A SYMPOSIUM OF

OIL & GAS FIELDS

THE ROSWELL GEOLOGICAL SOCIETY

1950

OF

SOUTHEASTERN NEW MEXICO

1995

Samson Exhibit 17
NMOCD Case Nos. 13492/13493
Submitted 8/10/06

OIL AND GAS IN THE NEW MEXICO PART OF THE PERMIAN BASIN

Ronald F. Broadhead, New Mexico Bureau of Mines and Mineral Resources, Socorro, NM
Stephen W. Speer, Independent Geologist, Roswell, NM

Abstract

The Permian Basin is one of the premier oil and gas producing regions of the United States. The New Mexico part of the basin has produced a cumulative total of 4.3 billion bbls oil (BBO) and 19.7 trillion ft^3 (TCF) natural gas. It contains 1,164 designated, discovered oil reservoirs and 692 designated, discovered gas reservoirs. Of these reservoirs, 1,853 have been grouped into 17 plays based on common geologic characteristics.

The Permian section has dominated production with 10 plays that have produced 3.3 BBO and 12.2 TCF gas. Production of both oil and gas are dominated by Leonardian- and Guadalupian-age dolostones and sandstones of the Abo, Yeso, Glorieta, San Andres, Grayburg, Queen, and Yates formations. Most of the reservoirs in these formations were deposited in a back-reef, restricted-shelf setting. The most prolific Abo reservoirs were deposited in a shelf-margin reef setting. Significant production is also obtained from basinal carbonates and sandstones of the Bone Spring Formation and basinal sandstones of the Delaware Mountain Group.

The pre-Permian section has also yielded major volumes of oil and gas. Reservoirs in the 7 pre-Permian plays have produced 1.0 BBO and 7.5 TCF gas. Pre-Permian oil production is dominated by restricted-shelf dolostones of the Ellenburger, Simpson, and Montoya formations (Ordovician), restricted-shelf dolostones of the Thirtyone and Fusselman formations (Silurian) and open shelf-shelf margin limestones and dolostones of the Canyon and Cisco sections (Pennsylvanian: Missourian-Virgilian). Pre-Permian gas production is dominated by fluvial, deltaic, strandplain, and submarine fan sandstones of the Morrowan section (Pennsylvanian) and open shelf to shelf margin limestones and dolostones of the Canyon and Cisco sections.

Introduction

The Permian Basin produces oil and natural gas from 4 counties in southeast New Mexico: Lea, Eddy, Chaves, and Roosevelt (Fig. 1). Through the end of 1993, oil and gas reservoirs (pools) in these counties had produced a total of 4,273 million bbls oil and condensate (MMBO) and 19,744 billion ft^3 (BCF) gas. During 1993, production in these counties was 64.7 MMBO worth approximately $1.04 billion and 515 BCF gas worth approximately $0.936 billion. As of December 1993, southeast New Mexico had proved reserves of 706 million bbls crude oil and lease condensate; proved gas reserves were 3,338 BCF (Energy Information Administration, 1994). Approximately 93% of the state's oil production and 36% of the state's gas production is obtained from the Permian Basin. In 1993, the State of New Mexico

Modified and updated from an article published in the 1993 New Mexico Geological Society Guidebook to the Carlsbad region, New Mexico and west Texas.

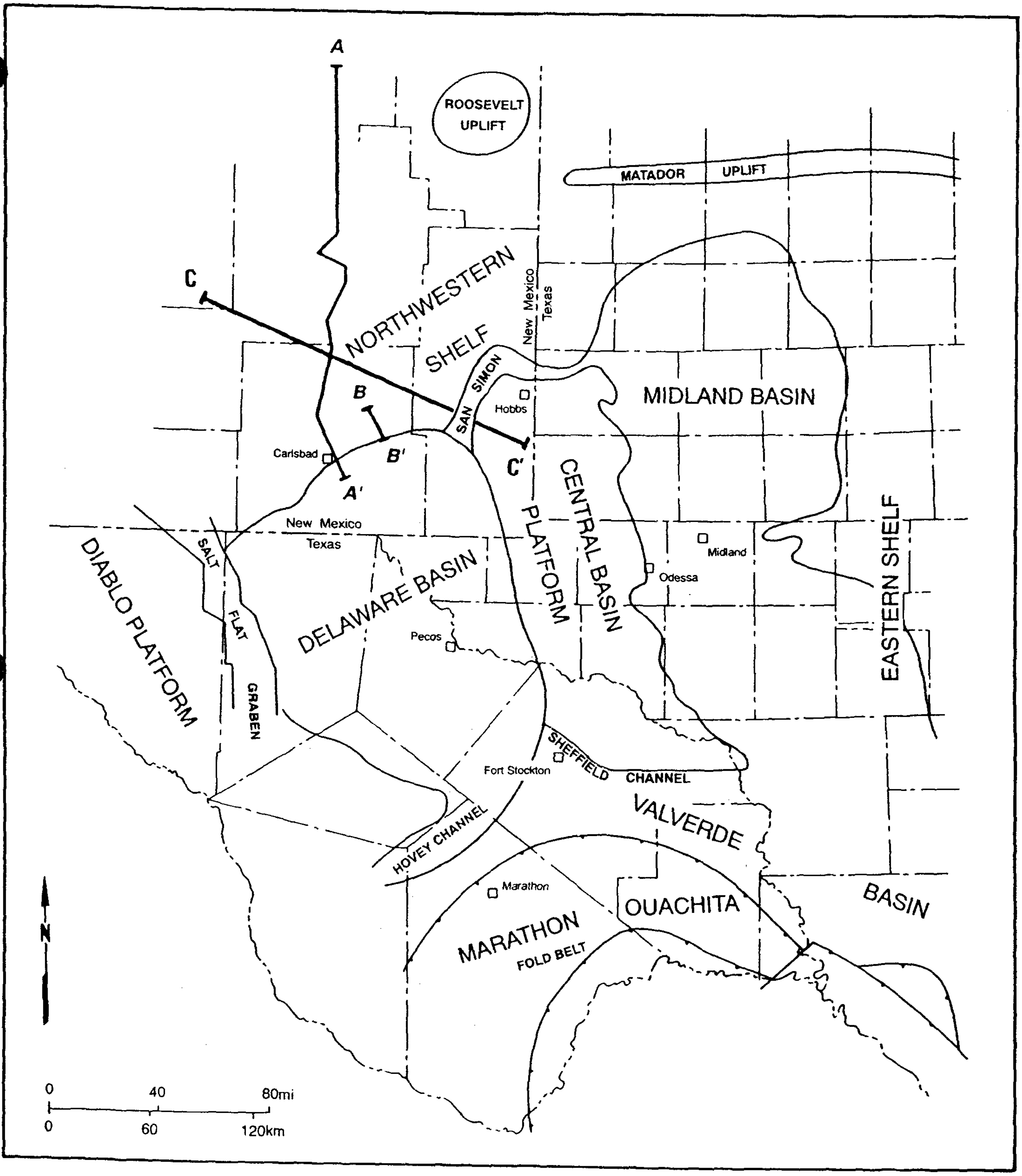

Figure 1. Principal structural elements in southeast New Mexico. After Hills (1984).

received more than $832 million from taxes, royalties, and investment earnings derived from oil and gas exploration and production throughout the state (New Mexico Oil and Gas Association, 1992).

The Permian Basin of southeast New Mexico contains 1,164 designated, discovered oil reservoirs (pools) and 692 designated, discovered gas reservoirs (pools). Most oil reservoirs have produced between 0.01 and 1 MMBO and less than 0.1 BCF gas (Fig. 2a, b). Most gas reservoirs have produced between 0.1 and 10 BCF gas and less than 0.01 MMBO (as condensates; Fig. 2c, d). Eighty-eight percent of the oil has been produced from reservoirs that have yielded more than 1 MMBO; 93% of the gas has been produced from reservoirs that have yielded more than 5 BCF gas. The designated oil and gas reservoirs have been grouped into 17 plays based on common geologic characteristics (Table 1). These plays are briefly discussed below.

Ordovician Play

Reservoirs of the Ordovician play are found primarily on structures associated with the Central basin platform, although a significant subcrop gas play can be found on the Northwest shelf in Chaves County (Fig. 1); 115 MMBO and 255 BCF gas have been produced from the 39 designated reservoirs in this play. Production is from dolomites in the Ellenburger and Montoya formations and sandstones (primarily the Connell, Waddell, and McKee sandstones) of the Simpson Group (Table 1). Trapping occurs on anticlines, faulted anticlines, and along subcrop unconformities (Figs. 3, 4).

Ellenburger and Montoya reservoirs are generally comprised of siliceous, fine- to coarse-crystalline dolomite which was deposited in a stable restricted shelf setting (Wright, 1979). These dolomites exhibit excellent permeability from vugular and fracture porosity developed as a result of tectonic and diagenetic (erosional and dissolutional) processes (Kerans, 1988). Simpson reservoirs are composed of rounded, fine- to coarse-grained sandstones deposited along the ancestral Central basin platform as a series of coalescing strandline deposits (Wright, 1979). Depth to production ranges from 6,000 ft on the Northwest shelf and Central basin platform to more than 15,000 ft in the Delaware Basin.

Siluro-Devonian Play

One hundred twenty-two designated Siluro-Devonian reservoirs are found in southeast New Mexico. Cumulative production from this play totals 443 MMBO and 452 BCF gas (Table 1). Most of the hydrocarbons are trapped by anticlines bounded on one or more sides by high-angle faults. Production is found in highly permeable dolomites of the Fusselman (Silurian) and Thirtyone (Devonian; Hills and Hoenig, 1979) formations at depths ranging from 7,000 to more than 17,000 ft.

Siluro-Devonian dolomite reservoirs are similar to those found in the Ordovician section both in their depositional and burial/diagenetic histories. Most porosity is secondary and is commonly vugular or fractured in nature. Although most of the traps are formed by anticlines, major production is also obtained from subcrop unconformity traps located on the flanks of higher structures on the Central basin platform (Figs. 3, 4). The presence of numerous exposure surfaces within these dolomite sections offers the potential for numerous stratigraphic or combination traps

Table 1. Summary of oil and gas plays in New Mexico part of Permian Basin. MMBO = million bbls oil ± condensate. BCF = billion ft^3 gas.

Play	Reservoir Age	Principal Productive Stratigraphic Units	Depositional Setting	Main Reservoir Lithology	Main Trap Types	Cumulative Production (1/1/92) Oil + condensate (MMBO)	Cumulative Production (1/1/92) Gas (BCF)	No. of Reservoirs	Reservoirs with most production: Oil	Reservoirs with most production: Gas
Ordovician	Ordovician	Montoya, Simpson, Ellenburger	shallow restricted shelf	dolostone, sandstone	anticlines, faulted anticlines, unconformity	115	255	39	Brunson (Ellenburger) (28 MMBO) (19 BCF)	Monument (McKee/Ellenburger) (63 BCF) (0.6 MMBO)
Silurian-Devonian	Silurian, Devonian	Thirtyone, Fusselman	shallow restricted shelf	dolostone	anticlines, faulted anticlines, unconformity, stratigraphic(?)	443	452	122	Denton (99 MMBO) (53 BCF)	Crosby (95 BCF) (0.9 MMBO)
Mississippian	Mississippian	Mississippian	shallow open shelf	limestone	stratigraphic	2	19	23	Bronco (0.4 MMBO) (0.35 BCF)	Austin (12 BCF) (0.2 MMBO)
Morrow	Pennsylvanian	Morrow	fluvial, deltaic, strandplain, submarine fan	sandstone	stratigraphic, combination	22	3062	219	Quail Ridge (1.5 MMBO) (43 BCF)	Carlsbad South (238 BCF) (0.07 MMBO)
Atoka	Pennsylvanian	Atoka	fluvial, strandplain, shelf, shelf margin	sandstone, limestone	stratigraphic, combination	6	529	141	Antelope Ridge (2.1 MMBO) (84 BCF)	Antelope Ridge (84 BCF) (2.1 MMBO)
Strawn	Pennsylvanian	Strawn	shallow open shelf, ramp	limestone	stratigraphic, combination	48	359	101	Lusk (20 MMBO) (99 BCF)	Lusk (99 BCF) (20 MMBO)
Upper Pennsylvanian	Pennsylvanian	Cisco, Canyon	shallow open shelf, shelf margin	limestone, dolostone	stratigraphic, combination	369	2841	201	Vada (53 MMBO) (136 BCF)	Indian Basin (1343 BCF) (8.4 MMBO)
Granite Wash	Permian (Wolfcampian)	Granite Wash	alluvial fan	sandstone, conglomerate, granite(?)	combination	7	34	4	Wantz (7.1 MMBO) (36 BCF)	Wantz (36 BCF) (7.1 MMBO)
Wolfcamp Carbonate	Permian (Wolfcampian)	Wolfcamp	shelf, shelf margin, basin	limestone	stratigraphic	124	341	200	Denton (40 MMBO) (10 BCF)	Kemnitz (69 BCF) (16 MMBO)
Abo Fluvial/Deltaic Sandstone	Permian (Leonardian)	Abo	fluvial-deltaic	red-bed sandstone	stratigraphic(?)	0.05	324	5	Pecos Slope (0.04 MMBO) (271 BCF)	Pecos Slope (271 BCF) (0.04 MMBC)
Abo Platform Carbonate	Permian (Leonardian)	Abo	shelf-margin reef, restricted shelf	dolostone	stratigraphic	438	771	63	Empire (221 MMBO) (312 BCF)	Empire (312 BCF) (221 MMBO)

Table 1 continued

Play	Reservoir Age	Principal Productive Stratigraphic Units	Depositional Setting	Main Reservoir Lithology	Main Trap Types	Cumulative Production (1/1/92) Oil + condensate (MMBO)	Cumulative Production (1/1/92) Gas (BCF)	No. of Reservoirs	Reservoirs with most production: Oil	Reservoirs with most production: Gas
Yeso Platform	Permian (Leonardian)	Yeso (Drinkard, Tubb, and Blinebry zones)	restricted shelf	dolostone, sandstone	anticlines	257	3093	69	Drinkard (72 MMBO) (662 BCF)	Blinebry (999 BCF) (36 MMBO)
Bone Spring Basinal Sediments	Permian (Leonardian)	Bone Spring	deep basin	dolostone	stratigraphic	57	112	131	Scharb (14 MMBO) (13 BCF)	Avalon East (18 BCF) (0.6 MMBO)
Glorieta and upper Yeso shelf	Permian (Leonardian)	Glorieta, Paddock, Yeso	restricted shelf	dolostone	anticlines	137	359	33	Vacuum (66 MMBO) (81 BCF)	Vacuum (81 BCF) (66 MMBO)
San Andres and Grayburg Platform	Permian (Guadalupian)	Garyburg, San Andres	restricted shelf	dolostone, sandstone	stratigraphic, combination	1600	1904	185	Eunie-Mounument (376 MMBO) (647 BCF)	Eunice-Monument (647 BCF) (376 MMBO)
Delaware Mountain Basinal Sandstone	Permian (Guadalupian)	Delaware	deep basin	sandstone	stratigraphic	78	133	155	Paduca (14 MMBO) (16 BCF)	Loving (19 BCF) (5 MMBO)
Upper Guadalupian Platform	Permian (Guadalupian)	Yates, Queen	restricted shelf	sandstone	stratigraphic anticlines	567	5147	162	Langlie-Mattix (131 MMBO) (457 BCF)	Jalmat (1,994 BCF) (74 MMBO)

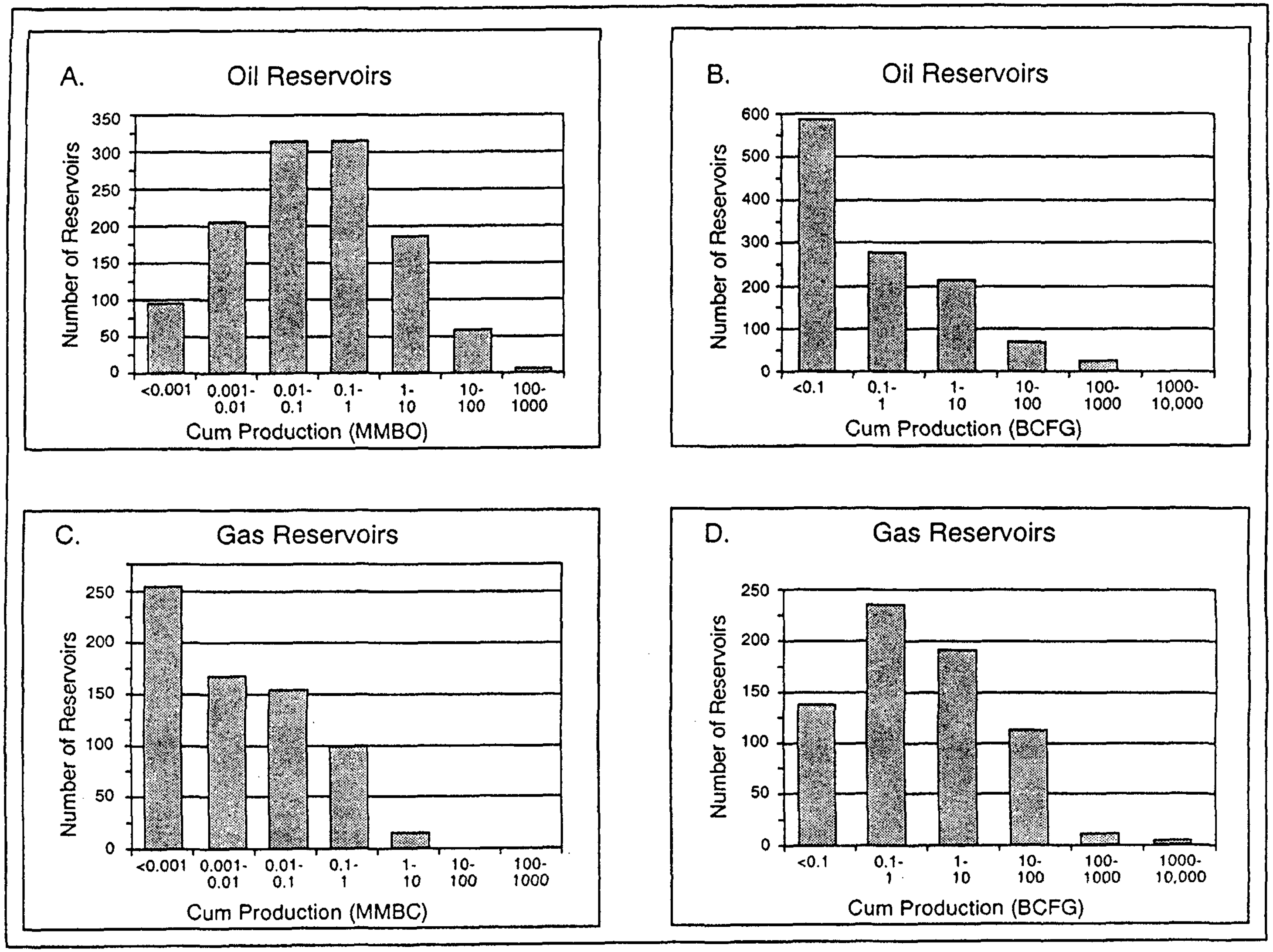

Figure 2. Size distribution of oil and gas reservoirs in the New Mexico part of the Permian Basin, defined by cumulative production as of 12/31/93.

a. cumulative oil production from oil reservoirs;
b. cumulative associated gas production from oil reservoirs;
c. cumulative condensate production from gas reservoirs;
d. cumulative nonassociated gas production from gas reservoirs.

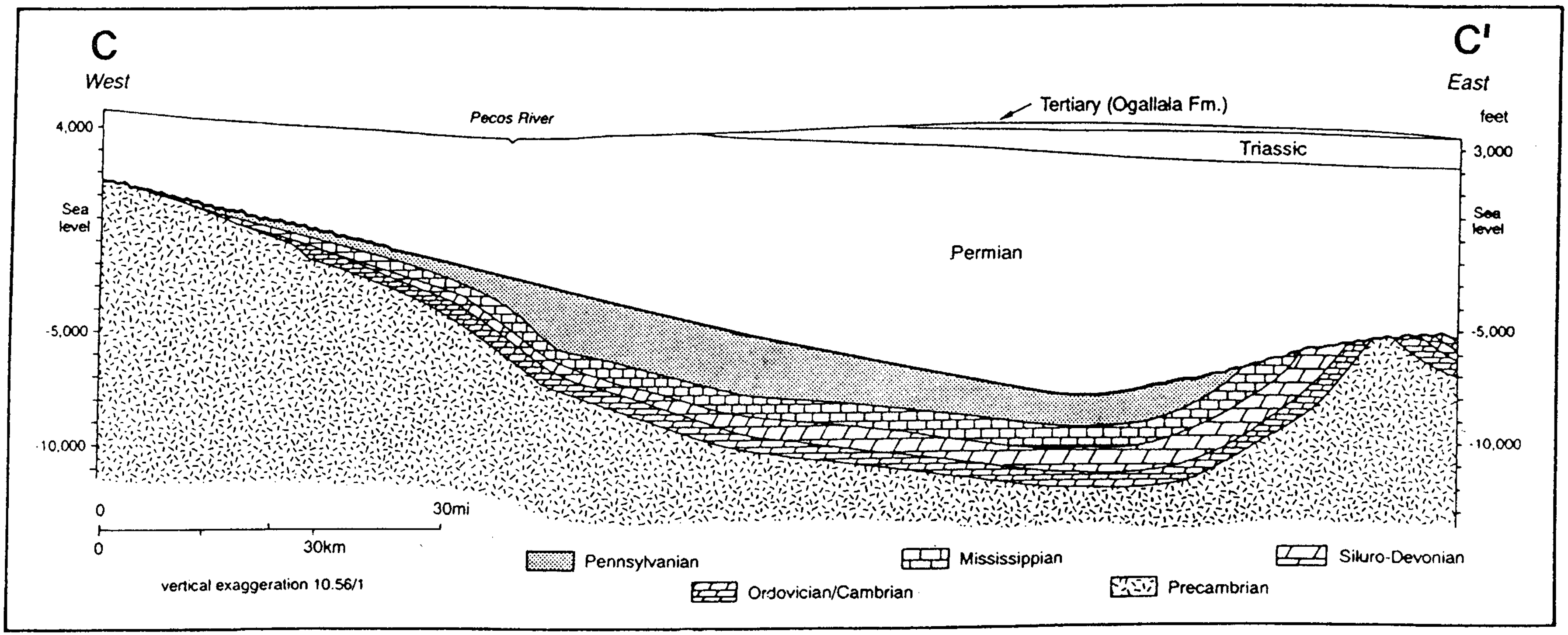

Figure 3. Cross section from the Northwest shelf/Delaware Basin on the west to the Central basin platform on the east. After Grant and Foster (1989).

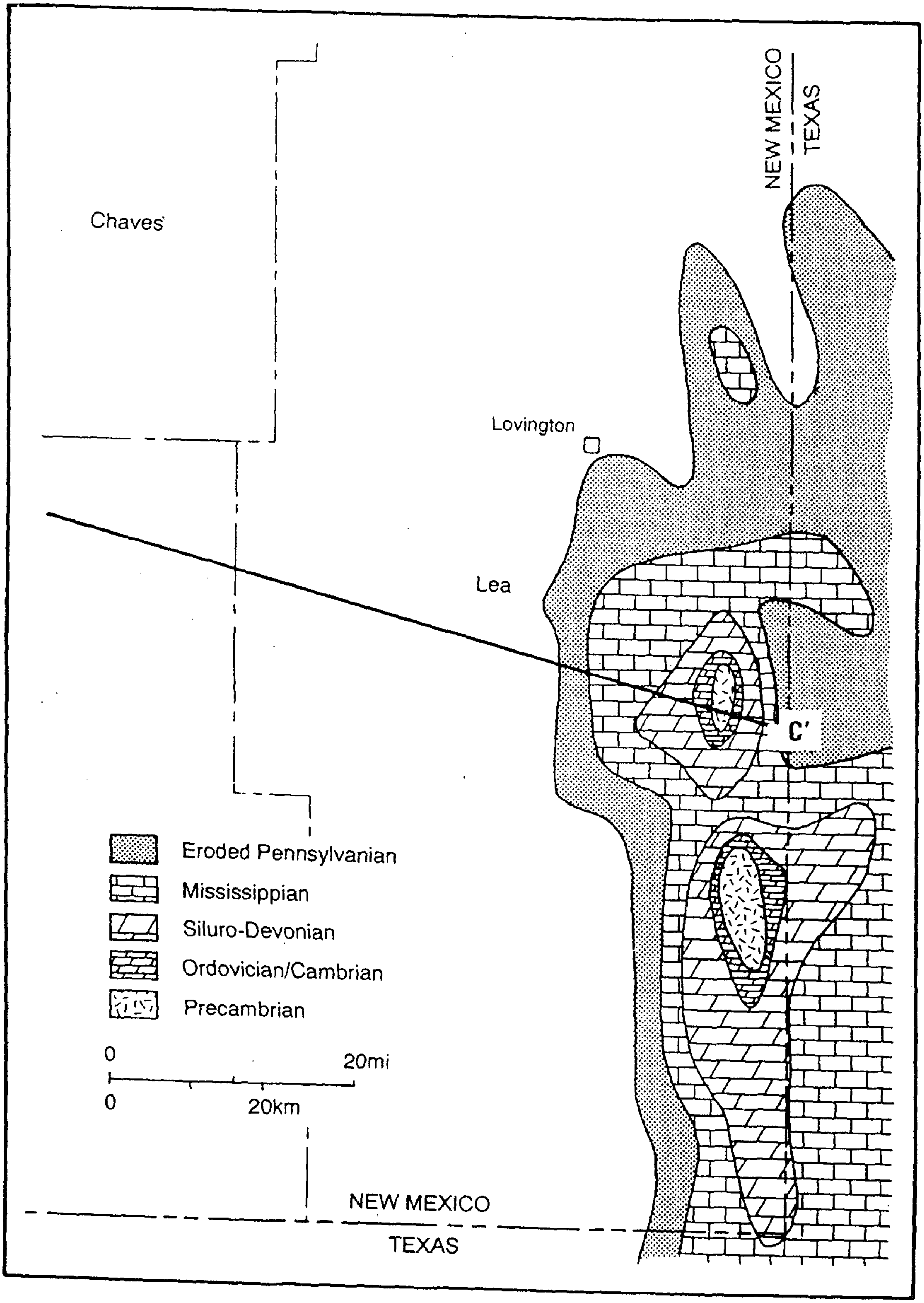

Figure 4. Pre-Permian subcrop patterns developed by Wolfcampian erosion of the Central basin platform. After Grant and Foster (1989) and Oriel et al. (1967).

that have not yet been recognized (Mazzullo, 1990). With improved geological and geophysical methods and models, it may be possible to further develop this already significant play.

Mississippian Play

The Mississippian play in southeast New Mexico is relatively insignificant as to overall production, having accumulated a total of 2 MMBO and 19 BCF gas (Table 1) from 23 designated reservoirs. Production is obtained from northern Lea and eastern Chaves counties (Fig. 1) and comes mostly from isolated bioclastic limestone shoals of limited permeability. Hydrocarbons are trapped either stratigraphically or in combination with associated structures. Approximately 40% of the total production at the 10-well Austin reservoir has come from the 1957 discovery well.

Morrow Play

The Morrow Formation is one of the most significant gas producing zones in southeast New Mexico. The 219 designated Morrow reservoirs, located primarily in Eddy, Lea, and southernmost Chaves counties (Fig. 1), have combined production of over 3,062 BCF of nonassociated gas and 22 MMB of condensate (Table 1). Most of these reservoirs have been developed on 320 acre spacing. Depth to production ranges from less than 7,000 ft to more than 15,000 ft in the deeper portions of the Delaware Basin (Fig. 1). Average reservoir depth is 11,100 ft.

The Morrow section can be subdivided into three distinct zones, commonly designated as the lower ("A"), middle ("B"), and upper ("C") intervals. Productive reservoirs are found almost exclusively in the siliciclastic lower and middle Morrow intervals and are generally composed of angular to subangular, medium- to very coarse-grained quartzose sandstone deposited principally in fluvially dominated (lower Morrow) and wave dominated (middle Morrow) deltaic settings (Anderson, 1977; James, 1985; Mazzullo and Mazzullo, 1985). Net pay is generally 20–30 ft thick, but can be more than 80 ft in distributary channel facies. Trapping commonly occurs by a combination of stratigraphic, structural, and/or diagenetic factors; silica and clay cements significantly affect reservoir characteristics (Anderson, 1977; James, 1985; Mazzullo and Mazzullo, 1985).

Atoka Play

One hundred forty-one Atokan age reservoirs have combined to produce 529 BCF of primarily nonassociated gas and 6 MMB of condensate (Table 1) in southeast New Mexico. The bulk of these reservoirs lie either in the Delaware Basin or near its margin on the Northwest shelf. Reservoirs can be found at depths ranging from 8,500 ft to more than 14,000 ft. Production is generally obtained from fluvial-deltaic and strandline sandstones derived primarily from the Pedernal Highlands to the northwest. Porosity of productive sandstones averages 10%. However, significant, but scattered production is also found in southern Lea and Eddy counties from a trend of low porosity carbonate mounds (James, 1985). Reservoirs of limited extent are common in the Atoka and trapping generally occurs by a combination of structural and stratigraphic mechanisms. Many of the deeper Atoka reservoirs are significantly overpressured and require extreme care when drilling.

Strawn Play

Both clastics and carbonates have combined to produce 48 MMB of oil and condensate and 359 BCF gas from the 101 designated Strawn reservoirs found in southeast New Mexico (Table 1). By far the most significant production has been established in isolated biohermal shelf limestones and associated facies that are located along a northeasterly-trending shelf break in central Lea and Eddy counties. Depth to Strawn production ranges from less than 8,000 ft to more than 12,000 ft. Many of the deeper reservoirs are overpressured. Net pay in most productive bioherms averages 10 to 50 ft, but can be as thick as several hundred feet in the better reservoirs (Thornton and Gaston, 1967). Porosity values in the productive carbonates are generally quite low, averaging from 2 to 9%; however, permeability can be quite high (more than 100 millidarcies). Traps are generally stratigraphic, but many are structurally enhanced.

Upper Pennsylvanian Play

Upper Pennsylvanian reservoirs found in the Cisco/Canyon section are significant contributors to both oil and gas production in southeastern New Mexico. The 201 designated Upper Pennsylvanian reservoirs have produced over 2,841 BCF gas and 369 MMB oil and condensate (Table 1). They are found at depths ranging from 5,900 to 11,500 ft and have undergone steady exploration and development since the 1950s. The most significant development activity in recent years has occurred in the Indian Basin/Dagger Draw reservoir complex of west-central Eddy County.

Upper Pennsylvanian production comes almost exclusively from carbonate reservoirs located in either of two distinctly separate areas: 1) a northeastern area comprised of northern Lea, eastern Chaves, and southern Roosevelt counties, or 2) western Eddy County (Fig. 1). Reservoirs in these areas are unique to each other in that those found in the northeastern area, commonly referred to as the Tatum Basin, produced oil and associated gas from thin (10 to 35 ft), laterally extensive biohermal shelf limestones (Carleton, 1977), while the reservoirs of Eddy County produce lighter condensate as well as both associated and nonassociated gas from shelf margin dolomite banks which can locally be more than 750 ft thick (David, 1977; Frenzel, 1988). Trapping in both types of reservoirs is primarily stratigraphic, although in both cases it appears that carbonate development oftentimes is localized on older, deeper-seated structures.

Granite Wash Play

The Granite Wash play is small and localized in extent, being found only in areas on or adjacent to remnants of major Pennsylvanian uplifts that persisted as emergent areas into early Permian time. Only four Granite Wash reservoirs have been designated. By far the most prominent is Wantz Granite Wash, which is found near the crest of the Central basin platform in southern Lea County. Cumulative production from this play is 34 BCF gas and 7 MMBO. Most of the reservoir rocks are sandy conglomerates and petrologically immature sandstones of alluvial fan and fluvial origin (Bowsher and Abendshein, 1988).

Wolfcamp Carbonate Play

Reservoirs of the Wolfcamp Carbonate

play lie on the Northwest shelf and in the Delaware Basin. The 200 reservoirs in this play have produced 124 MMBO and 341 BCF gas (Table 1). Reservoir rocks are limestones. Most reservoirs on the shelf produce oil and associated gas by solution-gas drive. Reservoirs in the basin produce nonassociated gas; many nonassociated gas reservoirs in the western part of the basin produce substantial volumes of condensate. Traps are mostly stratigraphic. Depth to production ranges from 8,000 ft on the Northwest shelf to more than 13,000 ft in the Delaware Basin.

Wolfcamp reservoirs were deposited in several different depositional environments (Table 1). Barrier reefs were formed along the shelf edge, which occupied the approximate position of the Abo shelf edge (Fig. 5; Malek-Aslani, 1970); production is obtained from reef wall boundstones, backreef skeletal grainstones, and forereef talus. Reservoirs north of the barrier reefs are formed mostly by phylloid-algal patch reefs deposited on a shallow shelf; some patch reefs are capped by porous grainstones which contribute significantly to production (Malek-Aslani, 1985; Cys, 1986). South of the barrier reef, reservoirs were deposited in a basinal setting, either as small algal mounds interbedded with basinal shales (Anderson, 1977) or as carbonate debris flows near the shelf edge (Loucks et al., 1985). Trapping mechanisms are principally stratigraphic. Net pay ranges from 10 to 30 ft.

Abo Fluvial-Deltaic Sandstone play

Reservoirs of the Abo Fluvial-Deltaic Sandstone play lie on the Northwest shelf in northwestern Chaves County. The five reservoirs in this play have produced 324 BCF gas and 0.05 MMBO (Table 1). Reservoirs are in "tight", fine- to very fine-grained, silty, arkosic, red-bed sandstones of the Abo Formation. The reservoirs produce nonassociated gas and minor condensate by pressure-depletion drive. Because of the low permeability of the Abo, most wells must be artificially fractured before they can be produced economically. Depth to productive reservoirs ranges from 2,500 ft to 4,700 ft.

The Abo sandstone reservoirs were deposited as a red-bed facies in a south-flowing fluvial-deltaic complex north of the Abo shelf edge (Fig. 5; Broadhead, 1984; Bentz, 1992). The sandstones are lenticular and are interbedded with red shales. The trapping mechanism for Abo gas is poorly understood, but appears to be largely stratigraphic. Production is confined to the sandy distal lobes of the fluvial system. Updip limits may be formed by capillary pressure barriers. The Abo is 400 to 650 ft thick in the producing areas, but net pay averages approximately 30 ft.

Abo Platform Carbonate play

Reservoirs of the Abo Platform Carbonate play lie on the Central basin platform and on the Northwest shelf. The 63 reservoirs in this play have produced 438 MMBO and 771 BCF gas (Table 1). Reservoirs are in dolostones. Most reservoirs produce oil and associated gas by a combination of solution-gas and water drive. Nine smaller reservoirs have produced nonassociated gas. Depth to production ranges from 6,000 ft to approximately 9,000 ft.

Abo carbonate reservoirs fall into two distinct groups. One group produces from a trend of fringing barrier reefs that grew along the southern edge of the Northwest shelf (Fig. 5; LeMay, 1972). In this group, traps are predominantly stratigraphic and are located in porous reefal masses of dolostone 5 to 13 mi long and 1 to 5 mi wide. Net pay ranges from less than 50 ft in the smaller reservoirs to a maximum of 726 ft in the large Empire reservoir.

A second group of Abo carbonate reservoirs produces from shallow-shelf dolostones on the Central Basin platform and on the Northwest shelf, north of the Abo reef trend (Fig. 5). On the Central basin platform, traps are formed by broad low-relief anticlines. Known reservoirs on the Northwest shelf are sparsely scattered; many appear to have an anticlinal component to their trapping mechanism. Net pay is typically 20 ft.

Yeso Platform play

Most reservoirs of the Yeso Platform play lie on the Central Basin platform. A few minor reservoirs are located on the southeasternmost part of the Northwest shelf. Reservoirs in this play produce from (ascending) the Drinkard, Tubb, and Blinebry members of the Yeso Formation (Permian). Drinkard and Blinebry reservoirs are principally in dolostones and limestones. Tubb reservoirs are principally in sandstones. The 69 designated reservoirs in this play have produced 257 MMBO and 3,093 BCF gas (Table 1). The reservoirs produce oil and associated gas primarily by solution-gas drive; many reservoirs had a primary gas-cap drive. Depth to production ranges from 5,000 ft to more than 7,000 ft.

The Yeso reservoirs were deposited on a restricted shallow-marine shelf. The dolostone, limestone, and sandstone reservoirs are interbedded with shale and anhydrite. The carbonate reservoirs are generally in a peritidal facies. Most traps are formed by anticlines, but some are formed by pinchout of permeable zones on the flanks of structural noses. Net pay is typically 20 to 30 ft.

Bone Spring Basinal Sediments play

Reservoirs of the Bone Spring Basinal Sediments play are present in the Delaware Basin. The 131 reservoirs in this play have produced 57 MMBO and 112 BCF gas (Table 1). Reservoirs are in dolostones and sandstones of the Bone Spring Formation. Most of the reservoirs produce oil and associated gas by solution-gas drive, but six are designated as gas reservoirs that produce by pressure depletion. Depths to Bone Spring reservoirs range from 5,000 ft to more than 10,000 ft in the deeper parts of the basin.

Bone Spring dolostone reservoirs were deposited as carbonate debris flows downslope of the Abo-Yeso shelf edge (Fig. 5) and Bone Spring sandstone reservoirs were deposited as siliciclastic turbidites (Gawloski, 1987; Mazzullo and Reid, 1987; Saller et al., 1989). The reservoir rocks are interbedded with dark basinal shales and micritic carbonates. The dolostones are the principal reservoirs. Traps are stratigraphic or combination stratigraphic-structural. The porous debris flow carbonates and turbidite sandstone reservoirs were deposited in channels perpendicular to the shelf margin. The reservoir rocks pinchout depositionally updip as they rise onto the submarine slope. Net pay is typically 20 to 30 ft.

Glorieta and Upper Yeso Shelf play

Reservoirs of the Glorieta and Upper Yeso Shelf play lie along the western part of the Central basin platform and along the southern edge of the Northwest shelf where they are coincident with the Abo reef trend.

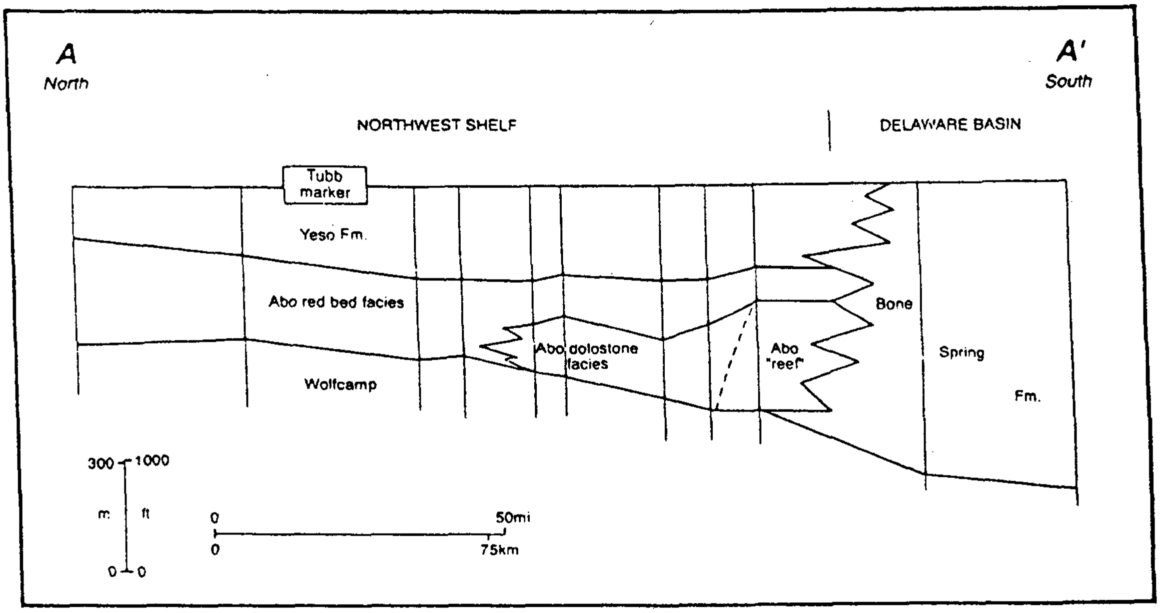

Figure 5. North-south stratigraphic cross section through Abo and lower Yeso strata. See Fig. 1 for location. After Broadhead (1984).

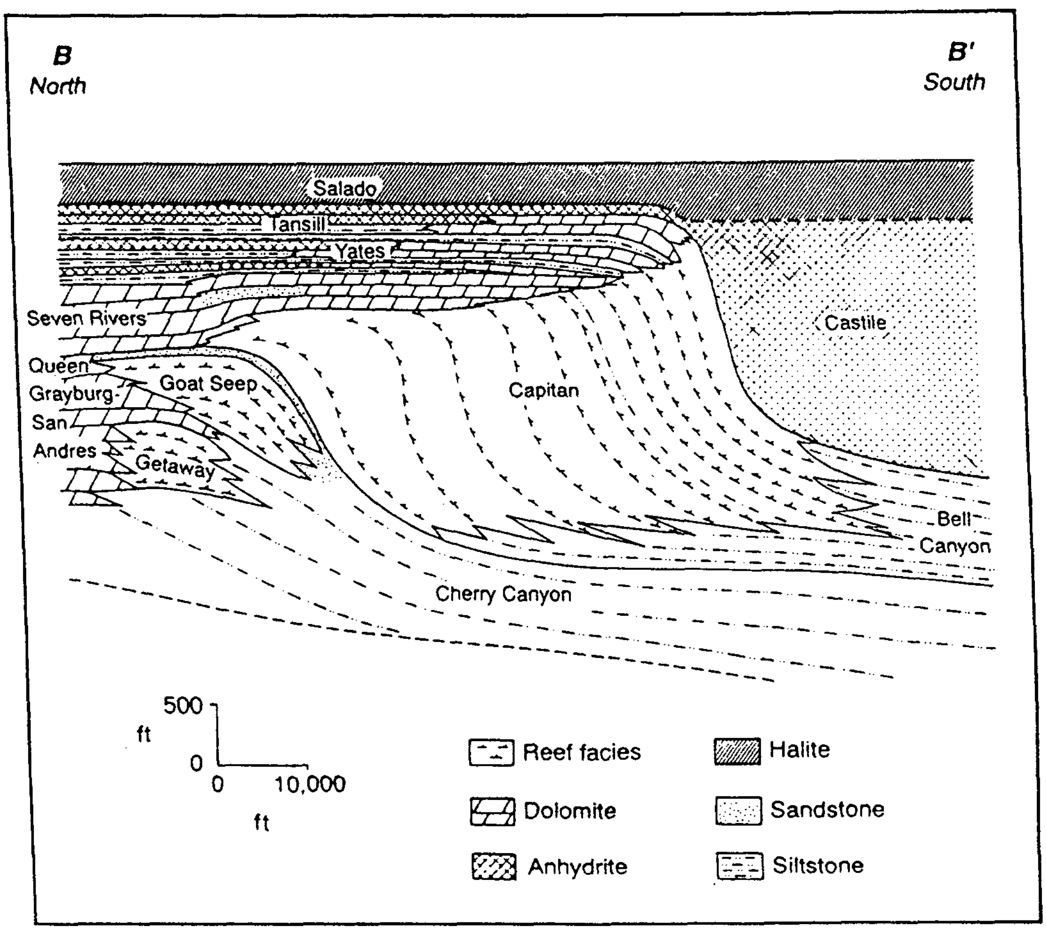

Figure 6. North-south cross section through Guadalupian and Ochoan strata, showing Getaway, Goat Seep, and Capitan shelf-margin carbonate buildups. See Fig. 1 for location. After Garber et al. (1989).

The 33 reservoirs in this play have produced 137 MMBO and 359 BCF gas (Table 1). Reservoirs are in dolostones and sandstones. Most of the reservoirs produce oil and associated gas by solution gas or water drive, but reservoirs on the southern part of the Central basin platform produce nonassociated gas. Depths to reservoirs range from 2,500 ft to more than 6,000 ft.

Glorieta and upper Yeso reservoirs were deposited on a restricted shallow marine shelf. Most production is obtained from dolostones. Sandstones contribute to production in northern Eddy County. To the east in Lea County, sandstone beds are thin or absent. Most traps are formed by anticlines.

San Andres and Grayburg Platform play

Reservoirs of the San Andres and Grayburg Platform play lie on the Northwest shelf and on the Central basin platform. The 185 reservoirs in this play have produced 1,600 MMBO and 1,904 BCF gas (Table 1). Reservoirs are in dolostones and sandstones. Most of the reservoirs produce oil and associated gas by solution-gas drive, but water drive is the dominant producing mechanism in some reservoirs. Depths to reservoirs range from 1,600 ft in western Eddy County to more than 4,000 ft along the New Mexico–Texas border.

In the lower San Andres Formation, production is obtained from dolostones deposited in subtidal and peritidal environments on a restricted shelf north and east of the Getaway and Goat Seep shelf-margin and reef complexes (Fig. 6). These productive dolostones occur mostly along an east-west trend centered on the border between Lea and Roosevelt counties. Traps are largely stratigraphic with porosity zones pinching out updip to the north and northwest (Gratton and LeMay, 1969; Ward et al., 1986). Net pay typically ranges from 20 to 40 ft.

In the upper San Andres and Grayburg formations, production is obtained from dolostones and dolomitic sandstones deposited in a back-reef environment north of the Goat Seep reef complex (Fig. 6; Ward et al., 1986; Lindsay, 1991). In most reservoirs, production is obtained primarily from the Grayburg Formation. These reservoirs are present mostly on the Central basin platform and on the Northwest shelf along an east-west trend in northern Eddy and central Lea counties. Traps are mainly stratigraphic and are formed by diagenetic plugging of porosity with evaporites in an updip direction. Net pay typically ranges from 100 to 140 ft in the larger reservoirs.

Upper Guadalupian Platform play

Reservoirs in the Upper Guadalupian Platform play lie principally on the Northwest shelf and Central basin platform. Most reservoirs on the Northwest shelf are located along an east-west trend in northern Eddy and central Lea counties. These reservoirs produce from the Artesia Group (upper Guadalupian); sandstones in the Yates and Queen formations dominate production, but dolostones in the Tansill, Yates, and Seven Rivers formations form significant reservoirs in some fields. Several important Queen reservoirs are present in southeast Chaves County, north of the main productive trend. The 162 reservoirs in this play have produced 567 MMBO and 5,147 BCF gas (Table 1). Most of the reservoirs produce oil and associated gas by solution-gas and water drive; the 33 designated gas reservoirs have pressure-depletion drive. Depths to reservoirs range from 1,400 ft on the Northwest shelf to more than 4,000 ft in the San Simon syncline.

Upper Guadalupian reservoirs were deposited on a restricted shallow marine shelf. The reservoirs are found north of the shelf edge defined by the Capitan reef complex (Fig. 6; Ward et al., 1986; Borer and Harris, 1991). Traps are largely stratigraphic. Most production in the Yates is obtained from sandstones of the middle shelf; porosity is plugged in an updip shoreward direction by the impermeable evaporitic facies of the inner shelf. Much of the production in the Queen is obtained from aeolian sandstones of the inner shelf; porosity in these Queen sandstones is plugged in an updip direction by dolomite and anhydrite cements (Malicse and Mazzullo, 1990). Net pay is 10 to 30 ft in most reservoirs.

Delaware Mountain Basinal Sandstone play

Reservoirs of the Delaware Mountain Basinal Sandstone play are present in the Delaware Basin. Production is obtained from sandstones in all three formations that constitute the Delaware (ascending): Brushy Canyon, Cherry Canyon, Bell Canyon. The 155 reservoirs in this play have produced 78 MMBO and 133 BCF gas (Table 1). The major reservoirs produce by solution-gas drive. All but seven of the reservoirs produce oil and associated gas; the other seven produce nonassociated gas. Depth to production ranges from 4,000 ft to more than 7,000 ft.

Delaware sandstone reservoirs were deposited on submarine fans by shelf-derived density currents (Harms and Williamson, 1988; Broadhead et al., in press). Traps are stratigraphic or combination stratigraphic-structural. Production is obtained from channel fill sandstones of the upper and middle fan environments (Berg, 1979; Harms and Williamson, 1988; Broadhead et al., in press). Net pay is 15 to 20 ft in most reservoirs.

The Delaware play has recently been the most active play in southeast New Mexico and one of the most active plays in the United States. Recent exploratory drilling has mostly been targeted at traps in the lower two units of the Delaware Mountain Group (Brushy Canyon and Cherry Canyon formations). Production in older fields has been obtained primarily from Bell Canyon sandstones in the uppermost Delaware Mountain Group. Most reservoirs in Brushy Canyon have been discovered in the last 5-6 years. Their relative contribution to production is still small but will increase as more reservoirs are discovered in this young play and as these reservoirs reach peak development.

Acknowledgments

The ideas and data presented in this paper are partially abstracted from the Atlas of Major Rocky Mountain Gas Reservoirs (New Mexico Bureau of Mines and Mineral Resources, 1993) which was funded principally by the Gas Research Institute. Jim Adams and Frank Kottlowski thoughtfully and thoroughly reviewed early versions of the manuscript. Cindie Salisbury and Kathryn Campbell drafted the illustrations and Lynne Hemenway and Terry Telles typed the manuscript.

References:

Anderson, R., 1977, Carlsbad field, Eddy County, New Mexico; *in* A symposium of the oil and gas fields of southeastern

New Mexico, 1977 supplement: Roswell Geological Society, pp. 21-28.

Bentz, L. M., 1992, Pecos Slope field, U.S.A.; *in* N. H. Foster and E. A. Beaumont, eds., Stratigraphic traps III: American Association of Petroleum Geologists, Treatise of petroleum geology, Atlas of oil and gas fields, pp. 129-153.

Berg, R. R., 1979, Reservoir sandstones of the Delaware Mountain Group, southeast New Mexico; *in* N. M. Sullivan, ed., Guadalupian Delaware Mountain Group of west Texas and southeast New Mexico, 1979 symposium and field conference guidebook: Permian Basin Section SEPM, Publication 79-18, pp. 75-95.

Borer, J. M., and Harris, P. M., 1991, Lithofacies and cyclicity of the Yates Formation, Permian Basin: Implications for reservoir heterogeneity: American Association of Petroleum Geologists, Bulletin, v. 75, pp. 726-779.

Bowsher, A. L., and Abendshein, M., 1988, Wantz Granite Wash (oil); *in* A symposium of the oil and gas fields of southeastern New Mexico, 1988 supplement: Roswell Geological Society, pp. 328-329.

Broadhead, R. F., 1984, Stratigraphically controlled gas production from Abo red beds (Permian), east-central New Mexico: New Mexico Bureau of Mines and Mineral Resources, Circular 183, 35 pp., 3 appendices.

Broadhead, R. F., Luo, F., and Speer, S. W., in press, Oil and gas resource estimates of the WIPP site: New Mexico Bureau of Mines and Mineral Resources.

Carleton, A. T., 1977, Vada Pennsylvanian; *in* A symposium of the oil and gas fields of southeastern New Mexico, 1977 supplement: Roswell Geological Society, pp. 212-213.

Cys, J. M., 1986, Lower Permian grainstone reservoirs, southern Tatum Basin, southeastern New Mexico; *in* J. L. Ahlen and M. E. Hanson, eds., Southwest Section of AAPG transactions and guidebook of 1986 convention, Ruidoso, New Mexico: New Mexico Bureau of Mines and Mineral Resources, pp. 115-120.

David, E. K., 1977, Springs Upper Penn gas; *in* A symposium of the oil and gas fields of southeastern New Mexico, 1977 supplement: Roswell Geological Society, pp. 188-189.

Energy Information Administration, 1994, U.S. crude oil, natural gas, and natural gas liquids reserves, 1993 annual report: U.S. Department of Energy, Energy Information Administration, Report DOE/EIA-0216(93), 155 pp.

Frenzel, H. N., 1988, The Indian Basin Upper Pennsylvanian gas field, Eddy County, New Mexico; *in* Guadalupe Mountains revisited, Texas and New Mexico: West Texas Geological Society, 1988 Field Seminar, pp. 169-170.

Garber, R. A., Grover, G. A., and Harris, P. M., 1989, Geology of the Capitan shelf margin-subsurface data from the northern Delaware Basin; *in* P. M. Harris and G. A. Grover, eds., Subsurface and outcrop examination of the Capitan shelf margin, northern Delaware Basin: SEPM, Core workshop no. 13, pp. 3-272.

Gawloski, T. F., 1987, Nature, distribution, and petroleum potential of Bone Spring detrital sediments along the Northwest shelf of the Delaware Basin; *in* D. Cromwell and L. Mazzullo, eds., The Leonardian facies in W. Texas and S.E. New Mexico and Guidebook to the Glass Mountains, west Texas: Permian Basin Section SEPM, Publication 87-27, pp. 84-105.

Grant, P. R., Jr., and Foster, R. W., 1989, Future petroleum provinces in New Mexico— discovering new reserves: New Mexico Bureau of Mines and Mineral Resources, 81 pp.

Gratton, P. J. F., and LeMay, W. J., 1969, San Andres oil east of the Pecos; *in* W. K. Summers and F. E. Kottlowski, eds., The San Andres Limestone, a reservoir for oil and water in New Mexico: New Mexico Geological Society, Special Publication no. 3, pp. 37-43.

Harms, J. C., and Williamson, C. R., 1988, Deep-water density current deposits of Delaware Mountain Group (Permian), Delaware Basin, Texas and New Mexico: American Association of Petroleum Geologists Bulletin, v. 72, pp. 299-317.

Hills, J. M., 1984, Sedimentation, tectonism, and hydrocarbon generation in Delaware Basin, west Texas and southeastern New Mexico: American Association of Petroleum Geologists, Bulletin, v. 68, pp. 250–267.

Hills, J. M., and Hoenig, M. A., 1979, Proposed type sections for Upper Silurian and Lower Devonian subsurface units in Permian Basin: American Association of Petroleum Geologists, Bulletin, v. 63, no. 9, pp. 1510–1521.

James, A. D., 1985, Producing characteristics and depositional environments of lower Pennsylvanian reservoirs, Parkway-Empire South area, Eddy County, New Mexico: American Association of Petroleum Geologists, Bulletin, v. 69, no. 7, pp. 1043–1063.

Kerans, C., 1988, Karst-controlled reservoir heterogeneity in Ellenburger Group carbonates of west Texas: American Association of Petroleum Geologists, Bulletin, v. 72, no. 10, pp. 1160–1183.

LeMay, W. J., 1972, Empire Abo field, southeast New Mexico; *in* R. E. King, ed., Stratigraphic oil and gas fields—classification, exploration methods, and case histories: American Association of Petroleum Geologists, Memoir 16, pp. 472-480.

Lindsay, R. F., 1991, Grayburg Formation (Permian-Guadalupian): comparison of reservoir characteristics and sequence stratigraphy in the northwest Central basin platform with outcrops in the Guadalupe Mountains, New Mexico; *in* S. Meader-Roberts, M. P. Candelaria, and G. E. Moore, eds., Sequence stratigraphy, facies, and reservoir geometries of the San Andres, Grayburg, and Queen formations, Guadalupe Mountains, New Mexico and Texas: Permian Basin Section SEPM, Publication no. 91-32, pp. 111-118.

Loucks, R. G., Brown, A. A., Achauer, C. W., and Budd, D. A., 1985, Carbonate gravity-flow sedimentation on low-angle slopes off the Wolfcampian Northwest shelf of the Delaware Basin; *in* P. D. Crevello and P. M. Harris, eds., Deep-water carbonates: buildups, turbidites, debris flows and chalks: SEPM core workshop no. 6, pp. 56-92.

Malek-Aslani, M., 1970, Lower Wolfcampian reef in Kemnitz field, Lea County, New Mexico: American Association of Petroleum Geologists Bulletin, v. 54, pp. 2317-2335.

Malek-Aslani, M., 1985, Permian patch-reef reservoir, North Anderson Ranch field, southeastern New Mexico; *in* P. O. Roehl and P. W. Choquette, eds., Carbonate petroleum reservoirs: Springer-Verlag, New York, pp. 265-276.

Malicse, A., and Mazzullo, J., 1990, Reservoir properties of the desert Shattuck Member, Caprock field, New Mexico; *in* Barwis, J. H., McPherson, J. G., and Studlick, J. R. J., eds., Sandstone petroleum reservoirs: Springer-Verlag, New York, pp. 133-152.

Mazzullo, L. J., 1990, Implications of sub-Woodford geologic variations in the exploration for Silurian-Devonian reservoirs in the Permian Basin; *in* Permian Basin oil and gas fields: innovative ideas in exploration and development: West Texas Geological Society, Symposium, Publication No. 90-87, pp. 29-42.

Mazzullo, L. J., and Mazzulo, J. M., 1985, Geology and clay mineralogy of the Morrow Formation, southeastern New Mexico: Society of Petroleum Engineers/Department of Energy Low Permeability Gas Reservoirs Symposium, Paper SPE/DOE 13849, 8 p.

Mazzullo, L. J., and Reid, A. M., II, 1987, Stratigraphy of the Bone Spring Formation (Leonardian) and depositional setting in the Scharb field, Lea County, New Mexico; *in* D. Cromwell and L. J. Mazzullo, eds., The Leonardian facies in W. Texas and S.E. New Mexico and Guidebook to the Glass Mountains, west Texas: Permian Basin Section SEPM, Publication 87-27, pp. 107-111.

New Mexico Bureau of Mines and Mineral Resources, 1993, Atlas of major Rocky Mountain gas reservoirs: New Mexico Bureau of Mines and Mineral Resources, 208 pp., 10 plates, 3 floppy diskettes.

New Mexico Oil and Gas Association, 1992, New Mexico oil and gas facts '92: New Mexico Oil and Gas Association, pamphlet.

Oriel, S. S., Myers, D. A., and Crosby, E. J., 1967, West Texas Permian Basin region, in Paleotectonic investigations of the Permian System in the United States: U.S. Geological Survey, Professional Paper 515-C, pp. 17-60.

Saller, A. H., Barton, J. W., and Barton, R. E., 1989, Mescalero Escarpe field, oil from carbonate slope detritus, southeastern New Mexico; *in* J. E. Flis, R. C. Price, and J. F. Sarg, eds., Search for the subtle trap, hydrocarbon exploration in mature basins: West Texas Geological Society, Publication 89-85, pp. 59-74.

Thornton, D. E., and Gaston, H. H., Jr., 1967, Lusk Strawn field; *in* A symposium of the oil and gas fields of southeastern New Mexico, 1967 supplement: Roswell Geological Society, pp. 15-20.

Ward, R. F., St. C. Kendall, C. G., and Harris, P. M., 1986, Upper Permian (Guadalupian) facies and their association with hydrocarbons—Permian Basin, west Texas and New Mexico: American Association of Petroleum Geologists, Bulletin, v. 70, pp. 239-262.

Wright, W. F., 1979, Petroleum geology of the Permian Basin: West Texas Geological Society, Publication No. 79-71, pp. 13-42.