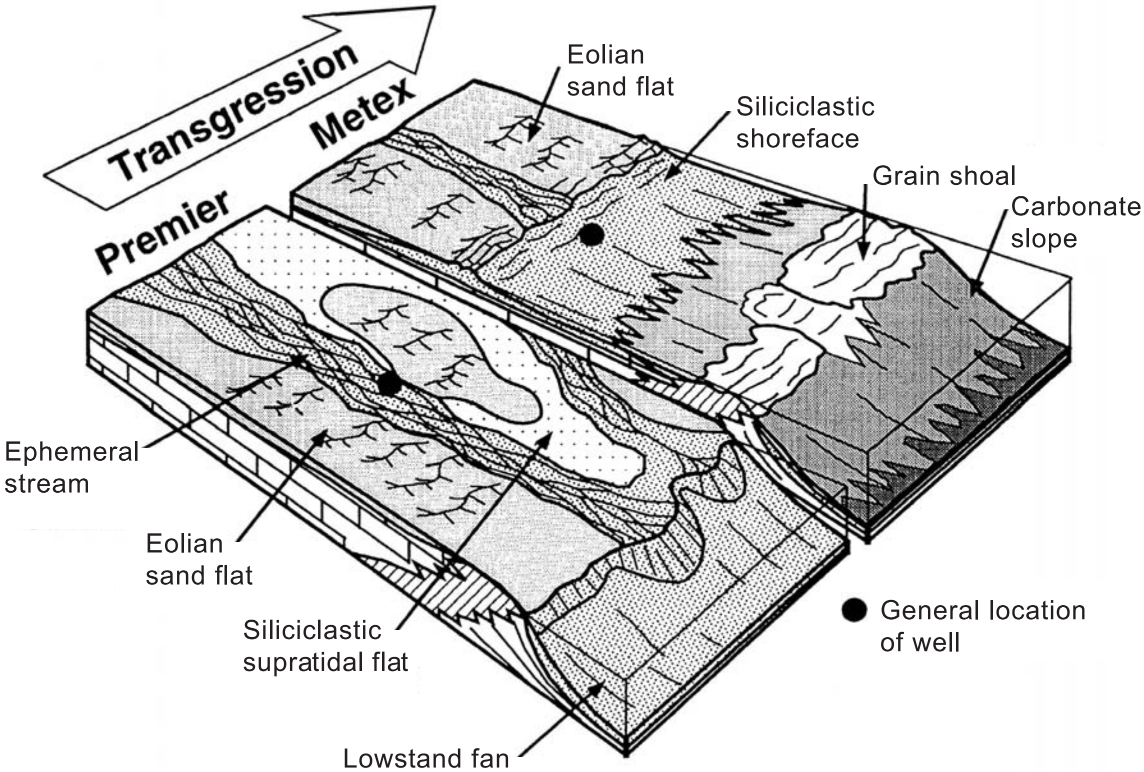

Figure 91. Depositional model of the Grayburg Formation during a base-level rise. From Handford and others (1996). The general location of the H. E. West “A” No. 22 well shown in figure 90 is indicated.

full development of reservoirs impossible with vertical wells drilled on standard 40-acre spacing.

Enhanced recovery techniques have been successful in reservoirs of the Upper San Andres and Grayburg Platform Mixed—Artesia Vacuum Trend Play. Many of the reservoirs in this play have been successfully waterflooded. CO_2 flooding has been employed in portions of the Vacuum reservoir with positive results (Pranter and others, 2004), and the CO_2 flood was expanded in the late 1990’s. The presence of complex systems of internal reservoir compartments has resulted in parts of the reservoir being unswept by enhanced recovery operations.

There is significant potential for enhancing production from San Andres carbonates by drilling horizontal laterals from existing vertical well bores, as has been done at the Vacuum reservoir (Pranter and others, 2004). This reservoir, discovered in 1929, is mature. Large parts of it have been waterflooded and, as mentioned earlier, a successful CO_2 flood has been employed in part of the reservoir. Although these enhanced-recovery methods have increased production substantially, vertical and horizontal compartmentalization has resulted in significant bypassed pay that has not been drained adequately by vertical wells or completely swept during enhanced recovery. Fault-block boundaries and bypassed-pay zones have been identified by a combination of 3-D seismic surveys and well data (Pranter and others, 2004). Horizontal laterals aimed at intersecting undrained pay were drilled from an existing vertical well and resulted in an increase in production approximately 20-fold, when compared with what the preexisting vertical well yielded (Pranter and others, 2004). Production from existing vertical-offset wells was not affected by the newer lateral wells, indicating that the lateral wells penetrated untapped reservoir compartments. Rather than the horizontal laterals being drilled as flat segments, they were drilled in a serpentine pattern so that multiple vertical reservoir compartments were penetrated by a single well bore.

Another example of a development practice that significantly enhanced production is derived from a lease in Section 13 T17S R30E in the Grayburg-Jackson reservoir (B. Brister, personal communication, 2003). This area is located along the crest of the Artesia-Vacuum Arch and is sufficiently high structurally that the karsted, highly permeable Jackson zone of the San Andres reservoir is above the oil-water contact. Production in the Grayburg-Jackson reservoir was obtained mostly from dolostones in the San Andres from the 1920’s until the mid-1990’s, when these wells were recompleted in the Grayburg. Open-hole logs had never been run in the older wells, and the Grayburg was located behind casing. Neutron logs failed to show Grayburg pay zones behind casing because of high gas saturations in reservoir zones. Locations of Grayburg pay zones were inferred from regional correlations, and Grayburg recompletions targeted the inferred zones. This methodology resulted in significantly increased levels of both gas and oil production (fig. 89). Current development practices of completing Grayburg pay separately from San Andres pay will limit production to a more homogeneous reservoir than with commingled Grayburg-San Andres completions. One result may be more uniform flooding and improved recovery if enhanced recovery is employed.

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San Andres/Grayburg Lowstand Carbonate (Play 126)

The 19 reservoirs in the San Andres/Grayburg Lowstand Carbonate play have produced 681.1 MMbbl (1.08×10^8 m^3) of oil from the San Andres and Grayburg Formations in the Midland Basin (table 32, fig. 92). The reservoirs are structurally and topographically well below San Andres and Grayburg shelf-margin production on the Central Basin Platform and Northwest Shelf. The shallow-water facies in these reservoirs are interpreted as having been deposited in the Midland Basin during periods of sea-level lowstand. In contrast to San Andres and Grayburg reservoirs on the Central Basin Platform, oolite grainstones are common reservoir facies in this play. Positions of the isolated reservoirs on the east side of the play—Pegasus, Brazos, Azalea, Germania, and Phoenix—are probably controlled by paleostructures, where shallow-water facies were localized.

Regional subsurface sequence stratigraphic relationships of the San Andres and Grayburg on the Central Basin Platform and in the Midland Basin were established by Dedmon and Dorobek (1993). They concluded that the San Andres platform experienced a prolonged period

Table 32. San Andres/Grayburg Lowstand Carbonate play (play 126). 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
570001	8A	ADAIR		TX	GAINES	1947	4874	913,427	66,079,283
4605444	8	AZALEA	GRAYBURG	TX	MIDLAND	1967	4088	34,643	2,064,038
9116500	8	BLOCK 2	GRAYBURG	TX	ANDREWS	1957	4736	182,213	3,116,332
11601500	8	BRAZOS	SAN ANDRES	TX	MIDLAND	1982	4433	58,217	1,934,677
16580001	8A	CEDAR LAKE		TX	GAINES	1939	4800	2,369,564	105,374,960
16585500	8A	CEDAR LAKE, SE.	SAN ANDRES	TX	DAWSON	1953	4940	13,074	1,649,672
34563400	8	GERMANIA	GRAYBURG	TX	MIDLAND	1952	3940	68,968	5,351,696
56378001	8	MABEE		TX	ANDREWS	1943	4704	1,811,218	115,007,221
56159200	8	M.F.E.	GRAYBURG	TX	ANDREWS	1991	4936	174,577	3,556,164
61118001	8	MIDLAND FARMS		TX	ANDREWS	1945	4800	1,032,777	161,255,366
61119333	8	MIDLAND FARMS, E	GRAYBURG UPPER	TX	ANDREWS	1969	4780	0	2,460,219
61120500	8	MIDLAND FARMS, NORTH	GRAYBURG	TX	ANDREWS	1953	4943	72,536	16,927,251
56432700	8A	MTS	SAN ANDRES	TX	DAWSON	1984	4922	70,894	3,011,168
70279625	7C	PEGASUS	SAN ANDRES	TX	MIDLAND	1954	5584	55,789	11,051,115
71267500	8	PHOENIX	GRAYBURG	TX	MARTIN	1972	3930	104,273	4,620,068
82275500	8	SERIO	GRAYBURG	TX	ANDREWS	1970	4806	154,358	4,834,677
85281001	8A	SPRABERRY		TX	DAWSON	1946	3930	53,522	2,381,850
88000500	8A	TLOC	SAN ANDRES	TX	TERRY	1980	4904	52,796	1,457,257
96062001	8A	WELCH		TX	DAWSON	1941	5000	2,134,395	168,998,863
		Totals						**9,357,241**	**681,131,877**

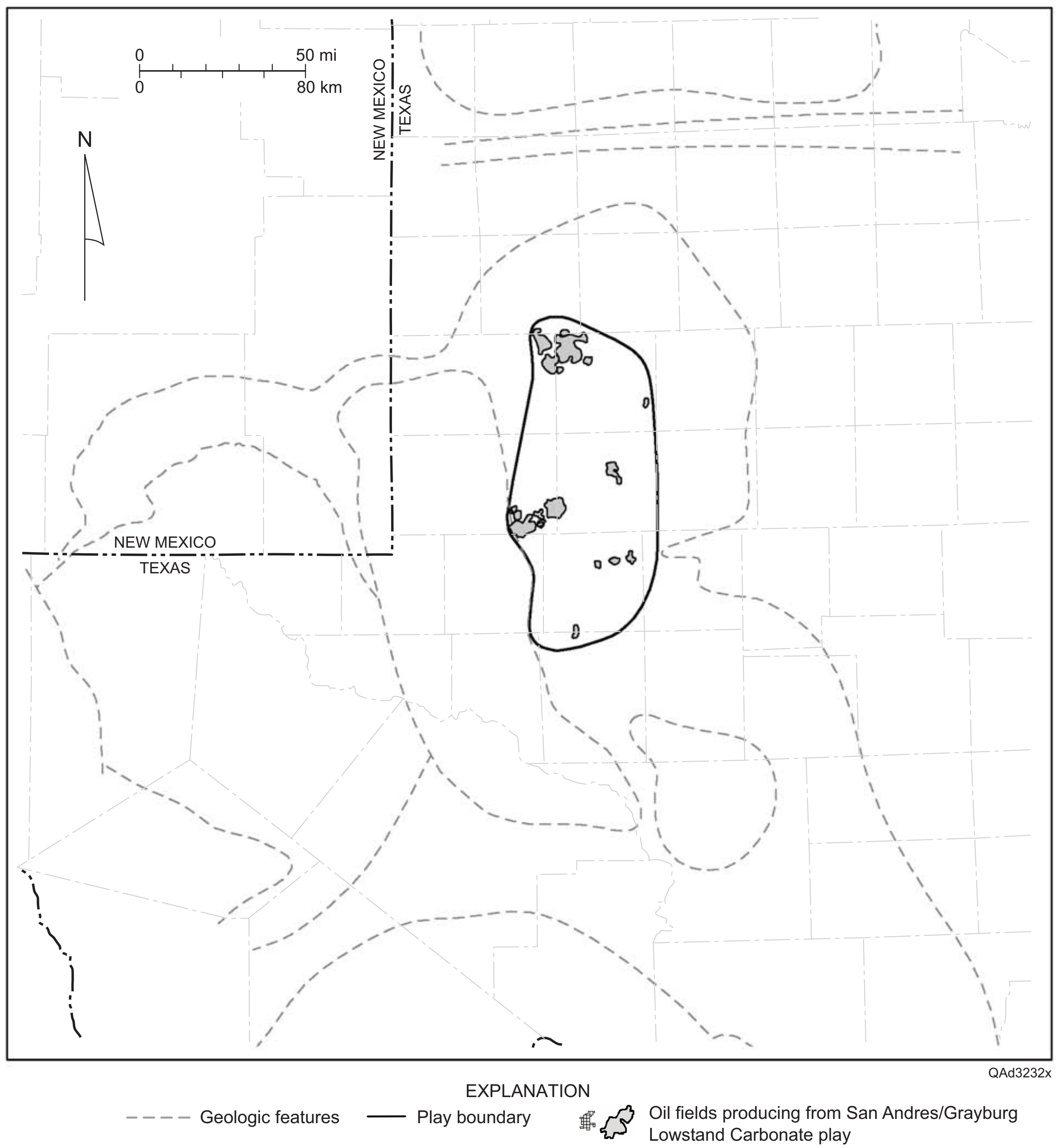

Figure 92. Play map for the San Andres/Grayburg Lowstand Carbonate play, showing location of reservoirs having >1 MMbbl cumulative production, the play boundary, and geologic features. See figure 1 for county names and figure 2 for identification of geologic features.

of subaerial exposure before Grayburg deposition. Logs at Midland Farms field show initial Grayburg onlap of the platform downdip of the terminal San Andres margin and indicate that the San Andres-Grayburg contact is a Type 1 sequence boundary.

Mabee field in Andrews County produces from upper San Andres dolomites that are draped over a deep Ordovician structure (Urschel and others, 1986; Friedman and others, 1990; Dull, 1992, 1994; Miller, 1992). The production comes from dolomitized subtidal mudstone/wackestone/peloid packstone and oolite packstone/grainstone facies (fig. 93) (Dull, 1994). Average porosity is 10.5 percent, and geometric mean permeability is 1 md (1×10^{-3} μm^2). Sandstones that interfinger with the ooid facies are tightly cemented and act as barriers within the reservoir (Miller, 1992). The reservoir seal is formed by low-permeability supratidal dolomite containing anhydrite nodules and cement (Urschel and others, 1986; Friedman and others, 1990).

Carbonates in reservoir zones 1 and 2 of Mabee field (fig. 93) are the target of a miscible CO_2 flood. Although ooid facies in zone 3 have produced considerable oil, this interval is not being flooded. Zones of high porosity and permeability associated with vuggy porosity and fractures in zone 3 could act as thief zones for injected CO_2 (Dull, 1994). Natural fractures appear to be an important component of the heterogeneity in Mabee field. The main direction of natural-fracture orientation in Mabee field is N70W, and the present maximum horizontal compressive stress direction is N45E (Qui and others, 2001). During primary production, horizontal wells should be placed to intersect the maximum number of open fractures, but Qui and others (2001) recommended that fracture intersection be minimized during secondary and tertiary recovery. During a waterflood or CO_2 flood, open fractures located between an injector and producer well will rapidly conduct the injected fluid to the producing well without moving

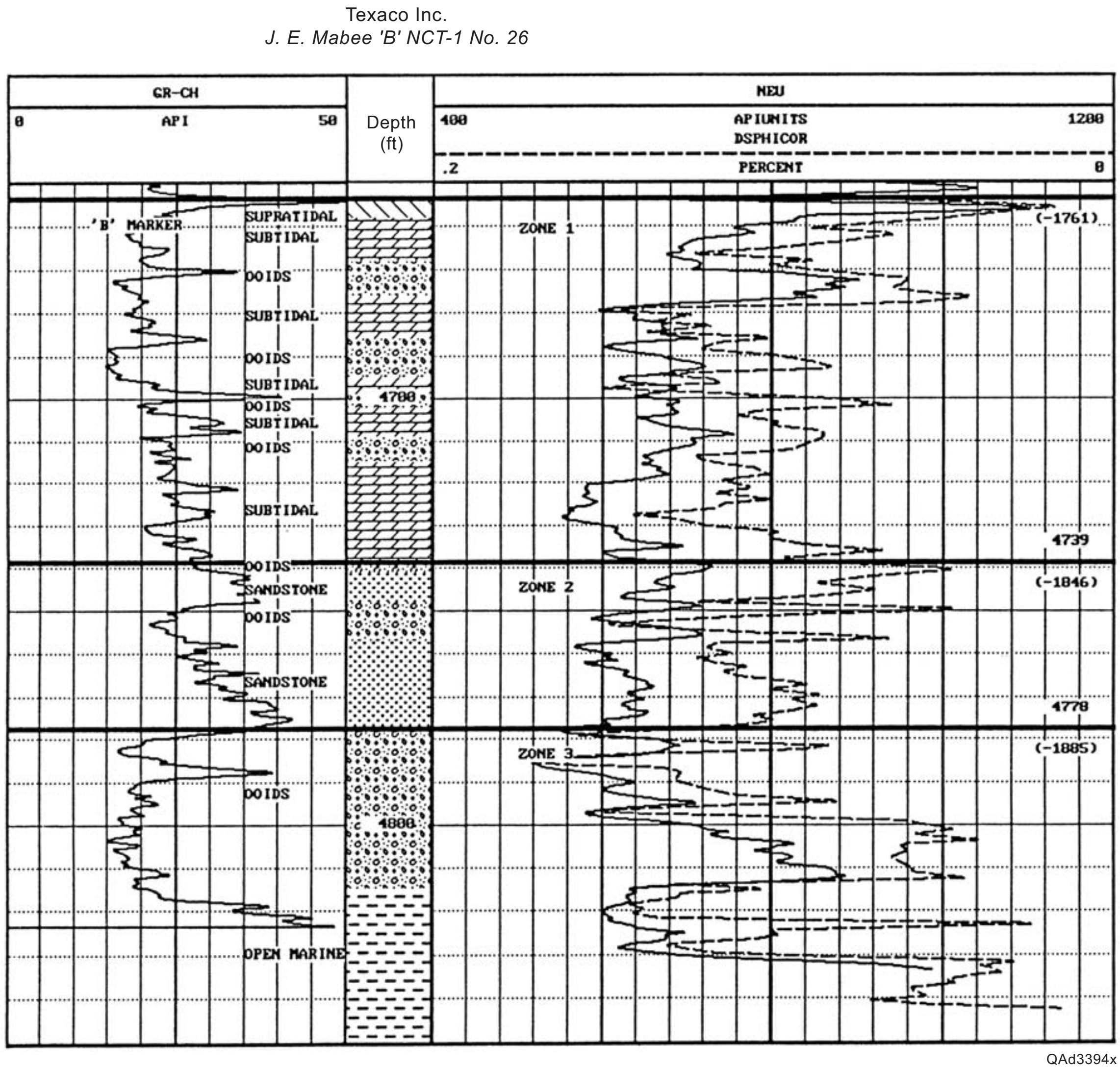

Figure 93. Type log for Mabee field showing vertical facies succession. From Dull (1994).

additional oil. In Mabee field, horizontal wells oriented east-west would minimize the intersection with open fractures (Qui and others, 2001).

Welch field is located northeast of the Central Basin Platform and southeast of the Northwest Shelf (fig. 92). The San Andres rocks in Welch field were deposited in an arid, nearshore, shallow-water sabkha environment (Hinterlong and Taylor, 1996). The reservoir interval is composed of four upward-shallowing carbonate cycles (Watts and others, 1998), in which subtidal mudstones and wackestones grade upward into tight packstones and grainstones deposited in a high-energy environment. The subtidal facies thin to the north in the field and are capped by supratidal facies consisting of thick anhydrite and anhydritic dolomite that forms the trap. A 3-D seismic volume and cross-well tomography were used to map the distribution of average porosity in interwell areas and guide the drilling of infill wells. Three seismic attributes—structure, amplitude, and phase—had high correlation with porosity (Watts and others, 1998). Seismic-guided estimates of average porosity were found to be within 1 porosity unit of log-determined porosity in 10 infill wells that were drilled on the basis of the 3-D seismic porosity model. An additional 300,000 bbl (4.77×10^4 m^3) of oil reserves were discovered in West Welch unit using the 3-D seismic interpretation of porosity (Schatzinger, 2003).

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Grayburg Platform Mixed Clastic/Carbonate (Play 127)

The Grayburg Platform Mixed Clastic/Carbonate play is composed of three reservoirs on the Central Basin Platform in Texas (fig. 94), located to the northwest of the Grayburg Platform Carbonate play (play 128). The play produced 669.7 MMbbl (1.06×10^8 m^3) through 2000 (table 33). The three reservoirs in this play have been designated as separate from the Grayburg Platform Carbonate play because much of their production is from Grayburg sandstones and siltstones, as well as San Andres and Grayburg carbonates. In that respect the play is similar to the Upper San Andres and Grayburg Platform Mixed—Central Basin Platform Trend play (play 124).

Fuhrman-Mascho field produces from the Grayburg Formation and the upper and lower San Andres Formation in Andrews County (fig. 95). A stratigraphic framework was developed for the University Block 10 area of Fuhrman-Mascho field (Ruppel, 2001). Where core was unavailable, spectral gamma-ray and borehole-imaging logs were used to identify facies and correlate cycles (Ruppel, 2001). Grayburg production in Fuhrman-Mascho field is mainly from porous and permeable fine-grained sandstone and coarse siltstone in the lower Grayburg. Porosity is as high as 25 percent, and permeability can exceed 100 md (100×10^{-3} μm^2). Siliciclastic beds form the base of cycles and are capped by tidal-flat carbonates (fig. 96). The siliciclastics are interpreted to be eolian facies that were deposited during sea-level falls and

Table 33. Grayburg Platform Mixed Clastic/Carbonate play (play 127). 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
21289001	8	COWDEN, NORTH		TX	ECTOR	1930	4400	6,827,269	541,669,047
33176001	8	FUHRMAN-MASCHO		TX	ANDREWS	1930	4700	918,794	119,367,788
91350300	8	TRIPLE-N	GRAYBURG	TX	ANDREWS	1964	4338	60,777	8,690,502
				TX					
		Totals						**7,806,840**	**669,727,337**

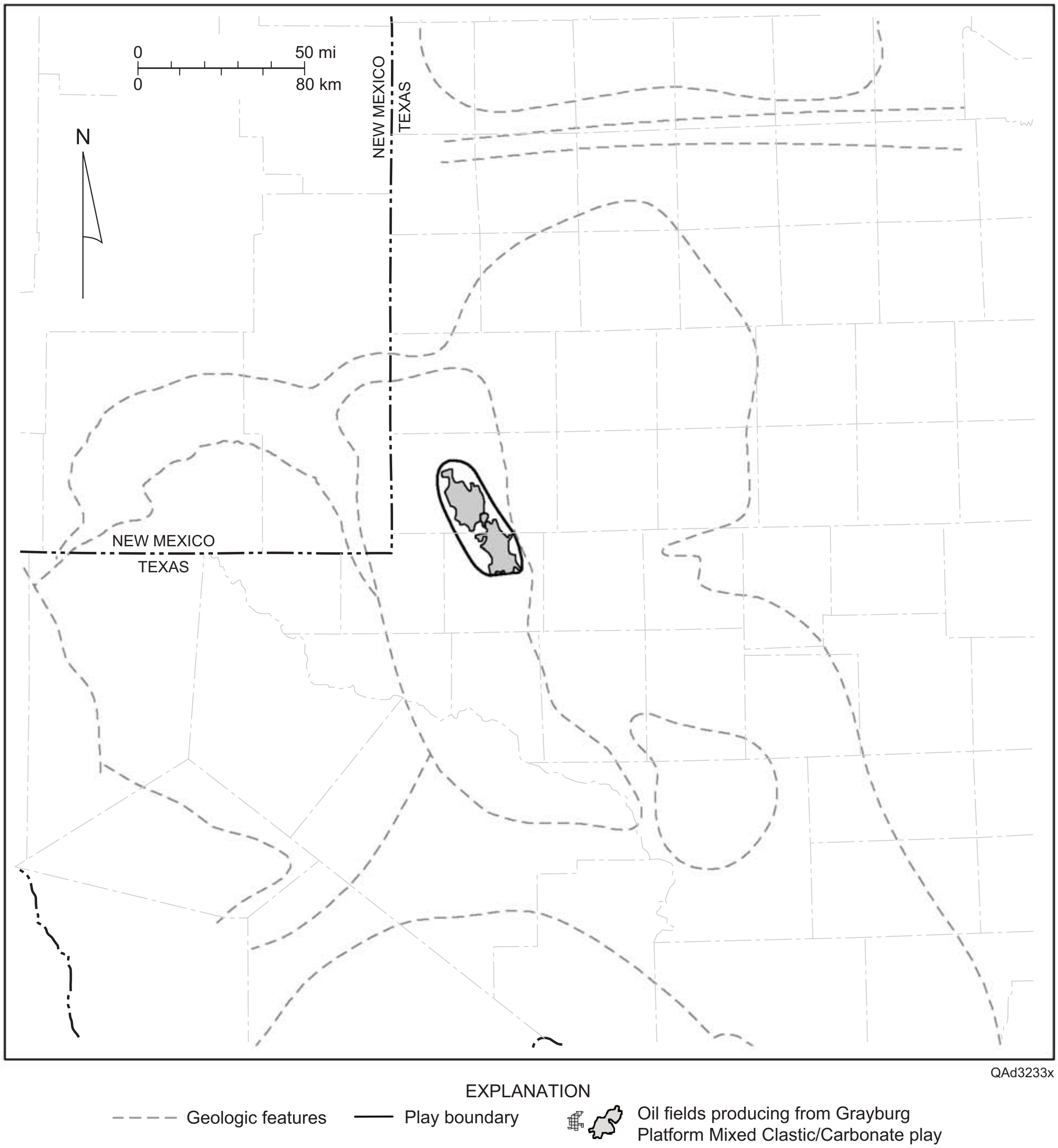

Figure 94. Play map for the Grayburg Platform Mixed Clastic/Carbonate play, showing location of reservoirs having >1 MMbbl cumulative production, the play boundary, and geologic features. See figure 1 for county names and figure 2 for identification of geologic features.

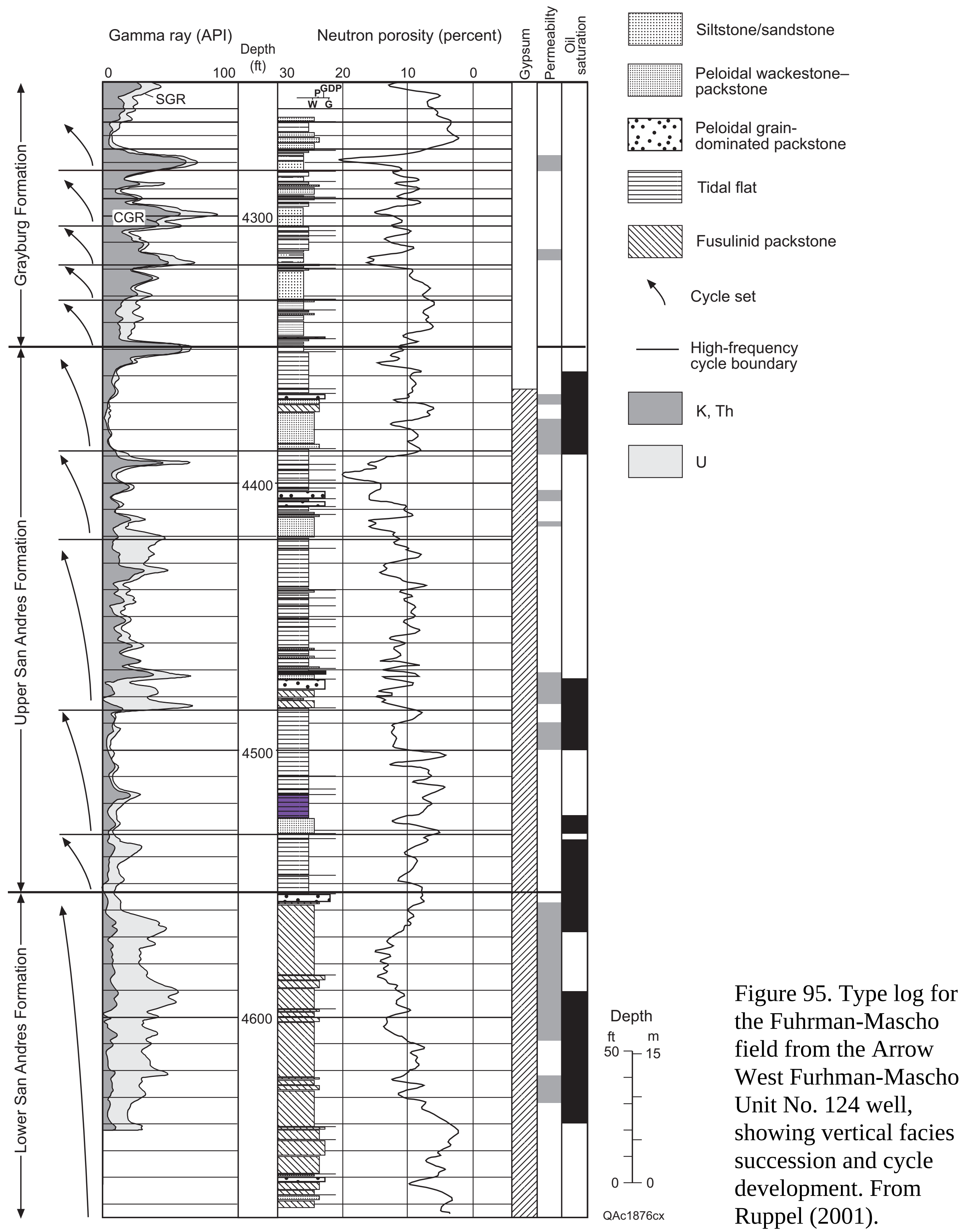

Figure 95. Type log for the Fuhrman-Mascho field from the Arrow West Furhman-Mascho Unit No. 124 well, showing vertical facies succession and cycle development. From Ruppel (2001).

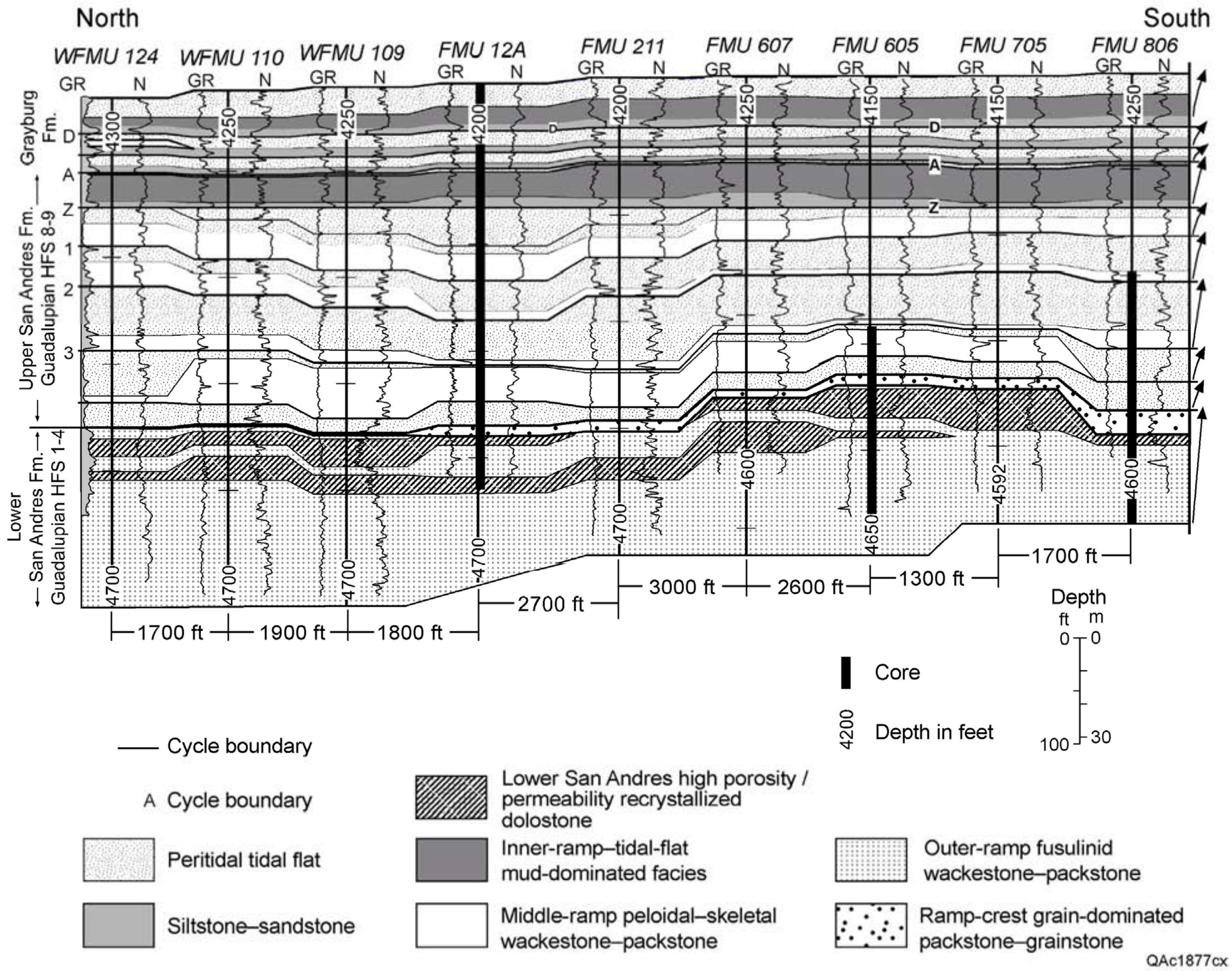

Figure 96. North-south cross section of Fuhrman-Mascho field showing the cycle stratigraphy of the Grayburg and San Andres reservoir section based on cored wells. From Ruppel (2001). See Ruppel (2001) for location of cross section.

reworked during subsequent sea-level rises (Ruppel, 2001). Production from the upper San Andres interval is from permeable subtidal carbonate facies that are most abundant in the south part of the field. Production from the lower San Andres is from the interval immediately underlying the middle San Andres unconformity (fig. 96), where good porosity is developed as a result of diagenesis in a 70-ft-thick (20-m) zone of burrowed dolomite below the unconformity (Ruppel, 2001). Waterflooding is interpreted to be an efficient recovery method in two laterally continuous reservoir intervals—the Grayburg clastics and the unconformity-related porous interval at the top of the lower San Andres (Ruppel, 2001). Because the better reservoir-quality zones in the upper San Andres are more discontinuous, these rocks are probably better candidates for infill drilling.

The largest reservoir in the play is North Cowden, which has produced 541.7 MMbbl (8.61×10^7 m^3) (table 33). Two units within North Cowden field, East Cowden Grayburg (Petersen and Jacobs, 2003) and Corrigan Cowden (Entminger and others, 2000), are undergoing modifications to improve waterflood recovery. East Cowden Grayburg unit of North Cowden field produces from both carbonates and clastics (Petersen and Jacobs, 2003). Facies in the San Andres and Grayburg reservoir intervals include subtidal silty-sandy dolomite, shoal crossbedded skeletal grainstone, open-marine-shelf fusulinid wackestone/packstone, intertidal mudstone, supratidal intraclast wackestone/packstone, and intertidal/tidal flat sandstone/siltstone. Porosity in the carbonates is commonly 10 to 15 percent and as high as 21 percent. Permeability in the carbonates ranges from hundredths to hundreds of millidarcys. Porosity in the reservoir sandstones and siltstones is commonly 10 to 16 percent, but permeability is only 1 to 5 md (1 to 5×10^{-3} μm^2). Reservoir characterization of the unit has established a stratigraphic framework in which 21 zones were identified (Petersen and Jacobs, 2003). Bypassed pay in relatively low permeability siltstones is being targeted by horizontal drilling into those zones from existing vertical well bores.

Corrigan Cowden is located on the east side of North Cowden field. Detailed reservoir characterization was conducted to develop a stratigraphic framework for the reservoir and locate bypassed, swept, and thief (water-cycling) zones (Entminger and others, 2000). Of the four sequences recognized in the Grayburg, zone 4 has received little waterflood support, whereas zones 2 and 3 are cycling water. In response, a program of strategic plugbacks, redrilled and infill wells, and horizontal wells have targeted zone 4, resulting in increased oil production and reduced water cut.

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Grayburg Platform Carbonate (Play 128)

The 11 reservoirs of the Grayburg Platform Carbonate play have produced 1,271.2 MMbbl (2.02×10^8 m^3) of oil (table 34). Reservoirs in this play occur on the east side of the Central Basin Platform in Texas, along the south part of the platform (fig. 97). The more southerly location of Grayburg Platform Carbonate reservoirs compared with that of the San Andres Platform Carbonate reservoirs (fig. 79) is interpreted as resulting from filling of the north half of the Midland Basin during San Andres time, which constricted the basin-rimming Grayburg facies to the remaining south half of the basin (Kosters and others, 1989). The entire facies tract prograded eastward during the early Guadalupian, so the trend of older San Andres reservoirs lies generally platformward (west) of the trend of the younger Grayburg reservoirs (Tyler and others, 1991). This shift is illustrated by Penwell, Jordan, Waddell, Dune, and McElroy fields (fig. 98). The platform interior fields— Penwell, Jordan, Waddell—produce from the San Andres Formation, and Dune and McElroy fields, at the platform structural edge, produce from the Grayburg Formation (Major and others, 1988).

Depositional style and petrophysical properties of Grayburg Platform Carbonate reservoirs are similar to those of the San Andres; both are developed in thick, dolomitized,

Table 34. Grayburg Platform Carbonate play (play 128). 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
9358630	8	BLOCK 31	GRAYBURG	TX	CRANE	1956	3200	523	4,918,490
21292001	8	COWDEN, SOUTH		TX	ECTOR	1932	5050	877,505	161,204,532
21517001	8	CRANE COWDEN		TX	CRANE	1932	2550	10,966	5,824,566
25742500	8	DOUBLE -H-	GRAYBURG	TX	ECTOR	1955	4456	39,062	4,217,866
26538001	8	DUNE		TX	CRANE	1938	3270	849,214	192,685,765
27739001	8	EDWARDS		TX	ECTOR	1935	3400	43,924	9,431,134
32309001	8	FOSTER		TX	ECTOR	1935	4300	2,033,797	284,565,604
47007001	8	JOHNSON		TX	ECTOR	1934	4200	370,516	35,981,707
59337001	8	MCELROY		TX	CRANE	1926	2900	5,863,727	569,725,971
61269500	7C	MIETHER	GRAYBURG	TX	UPTON	1956	3241	4,009	1,049,526
63143500	8	MOSS	GRAYBURG	TX	ECTOR	1955	3543	10,961	1,627,164
		Totals						**10,104,204**	**1,271,232,325**

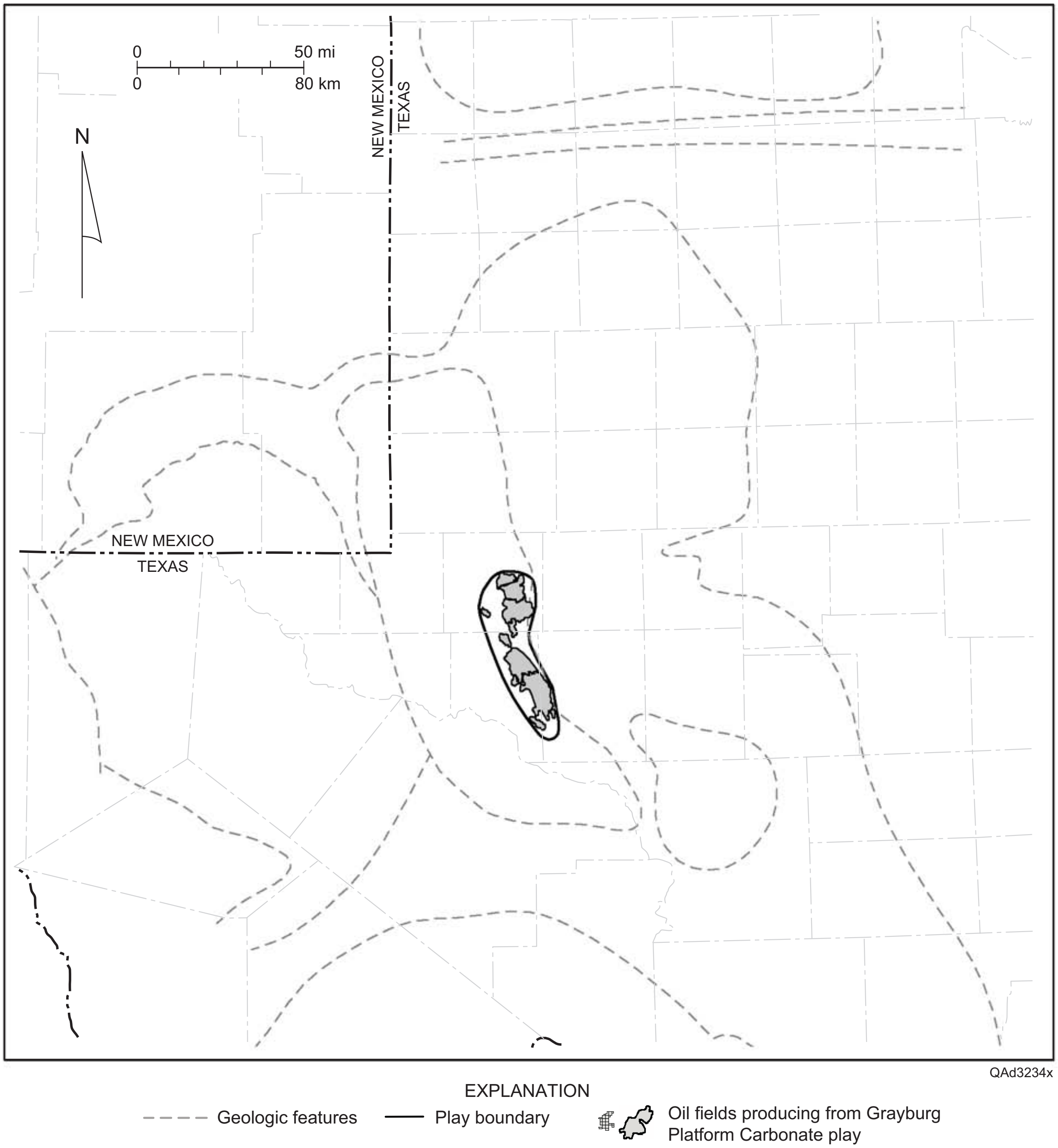

Figure 97. Play map for the Grayburg Platform Carbonate play, showing location of reservoirs having >1 MMbbl cumulative production, the play boundary, and geologic features. See figure 1 for county names and figure 2 for identification of geologic features.

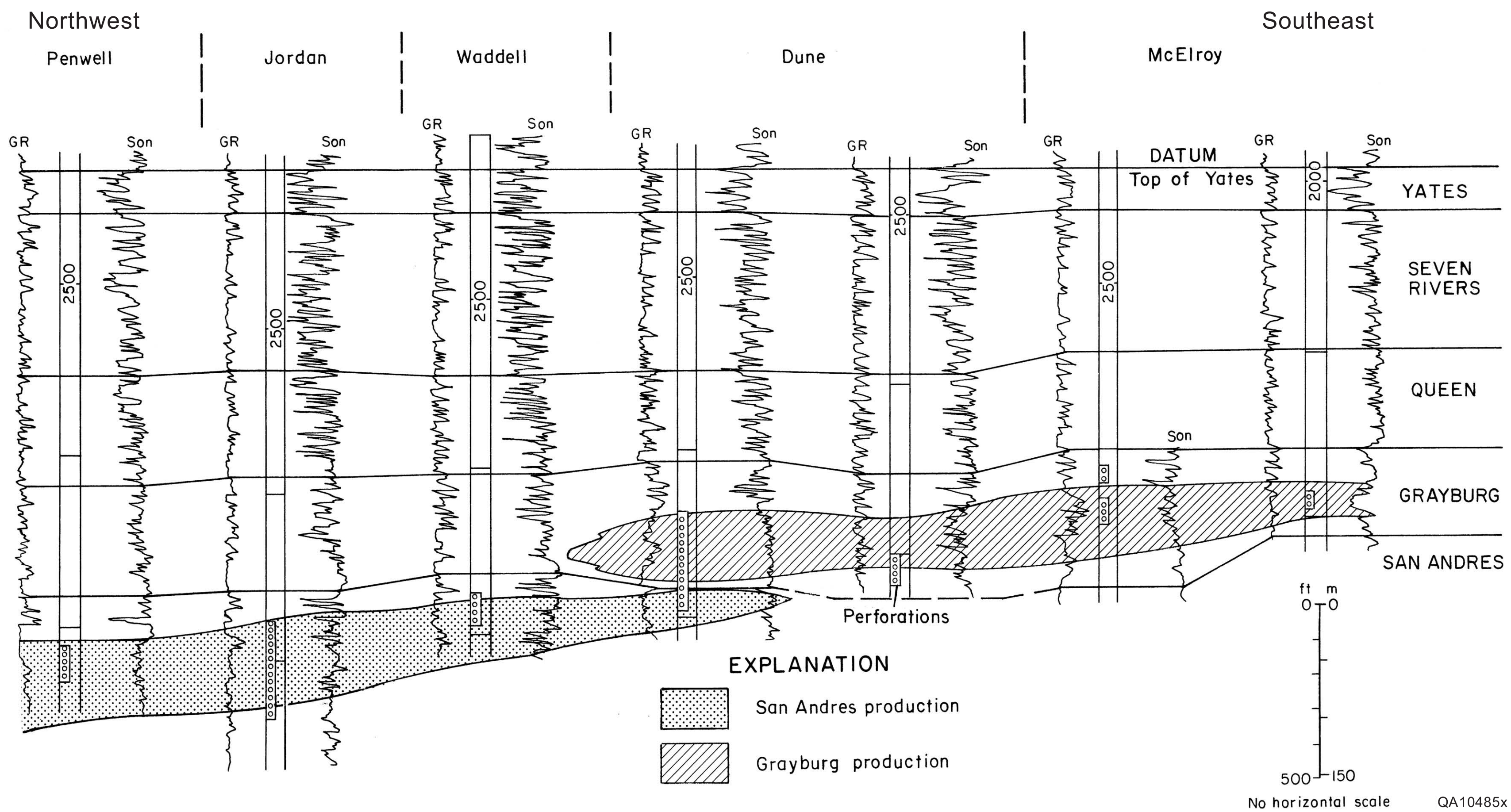

Figure 98. Northwest-southeast stratigraphic cross section of Penwell, Jordan, Waddell, Dune, and McElroy fields. From Kosters and others (1989; after Major and others (1988). The perforated intervals are in the San Andres Formation in the northwest and in the Grayburg Formation in the southeast, in Dune and McElroy fields. See Kosters and others (1989) for location of cross section.

subtidal parts of upward-shoaling cycles (Bebout and others, 1987; Tyler and others, 1991). Siliciclastic siltstone is abundant in the top part of the Grayburg, where it grades into the overlying interbedded Queen siltstone and anhydrite. Outcrop studies in the Guadalupe Mountains (Kerans and Nance, 1991; Kerans and Fitchen, 1995) and Brokeoff Mountains (Barnaby and Ward, 1995) developed a sequence and cycle stratigraphic framework of the Grayburg Formation that can be used for correlating the Grayburg at regional and reservoir scales.

South Cowden field in Ector County, which had produced 161.2 MMbbl (2.56×10^7 m^3) through 2000 (table 34), has been the subject of several reservoir characterization studies. Investigations of Moss, Emmons, and South Cowden units were published by Lucia and Ruppel (1996), Ruppel and Lucia (1996), Jennings and others (1998), Lucia (2000), Ruppel and Bebout (2001), and Ruppel and others (2002). The Grayburg Formation at South Cowden field was divided into four high-frequency sequences (HFS's) (fig. 99). The lower two HFS's record platform flooding and backstepping, HFS 3 records maximum flooding, and HFS 4 records aggradation and progradation of the platform during sea-level highstand (Ruppel and Lucia, 1996; Jennings and others, 1998). The reservoir is developed mainly in HFS 3 and 4, and these sequences were divided into chronostratigraphic high-frequency cycles to provide a detailed geologic framework (fig. 100). Reservoir quality at South Cowden has been strongly overprinted by diagenesis, particularly dolomite alteration and anhydrite alteration and removal (Ruppel and Lucia, 1996; Jennings and others, 1998). The reservoir interval is composed mainly of grain-dominated dolopackstones, medium crystalline mud-dominated dolostones, and a touching-vug pore system composed of dissolved anhydrite nodules, molds of fusulinids, and microfractures (Lucia, 2000).

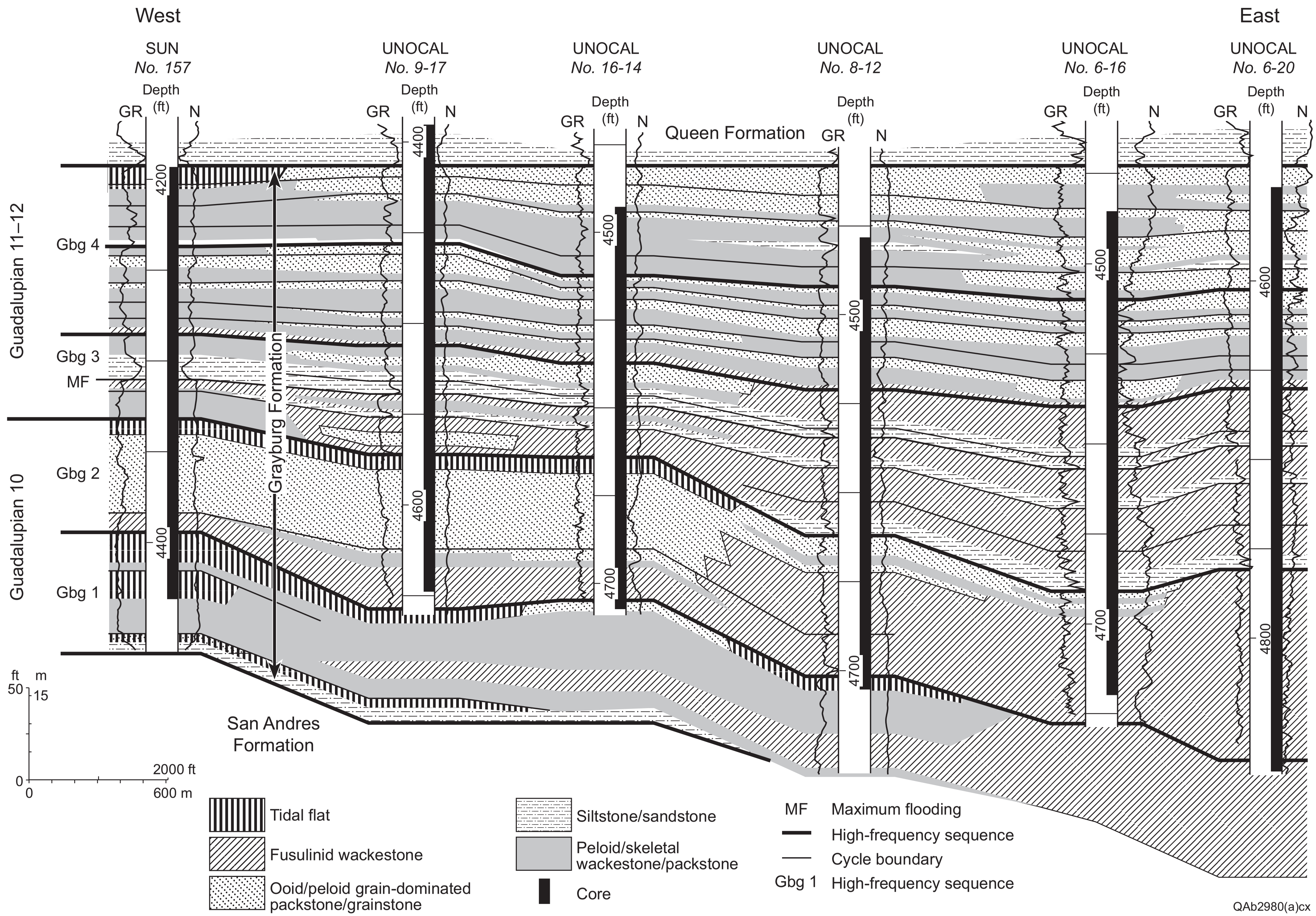

Figure 99. West-east cross section showing Grayburg sequence framework in South Cowden field. From Ruppel and Bebout (2001). See Ruppel and Bebout (2001) for location of cross section, which approximates depositional dip.

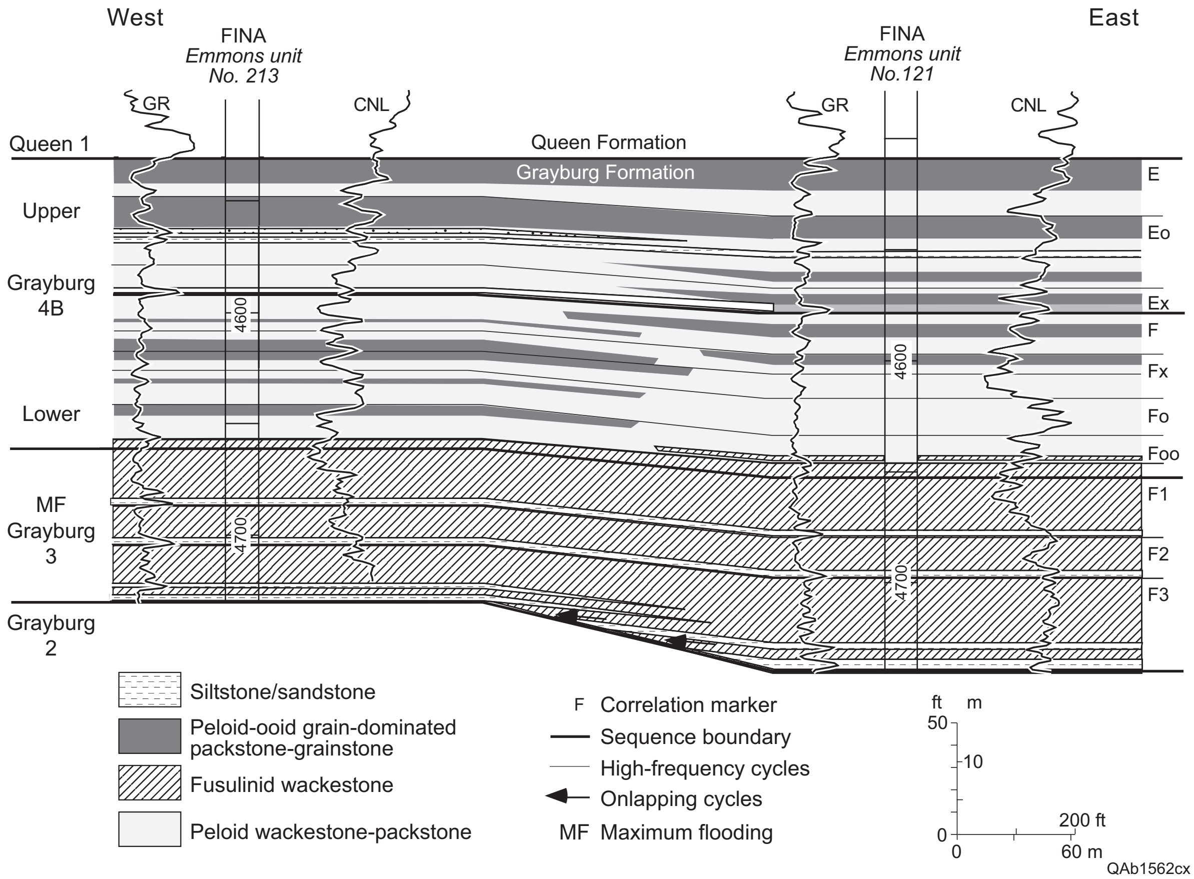

Figure 100. West-east cross section showing high-frequency cycles in Grayburg highstand deposits in South Cowden field. From Ruppel and Lucia (1996). The cycles, averaging 10 to 15 ft in thickness, are correlative throughout the field. See Ruppel and Lucia (1996) for location of cross section.

Highest porosity and permeability in the field are on the east and south margins of the field (Ruppel and Lucia, 1996; Saller and Henderson, 1998), where diagenetic alteration has been most extensive (fig. 101). In this area, permeability distribution generally crosscuts stratigraphy. To the west, where the diagenetic overprint is less severe, porosity and permeability distribution are a function of facies heterogeneity, which is, in turn, controlled by high-frequency cycles (Ruppel and Lucia, 1996). Average porosity in the Grayburg reservoir is 8.8 percent and average permeability is 15 md (15×10^{-3} μm^2). On the east side of the field, in zones of leached anhydrite, porosity is as high as 20 percent, and permeability reaches several hundred millidarcys

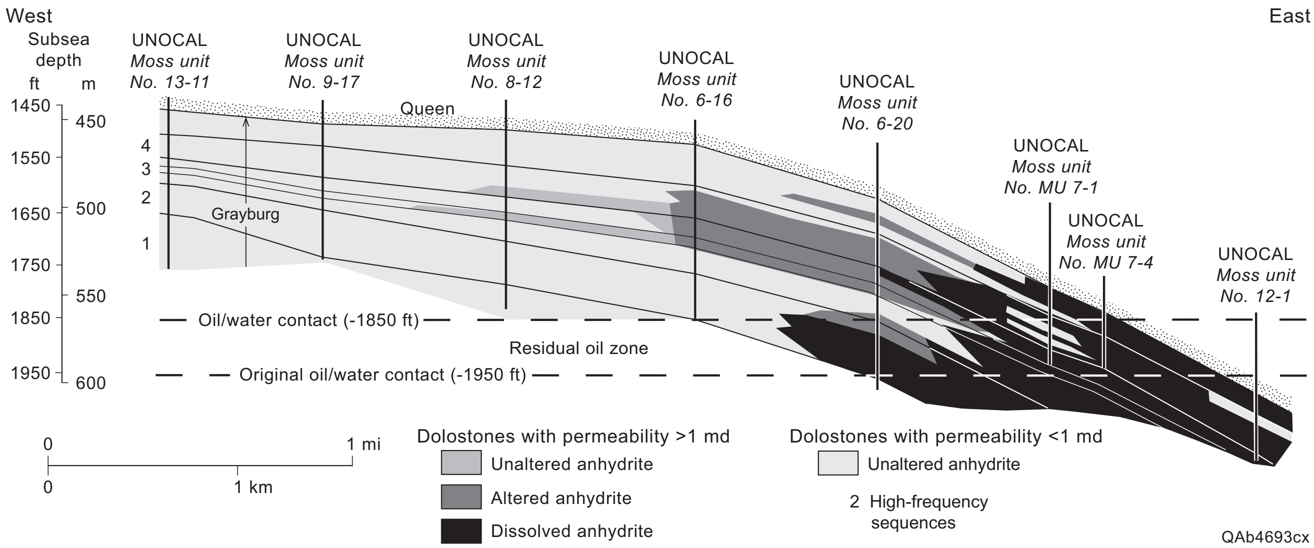

Figure 101. West-east cross section showing that permeability in South Cowden Grayburg is better developed to the east, in the downdip margins of the field where dolomite alteration and anhydrite dissolution have been most extensive. From Ruppel and Lucia (1996). See Ruppel and Lucia (1996) for location of cross section.

(Saller and Henderson, 1998; Lucia, 2000). In the central to west side of the field, porosity averages 4 to 5 percent, and permeability 0.1 to 0.3 md (0.1 to 0.3 × 10^{-3} μm^2) (Saller and Henderson, 1998). Comparison of wireline logs and 3-D seismic amplitude data suggests that amplitude can be used to map horizontal-porosity distribution in the reservoir (Ruppel and others, 2002).

Waterflooding at South Cowden field has been disappointing, having only recovered 21 percent of OOIP, which is 46 percent of the estimated displaceable oil (Jennings and others, 1998; Lucia, 2000). Poor waterflood recovery is due partly to completion of injection and production wells in only the top half of the formation. Bypassed mobile oil remains in zones having permeability of 0.1 to 1.0 md (0.1 to 1.0 × 10^{-3} μm^2) because no water is injected into these lower permeability units (Lucia, 2000). Mobile oil also remains in higher permeability zones between injection wells in areas of high permeability-thickness (kh) because floodwater streams from the injector to the producer.

Production from South Cowden unit was increased moderately by a CO_2 flood using horizontal CO_2 injection wells drilled into zones of higher quality reservoir rock (Phillips Petroleum Company, 2002; Schatzinger, 2003). Inability to maintain CO_2 injection rate in the targeted zones resulted in poor oil response from many of the wells. However, oil response was good in wells where CO_2 injection rates could be maintained in desired injection intervals.

Reservoir characterization and three-dimensional seismic inversion were conducted in Foster and South Cowden fields to identify productive zones in the Grayburg reservoir (Weinbrandt and others, 1998; Trentham and Widner, 1999; Trentham and others, 2000; Schatzinger, 2003). Application of inversion modeling techniques by relating seismic velocity to neutron density enabled detailed porosity mapping to identify bypassed oil zones. The modeling was used to target 3 reentry wells, 4 new wells, and 12 workovers; this work increased production from 37 bbl/d (5.9 m^3/d) to as much as 467 bbl/d (74.2 m^3/d). After 2 years, production was maintaining a rate of 280 bbl/d (44.5 m^3/d) (Schatzinger, 2003).

Seismic-attribute analysis of the Grayburg was also used in Corrigan Cowden unit (Ferdinand and others, 2002). A statistically significant relationship between porosity × thickness (PhiH) and relative amplitude was used to map PhiH across the unit. Areas of high PhiH that had not previously been penetrated by wells were identified. These areas were targeted by eight lateral wells drilled from existing vertical boreholes, and production was increased by 306 bbl/d (48.7 m^3/d).

McElroy field, which produced 569.7 MMbbl (9.06×10^7 m^3) of oil through 2000 and is the largest reservoir in the play (table 34), has been the target of numerous reservoir characterization studies (Longacre, 1980, 1983, 1990); Harris and others, 1984; Walker and Harris, 1986; Harris and Walker, 1990a, b; Tucker and others, 1998; Dehghani and others, 1999). The reservoir produces from a combined structural-stratigraphic trap (Harris and Walker, 1990a). Prior to deposition of the Grayburg Formation at McElroy field, a regression exposed the underlying San Andres carbonate platform. During subsequent reflooding of the platform, an upward-shoaling sequence of Grayburg carbonate-shelf deposits accumulated (Harris and Walker, 1990a). Open-shelf deposits at the base of the sequence are overlain by shallow-shelf facies and capped by shallow-shelf to intertidal sediments of the upper Grayburg. The Grayburg carbonate deposits at McElroy field are anhydritic dolostones that are more evaporitic and silty toward the top of the formation (Tucker and others, 1998). Terrigenous and evaporite sediments of the Queen Formation, deposited in a supratidal environment, form the reservoir top seal. The main pay interval produces from peloidal dolograinstones and packstones having interparticle and intercrystalline porosity (Tucker and others, 1998). Anhydrite and gypsum reduce interparticle porosity in some areas, and in other areas dissolution of dolomitized grains created vuggy and moldic pores.

McElroy field produces ~17,000 bbl/d (2.70×10^3 m^3/d) from a mature waterflood (Dehghani and others, 1999). Thin zones of high vuggy porosity and permeability in the central part of the field decrease waterflood effectiveness and result in bypassed oil being left in the lower permeability matrix. A method was developed to incorporate vuggy zones into reservoir simulation models. History matching of the simulation models indicates that core data underestimate the permeability of vuggy zones (Dehghani and others, 1999).

Part of McElroy field is undergoing a CO_2 pilot flood (Bashore and others, 1995; Tucker and others, 1998). Cross-well seismic data were acquired in the area of the pilot flood and combined with core and log data to provide information about interwell-scale heterogeneity. Velocity and acoustic impedance are controlled mainly by total porosity and changes in mineralogy. Reservoir quality is controlled by a combination of depositional textures and diagenetic overprint. Because both cross-well seismic and log data respond to the diagenetic overprint and petrophysical properties, log facies were used for correlating reservoir flow units and relating them to cross-well images (Tucker and others, 1998).

Dune field lies northwest of McElroy field (fig. 97). The structure on which Dune and McElroy fields are located appears to be controlled by drape over buried Pennsylvanian fault blocks. Dune field produces from multiple cycles of subtidal to tidal-flat sediments (Bebout and others, 1987). OOIP of Dune field was estimated to be 978 MMbbl (1.55×10^8 m^3), and the field had produced 192.7 MMbbl (3.06×10^7 m^3) through 2000. Black-oil simulation experiments indicate that geologically targeted infill wells would improve recovery (Fogg and Lucia, 1990). Mobile-oil recovery efficiency is 45 to 50 percent at the current well spacing of 10 acres. Simulations indicate that reducing well spacing to 2.5 acres would increase mobile-oil recovery efficiency by about 30 percentage points (Fogg and Lucia, 1990; Tyler and others, 1991).

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Grayburg High-Energy Platform Carbonate—Ozona Arch (Play 129)

The Grayburg High-Energy Platform Carbonate—Ozona Arch play consists of 21 reservoirs located on the Ozona Arch in Crockett and Reagan Counties (fig. 102) that had produced >1 MMbbl (1.59×10^5 m^3) of oil through 2000; cumulative production from the play is 298.4 MMbbl (4.74×10^7 m^3) (table 35). The reservoirs in the play produce from the upper San Andres and Grayburg Formations. By Grayburg time, the Midland Basin was small and shallow, and the Ozona Arch was a shallow-water platform, across which water was exchanged between the open ocean to the south and the restricted basin to the north (Tyler and others, 1991).

The reservoir section in these fields, commonly >300 ft (>90 m) thick, is composed of numerous upward-shoaling cycles that are 15 to 40 ft (5 to 12 m) thick (Tyler and others, 1991). Siltstone and silty mudstones to wackestones in the lower part of each cycle grade upward into packstone to grainstone in the upper part. Each cycle represents subtidal, low-energy conditions in the lower part and stable-grain-flat to high-energy-bar environments at the top

Table 35. Grayburg High-Energy Platform Carbonate—Ozona Arch play (play 129). 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
7919001	7C	BIG LAKE		TX	REAGAN	1923	3000	304,598	133,973,558
9521500	7C	BLOCK 49	2450	TX	REAGAN	1955	2456	47,125	2,134,823
18500001	7C	CLARA COUCH		TX	CROCKETT	1941	2186	31,529	6,596,133
30243500	7C	FARMER	SAN ANDRES	TX	CROCKETT	1953	2240	588,661	28,675,225
36565001	7C	GRAYSON		TX	REAGAN	1928	3050	7,320	1,482,688
38156001	7C	HALFF		TX	CROCKETT	1951	1680	12,847	3,991,162
46935500	7C	JOHN SCOTT	GRAYBURG	TX	REAGAN	1953	2534	71,464	5,505,146
61204875	7C	MIDWAY LANE	1300	TX	CROCKETT	1953	1300	8,181	1,712,554
61204500	7C	MIDWAY LANE	PERMIAN	TX	CROCKETT	1956	1124	99,118	7,686,681
67284001	7C	OLSON		TX	CROCKETT	1940	1828	181,097	16,082,538
73085500	7C	PRICE	GRAYBURG	TX	REAGAN	1953	2410	140,825	6,437,211
73468001	7C	PURE-BEAN		TX	CROCKETT	1952	1360	8,747	1,876,345
82663568	7C	SHANNON	SAN ANDRES	TX	CROCKETT	1943	2406	43,596	12,449,849
83703001	7C	SIMPSON		TX	CROCKETT	1938	1985	23,756	1,118,315
89198500	7C	TEXON, S	GRAYBURG	TX	REAGAN	1968	3266	16,426	1,275,271
90314400	7C	TODD	SAN ANDRES	TX	CROCKETT	1951	1440	22,675	2,183,638
93264001	7C	VAUGHN		TX	CROCKETT	1947	1445	54,241	13,265,577
95867500	7C	WEGER	SAN ANDRES	TX	CROCKETT	1955	2268	27,872	2,934,749
95869001	7C	WEGER, NORTH		TX	CROCKETT	1955	2318	21,190	1,173,145
98796001	7C	WORLD		TX	CROCKETT	1925	2600	166,896	45,886,544
99023001	7C	WYATT		TX	CROCKETT	1940	1224	90,521	1,937,617
		Totals						**1,968,685**	**298,378,769**

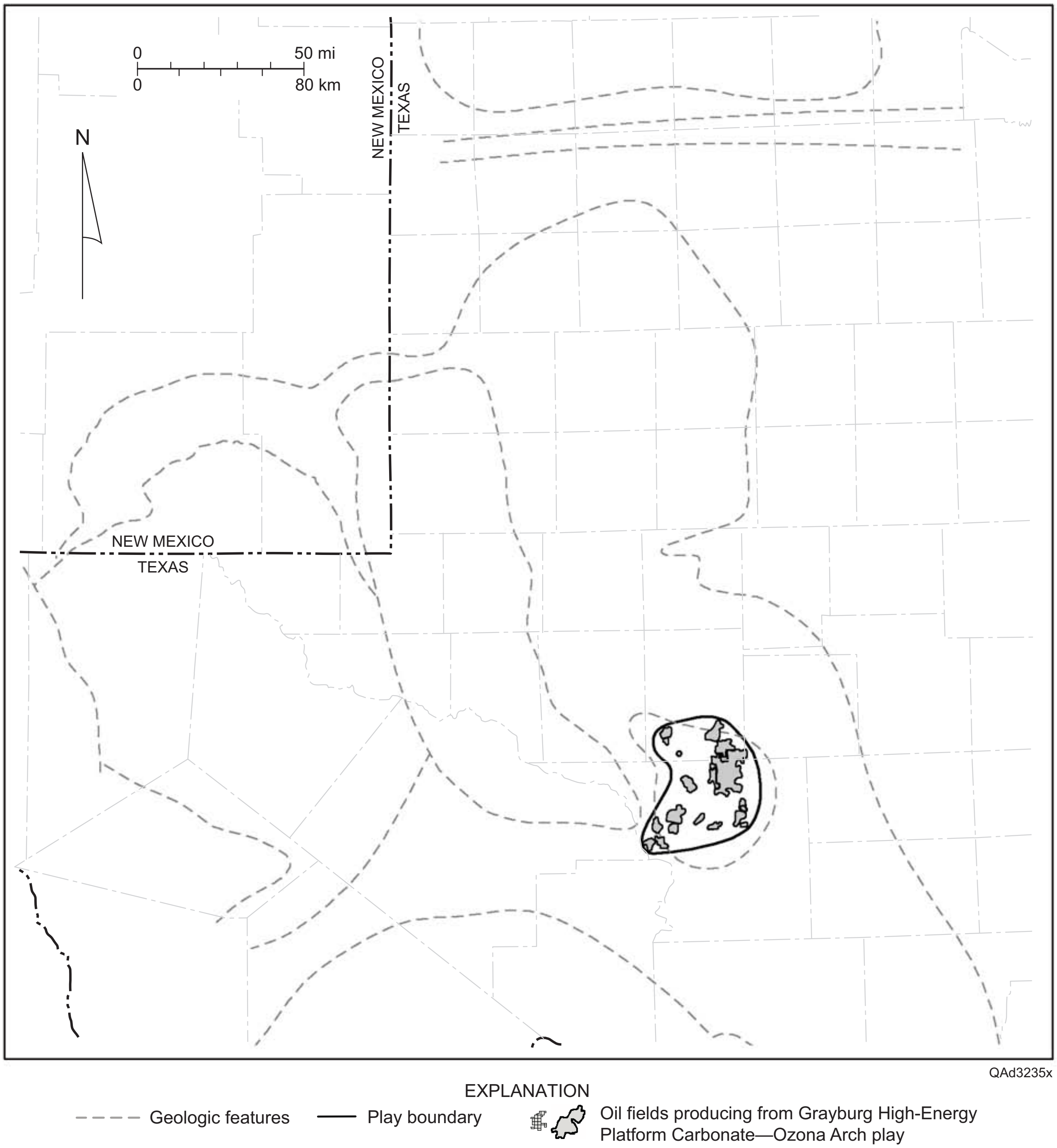

Figure 102. Play map for the Grayburg High-Energy Platform Carbonate—Ozona Arch play, showing location of reservoirs having >1 MMbbl cumulative production, the play boundary, and geologic features. See figure 1 for county names and figure 2 for identification of geologic features.

(Tyler and others, 1991). Zones of intergranular porosity occur in the grainstones. Intercrystalline dolomite porosity in the mudstone and wackestone facies of the lower parts of the cycles is correlative from well to well and occurs in thicker sections, but permeability in these facies is low (Tyler and others, 1991). Low-relief structures are present in all reservoirs of this play, but porosity loss because of facies change is a major factor in formation of the trap.

Farmer field has produced 28.7 MMbbl (4.56×10^6 m^3) (table 35) from the San Andres, Grayburg, and lower part of the Queen Formation (Bebout, 1994); most production is from the Grayburg Formation (fig. 103). The Grayburg reservoir interval is approximately 350 ft (107 m) thick and is composed of 14 upward-shoaling cycles (figs. 103, 104) (Tyler and others, 1991). An ideal cycle has siltstone, silty dolomite, and skeletal wackestone at the base, skeletal and pelletal packstone and fine-grained grainstones in the middle, and coarse-grained grainstone at the top (Bebout, 1994). Grayburg cycles can be recognized using a combination of gamma-ray and resistivity logs (Bebout, 1994). The gamma-ray log responds to presence of silt at the base and decrease in silt content upward in each cycle. High resistivity at the top of each cycle reflects the presence of coarse-grained grainstones cemented with gypsum (fig. 104). Thus, the top of each cycle has low gamma-ray values (<30 API units) and high resistivity (>1,000 ohm-m) (Bebout, 1994). Grainstone units are thicker on the west side of the field, whereas siltstones, wackestones, and packstones are thicker to the east (fig. 104).

Two basic pore types are present in the Farmer Grayburg reservoir: mud-dominated packstones, wackestones, and mudstones with intercrystalline pores between 10-µm dolomite crystals and grain-dominated packstones and grainstones with intergranular pores and intragranular microporosity. Porosity ranges from 1 to 21 percent and averages 12 percent.

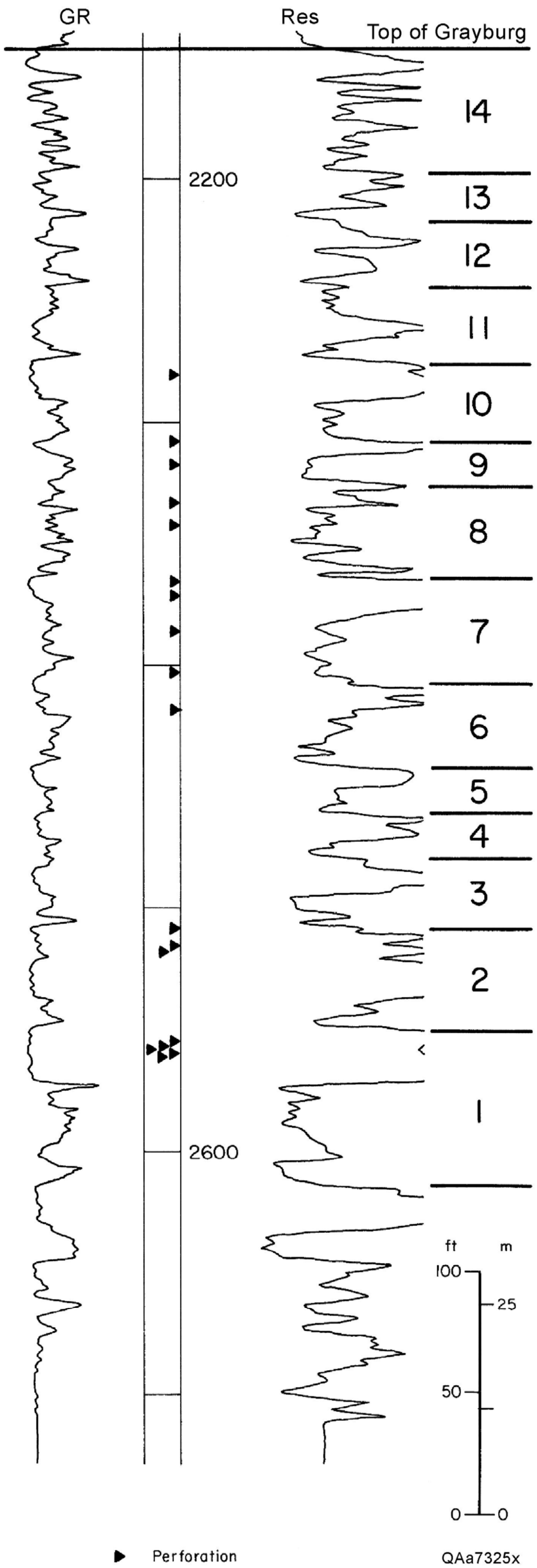

Figure 103. Typical gamma-ray/resistivity log from Farmer field, Crockett County. From Bebout (1994). The log is from the Marathon University P5 well; see Bebout (1994) for well location. Fourteen upward-shoaling cycles in the reservoir interval have been identified.

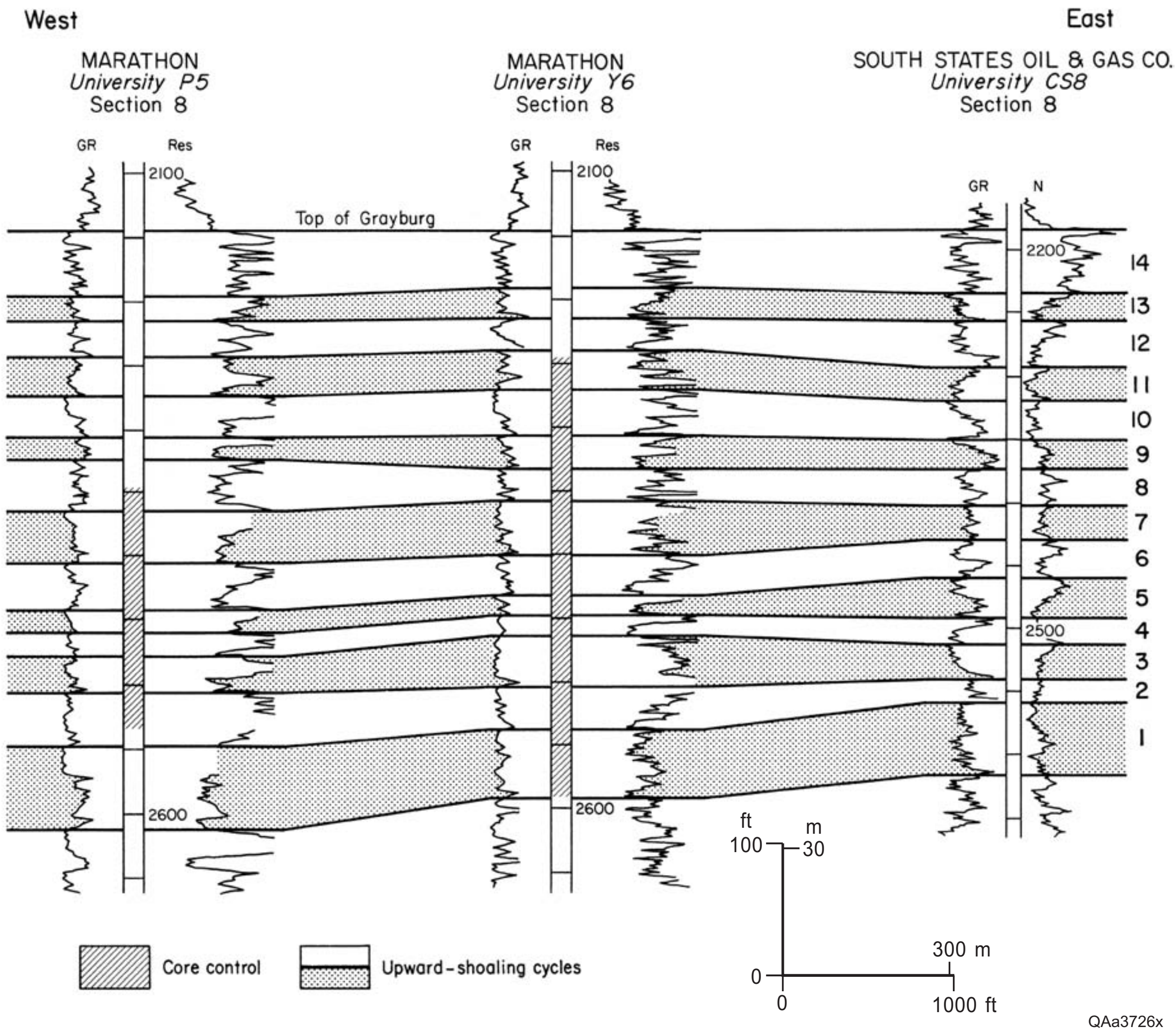

Figure 104. West-east cross section showing upward-shoaling cycles in Farmer field, Crockett County. From Bebout (1994). See Bebout (1994) for location of cross section.

Permeability ranges from <0.01 to 19 md (<0.01 to 19 × 10^{-3} μm^2) and averages 4 md (4 × 10^{-3} μm^2) (Bebout, 1994). Core-analysis porosity was calibrated with acoustic-log porosity because large volumes of gypsum were present.

Olson field in Crockett County (fig. 102) produces from a fractured ooid- grainstone reservoir (Zahm and Tinker, 2000; Hurley and others, 2001). Production is from ooid grainstones and fusulinid grain-dominated packstones that prograded in a basinal direction from the Ozona Arch (Zahm and Tinker, 2000). The tops of the ooid grainstones have low porosity and permeability because anhydrite cement fills the intergranular pore space. The best reservoirs are in the toes of the ooid shoals, which were not cemented by anhydrite.

Big Lake, the largest reservoir in this play, produced 134.0 MMbbl (2.13×10^7 m^3) through 2000 (table 35). Big Lake field was the site of the original oil discovery on University of Texas lands by the Texon Oil and Land Company Santa Rita No. 1 well (Galloway and others, 1983). Following the Railroad Commission of Texas, we have assigned all production from Big Lake to the Grayburg reservoir, but ~21 MMbbl (~3.34×10^6 m^3) of that production probably came from the Ellenburger (see play 101, Ellenburger Selectively Dolomitized Ramp Carbonate). Big Lake Grayburg reservoir produces from high-energy, shallow-water carbonate facies that were deposited on a structurally high fault block (Curran, 1996). The gross pay interval in the Grayburg is 170 ft (52 m), and the net pay thickness is 120 ft (37 m). Porosity ranges from 6 to 33 percent, and permeability ranges from 0.01 to 90 md (0.01 to 90×10^{-3} μm^2). Average permeability in dolomite is 20 md (20×10^{-3} μm^2), compared with an average of 2 md (2×10^{-3} μm^2) in limestone facies (Curran, 1996).

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Delaware Mountain Group Basinal Sandstone (Play 130)

Introduction

The reservoirs in the Delaware Mountain Group Basinal Sandstone play produce from deepwater sandstones of the Delaware Mountain Group in the Delaware Basin (fig. 105). The play consists of 78 reservoirs in Texas and New Mexico that had produced >1 MMbbl (1.59×10^5 m^3) of oil through 2000; cumulative production from these reservoirs was 351.9 MMbbl (5.59×10^7 m^3) (table 36). All three formations in the Delaware Mountain Group

Table 36. Delaware Mountain Group Basinal Sandstone play (play 130). 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	SUBPLAY
9288500	8	BLOCK 17, SOUTHEAST	DELAWARE	TX	WARD	1956	5003	40,324	1,722,191	Bell Canyon
15499380	8	CAPRITO	DELAWARE MIDDLE	TX	WARD	1974	6164	193,628	5,587,028	Cherry Canyon
17029001	8	CHAPMAN		TX	REEVES	1948	2900	10,149	1,578,789	Bell Canyon
19665200	8	COLLIE	DELAWARE	TX	WARD	1981	4725	115,115	3,479,423	Bell Canyon
21382250	8	COYANOSA	DELAWARE SD.	TX	PECOS	1959	4793	20,112	1,327,118	Bell Canyon
21384666	8	COYANOSA, N.	DELAWARE	TX	PECOS	1966	4809	18,136	3,249,484	Bell Canyon
24853400	8	DIMMITT	CHERRY CANYON	TX	LOVING	1980	6226	230,734	8,574,522	Cherry Canyon
28019500	8	EL MAR	DELAWARE	TX	LOVING	1959	4532	218,771	18,927,176	Bell Canyon
31908500	8	FORD, EAST	DELAWARE SAND	TX	REEVES	1963	2730	93,295	3,401,021	Bell Canyon
31913500	8	FORD, WEST	4100	TX	CULBERSON	1963	4143	33,736	3,010,344	Cherry Canyon
34529200	8	GERALDINE	DELAWARE 3400	TX	CULBERSON	1982	3454	7,645	1,598,553	Bell Canyon
34529666	8	GERALDINE	FORD	TX	REEVES	1957	2557	121,301	30,222,300	Bell Canyon
36924500	8	GRICE	DELAWARE	TX	LOVING	1956	4510	98,088	10,207,517	Cherry Canyon
43106200	8	HUBBARD	CHERRY CANYON	TX	LOVING	1982	5286	39,418	1,145,161	Cherry Canyon
46296300	8	JESS BURNER	DELAWARE 3800	TX	REEVES	1982	3802	49,375	2,828,941	Cherry Canyon
48754500	8	KEN REGAN	DELAWARE	TX	REEVES	1954	3350	62,249	4,370,922	Bell Canyon
53989250	8	LITTLE JOE	DELAWARE	TX	WINKLER	1965	5034	21,409	1,728,191	Bell Canyon
58099001	8	MASON		TX	LOVING	1937	3900	3,393	3,020,075	Bell Canyon
58101500	8	MASON, N.	DELAWARE SAND	TX	LOVING	1952	4055	15,383	6,709,456	Bell Canyon
62494001	8	MONROE		TX	WARD	1931	4600	4,664	4,146,637	Bell Canyon
67074500	8	OLDS	DELAWARE	TX	REEVES	1958	3029	7,490	1,340,153	Bell Canyon
67604500	8	ORLA, SOUTH	DELAWARE SAND	TX	REEVES	1953	3562	0	1,044,747	Bell Canyon
71542400	8	PINAL DOME	CHERRY CANYON	TX	LOVING	1984	6485	68,790	1,432,297	Cherry Canyon
73926500	8	QUITO	DELAWARE SAND	TX	WARD	1953	4934	365	2,444,299	Bell Canyon
73933500	8	QUITO, WEST	DELAWARE	TX	WARD	1955	4732	231,531	5,329,219	Bell Canyon
76184333	8	RHODA WALKER	CANYON 5900	TX	WARD	1967	6192	273,194	17,234,663	Cherry Canyon
77953250	8	ROJO CABALLOS	DELAWARE	TX	PECOS	1962	5253	13,649	1,097,828	Bell Canyon
79423500	8	SABRE	DELAWARE	TX	REEVES	1958	2968	55,697	5,913,660	Bell Canyon
81738200	8	SCOTT	CHERRY CANYON	TX	REEVES	1978	6134	41,377	1,013,358	Cherry Canyon
81738250	8	SCOTT	DELAWARE	TX	WARD	1946	4239	186,910	5,416,369	Bell Canyon
81821333	8	SCREWBEAN, NE.	DELAWARE	TX	REEVES	1961	2519	7,244	1,224,697	Bell Canyon
87025500	8	SULLIVAN	DELAWARE	TX	REEVES	1957	2665	11,204	1,861,453	Bell Canyon
90781200	8	TORO	DELAWARE	TX	REEVES	1961	5158	8,985	1,059,893	Bell Canyon
91817001	8	TUNSTILL		TX	REEVES	1947	3270	42,888	12,199,635	Bell Canyon
91818500	8	TUNSTILL, EAST	DELAWARE	TX	LOVING	1959	3652	25,779	2,870,757	Bell Canyon
92141333	8	TWOFREDS	DELAWARE	TX	LOVING	1957	4895	102,854	14,599,875	Bell Canyon
94648166	8	WAHA	DELAWARE	TX	PECOS	1960	4800	36,362	1,535,150	Bell Canyon
94650333	8	WAHA, NORTH	DELAWARE SAND	TX	REEVES	1960	4917	48,487	6,771,248	Bell Canyon
94656086	8	WAHA, W.	CONSOLIDATED DELAWARE	TX	REEVES	1974	6504	41,983	2,843,944	Cherry Canyon
94656111	8	WAHA, WEST	DELAWARE	TX	REEVES	1961	5034	21,072	2,514,728	Bell Canyon
95122200	8	WAR-WINK	CHERRY CANYON	TX	WARD	1965	6037	511,500	3,251,201	Cherry Canyon
95123875	8	WAR-WINK, E.	7000	TX	WINKLER	1994	7092	127,182	1,127,453	Cherry Canyon
96742001	8	WHEAT		TX	LOVING	1925	4300	51,409	22,583,024	Bell Canyon
96742300	8	WHEAT	CHERRY CANYON	TX	LOVING	1979	6610	86,088	2,118,654	Cherry Canyon
98817775	8	WORSHAM	DELAWARE SAND	TX	REEVES	1960	4932	33,238	1,691,018	Bell Canyon

Table 36, continued. Delaware Mountain Group Sandstone Play (Play 130).

FLDNAME	RESNAME	STATE	COUNTY	DISCYR	DEPTHTOP	2000 PROD	CUMPROD	SUBPLAY
AVALON	DELAWARE	NM	EDDY	1980	2550	252,989	4,952,379	Bell Canyon, Cherry Canyon, Brushy Canyon
BRUSHY DRAW	DELAWARE	NM	EDDY	1958	3200	221,902	6,967,405	Bell Canyon, Cherry Canyon
CABIN LAKE	DELAWARE	NM	EDDY	1987	5625	181,767	3,798,138	Brushy Canyon, Cherry Canyon
CATCLAW DRAW EAST	DELAWARE	NM	EDDY	1990	3074	75,490	1,219,588	Brushy Canyon, Bell Canyon, Cherry Canyon
CEDAR CANYON	DELAWARE	NM	EDDY	1976	5200	184,019	1,010,544	Cherry Canyon, Brushy Canyon
CORBIN WEST	DELAWARE	NM	LEA	1976	5030	106,008	2,746,804	**Bell Canyon**, Brushy Canyon
CRUZ	DELAWARE	NM	LEA	1961	5081	781	1,034,285	Bell Canyon
DOUBLE X	DELAWARE	NM	LEA	1961	4914	10,270	1,400,945	Bell Canyon
EL MAR	DELAWARE	NM	LEA	1959	4550	29,437	6,255,832	Brushy Canyon
ESPERANZA	DELAWARE	NM	EDDY	1969	3400	32,732	1,272,693	Bell Canyon, Cherry Canyon
HAT MESA	DELAWARE	NM	LEA	1989	6834	264,453	1,976,201	**Brushy Canyon**, Cherry Canyon
HERRADURA BEND	DELAWARE	NM	EDDY	1977	11086	25,209	1,012,833	Bell Canyon
HERRADURA BEND EAST	DELAWARE	NM	EDDY	1985	6062	112,309	1,555,292	Brushy Canyon
INDIAN DRAW	DELAWARE	NM	EDDY	1973	3262	54,625	3,316,622	Cherry Canyon
INGLE WELLS	DELAWARE	NM	EDDY	1989	8100	665,836	7,458,269	Brushy Canyon
LEA NORTHEAST	DELAWARE	NM	LEA	1988	5658	436,236	4,004,802	**Cherry Canyon**, Brushy Canyon
LIVINGSTON RIDGE	DELAWARE	NM	EDDY	1989	7091	355,051	5,155,100	**Brushy Canyon**, Cherry Canyon
LIVINGSTON RIDGE EAST	DELAWARE	NM	LEA	1992	7200	100,566	1,992,444	Brushy Canyon, Cherry Canyon
LOS MEDANOS	DELAWARE	NM	EDDY	1990	4218	178,629	2,894,378	Brushy Canyon
LOST TANK	DELAWARE	NM	EDDY & LEA	1991	6783	171,309	2,688,111	**Brushy Canyon**, Cherry Canyon
LOVING	BRUSHY CANYON	NM	EDDY	1993	6050	306,580	7,074,110	Brushy Canyon
LUSK WEST	DELAWARE	NM	LEA	1987	6450	163,949	2,753,235	**Brushy Canyon**, Cherry Canyon
MALAGA	DELAWARE	NM	EDDY	1951	2770	14,526	1,006,678	Bell Canyon, Cherry Canyon, Brushy Canyon
MASON EAST	DELAWARE	NM	LEA	1962	4370	19,378	1,427,836	Bell Canyon
MASON NORTH	DELAWARE	NM	EDDY & LEA	1954	4115	35,016	4,737,873	Bell Canyon, Cherry Canyon
NASH DRAW	BRUSHY CANYON	NM	EDDY	1992	6713	282,583	1,777,626	Brushy Canyon
PADUCA	DELAWARE	NM	LEA	1960	4636	29,690	13,922,378	Bell Canyon
PARKWAY	DELAWARE	NM	EDDY	1988	4135	386,121	3,307,433	Cherry Canyon, Brushy Canyon
RED TANK WEST	DELAWARE	NM	LEA	1992	8330	672,646	4,873,021	Brushy Canyon
SAND DUNES	CHERRY CANYON	NM	EDDY	1970	6020	10,723	1,076,059	Cherry Canyon
SAND DUNES WEST	DELAWARE	NM	EDDY	1992	7820	322,488	5,938,672	Brushy Canyon
SHUGART	DELAWARE	NM	EDDY	1958	4970	19,884	1,640,470	Cherry Canyon
SHUGART EAST	DELAWARE	NM	LEA	1985	5012	52,842	2,310,167	Cherry Canyon, Brushy Canyon
Totals						**9,208,247**	**351,912,395**	

Bold names indicate main productive zone

are productive—Bell Canyon, Cherry Canyon, and Brushy Canyon (fig. 3). The Bell Canyon has produced the greatest volume of oil (217.5 MMbbl [3.46×10^7 m^3]), followed by the Cherry Canyon (77.7 MMbbl [1.24×10^7 m^3]) and Brushy Canyon (56.7 MMbbl [9.01×10^6 m^3]) (Dutton and others, 2000). The main producing formation in each reservoir is listed in table 36 under the heading Subplay.

Depositional Model

Upper Permian Delaware Mountain Group strata compose a 4,500-ft-thick (1,375-m) succession of slope and basin deposits in the Delaware Basin. The Bell Canyon, Cherry Canyon,

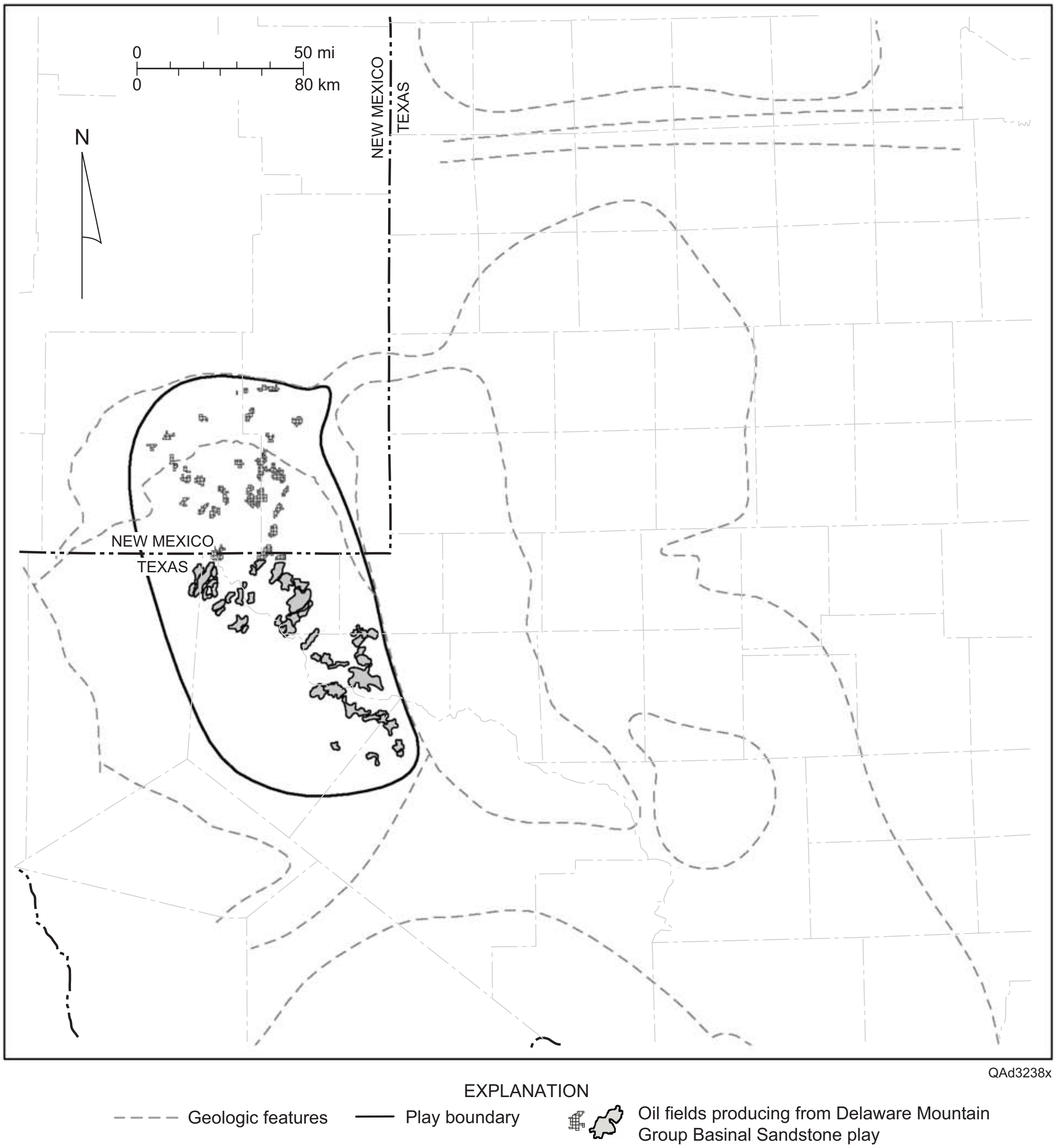

Figure 105. Play map for the Delaware Mountain Group Basinal Sandstone play, showing location of reservoirs having >1 MMbbl cumulative production, the play boundary, and geologic features. See figure 1 for county names and figure 2 for identification of geologic features.

and Brushy Canyon Formations are all composed of sandstones, siltstones, and minor amounts of carbonate. The cyclic interbedding of sandstones with organic-rich siltstones and limestones in the Delaware Mountain Group has been interpreted to record frequent changes in relative sea level (Meissner, 1972; Fischer and Sarnthein, 1988; Gardner, 1992, 1997a, b; Gardner and Sonnenfeld, 1996). During highstands in relative sea level, sands were trapped behind a broad, flooded shelf and prevented from entering the basin. Thin, widespread, organic-rich siltstones accumulated on the basin floor by the slow settling of marine algal material and airborne silt. Associated limestones were deposited by sediment gravity flows that originated by the slumping of carbonate debris along the flanks of a rapidly aggrading carbonate platform. During subsequent lowstands in relative sea level, the carbonate shelf was exposed, and sandstones bypassed to the basin floor.

Delaware Mountain Group sandstones have been interpreted by many workers as having been deposited by turbidity currents (Newell and others, 1953; Payne, 1976; Berg, 1979; Jacka, 1979; Gardner, 1992; Zelt and Rossen, 1995; Bouma, 1996; DeMis and Cole, 1996; Gardner and Sonnenfeld, 1996; Barton and Dutton, 1999; Beaubouef and others, 1999; Batzle and Gardner, 2000; Carr and Gardner, 2000; Gardner and Borer, 2000; Dutton and others, 2003). Textural characteristics of the sands, such as the absence of detrital clay-sized material and the lack of channels on the shelf, suggest that wind was an important agent in transporting the sands to the shelf margin (Fischer and Sarnthein, 1988). According to this model, dunes prograded to the shelf break during sea-level lowstands, and eolian sands were then carried into the basin by turbidity currents (Fisher and Sarnthein, 1988; Gardner, 1992). Paleocurrent indicators show that sands entered the basin from the Northwest Shelf and Central Basin Platform (Williamson, 1978, 1979).

Depositional models of Delaware sandstones have been developed mainly by outcrop studies, including recent studies of the Brushy Canyon (Beaubouef and others, 1999; Carr and Gardner, 2000; Gardner and Borer, 2000) and Bell Canyon (Barton and Dutton, 1999; Dutton and others, 1999; Dutton and others, 2003). Stratigraphic relationships in outcrop indicate that Bell Canyon sandstones were deposited in a basin-floor setting by a system of leveed channels having attached lobes and overbank splays that filled topographically low interchannel areas (fig. 106) (Barton and Dutton, 1999). Lobe sandstones, as much as 25 ft (8 m) thick and 2 mi (3.2 km) wide, display a broad tabular geometry. In a prograding system, lobe facies would have

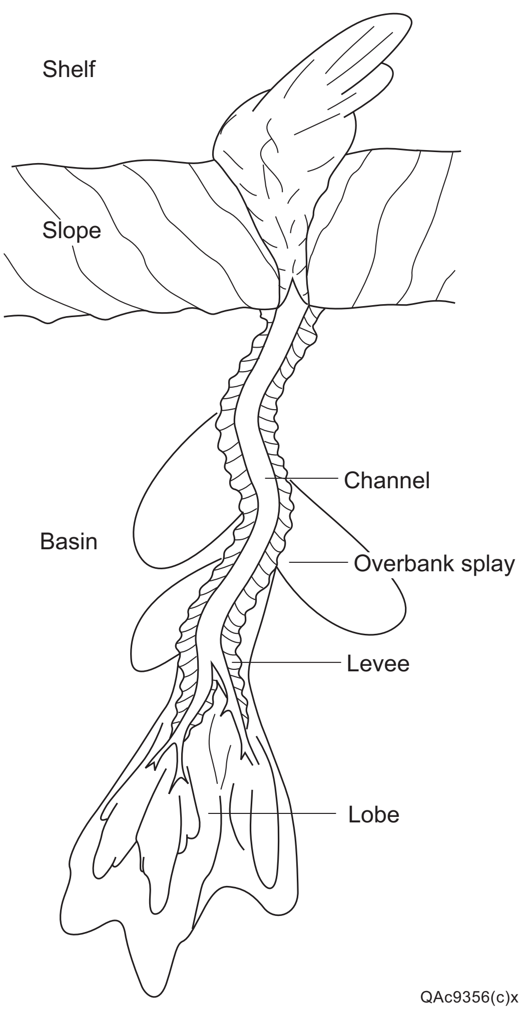

Figure 106. Depositional model proposed for the Bell Canyon sandstone, showing deposition in submarine channels with levees, overbank splays, and attached lobes. From Dutton and others (2003; modified from Galloway and Hobday (1996). From Dutton and others (2003), reprinted by permission of the AAPG, whose permission is required for further use. ©Copyright 2003. The American Association of Petroleum Geologists. All rights reserved.

been deposited first and then overlain and partly eroded by the channel-levee-overbank system. Channels are bound at the base by an erosion surface and are largely filled with massive and cross-stratified sandstones. Channels mapped in outcrop range from 10 to 60 ft (3 to 18 m) in thickness; most are 20 to 40 ft (6 to 12 m) thick (Barton and Dutton, 1999). Channel widths are 300 to 3,000 ft (90 to 900 m). Aspect ratios (width:thickness) range from 15 to 40. The channels bifurcate and widen downdip. Flanking the channels on both sides are wedge-shaped “wings” composed of thinly bedded sandstone and siltstone and interpreted to be levee deposits (Barton and Dutton, 1999). The width of levee deposits mapped in outcrop varies from ~500 ft (~150 m) to 3,000 ft (1 km) wide. The levees thin abruptly away from the channel, decreasing in thickness from 20 ft to 1 ft (6 to 0. 3 m). Overbank splays are composed of massive sandstones and display a broad, tabular, to irregular geometry. The splay sandstones are 3 to 25 ft (1 to 8 m) thick. Splays on the flanks of the channel system were at least 3,000 ft (900 m) wide and possibly much greater. Volumetrically the splays contain much of the sandstone in the system (Dutton and others, 2003).

A depositional model of the Bell Canyon reservoirs (fig. 107) in East Ford field, Reeves County, was developed using data from Bell Canyon outcrops and subsurface data (Dutton and others, 2000, 2003). The reservoir sandstones are interpreted as having been deposited in a channel-levee system that terminated in broad lobes; overbank splays filled topographically low interchannel areas. Individual channel-levee and lobe complexes stack in a compensatory fashion and are separated by laterally continuous, laminated siltstones (fig. 108). Reservoir sandstones consist of (1) broadly lenticular lobe deposits, (2) elongate channel deposits, and (3) irregular splay deposits. Porosity measured from core plugs ranges from 4.5 to 30.6 percent and averages 22 percent. Permeability ranges from 0.01 to 249 md (0.01 to 249 × 10^{-3} μm^2). Average

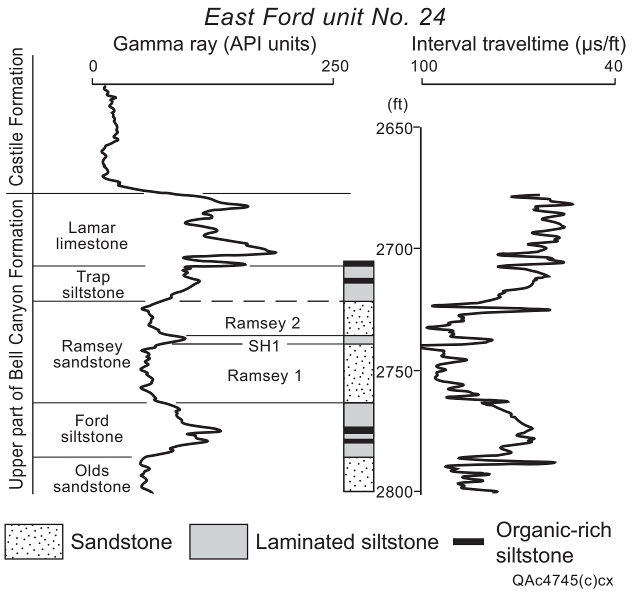

Figure 107. Typical log from East Ford field, which produces from the Ramsey sandstone in the upper Bell Canyon Formation. From Dutton and others (2003), reprinted by permission of the AAPG, whose permission is required for further use. ©Copyright 2003. The American Association of Petroleum Geologists. All rights reserved.

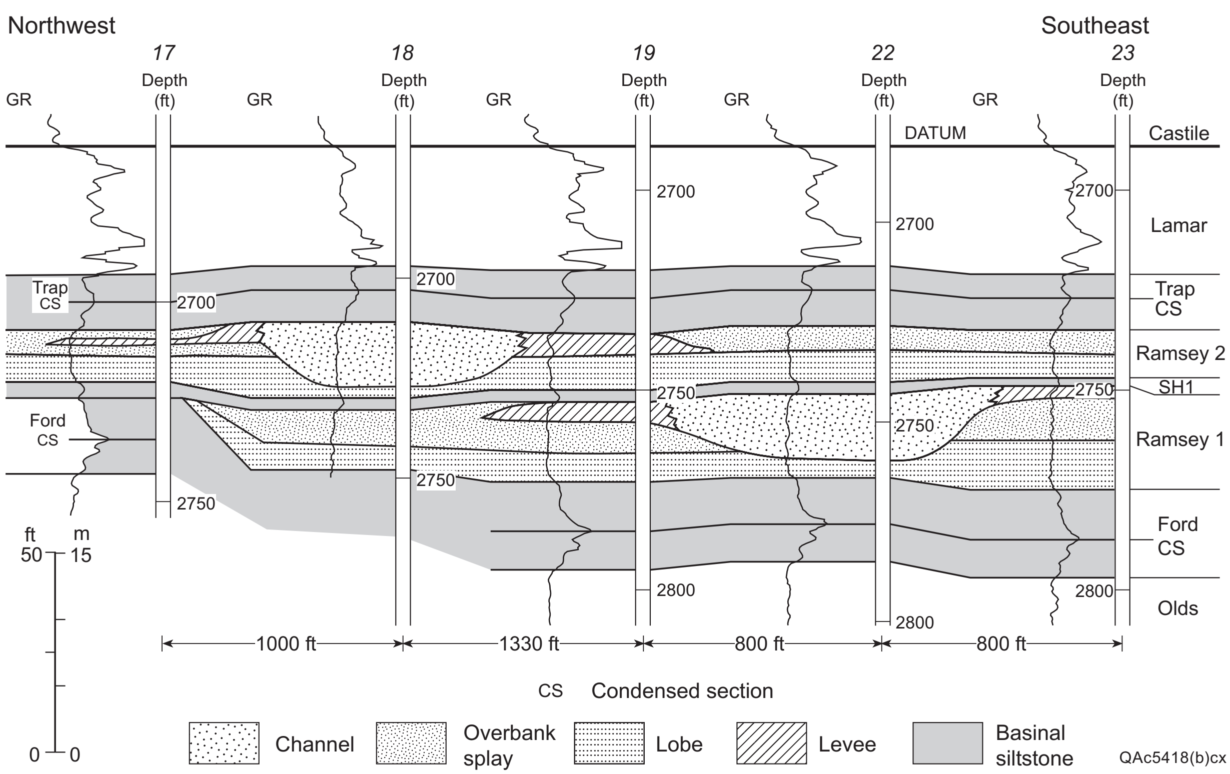

Figure 108. Northwest-southeast strike cross section of the central part of the East Ford unit. See Dutton and others (2003) for location of the cross section. From Dutton and others (2003), reprinted by permission of the AAPG, whose permission is required for further use. ©Copyright 2003. The American Association of Petroleum Geologists. All rights reserved.

permeability is 40 md ($40 \times 10^{-3}\ \mu m^2$), and geometric mean permeability is 22 md ($22 \times 10^{-3}\ \mu m^2$) (Dutton and others, 2003).

Reservoir Characteristics

Development of the Delaware Mountain Group Basinal Sandstone play began with the shallowest reservoirs. It is only within the last 15 years that exploration and development have concentrated on the deeper zones. Bell Canyon reservoirs lie at depths of 2,500 to 5,300 ft (750 to 1,600 m) (table 36). Cherry Canyon reservoirs lie at depths of 3,000 to 7,000 ft (900 to 2,100 m), and Brushy Canyon reservoirs lie at depths of 6,000 to 8,500 ft (1,800 to 2,600 m) (table 36). Most Bell Canyon reservoirs were discovered prior to 1970. Increased production from the play during the early 1990's resulted from the discovery and development of deeper reservoirs, primarily in the Brushy Canyon, but also in the Cherry Canyon.

Traps in the play are predominantly stratigraphic. Reservoir sandstones are complexly interbedded with nonreservoir siltstones and lower-permeability sandstones. Reservoir sandstones may also exhibit complex lateral relationships with nonreservoir facies (fig. 109). As a result, production is typically obtained from multiple separate sandstone layers within a single reservoir. Reservoirs are thought to have no single oil-water contact (Montgomery and others, 1999).

Delaware sandstone reservoirs produce via solution-gas drive. Typical production rates from wells completed in Delaware sandstones are 50 to 400 bbl (8.0 to 63.6 m^3) oil per day and 30 to 350 bbl (4.8 to 55.6 m^3) water per day (Montgomery and others, 1999, 2000). Estimated ultimate primary recovery is 50,000 to 100,000 bbl ($7.95 \times 10^3\ m^3$ to $1.59 \times 10^4\ m^3$) of oil

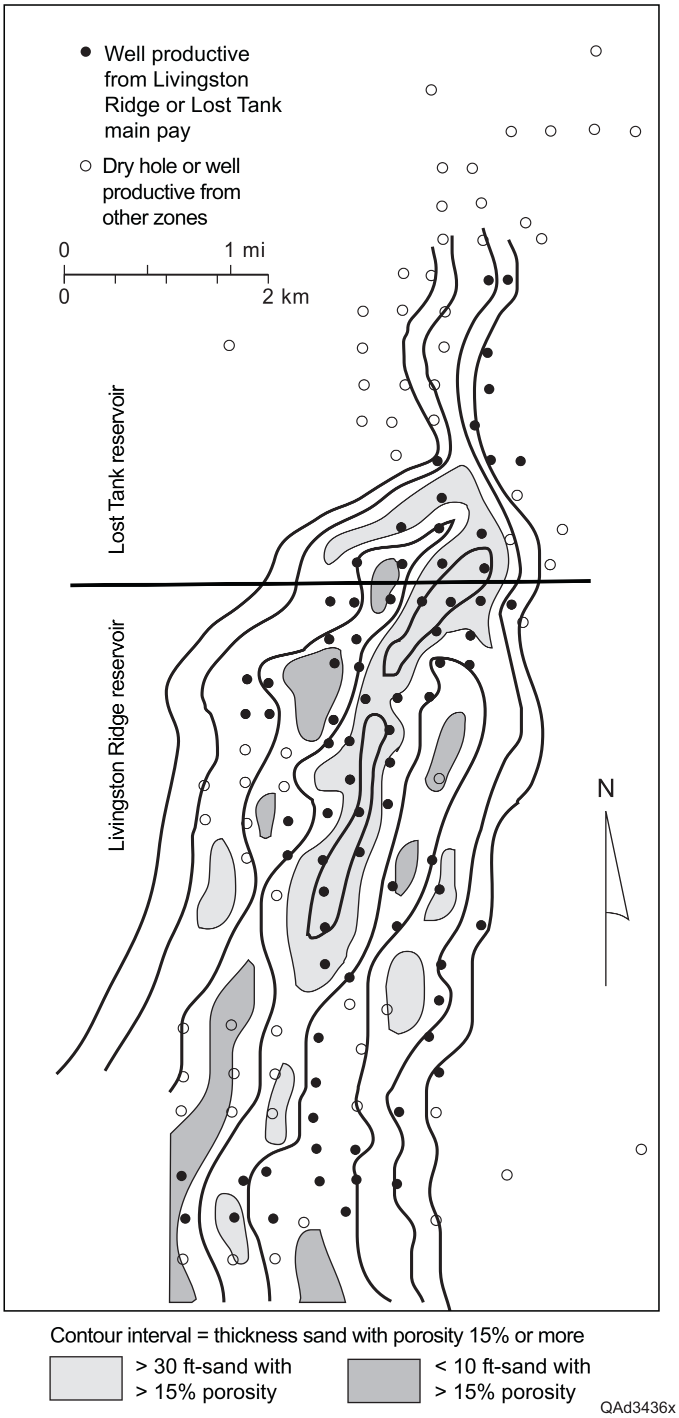

Figure 109. Net thickness of sandstone with porosity ≥15 percent in the main pay zone at the Livingston Ridge and Lost Tank reservoirs. After May (1996).

(Montgomery and others, 1999, 2000). Initial production may typically exceed 2,500 bbl/mo (3.97×10^2 m^3/mo) in a well but will rapidly decline to a few hundred bbl/mo (a few tens of m^3/mo) (or less) after 4 years (fig. 110) as solution gas is produced and reservoir pressures

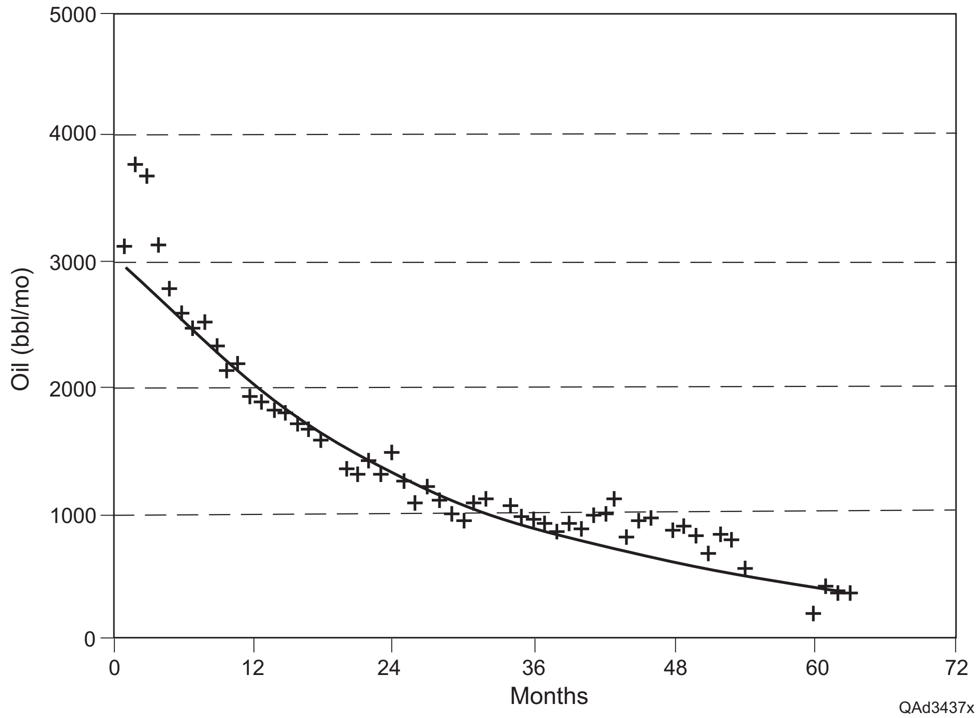

Figure 110. Average-production decline curve for wells productive from Livingston Ridge main pay, Livingston Ridge and Lost Tank reservoirs. From Broadhead and others (1998).

decrease below the bubble point. Injection of water for pressure maintenance can yield a good production response in some reservoirs (fig. 111). Pressure maintenance should be initiated early so that a secondary gas cap is not allowed to form (Mark Murphy, personal communication, 2003).

Primary production from Delaware sandstone fields is commonly <15 percent of OOIP (Dutton and others, 1999, 2003; Montgomery and others, 1999). Many Delaware sandstone reservoirs are characterized by relatively high amounts of mobile water at the time of discovery. Among the reasons for low primary production are (1) low solution gas:oil ratio, which results in limited natural drive energy; (2) expenditure of considerable solution-gas drive energy in the

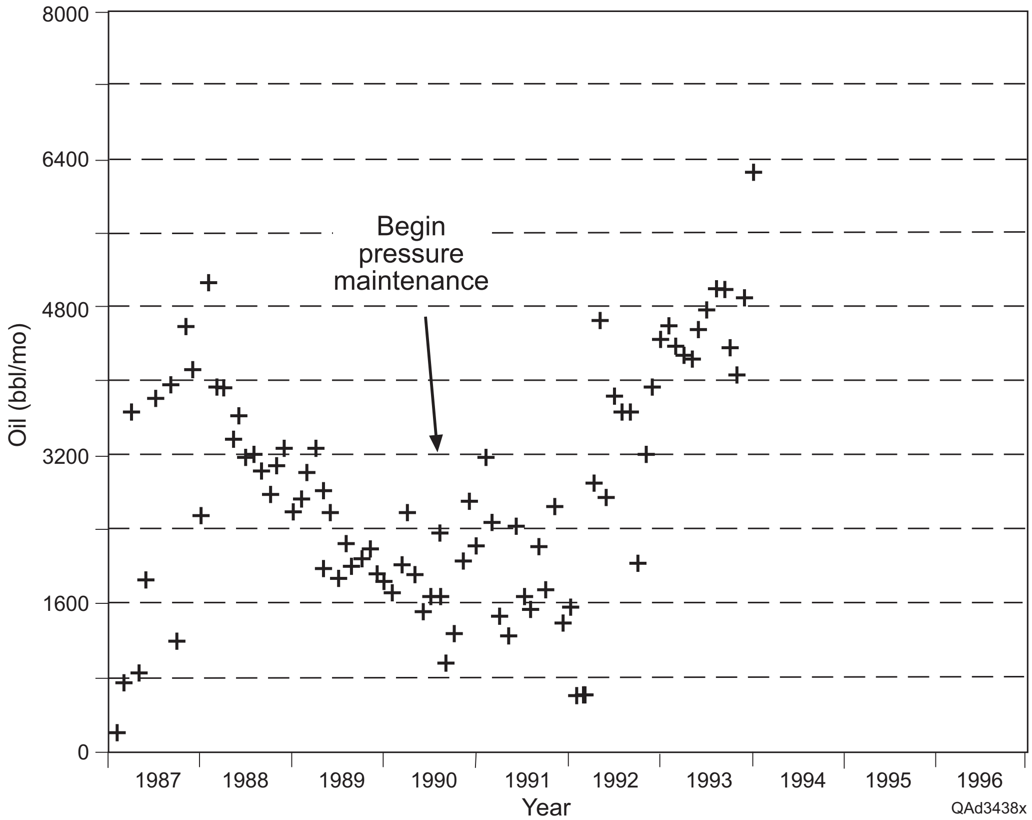

Figure 111. Historical monthly production of oil, Phillips Petroleum Company No. 2 James A well, Cabin Lake reservoir. Note increase in production as a result of water injection for the purpose of pressure maintenance. After Broadhead and others (1998).

recovery of water from the reservoir; and (3) lack of pressure support from an aquifer owing to limited water influx (Dutton and others, 2003).

Reservoir Development Examples

Secondary waterfloods in two Bell Canyon fields, Geraldine Ford and Twofreds, recovered only an additional 4 to 5 percent OOIP (Pittaway and Rosato, 1991; Flanders and DePauw, 1993). Waterflood recoveries in Bell Canyon sandstones have been low because of

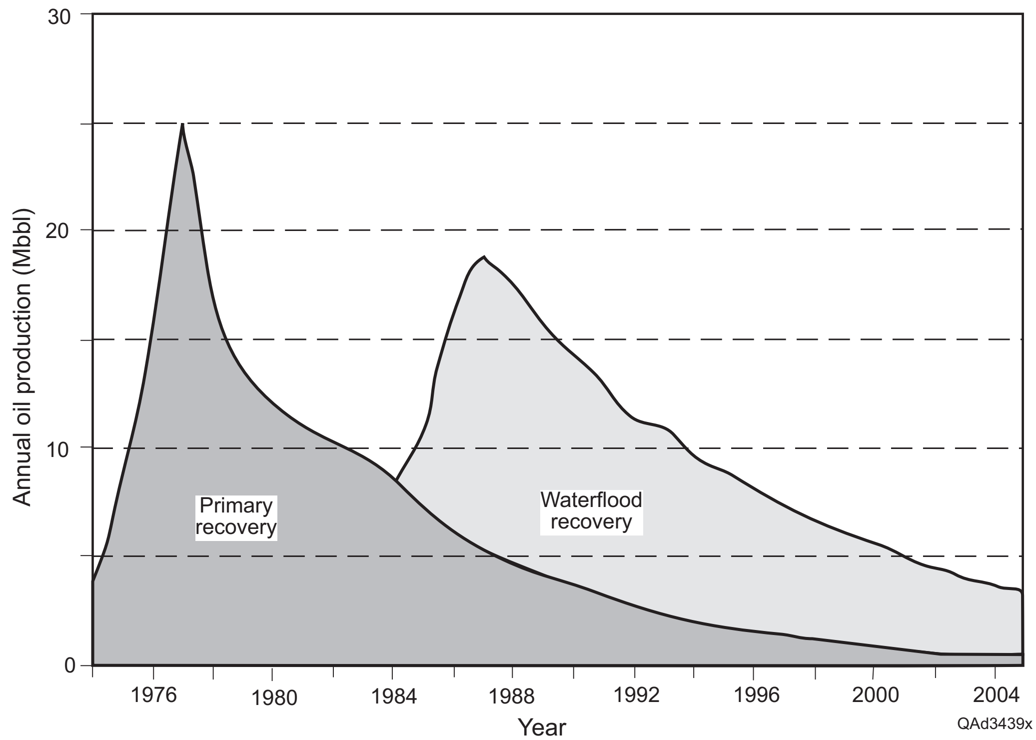

Figure 112. Annual production history of the Indian Draw Delaware reservoir, with production curves for primary and secondary (waterflood) recovery and estimated oil recovery by primary and secondary means. This reservoir is productive from the Cherry Canyon Formation of the Delaware Mountain Group. From Broadhead and others (1998).

poor sweep efficiency caused by (1) abundant mobile water present when the waterflood was started, (2) water injection above formation parting pressure, (3) lack of proper water filtration, and (4) patterns not arranged to exploit depositional characteristics.

Waterflooding of other Delaware sandstone reservoirs, such as Indian Draw, has yielded good results, with secondary recovery reserves equal to as much as 80 percent of primary recovery reserves in some cases (fig. 112). For optimal efficiency, water injection should commence before reservoir pressures decline to the point where a secondary gas cap is formed. The more proximal upper Brushy Canyon and lower Cherry Canyon reservoirs are thought to have less lateral sandstone heterogeneity than other reservoirs in the Brushy Canyon and Cherry Canyon and may be more favorable to waterflooding (Montgomery and others, 1999).

In other more heterogeneous Delaware reservoirs with complex internal sandstone distributions and lower permeability, gas injection may be required for optimal pressure maintenance, and carbon dioxide flooding may be needed for enhanced recovery (Montgomery and others, 1999). CO_2 floods have been conducted in Twofreds (Kirkpatrick and others, 1985; Flanders and DePauw, 1993), Geraldine Ford (Pittaway and Rosato, 1991), and East Ford fields (Dutton and others, 2003). In Twofreds unit, 12 percent of OOIP was recovered by the CO_2 flood; approximately 7 percent of OOIP in the flooded area of Ford Geraldine unit was recovered by the CO_2 flood (Dutton and others, 2003). Tertiary recovery from Ford Geraldine unit may be lower because a higher percentage of OOIP (23 percent) was recovered during primary and secondary production than in Twofreds unit (16 percent) owing to a stronger solution-gas drive at Ford Geraldine.

East Ford unit went directly from primary production to tertiary recovery by CO_2 flooding in 1995 (Dutton and others, 2003). Prior to initiation of the CO_2 flood, production from East Ford unit had declined to 30 bbl/d (4.8 m^3/d), from a high of >900 bbl/d (>143 m^3) in 1966. By 2001, production had increased to >185 bbl/d (>29.4 m^3) (fig. 113). Oil recovery has been improved substantially by the CO_2 flood, but not as much as expected. Geologic heterogeneities, such as interbedded siltstones, are apparently influencing reservoir displacement operations in East Ford unit by limiting cross-flow of fluids between injector and producer wells. Injection wells located in splay sandstones apparently have poor communication with wells in channel sandstones (fig. 108), perhaps because communication is restricted through levee and channel-margin deposits. The south part of the unit is responding well to the flood because injection and

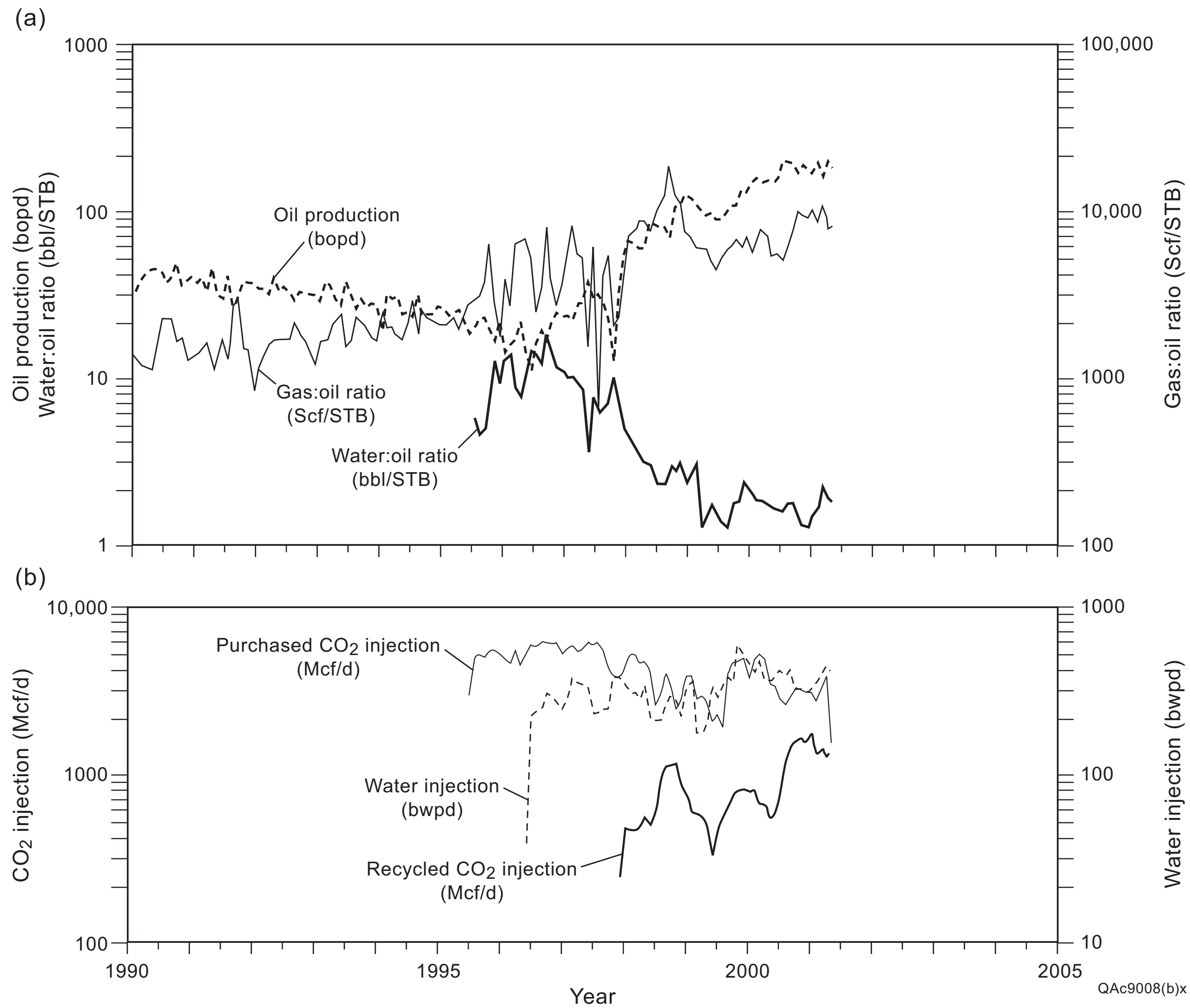

Figure 113. (a) Plot of oil production, water:oil ratio, and gas:oil ratio in East Ford unit since 1990; (b) plot of gas and water injection since 1995. From Dutton and others (2003). CO_2 flooding began in July 1995. From Dutton and others (2003), reprinted by permission of the AAPG, whose permission is required for further use.

production wells are in the same interconnected lobe depositional environment. Locating an adequate number of injectors and producers within the same depositional facies—whether channels, splays, or lobes—will maximize reservoir volume contacted and production rate and minimize displacement across restrictive depositional barriers and time to produce the reservoir.

Nash Draw field in Eddy County produces from the Brushy Canyon sandstone. Production at Nash Draw was increased by drilling vertical and horizontal wells that were targeted on the basis of high-quality 3-D seismic data. By using in-field VSP data to calibrate seismic reflection time to depth, turbidite packages ~100 ft (~30 m) thick at a depth of 7,000 ft (2,135 m) were detected and interpreted (Hardage and others, 1998a, b). Significant correlations were established between high-amplitude reflection areas and good producing wells (Hardage and others, 1998a, b).

Many additional studies of Delaware Mountain Group reservoirs have been published but are not cited in this summary. The references to those publications are listed separately, under Additional Delaware Mountain Group References. A volume focusing on the Brushy Canyon, published by the Permian Basin Section SEPM, contains many papers about Delaware sandstone fields (DeMis and Cole, 1996).

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Queen Tidal-Flat Sandstone (Play 131)

The 17 reservoirs in the Queen Tidal-Flat Sandstone play, which produce from the middle Guadalupian Queen Formation (fig. 3), had produced 179.6 MMbbl (2.86×10^7 m^3) of oil through 2000 (table 37). In the *Atlas of Major Texas Oil Reservoirs*, this play was called the Queen Platform/Strandplain Sandstone (Galloway and others, 1983). Queen Formation reservoirs in this play occur within eolian-sand-sheet, tidal-flat, tidal-channel, and shoreface deposits located on the east and south margins of the Central Basin Platform (fig. 114) (Tyler and others, 1991).

The vertical sequence of siliciclastic and evaporite sediments is the product of upward-shoaling environments. Sandstone facies are overlain by sabkha dolomudstones and massive anhydrite, and the massive anhydrite is commonly overlain by eolian sheet sands (Tyler and others, 1991). Queen sandstones at Yates field on the south part of the Central Basin Platform are interpreted as having been deposited on a coastal mud flat fed by eolian sands (Spencer and Warren, 1986). Some of the sands were probably reworked in tidal channels and ponds.

Table 37. Queen Tidal-Flat Sandstone play (play 131). 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
20004666	8	CONCHO BLUFF	QUEEN	TX	CRANE	1956	4131	47,654	8,689,957
20006500	8	CONCHO BLUFF, NORTH	QUEEN	TX	ECTOR	1956	4490	547,809	15,394,816
39242333	8A	HARRIS	QUEEN	TX	GAINES	1957	4148	16,438	1,672,816
56822625	8	MAGUTEX	QUEEN	TX	ANDREWS	1958	4862	87,928	4,868,087
59419664	8	MCFARLAND	QUEEN	TX	ANDREWS	1955	4790	201,349	42,782,895
59420500	8	MCFARLAND, EAST	QUEEN	TX	ANDREWS	1955	4789	26,551	2,560,021
60137500	8	MEANS	QUEEN SAND	TX	ANDREWS	1954	4024	77,759	39,045,231
60139500	8	MEANS, N.	QUEEN SAND	TX	GAINES	1955	4341	40,834	8,270,696
62781500	8	MOOSE	QUEEN	TX	ECTOR	1958	4512	255,601	9,078,764
65674001	7C	NOELKE		TX	CROCKETT	1940	1133	779	5,595,084
73167500	8	PRIEST & BEAVERS	QUEEN	TX	PECOS	1957	2180	7,958	2,387,501
82570700	8	SHAFTER LAKE	YATES	TX	ANDREWS	1952	3054	7,293	1,951,628
88562001	8	TAYLOR LINK		TX	PECOS	1929	1800	14,399	15,896,612
93958525	8	VIREY	QUEEN	TX	MIDLAND	1988	4299	151,810	1,991,053
94747001	8	WALKER		TX	PECOS	1940	2016	10,627	9,482,673
96875001	8	WHITE & BAKER		TX	PECOS	1934	1100	9,742	5,575,897
99295333	8	YATES	SMITH SAND	TX	PECOS	1944	1100	12,970	4,356,435
		Totals						**1,517,501**	**179,600,166**

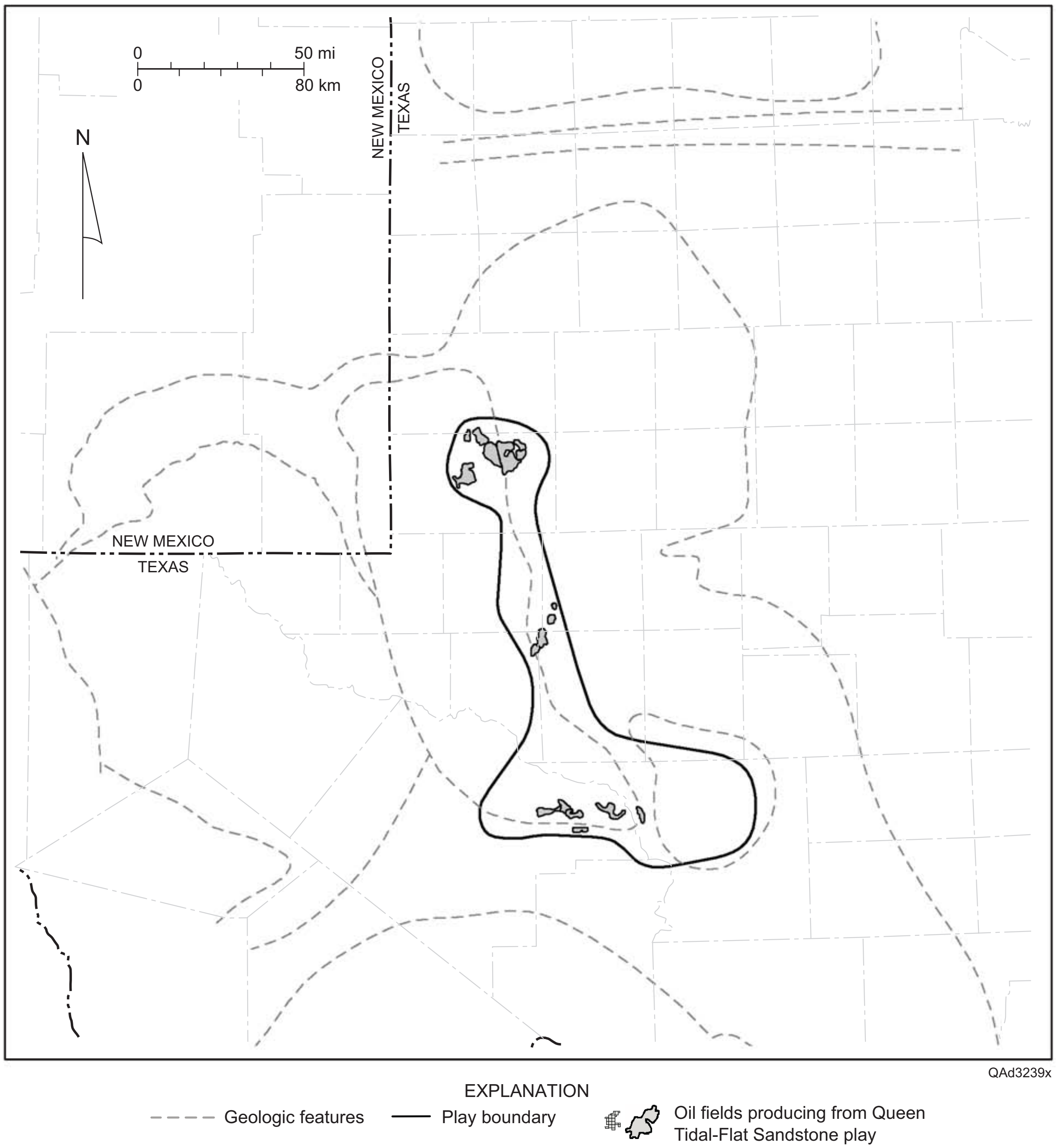

Figure 114. Play map for the Queen Tidal-Flat Sandstone play, showing location of reservoirs having >1 MMbbl cumulative production, the play boundary, and geologic features. See figure 1 for county names and figure 2 for identification of geologic features.

Production comes from multiple siltstone and very fine grained sandstone beds within the reservoirs (Price and others, 2000). Each sandstone is sealed by massive impermeable anhydrite on both the top and bottom, resulting in barriers to vertical fluid flow (Tyler and others, 1991). Thus, the sandstones act as separate reservoir units. Within the reservoir sandstones, flow continuity is further complicated by juxtaposition of tidal-channel, tidal-flat, shoreface, and eolian facies. Sandstone productivity is controlled both by depositional heterogeneities and postdepositional diagenesis. Porosity development is controlled mainly by the amount of dolomite and anhydrite cement filling intergranular pores. Porosity in productive sandstones ranges from 11 to 27 percent and averages 17 percent (Tyler and others, 1991).

Small anticlines, anticlinal noses, and irregularly shaped domes, combined with an overlapping seal of massive anhydrite, form the traps in these reservoirs (Tyler and others, 1991). The structures resulted from draping of the Queen Formation over preexisting paleotopography. Queen sandstone distribution was influenced by paleotopography associated with deep-seated structures (Trentham, 2003).

The McFarland Queen reservoir in Andrews County produces from two sandstones in the lower Queen Formation (fig. 115) (Tyler and others, 1991; Holtz, 1994). The sandstones, which form the bases of progradational, upward-shoaling cycles, were deposited in intertidal-flat, tidal-channel, and shoreface environments. They are overlain by supratidal dolomudstones and massive anhydrite at the top (Holtz, 1994). Production is highest where the sandstones are thickest, in areas interpreted to be tidal-channel deposits. Porosity ranges from 11 to 24 percent and averages 12 percent; permeability ranges from 3 to 24 md (3 to 24×10^{-3} μm^2) and averages 12 md (12×10^{-3} μm^2) (Holtz, 1994).

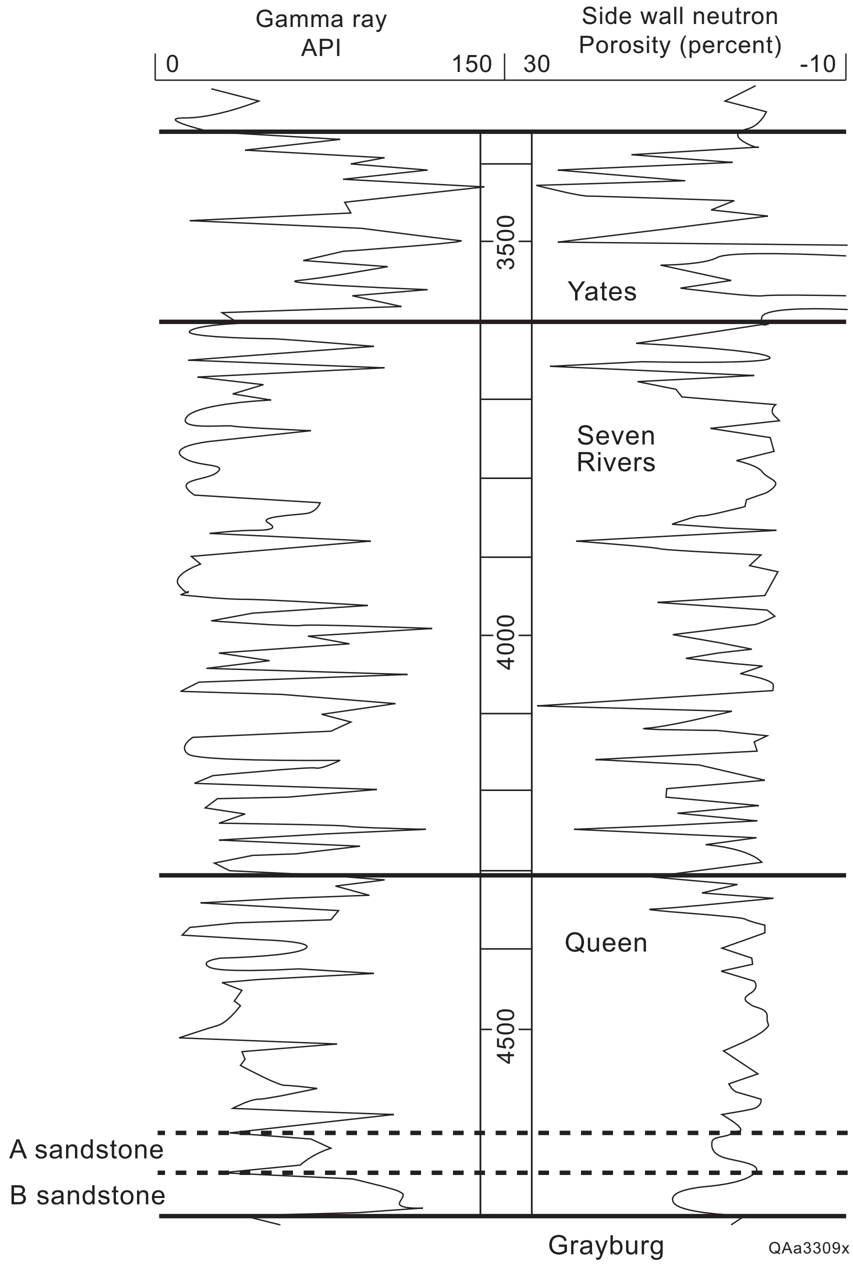

Figure 115. Typical log of upper Permian Queen, Seven Rivers, and Yates Formations in the McFarland Queen reservoir, Andrews County, showing producing Queen sandstones A and B. From Holtz (1994).

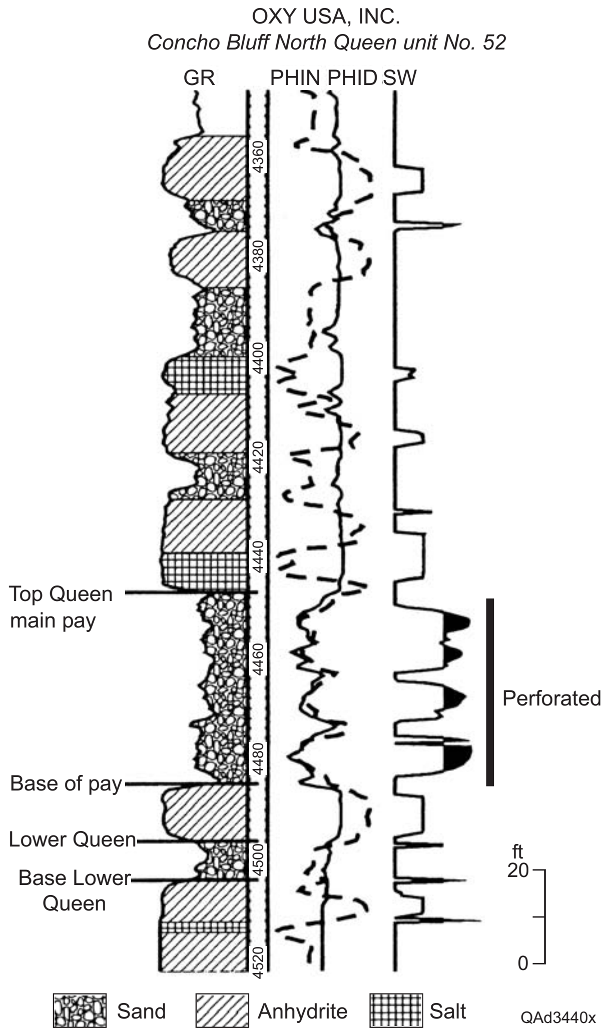

Figure 116. Typical log from Concho Bluff North Queen unit, Ector County, showing reservoir sandstones interbedded with halite and anhydrite. From Lufholm and others (1996).

The reservoir interval at North Concho Bluff field consists of several sandstones interbedded with anhydrite and salt in the upper Queen Formation (fig. 116) (Mazzullo and others, 1992; Lufholm and others, 1996). The depositional setting was a broad, low-relief shelf where clastics interfingered with evaporite deposits during lowstands of sea level. Permeability in the reservoir sandstones ranges from 1 to 1200 md (1 to 1200 × 10^{-3} μm^2) and averages 70 md (70 × 10^{-3} μm^2); porosity ranges from 9 to 26 percent and averages 16 percent (Mazzullo and others, 1992).

Production from the North Concho Bluff Queen reservoir had declined to 35 bbl/d ($5.6\ m^3/d$) by 1994. 3-D seismic data were acquired over the field, and a seismic-guided method to estimate reservoir properties was used to populate a reservoir model with average porosity and permeability values (Lufholm and others, 1996). Reservoir simulation identified areas of "banked oil" that were poorly swept by waterflooding. After two infill wells were drilled and two existing wells were converted to injectors, production increased to 200 bbl/d ($31.8\ m^3/d$). The reservoir model identified additional potential recoverable reservoirs of >2 MMbbl ($>3.18 \times 10^5\ m^3$) (Lufholm and others, 1994).

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Artesia Platform Sandstone (Play 132)

The Artesia Platform Sandstone play, which was called the Permian Sandstone and Carbonate Play in the *Atlas of Major Texas Oil Reservoirs* (Galloway and others, 1983), has produced 1,855.4 MMbbl (2.95×10^8 m^3) of oil from 77 reservoirs (table 38, fig. 117). Reservoirs that make up the play are in the Queen, Seven Rivers, and Yates Formations of the Artesia Group (figs. 3, 118) and are located along the west edge of the Central Basin Platform and on the Northwest Shelf (fig. 117). Queen reservoirs on the east side of the Central Basin Platform are in the Queen Tidal-Flat Sandstone play (play 131). Principal productive sandstones

Table 38. Artesia Platform Sandstone play (play 132). 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
292551	8	ABELL	PERMIAN 2200	TX	PECOS	1949	2200	22,870	1,074,575
4184666	8	ATAPCO	QUEEN	TX	CRANE	1959	2140	26,481	1,351,920
6853333	8	BELDING	YATES	TX	PECOS	1964	2672	100,936	1,138,199
14155001	8	BYRD		TX	WARD	1942	2700	5,047	1,148,651
25501500	8	DORR	QUEEN SAND	TX	WARD	1955	2291	21,036	1,045,088
28962001	8	EMPEROR, DEEP		TX	WINKLER	1935	3000	39,499	11,773,170
32124001	8	FORT STOCKTON		TX	PECOS	1944	2892	259,922	34,386,845
32124625	8	FORT STOCKTON	YATES LOWER	TX	PECOS	1943	3072	0	1,770,005
32344800	8	FOUR C	SAN ANDRES	TX	PECOS	1975	2302	51,217	1,110,536
38255001	8	HALLEY		TX	WINKLER	1939	3150	129,142	44,608,756
38260664	8	HALLEY, SOUTH	QUEEN SAND	TX	WINKLER	1960	3113	57,841	4,788,167
40354001	8	HENDERSON		TX	WINKLER	1936	3030	33,553	16,617,751
40406001	8	HENDRICK		TX	WINKLER	1926	3100	315,251	265,038,391
49038001	8	KERMIT		TX	WINKLER	1928	2800	215,702	111,012,043
49129132	8	KEYSTONE	COLBY	TX	WINKLER	1939	3300	219,044	75,325,366
53000830	8	LEHN-APCO	1600	TX	PECOS	1939	1700	6,812	3,296,731
53002666	8	LEHN-APCO, NORTH	1600	TX	PECOS	1946	1945	3,515	3,200,802
56761001	8	MAGNOLIA SEALY		TX	WARD	1939	3000	63,721	5,774,660
56766001	8	MAGNOLIA SEALY, SOUTH		TX	WARD	1940	2847	11,688	3,580,223
56949500	8	MALICKY	QUEEN SAND	TX	PECOS	1949	1964	7,577	3,604,412
58164001	8	MASTERSON		TX	PECOS	1929	1500	2	2,723,125
62415747	8	MONAHANS	QUEEN SAND	TX	WARD	1960	3269	29,452	6,505,467
62420666	8	MONAHANS, SOUTH	QUEEN	TX	WARD	1961	3108	25,049	8,027,310
64995001	8	NETTERVILLE		TX	PECOS	1934	2400	4,223	3,325,351
66588001	8	OATES		TX	PECOS	1947	790	47,335	1,595,709
69873001	8	PAYTON		TX	PECOS	1938	2000	46,004	14,835,765
70129580	8	PECOS VALLEY	HIGH GRAVITY	TX	PECOS	1928	1800	55,939	20,014,222
70129638	8	PECOS VALLEY	LOW GRAVITY	TX	PECOS	1928	1600	14,576	6,747,210
81392001	8	SCARBOROUGH		TX	WINKLER	1927	3200	23,055	37,034,546
81394001	8	SCARBOROUGH, NORTH		TX	WINKLER	1947	3286	3,290	3,443,096
81952500	8	SEALY, SOUTH	YATES	TX	WARD	1946	2700	4,676	1,229,767
82822001	8	SHEARER		TX	PECOS	1938	1400	0	4,684,529
83292500	8	SHIPLEY	QUEEN SAND	TX	WARD	1928	3075	34,250	29,037,233
85104001	8	SPENCER		TX	WARD	1941	2900	9,365	3,071,702
92304500	8	U S M	QUEEN	TX	PECOS	1964	3368	24,088	2,219,718
95138001	8	WARD, SOUTH		TX	WARD	1938	2700	280,237	108,366,864
95152001	8	WARD-ESTES, NORTH		TX	WARD	1929	3000	1,320,287	412,799,795
95970200	8	WEINER	COLBY SAND	TX	WINKLER	1941	3200	25,399	9,239,506
97201500	8	WICKETT, SOUTH	YATES	TX	WARD	1952	2640	7,080	1,894,254

are in the Yates and Queen Formations, although sandstones of the Seven Rivers Formation provide significant production in some reservoirs. Dolostones of the Queen, Seven Rivers, Yates, and Tansill Formations form secondary reservoirs. Production from the dolostones is generally commingled with production from the more prolific sandstone reservoirs.

Siliciclastic, carbonate, and evaporite rocks of the Artesia Group were deposited on a broad, shallow shelf in a back-reef lagoonal setting located updip of the shelf-margin reef carbonates that rimmed the Delaware Basin (Silver and Todd, 1969; Ward and others, 1986). The Yates and Seven Rivers Formations are the restricted-platform equivalents of the middle and lower Capitan Reef platform-margin carbonates, and the Queen Formation is the

Table 38, continued. Artesia Platform Sandstone Play (Play 132).

FLDNAME	RESNAME	STATE	COUNTY	DISCYR	DEPTHTOP	2000 PROD	CUMPROD
BARBER	YATES	NM	EDDY	1937	1442	4,831	1,973,771
BENSON NORTH	QUEEN GRAYBURG	NM	EDDY	1954	2844	19,518	3,468,936
BOWERS	SEVEN RIVERS	NM	LEA	1935	3553	11,527	4,234,123
CAPROCK	QUEEN	NM	CHAVES & LEA	1950	3030	24,082	74,210,930
CORBIN	QUEEN	NM	LEA	1938	4258	4,074	1,550,004
CORBIN CENTRAL	QUEEN	NM	LEA	1985	4228	26,201	1,091,714
DOLLARHIDE	QUEEN	NM	LEA	1952	3670	40,334	6,743,430
DOS HERMANOS	YATES SEVEN RIVERS	NM	EDDY	1955	1631	4,339	1,605,623
DOUBLE L	QUEEN	NM	CHAVES	1971	1980	11,290	3,511,218
E-K	YATES SEVEN RIVERS QUEEN	NM	LEA	1954	4387	166,428	6,559,436
E-K EAST	QUEEN	NM	LEA	1957	4387	6,233	1,315,635
EMPIRE	YATES SEVEN RIVERS	NM	EDDY	1926	1600	5,383	1,291,409
EUMONT	YATES SEVEN RIVERS QUEEN	NM	LEA	1953	2950	337,929	75,072,680
EUNICE SOUTH	SEVEN RIVERS QUEEN	NM	LEA	1930	3610	14,112	32,423,951
FREN	SEVEN RIVERS	NM	EDDY	1943	1940	0	6,680,361
GETTY	YATES	NM	EDDY	1954	1343	0	1,822,000
HACKBERRY NORTH	YATES SEVEN RIVERS	NM	EDDY	1953	2047	18,529	3,468,223
HIGH LONESOME	QUEEN	NM	EDDY	1939	1800	9,535	4,609,851
HUME	QUEEN	NM	LEA	1956	3950	0	1,389,000
JALMAT	TANSILL YATES SEVEN RIVERS	NM	LEA	1953	2800	397,842	77,336,091
LANGLIE MATTIX	SEVEN RIVERS QUEEN GRAYBURG	NM	LEA	1935	2852	726,379	136,874,684
LEONARD SOUTH	QUEEN	NM	LEA	1948	3400	4,419	2,098,167
LYNCH	YATES SEVEN RIVERS	NM	LEA	1929	3730	83,297	15,935,153
MESA	QUEEN	NM	LEA	1962	3350	2,225	1,701,072
MILLMAN EAST	QUEEN GRAYBURG SAN ANDRES	NM	EDDY	1959	2413	210,946	8,307,502
PEARL	QUEEN	NM	LEA	1955	4830	114,440	22,411,023
PEARSALL	QUEEN	NM	LEA	1940	3685	18,436	2,968,614
QUERECHO PLAINS	QUEEN	NM	LEA	1972	3910	38,554	1,289,650
RED LAKE EAST	QUEEN GRAYBURG	NM	EDDY	1960	1560	14,937	1,439,093
RHODES	YATES SEVEN RIVERS	NM	LEA	1927	3040	30,337	14,226,051
SCARBOROUGH	YATES SEVEN RIVERS	NM	LEA	1965	3050	12,160	17,437,636
SHUGART	YATES SEVEN RIVERS QUEEN GRAYBURG	NM	EDDY	1937	3440	390,172	28,507,187
SULIMAR	QUEEN	NM	CHAVES	1968	1960	8,489	2,334,105
TEAS	YATES SEVEN RIVERS	NM	LEA	1929	3343	51,371	3,555,628
TEAS WEST	YATES SEVEN RIVERS	NM	LEA	1959	3225	65,726	1,966,523
TURKEY TRACK	SEVEN RIVERS QUEEN GRAYBURG SAN ANDRES	NM	EDDY	1950	1655	50,856	3,885,863
WILSON	YATES SEVEN RIVERS	NM	LEA	1928	3815	62	9,303,607
YOUNG	QUEEN	NM	LEA	1945	3765	56,522	2,367,621
Totals						**6,526,676**	**1,855,409,025**

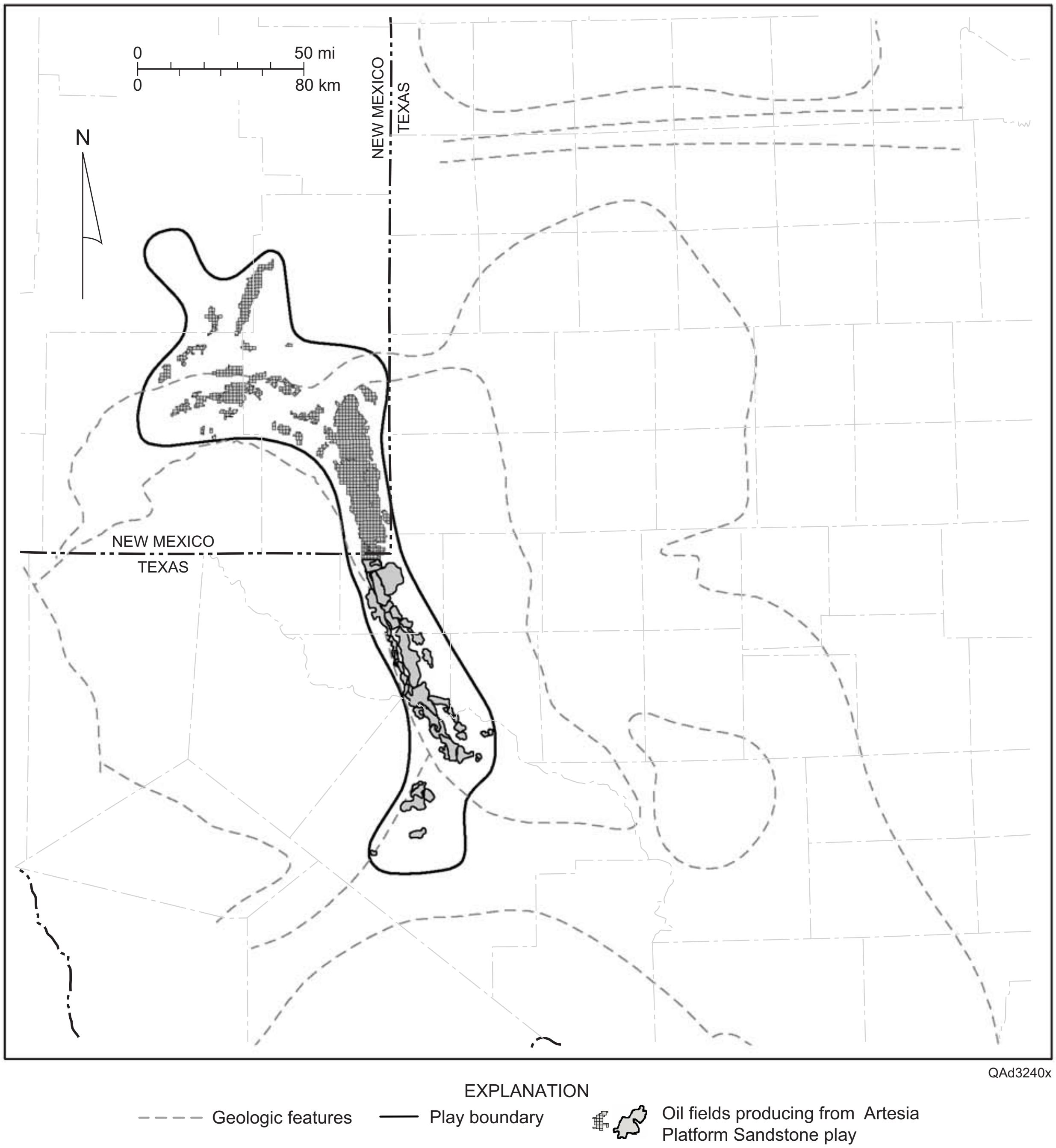

Figure 117. Play map for the Artesia Platform Sandstone play, showing location of reservoirs having >1 MMbbl cumulative production, the play boundary, and geologic features. See figure 1 for county names and figure 2 for identification of geologic features.

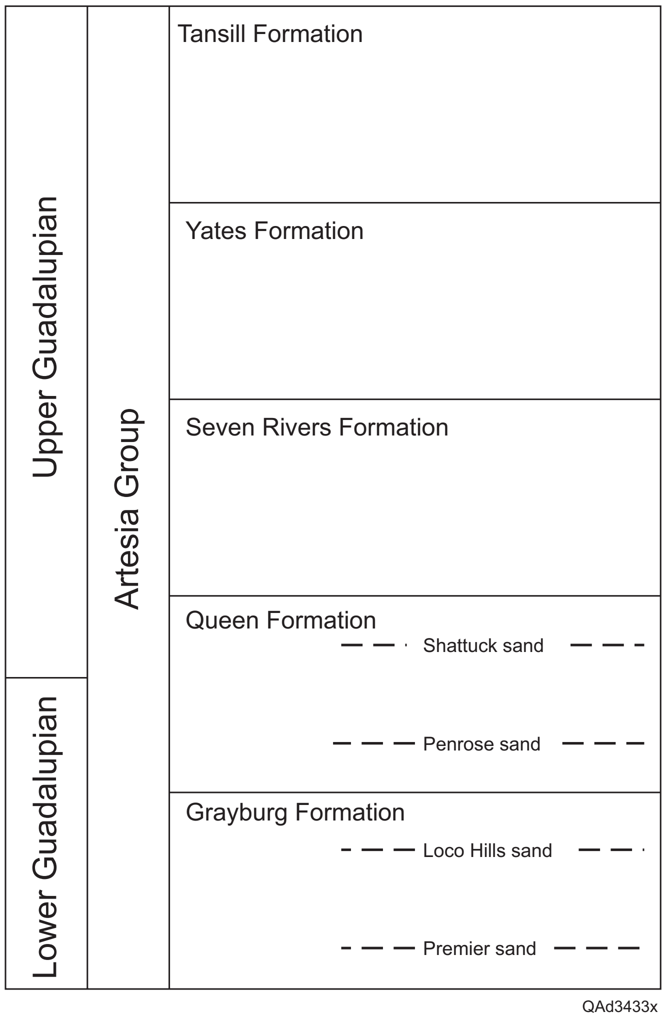

Figure 118. Stratigraphic column of Guadalupian Artesia Group, Central Basin Platform and Northwest Shelf.

restricted-platform equivalent of the older Goat Seep Reef (Silver and Todd, 1969; Ward and others, 1986). The Queen Formation on the west side of the Central Basin Platform is composed of interbedded clastics and carbonates, with minor amounts of evaporites (Eide and Mazzullo, 1993). The Seven Rivers Formation is composed mainly of evaporites and dolomites, with only minor siliciclastics (Sarg, 1981; Borer and Harris, 1991a; Andreason, 1992).

The Yates Formation marks a period of major siliciclastic shelf deposition (Andreason, 1992). The Yates Formation is an overall upward-shallowing sequence of cyclically interbedded siliciclastics associated with sabkha carbonates and evaporites (Ward and others, 1986; Casavant, 1988; Borer and Harris, 1991a; Andreason, 1992). The Yates is interpreted as having been deposited in a complex of coastal and lagoonal environments upslope of the shelf-margin reef (Andreason, 1992). Yates reservoirs produce mainly from fine-grained sandstone and siltstone; cement and clay matrix content vary greatly within reservoirs, contributing to heterogeneity. Siliciclastic sources of the Yates are from the Northwest and Eastern Shelves (Mear and Yarbrough, 1961; Ward and others, 1986; Trentham, 2003).

Traps in the play are largely stratigraphic, with an updip seal formed by evaporitic facies of the inner shelf. Many fields on the Central Basin Platform are trapped by a combination of facies change and northwest- southeast-trending, elongate anticlinal structures formed by compaction draping over buried structures (Tyler and others, 1991).

The Keystone Colby reservoir, Winkler County (fig. 117), produces from sandstone units of the Queen Formation that are interbedded with nonproductive dolomite and anhydrite (figs. 119, 120) (Major and Ye, 1992, 1997). Colby reservoir rocks are interpreted as having been deposited in a lagoonal setting behind a carbonate rimmed-bank margin, in a series of upward-shoaling cycles composed of sandstone and dolomite. During sea-level highstands the lagoon was flooded, and carbonate sediments were deposited. During sea-level lowstands the lagoonal carbonate sediments probably were exposed and subjected to erosion and dissolution (Major and Ye, 1992, 1997). As sea level rose again, windblown sand was deposited in marine and peritidal environments in the lagoon. The most porous sandstones are interpreted as having been deposited in a relatively shallow water marine setting (Major and Ye, 1992, 1997). Porosity in the sandstones ranges from 6 to 19 percent.

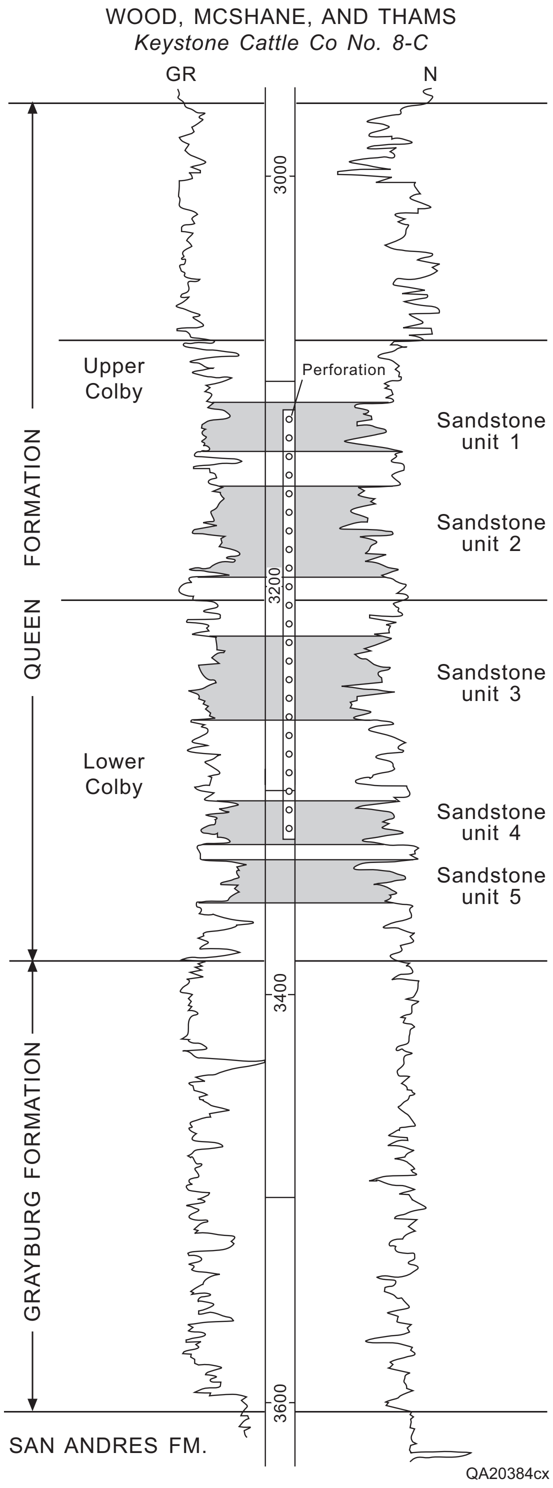

Figure 119. Representative log of the Keystone Colby reservoir illustrating the five major Queen sandstone packages. From Major and Ye (1992, 1997).

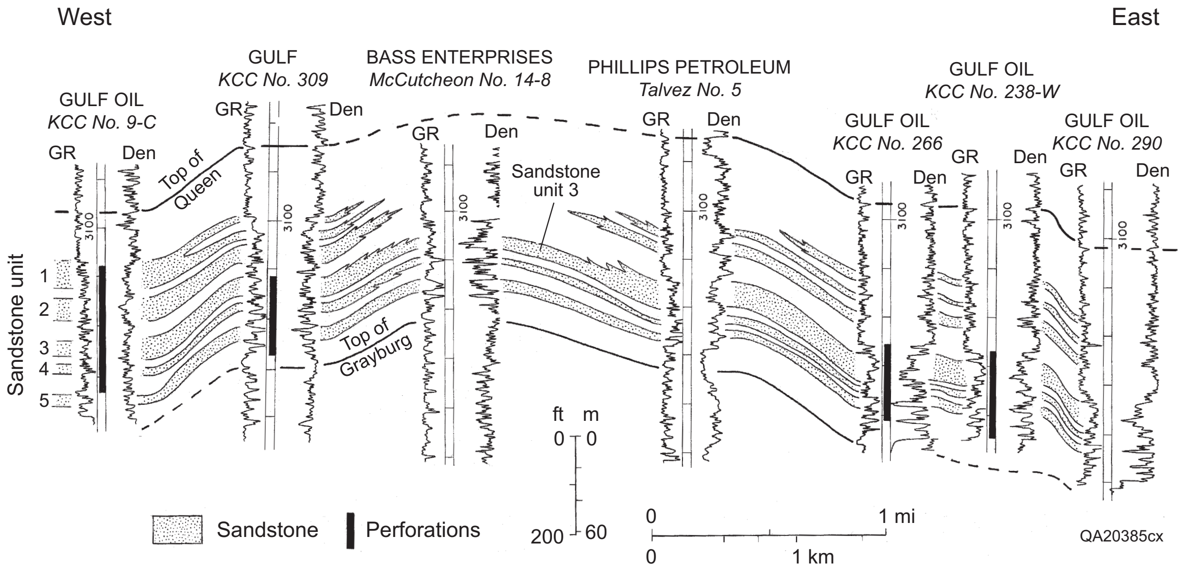

Figure 120. West-east cross section of Keystone Colby reservoir. From Major and Ye (1997). Pinch-out of sandstone units 1 and 2 toward the crest of the structure may indicate that the structure was syndepositional (Major and Ye, 1992, 1997).

Reservoirs in New Mexico that are productive solely from Queen sandstones occur along and north of a trend that extends from Hobbs to Artesia (fig. 117). The Queen sandstones in this area were deposited in coastal, sandy braided streams; fluvial sandflats and fluvial-dominated coastal sabkhas; and poorly channelized sheet deltas that filled in lagoonal areas (Mazzullo, 1992). Traps are largely stratigraphic, with porosity plugged updip by evaporites (Ward and others, 1986; Malisce and Mazzullo, 1990). Productive Queen sandstones are fine to medium grained; average reservoir porosities range from 17 to 22 percent.

The largest reservoir in the play is North Ward-Estes in Ward County (table 38), which produces from sandstones in the Yates, Seven Rivers, and Queen Formations (Andreason, 1992; Eide and Mazzullo, 1993; Bain, 1994; Mazzullo and others, 1996). Most of the production is from the Yates Formation, from very fine grained sandstones and siltstones interbedded with low-permeability dolomites (fig. 121) (Ring and Smith, 1995). North Ward-Estes is part of a

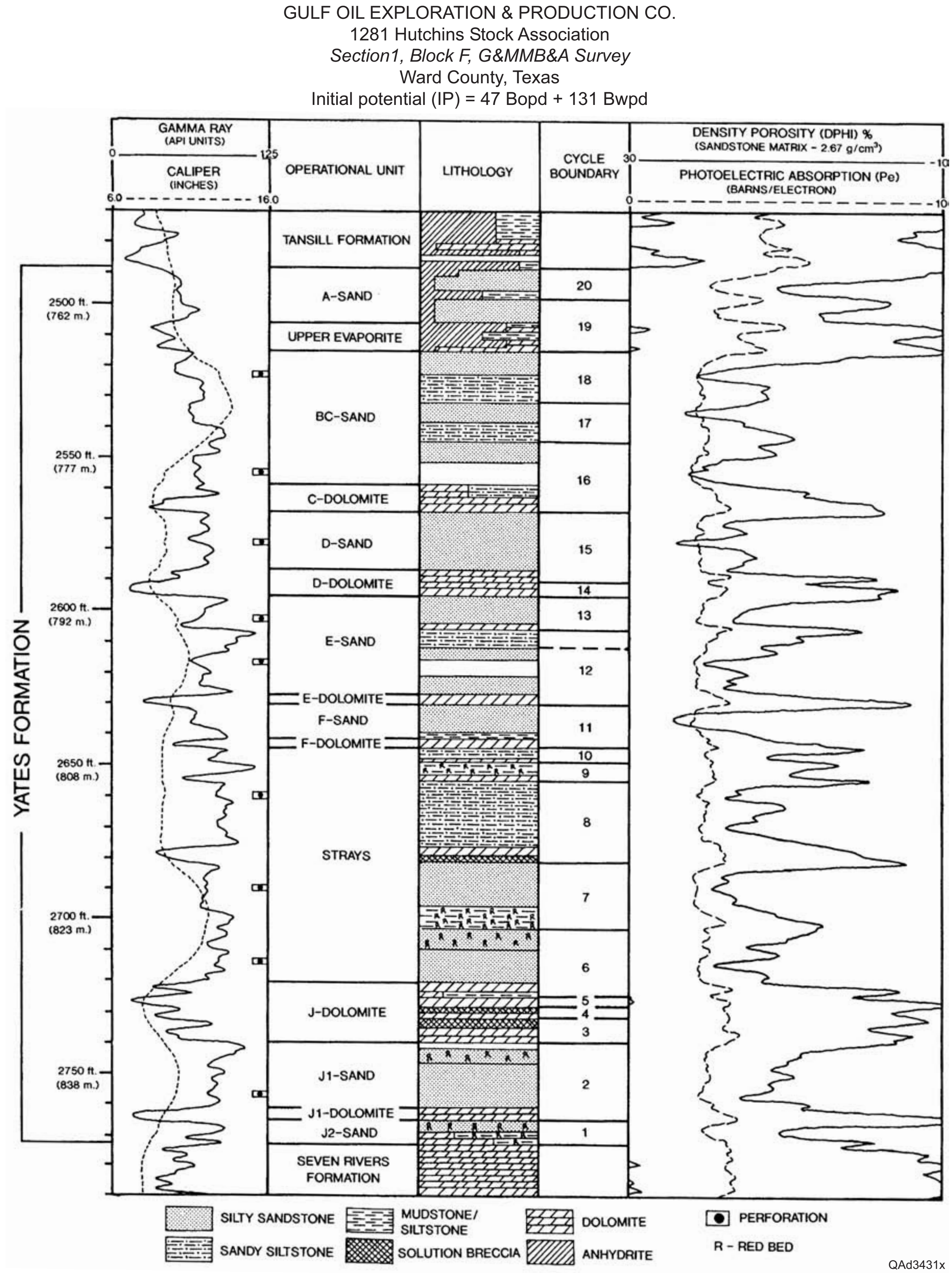

Figure 121. Typical log of Yates reservoir section in North Ward Estes field. From Andreason (1992). From Andreason (1992), reprinted by permission of the AAPG, whose permission is required for further use. ©Copyright 1992. The American Association of Petroleum Geologists. All rights reserved.

series of fields that produce from the Yates Formation on the west side of the Central Basin Platform (Ward and others, 1986). The Yates shelf was subdivided into three parts: (1) an outer carbonate shelf that included the Capitan reef, backreef flats, and pisolitic shelf crest; (2) a middle, siliciclastic-dominated shelf composed of stacked beach ridges and siliciclastic sabkhas; and (3) an evaporative inner shelf composed of playa mud flats, salinas, and stabilized sand sheets (Andreason, 1992). The siliciclastics were deposited during periods of shelf emergence during lowstand and transgressive periods, whereas carbonates were deposited mainly during highstand periods, when the shelf was submerged. Most hydrocarbon production comes from strike-oriented beach-ridge sandstones (Andreason, 1992).

Recovery in North Ward-Estes field during secondary waterflooding was improved by drilling infill wells, realigning patterns, and increasing water injection (Ring and Smith, 1995). A CO_2 flood was initiated in the Yates Formation in 1989 (Bain, 1994; Ring and Smith, 1995). Oil recovery during the CO_2 flood has been maximized by maintaining a consistent water-alternating-gas (WAG) process, optimizing use of CO_2, and maintaining a balance between patterns (Ring and Smith, 1995).

Productive Yates sandstones in New Mexico are poorly consolidated, silty, and fine grained with porosities of 15 to 28 percent (Borer and Harris, 1991a, b). Clean, productive sandstones are interbedded with argillaceous sandstones that form poor reservoirs. The sandstones occur in a clastic-rich belt on the middle shelf that separates the evaporitic inner shelf to the north from the carbonate-rich outer shelf to the south. Depositional processes that formed the reservoir sandstones are poorly understood (Borer and Harris, 1991a). Traps are largely stratigraphic, with an updip seal formed by evaporitic facies of the inner shelf.

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PRODUCTION ANALYSIS

The Permian Basin is a major oil-producing region in the United States. It produced 17 percent of total U.S. oil production in 2002 (fig. 122a), and it contains an estimated 22 percent of the proved oil reserves in the United States (fig. 122b) (Energy Information Administration, 2003). The Permian Basin produced only slightly less than the Offshore Gulf of Mexico and Alaska in 2002. In proved reserves, it ranked ahead of all oil-producing areas in 2002. Geographically, most of the production and proved reserves in the Permian Basin are in Texas (fig. 123).

The Permian Basin has the biggest potential for additional oil production in the country, containing 29 percent (17.6 Bbbl [2.80×10^9 m^3]) of estimated future oil reserve growth (Root and others, 1995). Original oil in place (OOIP) in the Permian Basin was about 106 Bbbl (1.69×10^{10} m^3) of oil (Tyler and Banta, 1989). After reaching a peak production of more than

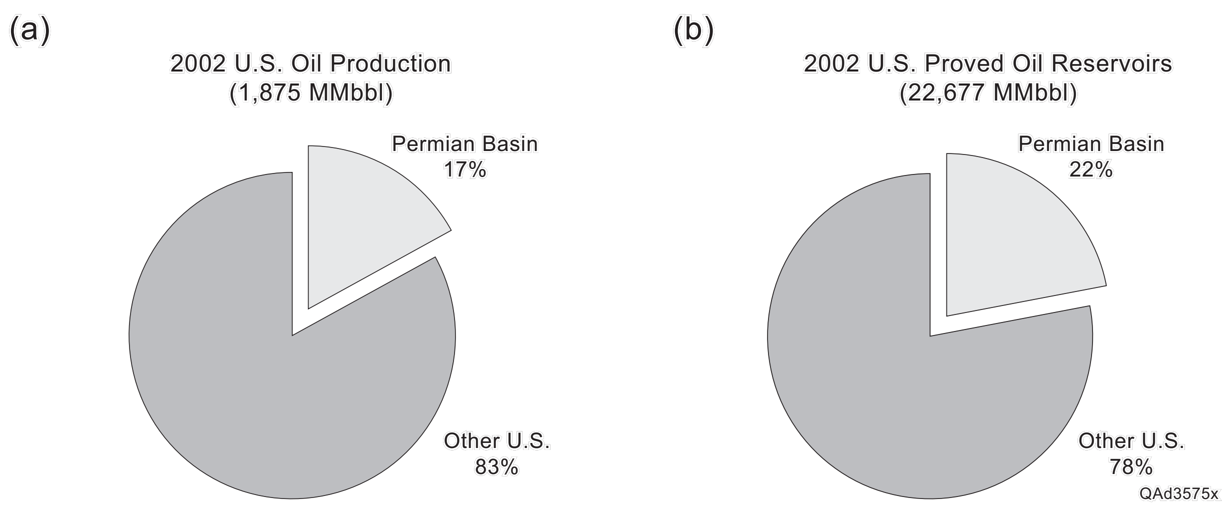

Figure 122. (a) Composition of 2002 U.S. oil production. (b) Composition of 2002 U.S. proved oil reserves. From Energy Information Administration (2003). Permian Basin numbers include production from reservoirs of all sizes, in Railroad Commission of Texas Districts 7C, 8, and 8A in Texas and the New Mexico East region. This area is somewhat larger than that in the definition of the Permian Basin used in this portfolio.

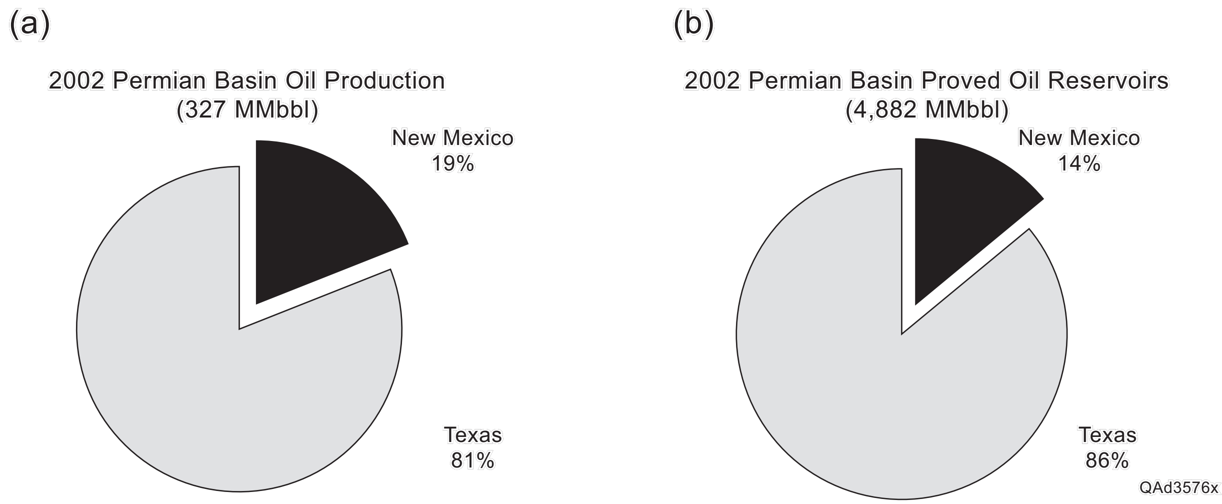

Figure 123. (a) Geographic distribution of 2002 Permian Basin oil production. (b) Geographic distribution of 2002 Permian Basin proved oil reserves. From Energy Information Administration (2003).

665 MMbbl (1.06×10^8 m^3) per year in the early 1970's, Permian Basin oil production has continuously fallen. By 2002, production had fallen to 327 MMbbl (5.20×10^7 m^3), or less than half its peak production (Energy Information Administration, 2003). Despite the continuing fall in production, the Permian Basin still holds a significant volume of oil. Although ~29 Bbbl (~4.61×10^9 m^3) of oil has been produced to date, this production represents only ~27 percent of the OOIP. Of the huge remaining resource in the basin, as much as 30 Bbbl (4.77×10^9 m^3) of mobile oil and 45 Bbbl (7.15×10^9 m^3) of residual oil remains as a target for improved technology and recovery strategies (Tyler and Banta, 1989). More than in any other region, increased use of preferred management practices in Permian Basin oil fields will have a substantial impact on domestic production.

Production analysis of this major oil-producing region was conducted to better understand production trends. Production data compiled for the 32 oil plays in the Permian Basin were utilized as the main data source (table 1). These oil plays included all significant-sized oil reservoirs in the Permian Basin having a cumulative production of >1 MMbbl (1.59×10^5 m^3) through December 31, 2000.

Discovery History

The Westbrook reservoir in the Leonard Restricted Carbonate Platform play, discovered in 1921 (fig. 124), was the first major oil reservoir in the Permian Basin. Since discovery, it has produced >107 MMbbl (>1.70×10^7 m^3). Shortly after that discovery, several major oil reservoirs were discovered in 1926 (fig. 124), including the Yates reservoir in the San Andres Karst-Modified Platform Carbonate play. Two of the largest oil reservoirs in the Permian Basin, the Wasson and Slaughter reservoirs in the Northwest Shelf San Andres Platform Carbonate

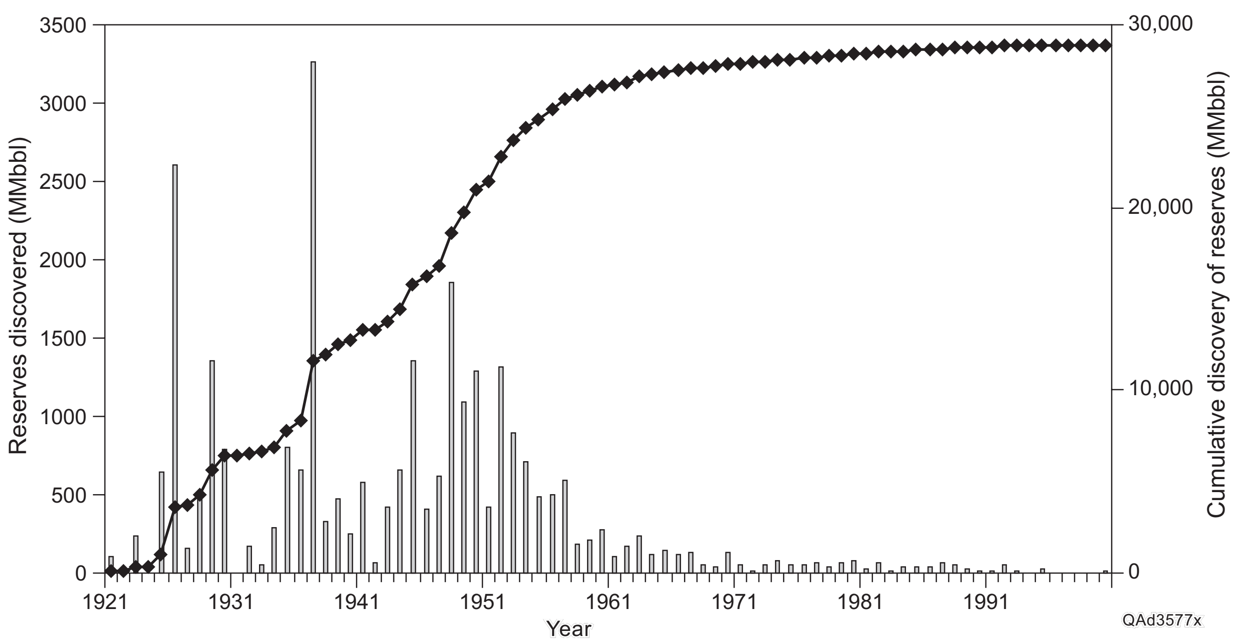

Figure 124. Permian Basin cumulative oil production discovered by year. Bars show years in which reservoirs were discovered, with height of bar indicating volume of oil produced by those reservoirs through 2000.

play, were discovered in 1937 (fig. 124). Another major oil reservoir in the Permian Basin, the Kelly-Snyder reservoir in the Pennsylvanian and Lower Permian Horseshoe Atoll Carbonate play, was discovered in 1948 (fig. 124). Although the Martin (Consolidated) reservoir, reported with a discovery year as 2000, is the last significant-sized oil reservoir discovered in the Permian Basin, this reservoir has been consolidated from various reservoirs that had been discovered prior to 2000. Therefore, the Geibel (CFA) reservoir, discovered in 1998, should be considered the last significant-sized oil reservoir discovered in the Permian Basin that had produced >1 MMbbl (1.59×10^5 m^3) through 2000.

Numerous large oil reservoirs have been discovered in the Permian Basin throughout its history, as seen in figure 124. However, the region is now mature, with fewer significant-sized oil reservoirs discovered after the late 1950's. An asymptote starts to form in the late 1950's as the cumulative reserves discovered in the Permian Basin levels off (fig. 124). When the significant-sized oil reservoirs of the Permian Basin are plotted in terms of a discovery-year histogram (fig. 125), it can be seen that more than 80 percent of the significant-sized oil reservoirs were discovered prior to the 1970's. The period between 1951 and 1960 represents the greatest number of significant-sized oil reservoirs discovered in the Permian Basin. The average discovery year of significant-sized oil reservoirs in the Permian Basin is 1959.

Production History and Attributes

Production data for significant-sized oil reservoirs in the Permian Basin was compiled from 1970 through 2000. When aggregated as a whole, Permian Basin oil production has steadily decreased through time (fig. 126). A noticeable increase in annual production can be seen in 1973, where the largest oil reservoirs in the Permian Basin reported significantly higher annual

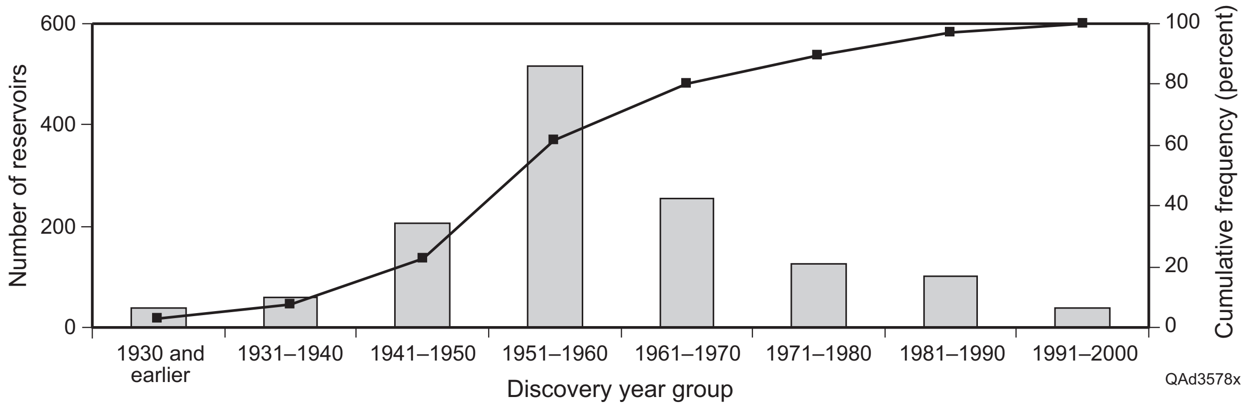

Figure 125. Reservoir discovery-year histogram of the 1,339 major oil reservoirs in the Permian Basin that produced >1 MMbbl through 2000.

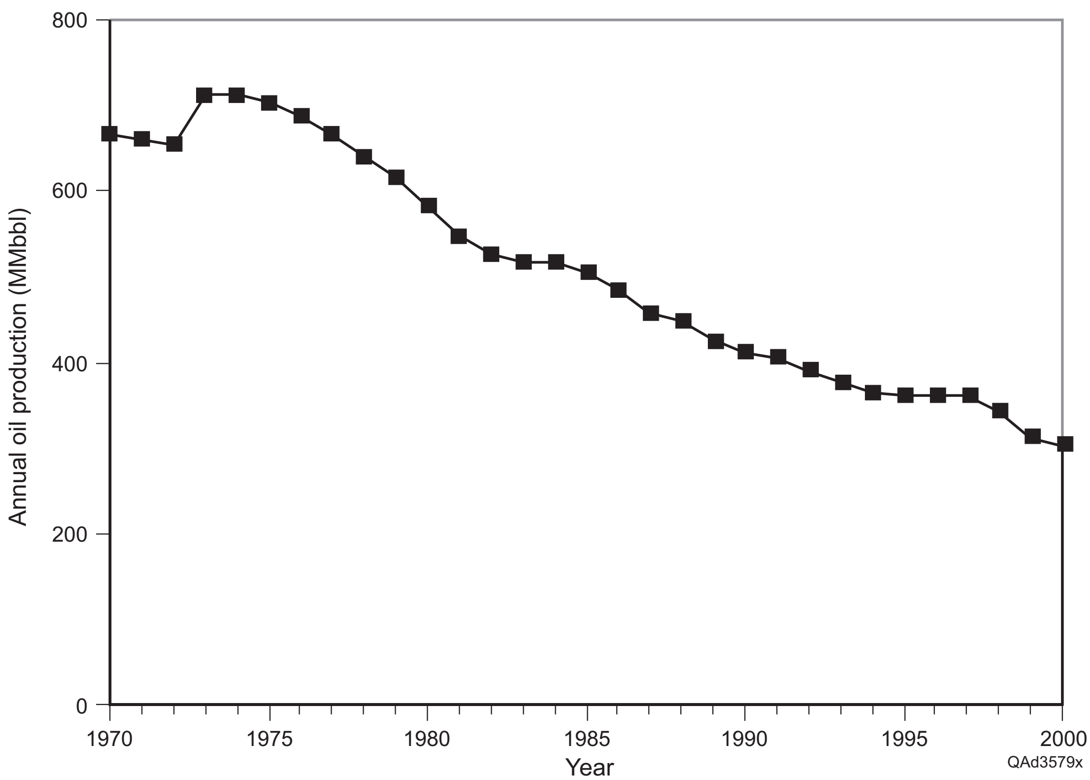

Figure 126. Permian Basin oil production history from 1970 through 2000 for the 1,339 significant-sized oil reservoirs in the Permian Basin.

production. The two largest oil plays in the Permian Basin, the Northwest Shelf San Andres Platform Carbonate and the Pennsylvanian and Lower Permian Horseshoe Atoll Carbonate plays, displayed significant incremental production. This incremental production can be attributed to the peak of U.S. oil production and that of Texas occurring around this time period and thereafter declining.

Historical production data of the significant-sized oil reservoirs composing each of the 32 oil plays in the Permian Basin were aggregated. Play-level data are provided in the GIS database and can be accessed by opening up the attribute file linked with the play boundaries. (Each of the 32 play-boundary shapefiles, contained in the play_bnd folder, appears as a separate layer within the ArcView™ project, and each of these layers is linked to a play-production data table.) In cases where the play boundary is separated into two parts, each part shows total play production, as well as other attribute data, for the play. Play-level production history revealed that the largest plays in the Permian Basin, such as the Northwest Shelf San Andres Platform Carbonate and the Pennsylvanian and Lower Permian Horseshoe Atoll Carbonate plays, have experienced significant decline. However, another large play, the Leonard Restricted Platform Carbonate play, revealed a relatively stable to slightly declining production history. Moreover, the Spraberry/Dean Submarine-Fan Sandstone play revealed a stable to slightly increasing production history.

Analysis of production data indicates that the Permian Basin remains a major oil-producing region. Oil production from significant-sized reservoirs in the Permian Basin having cumulative production >1 MMbbl (1.59×10^5 m^3) was 301.4 MMbbl (4.79×10^7 m^3) in 2000 (table 1). The largest production in 2000 was from the Wasson (22.9 MMbbl [3.64×10^6 m^3]) in Yoakum County in the Northwest Shelf San Andres Platform Carbonate play. Six major oil reservoirs—Wasson, Spraberry (Trend Area), Slaughter, Yates, Levelland, and Seminole (San Andres) produced >10 MMbbl (>1.59×10^6 m^3) in 2000. All of these major oil reservoirs are in Texas and are very mature, discovered prior to 1952.

The 2000 production data make it easy to see which reservoirs are still producing significant volumes of oil, versus those that are no longer producing. A histogram based on annual production in 2000 from the 1,339 significant-sized oil reservoirs of the Permian Basin revealed a lognormal distribution, with the majority of reservoirs producing ≤50,000 bbl (7.95×10^3 m^3). However, the few outlier, larger-sized reservoirs (those producing >500,000 bbl [7.95×10^4 m^3]) in 2000) accounted for 75 percent of the production in 2000. The top-four oil-producing plays in terms of 2000 annual production were the Northwest Shelf San Andres Platform Carbonate play (50.7 MMbbl [8.06×10^6 m^3]), the Leonard Restricted Platform Carbonate play (49.9 MMbbl [7.93×10^6 m^3]), the Spraberry/Dean Submarine-Fan Sandstone play (27.6 MMbbl [4.39×10^6 m^3]), and the San Andres Platform Carbonate play (26.4 MMbbl [4.20×10^6 m^3]).

Cumulative Permian Basin production through 2000 was 28.9 Bbbl (4.59×10^9 m^3) (table 1). The largest reservoir was Wasson (1.84 Bbbl [(2.93×10^8 m^3)]); three other major reservoirs had cumulative production >1 Bbbl (1.59×10^8 m^3) through 2000 (Yates, Kelly-Snyder, and Slaughter). A histogram based on cumulative production through 2000 from the significant-sized oil reservoirs of the Permian Basin also revealed a lognormal distribution, with 60 percent of the reservoirs having cumulative production ≤5 MMbbl (7.95×10^5 m^3). The few outlier, major reservoirs (>45 MMbbl [(7.15×10^6 m^3)] cumulative production), however, accounted for 69 percent of the cumulative production in the Permian Basin. The top four plays in terms of cumulative production are the Northwest Shelf San Andres Platform Carbonate play (3.97 Bbbl [6.31×10^8 m^3]), the Leonard Restricted Platform Carbonate play (3.30 Bbbl [5.25×10^8 m^3]), the Pennsylvanian and Lower Permian Horseshoe Atoll Carbonate play (2.70 Bbbl [4.29×10^8 m^3]), and the San Andres Platform Carbonate play (2.15 Bbbl [3.42×10^8 m^3]). The largest reservoir in each play is listed in table 39. The large variation in size of the largest reservoir in the different plays reflects the large differences in cumulative production from the plays.

Guadalupian-age reservoirs dominate both cumulative production and production in 2000, with 54 and 53 percent of the total, respectively (fig. 127). Leonardian- and Pennsylvanian-age reservoirs make up 18 and 13 percent, respectively, of cumulative Permian Basin oil production (fig. 127a). Leonardian- and Pennsylvanian-age reservoirs each make up 29 and 8 percent, respectively, of Permian Basin production in 2000 (fig. 127b). Production histories of significant-sized oil reservoirs in the Permian Basin by geologic age are shown in figure 128. Whereas Guadalupian- and Pennsylvanian-age reservoirs show a rapid decline in production, Leonardian-age reservoirs reveal a stable production trend.

Carbonate reservoirs dominate both cumulative production and production in 2000, with 75 and 74 percent of the total, respectively (fig. 129). Sandstone reservoirs contributed 14 percent of cumulative production and 16 percent of production in 2000. Oil reservoirs with mixed sandstone and carbonate lithology produced 8 percent of both cumulative production and production in 2000. Chert reservoirs produced 3 percent of cumulative production and 2 percent of production in 2000. Production histories of significant-sized oil reservoirs in the Permian Basin by lithology are shown in figure 130. Carbonate reservoirs reveal a rapidly decreasing production trend, whereas sandstone, mixed sandstone/carbonate, and chert reservoirs show a relatively stable production trend.

Table 39. Largest oil reservoir in each Permian Basin play.

Play	Largest reservoir	Cumulative production (MMbbl thru 2000)
Artesia Platform Sandstone	North Ward-Estes	412.8
Queen Tidal-Flat Sandstone	McFarland Queen	42.8
Delaware Mountain Group Basinal Sandstone	Geraldine Ford	30.2
Grayburg High-Energy Platform Carbonate—Ozona Arch	Big Lake	134.0
Grayburg Platform Carbonate McElroy	569.7	
Grayburg Platform Mixed Clastic/Carbonate	North Cowden	541.7
San Andres/Grayburg Lowstand Carbonate	Welch	169.0
Upper San Andres and Grayburg Platform Mixed —Artesia Vacuum Trend	Vacuum Grayburg San Andres	341.9
Upper San Andres and Grayburg Platform Mixed —Central Basin Platform Trend	Eunice Monument Grayburg San Andres	392.4
San Andres Platform Carbonate	Seminole San Andres	602.6
San Andres Karst-Modified Platform Carbonate	Yates	1,381.4
Eastern Shelf San Andres Platform Carbonate	Howard Glasscock	403.2
Northwest Shelf San Andres Platform Carbonate	Wasson	1,840.5
Spraberry/Dean Submarine-Fan Sandstone	Spraberry Trend Area	923.2
Bone Spring Basinal Sandstone and Carbonate	Scharb Bone Spring	14.1
Leonard Restricted Platform Carbonate	Fullerton	309.5
Abo Platform Carbonate	Empire Abo	225.1
Wolfcamp/Leonard Slope and Basinal Carbonate	SW Amacker-Tippett Wolfcamp	16.0
Wolfcamp Platform Carbonate	South Cowden Canyon 8790	43.0
Upper Pennsylvanian and Lower Permian Slope and Basinal Sandstone	Jameson Strawn	42.4
Pennsylvanian and Lower Permian Horseshoe Atoll Carbonate	Kelly Snyder	1,264.2
Pennsylvanian Platform Carbonate	Ropes	25.6
Northwest Shelf Upper Pennsylvanian Carbonate	Vada Pennsylvanian	53.3
Northwest Shelf Strawn Patch Reef	Lusk Strawn	20.7
Mississippian Platform Carbonate	Fluvanna	5.8
Devonian Thirtyone Ramp Carbonate	University Block 9 Devonian	23.6
Devonian Thirtyone Deepwater Chert	Block 31 Devonian	223.9
Wristen Buildups and Platform Carbonate	Denton Devonian	101.2
Fusselman Shallow Platform Carbonate	Dollarhide Silurian	41.0
Simpson Cratonic Sandstone	Running W Waddell	25.3
Ellenburger Karst-Modified Restricted Ramp Carbonate	Andector Ellenburger	177.7
Ellenburger Selectively Dolomitized Ramp Carbonate	Todd Deep Ellenburger	44.3

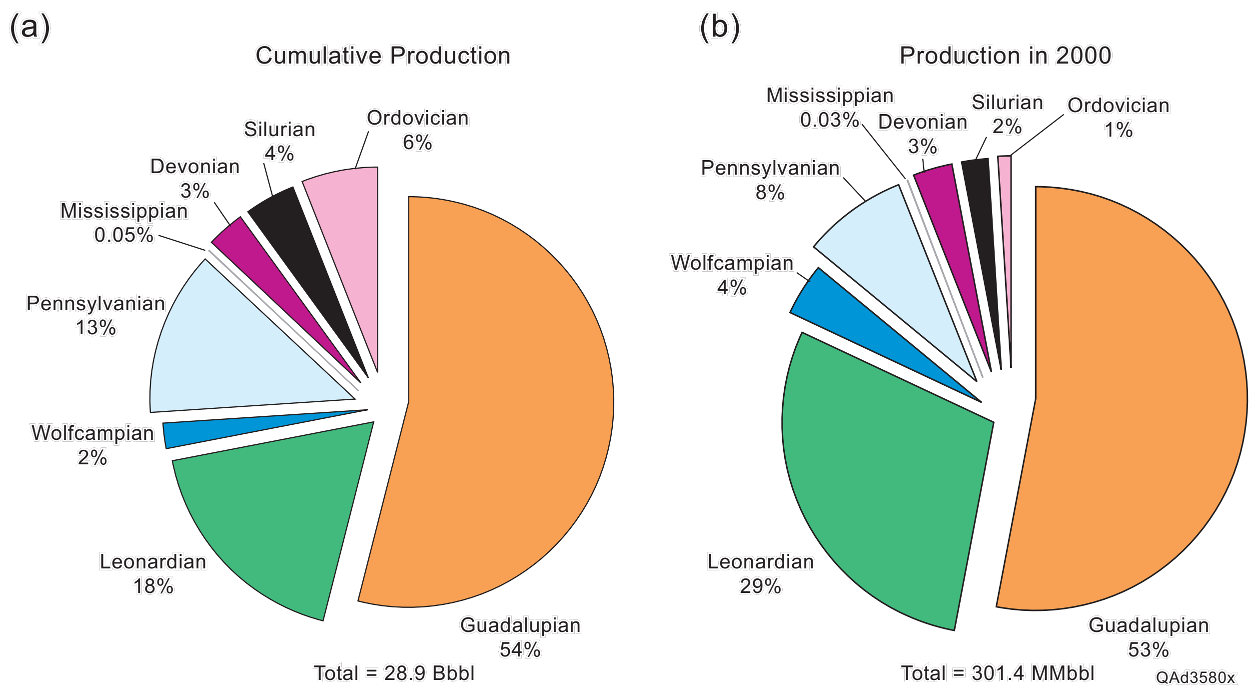

Figure 127. (a) Permian Basin cumulative production through 2000, by geologic age.
(b) Permian Basin production in 2000, by geologic age.

The 1,040 significant-sized reservoirs in the Texas part of the Permian Basin had cumulative production of 24.4 Bbbl (3.88×10^9 m^3) through 2000, and the 299 significant-sized reservoirs in New Mexico had cumulative production of 4.5 Bbbl (7.15×10^8 m^3). In 2000, the Texas reservoirs produced 253.7 MMbbl (4.03×10^7 m^3), and the New Mexico reservoirs produced 47.7 MMbbl (7.58×10^6 m^3). Thus, Texas has produced 84 percent of the cumulative production from the Permian Basin, and it also produced 84 percent of the 2000 production.

The 1,339 significant-sized reservoirs that had produced >1 MMbbl (1.59×10^5 m^3) through 2000 account for most of the production from the Permian Basin. Cumulative production through 2000 from reservoirs of all sizes is estimated at 30.4 Bbbl (4.83×10^9 m^3)—25.6 Bbbl (4.07×10^9 m^3) from Texas and 4.8 Bbbl (7.63×10^8 m^3) from New Mexico. Thus, the 1,339 reservoirs included in this report have accounted for 95 percent of Permian Basin production.

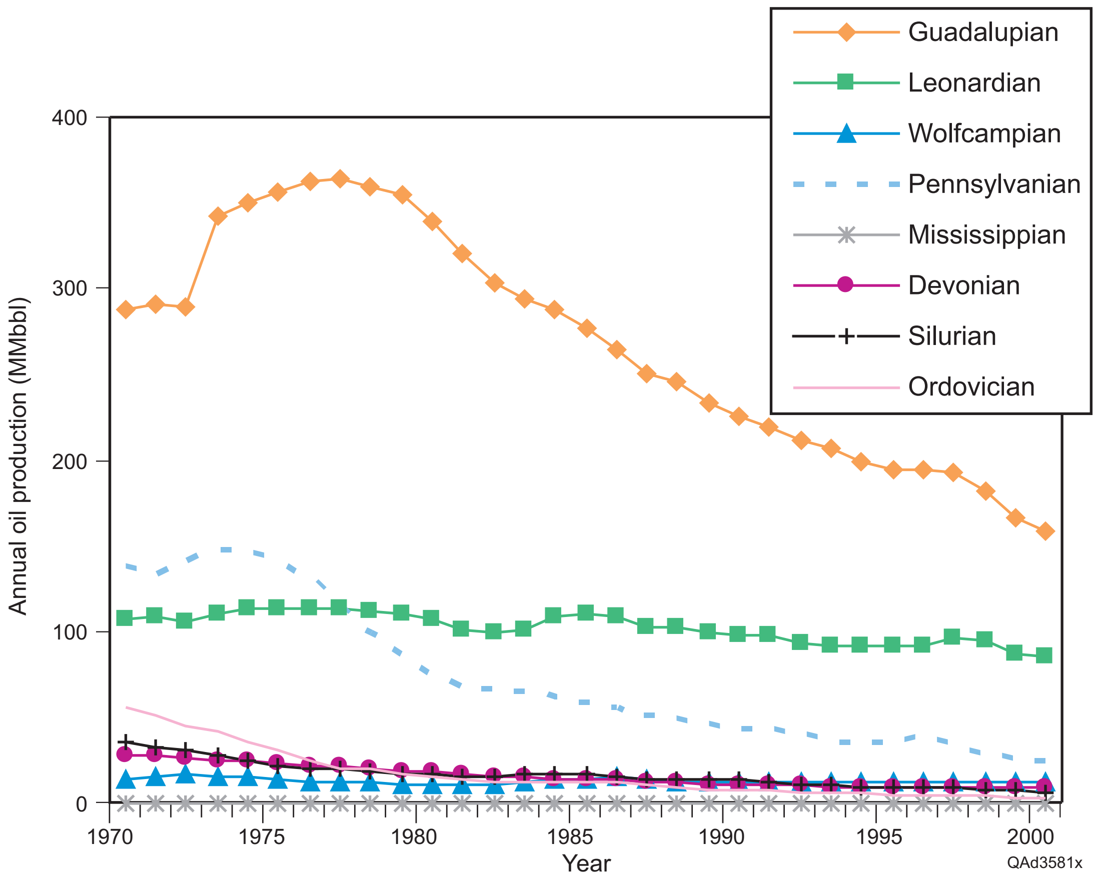

Figure 128. Production histories of significant-sized oil reservoirs in the Permian Basin by geologic age.

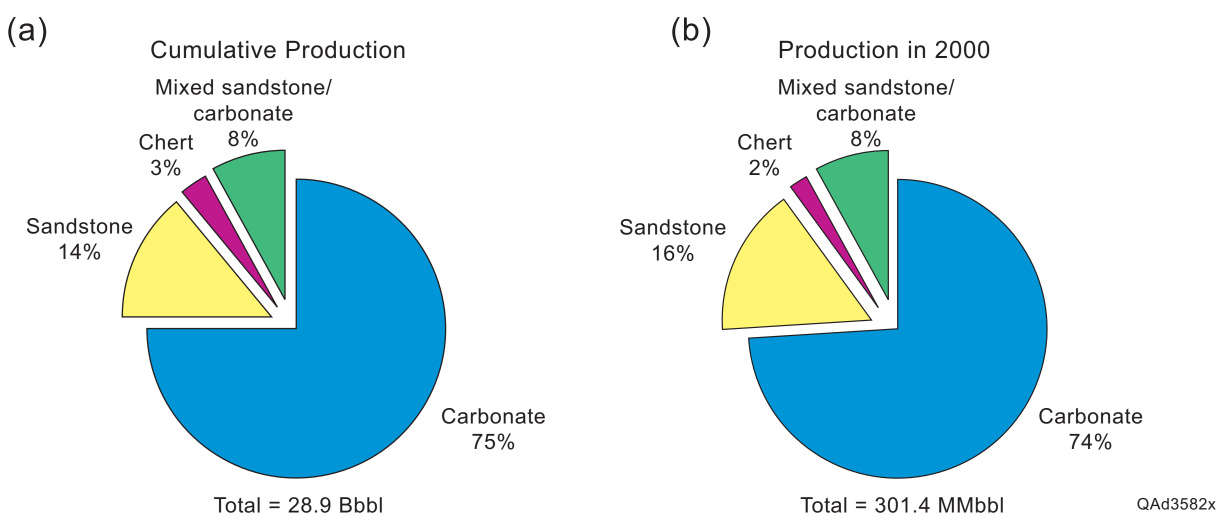

Figure 129. (a) Permian Basin cumulative production through 2000, by lithology. (b) Permian Basin production in 2000, by lithology.

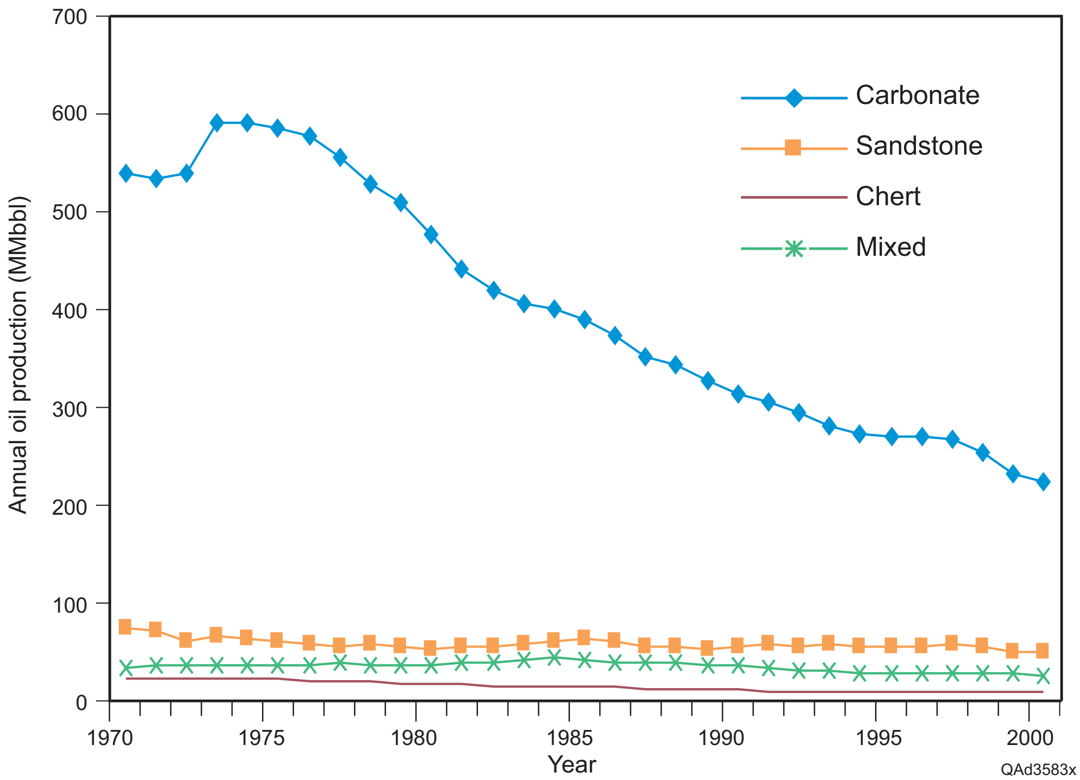

Figure 130. Production histories of significant-sized oil reservoirs in the Permian Basin by lithology.

Reservoir Depths

Approximately 80 percent of the significant-sized oil reservoirs in the Permian Basin produce from depths of <10,000 ft (<3,050 m) (fig. 131). Significant-sized oil reservoirs in the Permian Basin produce across a broad spectrum of reservoir depths, with the average depth being 7,069 ft (2,155 m). The shallowest production occurred at 500 ft (152 m) in the Toborg reservoir of the San Andres Karst-Modified Platform Carbonate play. The deepest production occurred at 13,939 ft (4,249 m) in the Nolley (Ellenburger) reservoir of the Ellenburger Karst-Modified Restricted Ramp Carbonate play. All of the deepest significant-sized oil reservoirs (>13,800 ft [4,206 m]) were in the Ellenburger Karst-Modified Restricted Ramp Carbonate play.

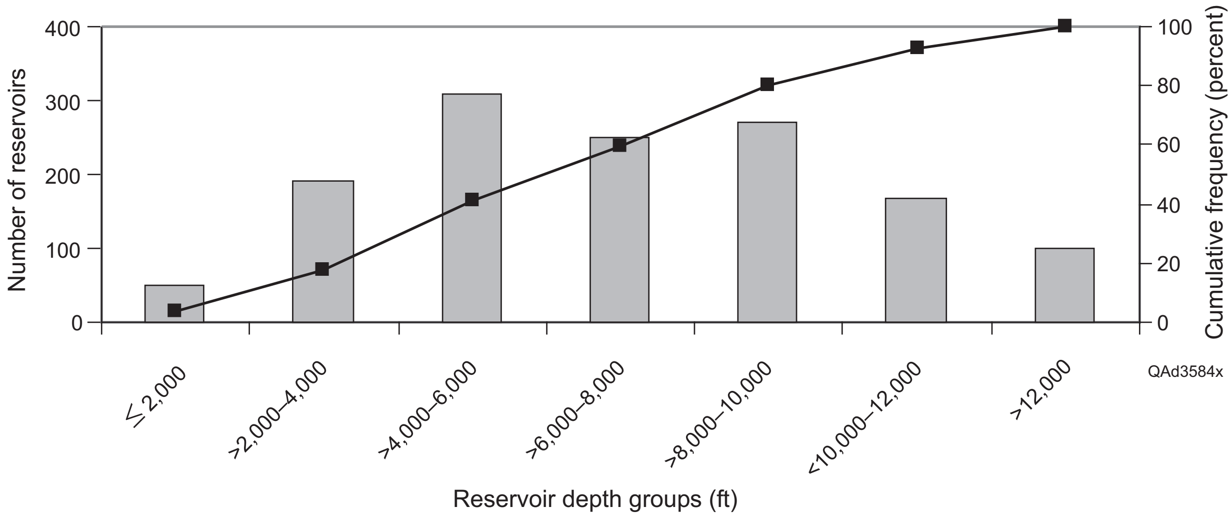

Figure 131. Reservoir-depth histogram of significant-sized oil reservoirs in the Permian Basin.

Remaining Reserves

Remaining reserves of the significant-sized oil reservoirs in the Permian Basin were estimated by using decline-curve analysis. This analysis is a widely accepted and utilized production-performance tool used in estimating remaining reserves to be recovered, future expected production rate, and remaining productive life. Decline-curve analysis is applicable once history is sufficient to show a trend in a performance variable that is a continuous function of either time or cumulative production. Common types of decline curves include linear, exponential, hyperbolic, and harmonic (Amyx and others, 1960). In general, most reservoirs exhibit a hyperbolic decline during early life and degenerate to exponential decline with progressive reservoir depletion. Because most significant-sized oil reservoirs in the Permian Basin are in mature stages of production and reaching depletion, exponential decline curves were utilized. Historical production profiles of the 32 oil plays in the Permian Basin were plotted using production data from 1970 through 2000. Production-decline curves were established for complete production histories since 1990, if a general decline trend was clearly established in its most recent history. When irregular production trends existed, decline-curve analysis was applied only for time periods where a steady decline trend could be established.

Remaining reserves to be produced from the 32 oil plays in the Permian Basin were calculated to year-end 2015. Total remaining oil reserves from the 32 oil plays of the Permian Basin and its significant-sized oil reservoirs are calculated as 3.25 Bbbl (5.17×10^8 m^3) (fig. 132, table 40). The Northwest Shelf San Andres Platform Carbonate and Leonard Restricted Platform Carbonate plays make up over 41 percent (1.34 Bbbl [2.13×10^8 m^3)]) of this total.

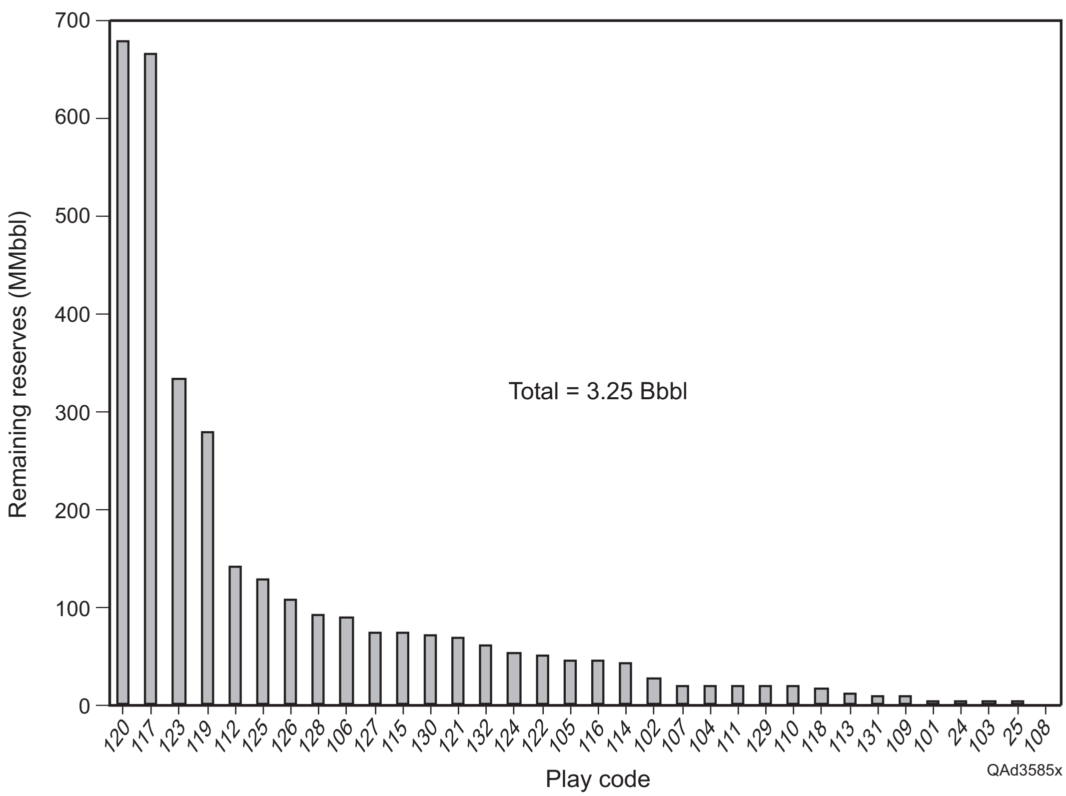

Figure 132. Permian Basin remaining reserves to 2015 by plays. Play codes listed in table 40.

Table 40. Permian Basin remaining reserves to 2015, by play.

Play code	Play name	Remaining reserves (MMbbl)
120	Northwest Shelf San Andres Platform Carbonate	679.8
117	Leonard Restricted Platform Carbonate	665.7
123	San Andres Platform Carbonate	331.9
119	Spraberry/Dean Submarine-Fan Sandstone	277.3
112	Pennsylvanian and Lower Permian Horseshoe Atoll Carbonate	139.5
125	Upper San Andres and Grayburg Platform Mixed—Artesia Vacuum Trend	128
126	San Andres/Grayburg Lowstand Carbonate	106.9
128	Grayburg Platform Carbonate	89.8
106	Devonian Thirtyone Deepwater Chert	89.2
127	Grayburg Platform Mixed Clastic/Carbonate	72.7
115	Wolfcamp/Leonard Slope and Basinal Carbonate	72.4
130	Delaware Mountain Group Basinal Sandstone	69
121	Eastern Shelf San Andres Platform Carbonate	66.9
132	Artesia Platform Sandstone	61
124	Upper San Andres and Grayburg Platform Mixed—Central Basin Platform Trend	52.8
122	San Andres Karst-Modified Platform Carbonate	48.3
105	Wristen Buildups and Platform Carbonate	44.7
116	Abo Platform Carbonate	43.4
114	Wolfcamp Platform Carbonate	41.3
102	Ellenburger Karst-Modified Restricted Ramp Carbonate	25.2
107	Devonian Thirtyone Ramp Carbonate	19
104	Fusselman Shallow Platform Carbonate	17.5
111	Pennsylvanian Platform Carbonate	17.3
129	Grayburg High-Energy Platform Carbonate—Ozona Arch	17.2
110	Northwest Shelf Upper Pennsylvanian Carbonate	17.2
118	Bone Spring Basinal Sandstone and Carbonate	16.9
113	Upper Pennsylvanian and Lower Permian Slope and Basinal Sandstone	11
131	Queen Tidal-Flat Sandstone	8
109	Northwest Shelf Strawn Patch Reef	7.9
101	Ellenburger Selectively Dolomitized Ramp Carbonate	3.8
24	Upper Pennsylvanian Shelf Sandstone (Permian Basin part only)	3.4
103	Simpson Cratonic Sandstone	3.2
25	Pennsylvanian and Lower Permian Reef/Bank (Permian Basin part only)	1.8
108	Mississippian Platform Carbonate	0.8
Total		**3,250.90**

It should be noted that the remaining reserves to be produced to year-end 2015 are that component of the resource base that has already discovered been discovered and is producing. Additional future production from the Permian Basin will be attributable to reserve growth and undiscovered resources.

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TECHNOLOGY TRANSFER

Technology transfer of project results has taken place in several ways during the project. Posters were displayed at the 2003 and 2004 annual meetings of the American Association of Petroleum Geologists (AAPG), the 2003 West Texas Geological Society (WTGS) Fall Symposium, and the 2004 annual meeting of the Southwest Section AAPG. A poster was also presented at the 2003 workshop New Methods for Locating and Recovering Remaining Hydrocarbons in the Permian Basin, sponsored by the Bureau of Economic Geology, PTTC Texas Region, and University Lands West Texas Operations in Midland, Texas. Papers about the project were published in the Class Act Newsletter, 2003 WTGS Fall Symposium volume, and Transactions of the Southwest Section AAPG. A project Web site is maintained at http://www.beg.utexas.edu/resprog/permianbasin/playanalysis.htm.

The following publications have resulted from the project.

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CONCLUSIONS

The target of this PUMP project was the Permian Basin of west Texas and southeast New Mexico, which is still one of the largest petroleum-producing basins in the United States. More than in any other region, increased use of preferred management practices in Permian Basin oil fields will have a substantial impact on domestic production because of the large remaining oil resource. Thirty-two oil plays covering both the Texas and New Mexico parts of the Permian Basin were defined. All 1,339 significant-sized reservoirs in the Permian Basin having cumulative production of >1 MMbbl (1.59×10^5 m^3) of oil were assigned to a play. A reservoir database was established that lists the RRC reservoir number and district (Texas only), official field and reservoir name, year reservoir was discovered, depth to top of the reservoir, production in 2000, and cumulative production through 2000. Some tables also list subplays.

The 1,339 significant-sized oil reservoirs were mapped by play in ArcView™ GIS. The GIS play maps from Texas and New Mexico were merged to form digital data files, or shapefiles, of each play in the Permian Basin. The final reservoir shapefile for each play contains the geographic location of each reservoir and all associated reservoir information within the linked dBASE data table. Play boundaries were drawn for each play. The final GIS product of this process is an ArcView project file containing the base map, the series of play-specific reservoir shapefiles, and play-boundary shapefiles.

Each oil play is described using information from published literature and illustrated by selected appropriate diagrams. Preferred upstream management practices that have been used in Permian Basin reservoirs are described so that successful recovery techniques can be applied to other, similar reservoirs in the play.

ACKNOWLEDGMENTS

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Mark H. Holtz, F. Jerry Lucia, and Robert G. Loucks generously provided their expertise on Permian Basin geology and hydrocarbon production to the project. Jianhua Zhou performed the GIS mapping of New Mexico oil fields. Drafting was by John T. Ames, a member of the Graphics staff of the Bureau of Economic Geology under the direction of Joel L. Lardon, Media and Information Technology Manager. Scott D. Rodgers produced the CD. Others contributing to the publication of this report were Lana Dieterich, word processing and editing, and Jamie H. Coggin, layout.

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LIST OF ACRONYMS AND ABBREVIATIONS

AAPG	American Association of Petroleum Geologists
Bbbl	Billion barrels
bbl/d	Barrels per day
BEG	Bureau of Economic Geology
CO_2	Carbon dioxide
GIS	Geographic Information System
HPAI	High-pressure air injection
MMbbl	Million barrels
NMBGMR	New Mexico Bureau of Geology and Mineral Resources
OCD	Oil Conservation Division of the New Mexico Energy, Minerals and Natural Resources Department
OOIP	Original oil in place
PUMP	Preferred upstream management practices
RRC	Railroad Commission of Texas
SACROC	Scurry Area Canyon Reef Operators Committee
WAG	Water alternating gas
WTGS	West Texas Geological Society