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Petroleum geology of the Palo Duro Basin and Pedernal Uplift provinces as a basis for estimates of undiscovered hydrocarbon resources

by

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INTRODUCTION

The purpose of this report is to review the geology and petroleum potential of the Palo Duro Basin and Pedernal Uplift provinces in Texas and eastern New Mexico (Fig. 1). The Palo Duro Basin province is located in the Texas Panhandle and eastern New Mexico. It contains about 20,905 square miles (53,517 square kilometers) in 17 Texas counties and 2 New Mexico counties. The Pedernal Uplift province covers 7747 square miles (19,832 square kilometers) in two counties in east-central New Mexico. The Tucumcari Basin is located largely within this province (Fig.2) and is the most important geologic feature in the province with regard to hydrocarbons. This review will form the geological basis for estimates of undiscovered hydrocarbon accumulations within these provinces.

For assessment purposes, the term province as used in this report, is a geographic area that contains one or more geologic features; often, but not always, a province includes a sedimentary basin. These areas contain, or are likely to contain, oil and/or gas accumulations. Oil and gas are produced from the Palo Duro Basin primarily from the northwestern boundary and the southern boundary of the province. The southern production, located on and near the Matador Arch, is the most important volumetrically but it is probably not indigenous to the province.

The central portion of the basin does not currently produce oil or gas. Hydrocarbon production does not currently exist in the Pedernal Uplift province.

The method used for assessment is play analysis. A play is defined as a group of prospects and/or discovered fields [or accumulations] having common geologic characteristics such as source rock, trapping mechanism, structural history, etc,[which]may contain gas and/or oil (Procter and others, 1982).

Estimates of undiscovered resources are limited to accumulations of greater than 1 million barrels of oil (1 MMBO) or 6 billion cubic feet of gas (6 BCFG). Production data and geologic data from accumulations greater than 1 MMBO or 6 BCFG were collected for analysis from the literature and from

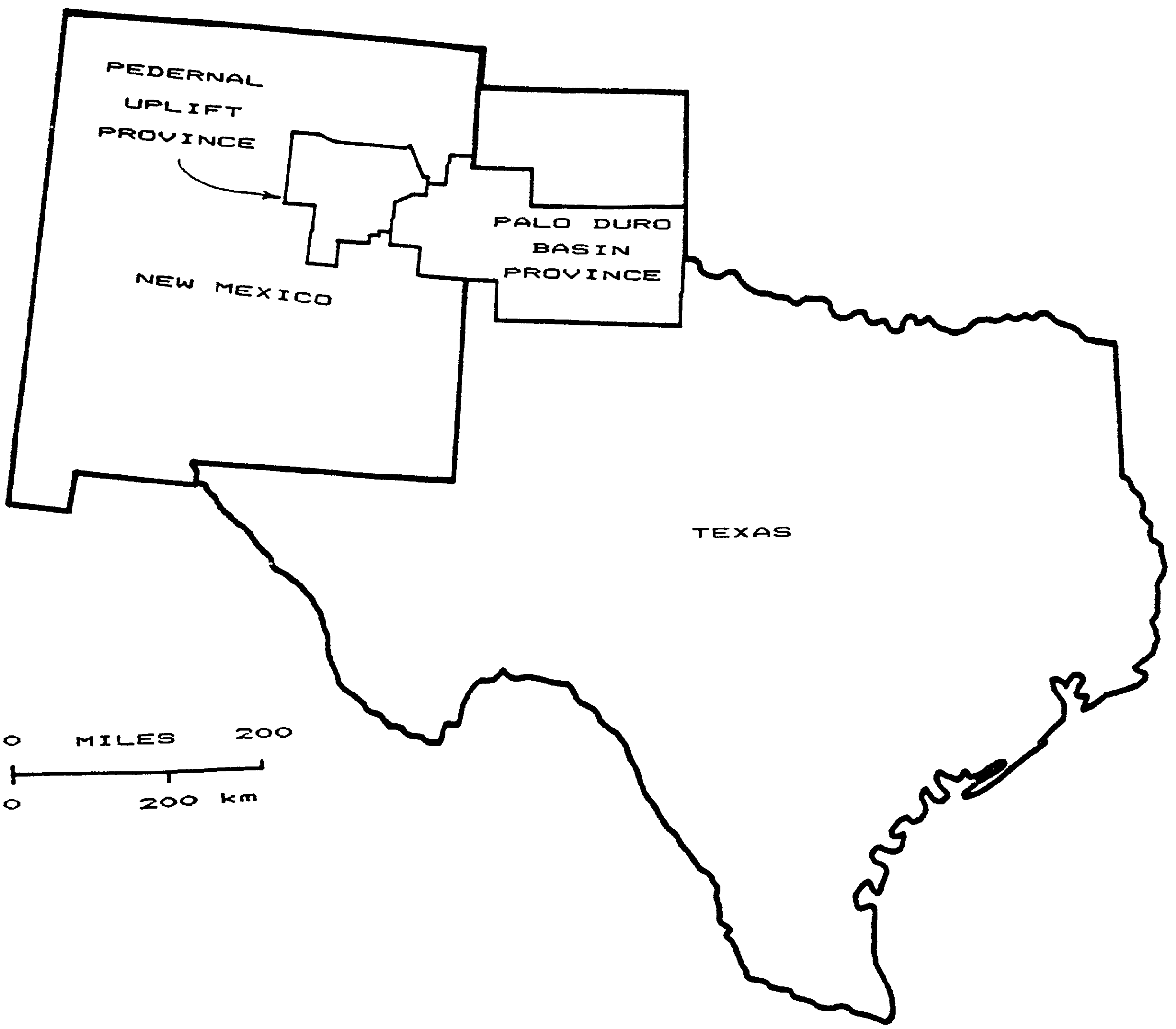

Figure 1. Palo Duro Basin and Pedernal Uplift province boundaries and location.

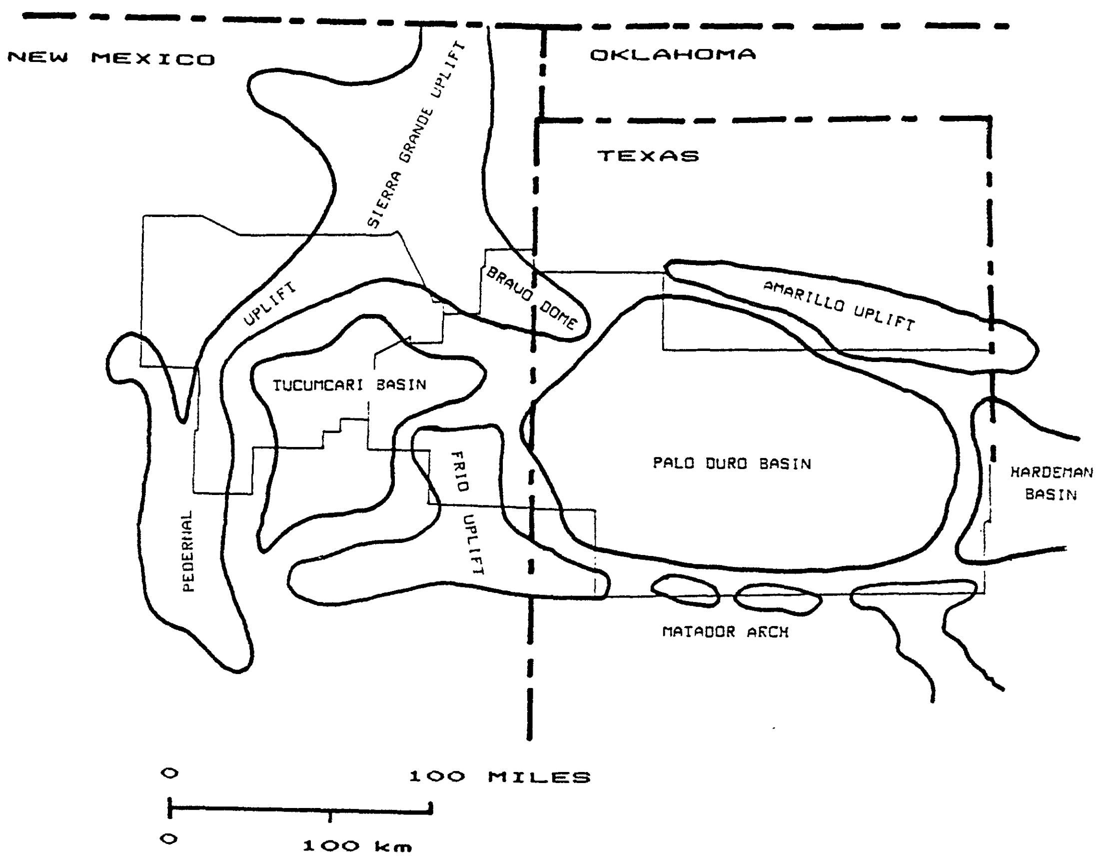

Figure 2. Location of major structural features within and near the two assessment provinces (modified from Petroleum Frontiers, 1986).

magnetically stored information such as the Petroleum Data System(PDS) data base where available.

Computer generated drilling density maps were made from PDS data to aid in visualization of production trends and promising show trends. These data supplemented geological information and aided in play definition in more maturely explored areas by showing, in map view, locations of dry holes and types of shows from tested wells. A brief discussion of the each play follows the review of the geology.

GEOLOGIC SETTING

General

The Palo Duro Basin and the Pedernal Uplift provinces contain two named basins, the Palo Duro Basin which is nearly confined to Texas and the Tucumcari Basin in New Mexico (Fig. 2). These basins are surrounded by structurally positive basement elements. The Palo Duro Basin is bordered by the Amarillo Uplift to the north and the Matador Arch to the south (Budnick and Smith, 1982). A minor structural high separates the Palo Duro Basin from the Hardeman Basin to the east (Budnick and Smith, 1982). The Tucumcari Basin is bound on the west and north by the Pedernal-Sierra Grande Uplift and on the south by the Frio Uplift. The Palo Duro and Tucumcari Basins are also separated by a small basement high between the Bravo Dome and the Frio Uplift (Totten, 1956).

The thickness of sedimentary rock reaches about 10,000 feet (3030 meters) in the Palo Duro Basin (Rose, 1986a; Fig.3) and about 9,000 feet (2727 meters) in the Tucumcari Basin (Roberts and others, 1976; Fig.4). The Palo Duro Basin generally becomes deeper from north to south; however, the deepest sedimentary rocks known are those on a down-dropped block south of the Amarillo Uplift (Dutton and others, 1982).

Structure

The tectonic activity that formed these basins began in Late Mississippian or Early Pennsylvanian (Ruppel, 1985). Deformation during the Pennsylvanian created complex structural patterns adjacent to the northern and southern borders of the Palo Duro Basin.

The apparent structural simplicity of the central part of the basin may be more the result of a lack of data than a lack of structure (Ruppel, 1985).

The geology of the Tucumcari Basin is not as well known as that of the Palo Duro Basin. However, similarity between sedimentary rocks of the Tucumcari and Palo Duro Basins and proximity suggest a similar history for the two basins. For this reason these two provinces are combined and assessed as a single unit.

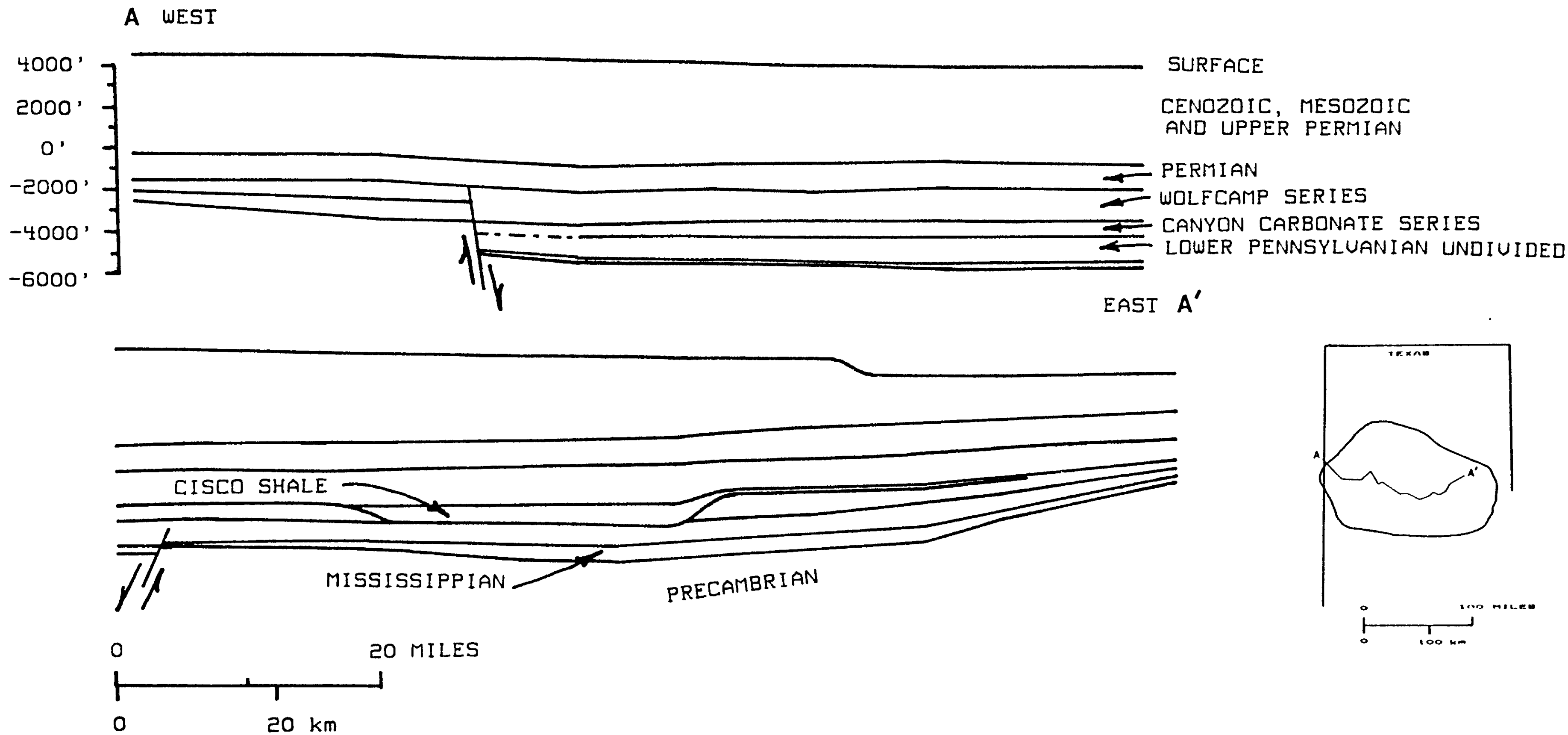

Figure 3. Structural cross section of the Palo Duro Basin (after Rose, 1986a, Exhibit 8A).

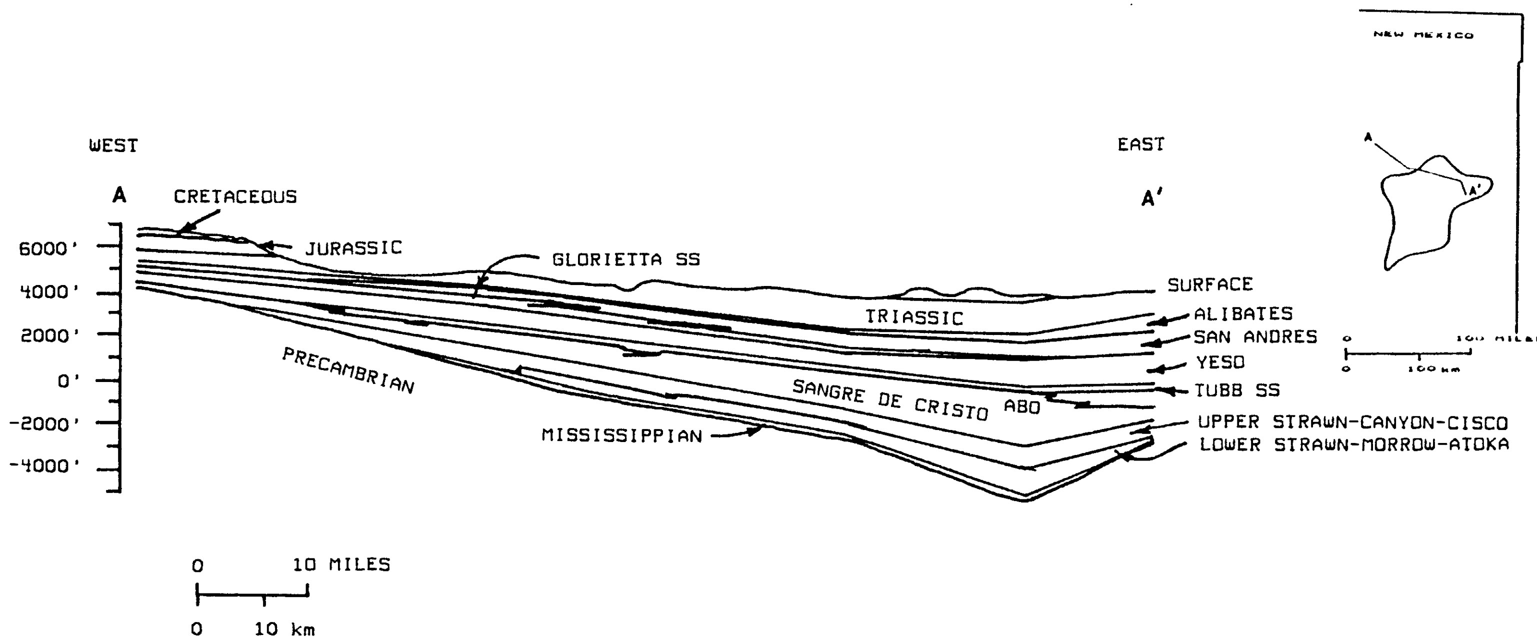

Figure 4. Structure cross section of the Tucumcari Basin (after Barnes and others, 1976, Figure 9).

STRATIGRAPHY-PALO DURO BASIN

CAMBRIAN SYSTEM

Directly above Precambrian basement lie thin beds of terrigenous siliciclastics, some shales and carbonates (Ruppel,1985). The exact age of these rocks is not unknown, however, they are believed to range from Cambrian to Ordovician (Ruppel, 1985; Fig. 5). Thicknesses of these beds are usually less than 50 feet (15 meters) but may reach 200 feet (61 meters) locally (Ruppel, 1985).

ORDOVICIAN SYSTEM

The Ordovician Ellenburger Group is represented by 200 to 500 feet (61 to 152 meters) of dolomite (Ruppel, 1985). Shale and sandstone are common in some areas and chert is common throughout the Ellenburger (Ruppel, 1985).

MISSISSIPPIAN SYSTEM

Silurian and Devonian rocks are unknown from the Palo Duro Basin; they apparently were removed by erosion during middle Denonian time (Huffman, 1959). A relatively thick sequence of up to 900 feet (275 meters) of Mississippian carbonates and some shales are present in the Palo Duro Basin. The lower part of the Mississippean section is composed primarily of cherty dolomite with some limestone and shale, the middle part is mostly limestone and the upper part is mostly limestone and sandstone (Rose, 1986a).

PENNSYLVANIAN SYSTEM

Pennsylvanian rocks record a history of uplift and erosion of nearby crystalline rocks and of basin subsidence (Roberts and others, 1976). These rocks consist of arkosic deltaic deposits, basinal shales, and shallow water limestones (Roberts and others, 1976).

Strawn Series

Strawn Series limestone beds are from 50 to 400 feet (15 to 121 meters) thick in the basin (Rose, 1986a).These rocks are mostly limestone with some finely-crystalline dolomite interpreted to result from shelf deposition (Rose, 1986a).

Canyon Series

Canyon Series carbonates range from about 700 to 1,200 feet (212 to 363 meters) thick and consist of two sub-parallel shelf

SYSTEM	SERIES	GROUP/FORMATION
TERTIARY		OGALLALA
CRETACEOUS	COMMANCHE	
TRIASSIC	DOCKUM	
PERMIAN	OCHOA	DEWEY LAKE ALIBATES SALADO
	GUADALUPE	ARTESIA GROUP SAN ANDRES
	LEONARD	GLORIETTA SANDSTONE UPPER CLEAR FORK TUBB SANDSTONE LOWER CLEAR FORK RED CAVE-WICHITA
	WOLFCAMP	WOLFCAMP
PENNSYLVANIAN	CISCO CANYON STRAWN	CISCO SHALE CANYON STRAWN
MISSISSIPPIAN	MISSISSIPPIAN	
ORDIVICIAN		ELLENBURGER GROUP
CAMBRIAN		
PRECAMBRIAN		

Figure 5. Generalized stratigraphic column of the Palo Duro Basin (modified from Rose, 1986a, Figure 2-1).

facies with a starved basin facies in between (Rose, 1986a). The shelf facies consists of skeletal limestones and dolomites, and the basin deposits are primarily organic-rich, lime mudstones (Rose,1986a).

Cisco Series

Cisco Series rocks are primarily basin deposits of dark organic-rich shales, some siltstone, sandstone and limestone (Rose, 1986a). They range in thickness from 0 to 1,400 feet (0 to 424 meters) (Rose, 1986a).

PERMIAN SYSTEM

The depositional environments of Lower Permian rocks are similar to thoes of Upper Pennsylvanian rocks. These rocks consist of fan-delta deposits, carbonate shelf deposits and basinal deposits (Dutton and others, 1982).

Wolfcamp Series

Wolfcamp Series rocks range from about 600 to 2,500 feet (182 to 758 meters) in thickness (Rose, 1986a). Basinal facies are composed of dark, calcareous shales, siltstones and tight, dark limestones (Rose, 1986a).

Leonard Series

The Wichita Group and Red Cave Formation form a genetic unit ranging from 500 to 900 feet (152-273 meters) thick (Rose, 1986a). The Wichita Group consists of anhydritic dolomite and thin red and green shale beds. The Red Cave Sandstone is primarily a red bed sequence reflecting alluvial fan and sabkha deposition (Rose, 1986a).

The Lower Clear Fork Formation and Tubb Sandstone form a genetic unit 400 to 800 feet (122 to 244 meters) thick similar to the Wichita/Red Cave sequence (Rose, 1986a). The Upper Clear Fork Formation is primarily a carbonate sequence and the Tubb Sandstone is a red bed sequence.

Post-Leonard Permian rocks

The Permian rocks overlying the Tubb Sandstone consist of evaporite and red beds. These rocks occur in thickness up to 4,000 feet (1212 meters) and include younger formations of the Leonard Series and formations of the Guadalupe and Ochoa Series (Rose, 1986a).

TRIASSIC SYSTEM

The Dockum Group of Triassic age consist of from 100 to 900 feet (30 to 273 m) of fluvial deltaic redbeds and lacustrine deposits (Rose, 1986a).

POST-TRIASSIC ROCKS

Cretaceous rocks are locally preserved as erosional remnants in the basin. The most important and conspicuous younger rock unit is the Tertiary Ogallala Formation. This unit ranges from about 100 to 900 feet (30 to 273 meters) thick, is composed of sand, silt and gravel, and forms the regions most important fresh water aquifer (Rose, 1986a).

STRATIGRAPHY-TUCUMCARI BASIN

PRE-PENNSYLVANIAN ROCKS

Pre-Pennsylvanian sediments were deposited largely in open shelf marine environments which were subjected to multiple transgressive/regressive events (Roberts and others, 1976;Petroleum Frontiers, 1986). These older rocks are primarily carbonates of the Mississippian Arroyo Penasco Group and possibly the Ordovician Ellenburger Group (Fig. 6). They reach a thickness of about 200 feet (61 meters) in the deeper part of the basin (Roberts and others, 1976).

PENNSYLVANIAN SYSTEM

Basinal sedimentation was initiated during the early Pennsylvanian (Roberts and others, 1976). Gray shales, sandstones and some coals were deposited in the northwestern part of the basin while abundant shelf carbonates were deposited to the south (Roberts and others, 1976). The maximum thickness of Pennsylvanian rocks is 2,000 feet (606 meters) in the Tucumcari Basin (Roberts and others, 1976).

PERMIAN SYSTEM

Wolfcamp Series

Lower Permian rocks are similar to underlying Upper Pennsylvanian rocks. They are continental red sandstones of the Sangre de Cristo/Abo Formations which grade into red shales and interbedded brown dolomites to the south and east (Roberts and others, 1976). These rocks are 2,500 feet (757 meters) thick in the Tucumcari Basin (Roberts and others, 1976).

Leonard Series

Leonard Series rocks are about 1,500 feet (455 meters) thick and include the Tubb Sandstone and Yeso Formation (Roberts and others, 1976). The Yeso Formation consists primarily of

SYSTEM	SERIES	GROUP/FORMATION
TERTIARY		OGALLALA
CRETACEOUS		CARLILE SHALE GREENHORN LIMESTONE GRANEROS SHALE DAKOTA SANDSTONE PAJARITO SHALE MESARICA SANDSTONE TUCUMCARI SHALE
JURASSIC		MORRISON FORMATION BELL RANCH FORMATION TODILTO FORMATION ENTRADA SANDSTONE
TRIASSIC		CHINLE FORMATION SANTA ROSA FORMATION
PERMIAN	GUADALUPE	BERNAL FORMATION SAN ANDRES LIMESTONE
	LEONARD WOLFCAMP	GLORIETTA SANDSTONE YESO FORMATION TUBB SANDSTONE ABO FORMATION SANGRE DE CRISTO FORMATION
PENNSYLVANIAN	VIRGIL	CISCO-CANYON
	MISSOURI	CANYON
	DES MOINES	STRAWN
	ATOKA	ATOKA
MISSISSIPPIAN	CHESTER MERAMAC OSAGE	ARROYO PENASCO GROUP
ORDIVICIAN?		ELLENBURGER GROUP?

Figure 6. Generalized stratigraphic column of the Tucumcari Basin (from Barnes and others, 1976; Foster and others, 1972; and Petroleum Frontiers, 1986).

shale, anhydrite and sandstone in the area (Roberts and others, 1976).

Guadalupe Series

Widespread marine transgression occurred in post-Leonard time resulting in deposition of a sequence of carbonates over much of this area (Roberts and others, 1976). The San Andres Formation of Leonardian to Guadalupian age is about 1,000 feet (303 meters) thick in the Tucumcari Basin (Roberts and others, 1976). It consists of dolomite, limestone, salt and sandstone (Kinney, 1969).

Post-Guadalupian Rocks

The Artesia Group and Bernal Formation are the youngest Paleozoic rocks in the Tucumcari Basin. These rocks are up to 1,100 feet (333 meters) thick and consist primarily of sandstone, siltstone, shale and some anhydrite (Foster and others, 1972).

TRIASSIC SYSTEM

The Dockum Group, which unconformably overlies the Permian rocks is a widespread continental deposit. These rocks are dominated by lacustrine, deltaic and fluval deposits consisting of sandstones, mudstones and shales (Foster and other, 1972; Broadhead, 1984).

The Santa Rosa Sandstone at the base of the Triassic ranges from 0 to over 400 feet (0 to 121 meters) and averages about 250 feet (76 meters) thick in the area (Foster and others, 1972).

The overlying Triassic rocks present are generally assigned to the Chinle Formation (Foster and others, 1972). These rocks may be over 1,000 feet (303 meters) thick and consist of brown to red variegated shales and siltstones with some sandstone present (Foster and others, 1972).

JURASSIC SYSTEM

Jurassic age rocks consist of the Entrada Sandstone, Toldito, Bell Ranch and Morrison Formations. The Entrada Formation is an eolian deposit of regional extent (Petroleum Frontiers, 1986). It ranges from 40 to 228 feet (12 to 70 meters) thick (Foster and others, 1972).

The Todilto Formation is present only in the northern part of the Tucumcari Basin (Petroleum Frontiers, 1986). It is a thin unit of limestone and gypsum which was deposited in a local saline embayment (Petroleum Frontiers, 1986).

The Bell Ranch Formation consists of 25 to 60 feet (8 to 18 meters) of shale, sandstone and limestone (Foster and others, 1972). Thes rocks were deposited in a lacustrine environment

(Petroleum Frontiers, 1986).

The Morrison Formation, composed mainly of shale and sandstone, is up to 250 feet (76 meters) thick in this area (Foster and others, 1972). It was deposited in a fluvial environment (Petroleum Frontiers,1986).

CRETACEOUS SYSTEM

Middle Cretaceous age deposition was characterized by the return of marine conditions (Petroleum Frontiers, 1986). The Tucumcari Shale is described as a basal transgressive shale deposit (Petroleum Frontiers, 1986). Above the Tucumcari Shale lies the Mesa Rica Sandstone, Pajarita Shale and Dakota Sandstone which were deposited in a fluvial-deltaic environment during a marine regression event (Petroleum Frontiers, 1986). This section of rock ranges from 120 to 200 feet (36 to 61 meters) thick (Foster and others, 1972).

The Graneros Shale, Greenhorn Limestone and Carlile Shale were deposited in the final marine transgressive event which marked the close of the Cretaceous (Petroleum Frontiers, 1986). The combined thickness of these three formations ranges from 160 to 580 feet (48 to 176 meters).

CENOZOIC ROCKS

The Tertiary Ogallala Formation and Quaternary alluvium complete the stratigraphic section in this area. The Ogallala Formation occurs in the subsurface in large areas of east-central New Mexico and in limited surface exposures within this province (Foster and others, 1972). It consists of conglomerate and sandstone and ranges from 0 to 550 feet (0 to 167 meters) thick (Foster and others, 1972). Quaternary material consists of unconsolidated detritus derived locally. This material consists of sand, silt, clay and gravel found in active dunes and alluvial deposits (Foster and others,1972).

SOURCE ROCKS

PALO DURO BASIN

Source rocks in the Palo Duro Basin are best developed in basinal shales near the Pennsylvanian-Permian boundary. Total organic carbon (TOC) content of these shales reaches up to 2.4 percent but probably averages less than 0.5 percent (Dutton and others, 1982). The isopleths showing higher TOC values (>0.5 percent) occur in the same general area as the inferred basin axis during Pennsylvanian time (Dutton and others, 1982; fig. 46). These TOC values appear to be given as weight percent, although that is not stated.

TUCUMCARI BASIN

A propietary report summarized by Petroleum Frontiers (1986) suggests that suitable source rocks exist in this basin. Lower Pennsylvanian shales are reported to contain from 0.5 to 2.0 percent TOC. These values appear to be given in weight percent, although that is not stated.

BURIAL HISTORY, THERMAL MATURITY AND MIGRATION

Erosional remnants of post-Paleozoic rocks suggest a deeper burial of the potential source rocks, discussed above, in the past. Estimates of maximum temperatures to which source rocks were subjected based on their current depth and the present day geothermal gradient are probably low. This is supported by thermal maturity data from the Tucumcari and Palo Duro Basins.

PALO DURO BASIN

Thermal maturity indicies measured by Dutton and others (1982) indicated that source rocks in the basin had been subjected to sufficient heat to begin hydorcarbon generation. Measured values for the thermal alteration index (TAI) and vitrinite reflectance (percent Ro) were about 3 (TAI) and about 0.48-0.49 percent Ro (Dutton and others, 1982).

TUCUMCARI BASIN

Thermal maturity data (Petroleum Frontiers, 1986) show that source rocks in this basin could have produced hydrocarbons. That report listed the following values; TAI = 3 to 4, percent Ro = 1.1 to 1.2. This increase of thermal maturity indicies, compared to those of the Palo Duro Basin, may reflect the effects of deeper burial and/or a higher geothermal gradient in the Tucumcari Basin. A very general southeast to northwest increase in the present day geothermal gradient across the state of New Mexico is suggested by data from Summers (1965).

Most of the structures in these two basins were formed during the Paleozoic and Mesozoic (Petroleum Frontiers, 1986; Rose, 1986a). The recent onset of hydrocarbon generation shown by Lopatin modelling (Rose, 1986b) implies favorable timing between possible hydrocarbon generation and trap forming structural deformation.

HYDROCARBON OCCURRENCE

PALO DURO BASIN

Total accumulated production from the Palo Duro Basin amounts to nearly 170 MMBO and 100 BCFG. Production is generally restricted to the northern and southern boundaries of the basin. Nearly ninety percent of the oil produced from this province has come from the Anton-Irish oil field located on the Matador Arch along the southern border.

Along the northern border of the basin in Oldham and Potter counties, Texas, oil is produced from structural traps within Pennsylvanian sandstones and carbonates. These traps are related to uplift and faulting near the Bravo Dome (Rose, 1986b).

East of this area, in a structurally similar setting, is a gas prone area which is now used mainly for gas storage. Traps here are also structural, related to the Amarillo Uplift, and occur in Pennsylvanian and Permian sandstones and carbonates.

Along the southern border of the basin is a linear producing trend which is nearly coincident with the Matador Arch. This trend accounts for 96 percent of the cumulative production of the basin. Oil here is found in structural and combination traps formed in Pennsylvanian and Permian carbonates.

TUCUMCARI BASIN

Tar sands exist near Santa Rosa, New Mexico. These sands occur as surface and near surface deposits which were mined during the 1930's for road surfacing material (Petroleum Frontiers, 1986). Budding (1979) estimates that over 90 MMBO exists in the tar sands. In addition to the tar sand deposits a heavy oil (API = 15 to 17 degrees) accumulation exists about 20 miles northeast of Santa Rosa at the Newkirk field. Two pilot steam-flood projects were begun in 1981 and by 1984, when the project was suspended, only 340 barrels of oil had been recovered (Petroleum Frontiers,1986). Many of the problems encountered were related to the thinness (rapid heat loss) and shallowness (low injection pressures to prevent excessive fracturing) of the reservoir beds (Petroleum Frontiers,1986).

IDENTIFIED PLAYS

PALO DURO BASIN

Four plays were identified in the Palo Duro basin. Three of these, the Northern Structural play, the Shelf-Carbonate play and the Matador Arch play produce or have produced hydrocarbons. The Pennsylvanian Stratigraphic play is hypothetical.

In the northern and southern parts of the basin proximity to bounding uplifted areas is the dominant characteristic shared by known accumulations. Because of the liklihood of two distinct sources for accumulations in these areas they have been separated into a Northern Structural play and a Matador Arch play.

Near the northern boundary there is also a possibility of traps within Pennsylvanian sandstone reservoirs that are not dominated by structure. This Lower Pennsylvanian Stratigraphic play is a hypothetical play and consists of reservoirs formed in arkosic fan-delta systems south of the bordering uplifts. Traps would be more stratigraphic than structural in nature.

The fourth play, the Shelf-Carbonate play, exists along and behind the shelf margins where porous carbonate zones occur. These traps are expected to be primarily stratigraphic in nature also.

Northern Structural Play

This play constitutes a major play in the Palo Duro Basin and probably represents the only area of accumulation of significant amounts of indigenous Palo Duro Basin hydrocarbons. It includes rocks which range in age from early Pennsylvanian to middle Permian and are composed of porous carbonates and granite wash material. Porosities range from 3 to 21 percent and average about 14 percent (Dutton and others, 1982). This play borders ancient highlands north of the Palo Duro and Tucumcari Basins (Fig. 7).

Traps in this play all display dominant structural control (Rose, 1986b) with some stratigraphic control in the form of limestone porosity variation and sandstones which pinch out in shales or tight limestones. Structural traps are low relief anticlines related to en echelon faulting near the Bravo Dome and the Amarillo Uplift (Rose, 1986b). Seals are probably shales and tight limestones (Dutton and others, 1982).

Source rocks for this play are probably the relatively rich (for this province) shales of Upper Pennsylvanian and Lower Permian basinal shale sequences. These rocks are down faulted in the area of the Whittenburg Trough and are probably more mature here than in other parts of the basin (Dutton and others, 1982; Rose, 1986b). Organic content reaches 2.4 percent, and these are generally poor to good quality source beds (Dutton and others, 1982).

Timing is favorable and proposed migration routes (Rose, 1986b) correlate well with the locations of probable source rocks and known hydrocarbon accumulations.

Reservoir rocks are known to exist at depths of from about 2,600 feet (787 meters) to about 10,000 feet (3030 meters).

The first discovery in this play was in 1924 and the most recent was in 1983. Twenty fields produce from this play, seventeen of them near the Bravo Dome which have a combined cumulative production of about 4 MMBO as of 1984 and three in the Whittenburg Trough with a combined cumulative production of nearly 100 billion cubic feet of gas and about 8 thousand barrels of oil as of 1984 (see Table 1).

This play is the most promising in terms of future discoveries of any true Palo Duro play identified. Limitations to future discoveries are the known areal extent of favorable

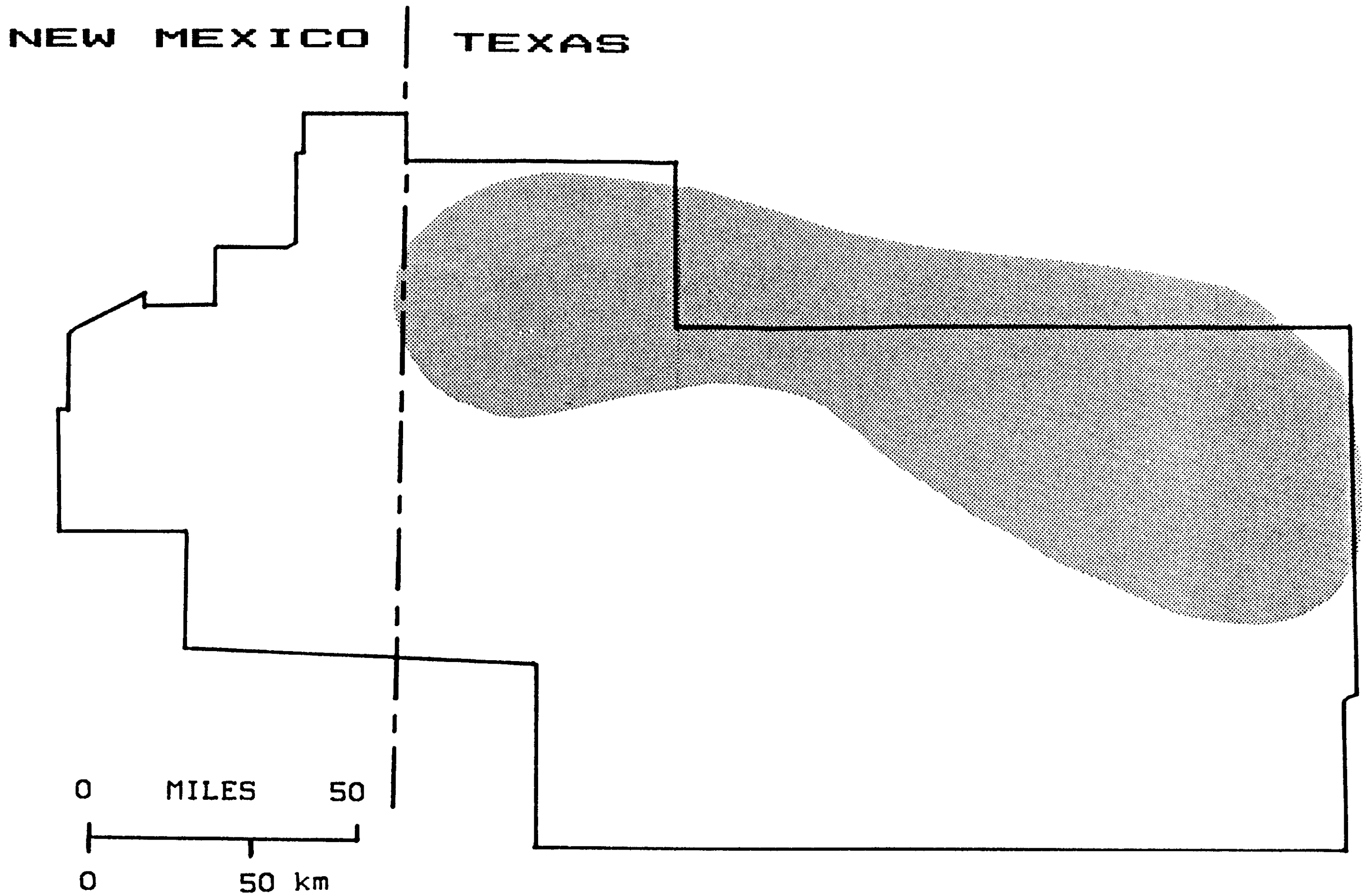

Figure 7. Shaded area indicates the Northern Strucyural play.

Table 1. Oil and/or gas fields with ultimate recovery greater than 1 MMBO or 6BCFG respectively (data from Rose, 1986b; play assignments this paper).

Field name	Disc. Date	Trap type	Reservoir type	Cumulative production
		Northern Structural Play		
Cliffside	1924	Structural	Wichita and Wolfcamp	98.0 BCFG
Hryhor	1982	Structural	Pennsylvanian	0.9 MMBO
Lambert One	1979	Structural	Pennsylvanian	1.6 MMBO
Manarte	1969	Structural	Pennsylvanian	2.9 MMBO
Sundance	1981	Structural	Pennsylvanian	0.9 MMBO
		Shelf-Carbonate Play		
Cee Vee	1975	Combination	Pennsylvanian	0.9 MMBO
		Matador Arch Play		
Anton, West	1950	Combination	Permian	1.6 MMBO
Anton-Irish	1945	Combination	Permian	150.0 MMBO
Illusion Lake	1957	Combination	Permian	2.1 MMBO
Littlefield	1953	Combination	Permian	4.7 MMBO
Roaring Springs	1957	Structural	Pennsylvanian	5.5 MMBO
Roaring Springs	1958	Structural	Pennsylvanian	2.0 MMBO

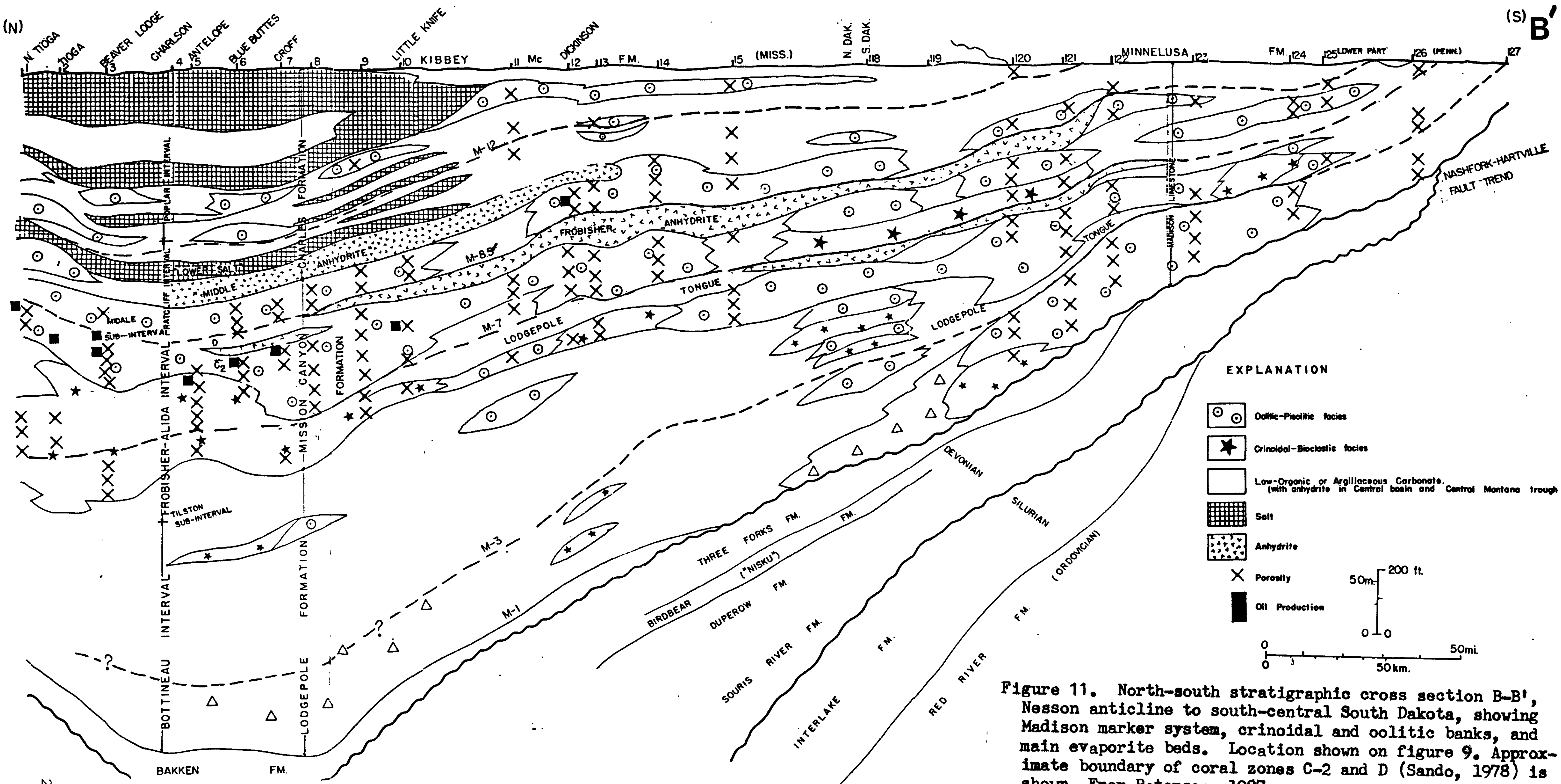

Figure 11. North-south stratigraphic cross section B-B', Nesson anticline to south-central South Dakota, showing Madison marker system, crinoidal and oolitic banks, and main evaporite beds. Location shown on figure 9. Approximate boundary of coral zones C-2 and D (Sando, 1978) is shown. From Peterson, 1987.

structural trap-forming elements and the limited volumes of source rocks which have reached thermal maturity.

Matador Arch Play

Known productive zones in this play are comprised entirely of porous carbonates which cross the Matador Arch (Fig. 8). Productive zones include one field of Mississippian age rocks, ten fields of Pennsylvanian age rocks, and ten fields of Permian age rocks (Table 1.).

Traps found along the Matador Arch are all related to structure and future discoveries are expected to follow this pattern. Because of the rather mature stage of development of the play more subtle stratigraphic traps will probably become increasingly important in future discoveries. Potential shale and evaporite unit seals are numerous in the section.

Source rocks in the Palo Duro Basin are generally lean and immature. Primarily for these reasons, Rose (1986a) believes that the fields along the Matador Arch were charged from the southwith oil migrating from the rich Permian Basin.

Timing is not a limiting factor as evidenced by the presence of production in the area.

Potential reservoir rocks are known to occur in this play from about 3,000 feet (909 meters) to almost 10,000 feet (3030 meters).

Lower Pennsylvanian Stratigraphic Play

This play consists primarily of clastic reservoir rocks which are not associated with major faulting near the Bravo Dome or the Whittenburg Trough (Fig. 9). These rocks were deposited by fan-delta complexes near the positive features to the north of the basin (Dutton and others, 1982). Porosity of these sandstones is variable from 3 to 21 percent and averages about 14 percent (Dutton and others, 1982).

Traps in this play are expected to be primarily stratigraphic, with porous sandstone facies pinching out within tight limestones or shales (Dutton and others, 1982).

Source rocks for this play are most likely the dark Pennsylvanian basinal shales deposited in the area. Geochemical analyses indicate that although these shales are not high quality, mature source rocks, they probably have generated some hydrocarbons (Dutton and others, 1982).

The relation between timing of oil migration and trap development does not seem to be a factor in hydrocarbon accumulation in this play. Rather shallow burial depth or low geothermal gradient (temprature effect) or both and the relatively low quality of the source rocks would indicate only marginal oil generation in the area. This would be the chief reason for the general lack of hydrocarbon accumulations in the basin.

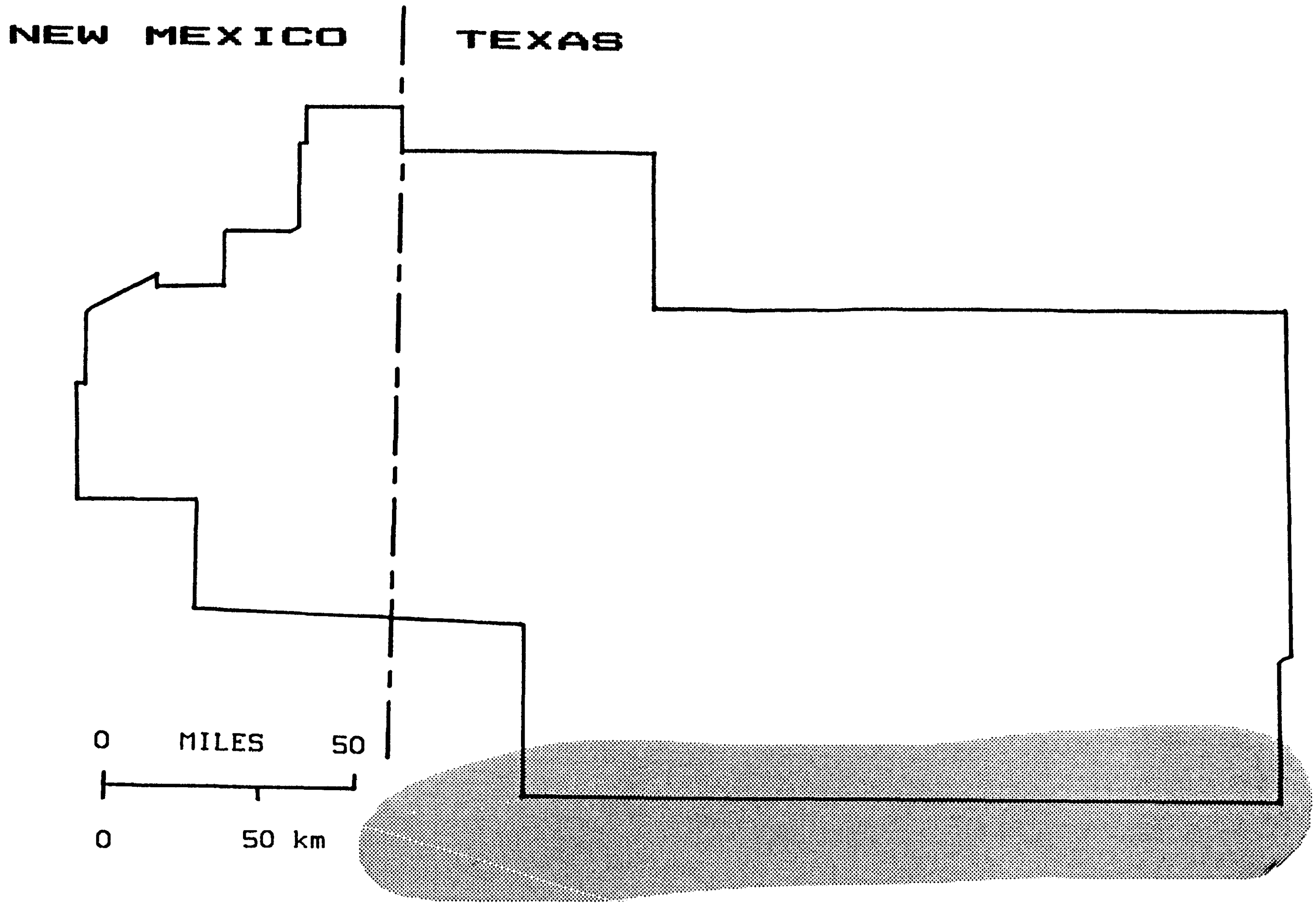

Figure 8. Shaded area indicates the Matador Arch play.

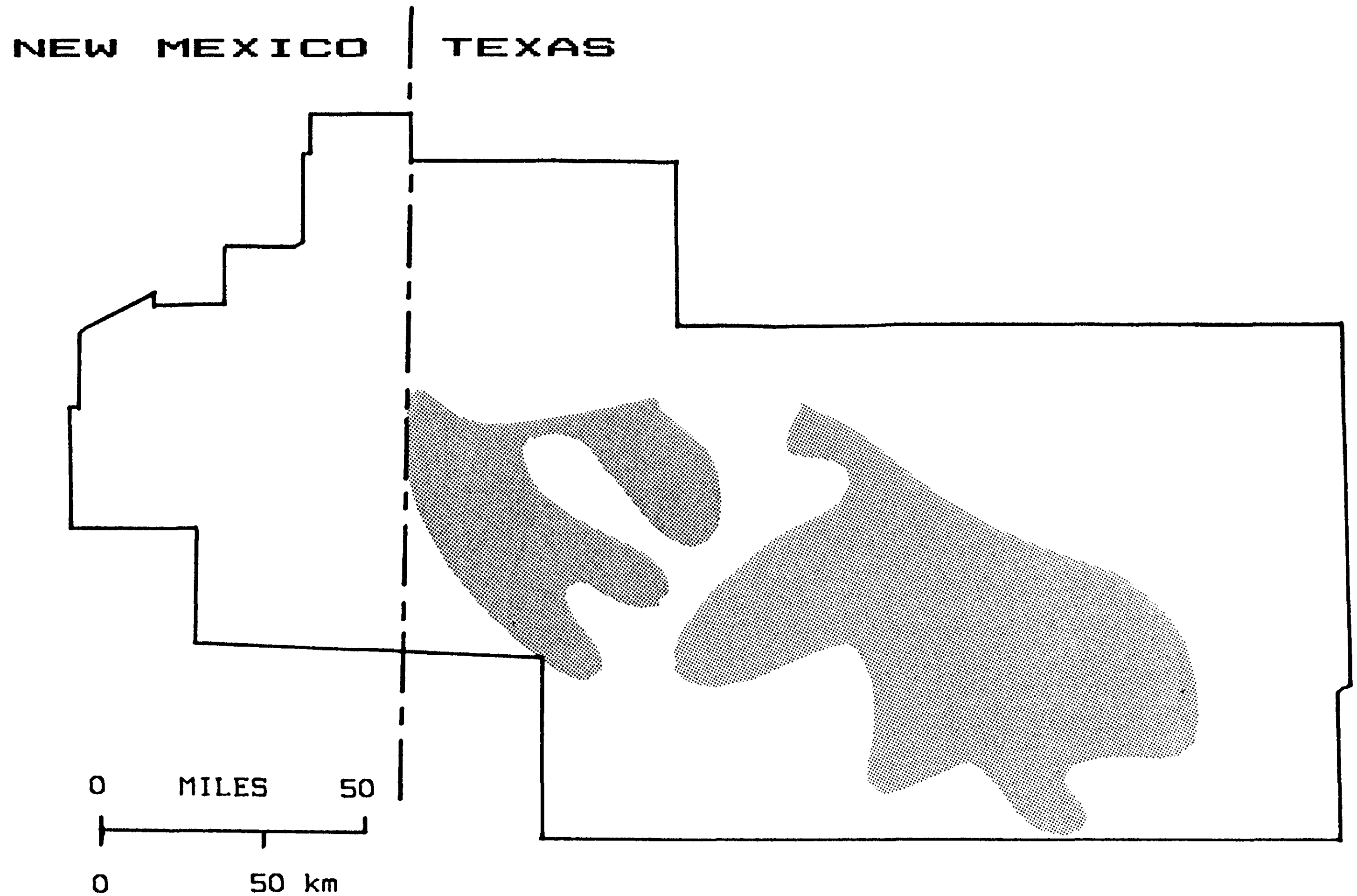

Figure 9. Shaded area indicates the Lower Pennsylvanian Stratigraphic play. Distribution of rocks forming this play from Dutton and others(1982).

Potential reservoir rocks in this play range in age from lower to middle Pennsylvanian and occur from about 3,000 feet (909 meters) to about 9,000 feet (2727 meters).

Shelf-Carbonate Play

The Shelf-Carbonate play is found in Pennsylvanian and Permian shelf carbonates in the Palo Duro and Tucumcari Basins (Fig. 10). The play is better defined in the Palo Duro Basin proper where the work of Hanford and Dutton (1980) and Dutton and others (1982) report the presence of porous carbonate facies which could form suitable reservoir rocks. The play is extended into the New Mexico portion of the province (Tucumcari Basin) by analogy with, and proximity to, the Palo Duro Basin but the actual development of good reservoir porosity is not known.

Reservoir rocks forming this play are primarily Strawn, Canyon, Wolfcamp and Leonard limestones and some Cisco limestones. These rocks display fair to excellent porosities of from 6 to 20 percent in places but are generally tight (Rose, 1986a). The play is primarily stratigraphic except near the extreme northern and southern province boundary where structural controls become most important. Seals in the central part of the Palo Duro Basin and in the Tucumcari Basin are probably formed by Cisco shales overlying porous zones of Strawn and Canyon rocks (Rose, 1986a).

Wolfcamp rocks are not as attractive as reservoirs because they are generally tight (Rose, 1986a). These rocks have produced small amounts of oil and gas in small structurally controlled accumulations near the Amarillo Uplift and the Matador Arch. The upper part of the Wolfcamp, which contains the most favorable porosity development has been shown to be a regional saline aquifer (Bassett and Bentley, 1983).

Source rocks in this play are probably basinal shales having total organic content (TOC) of over 0.5 percent as shown by Dutton and others (1982). These rocks are not yet fully mature with regard to petroleum generation.

Timing of migration is not a limiting factor for this play because traps and seals now exist and hydrocarbon generation is presently occurring. Migration pathways have been postulated by Rose (1986b) which indicate a general movement out of the basinal shales toward the north with minor directions toward the south, east and west. These proposed pathways are in good agreement with the known locations of productive areas within the province boundary. The reservoir rocks of this play occur at depths from about 3000 feet (909 meters) to about 10,000 feet (3030 meters). There has been some production from this play from the Cee Vee field (see Table 1).

Future resource discoveries found in this play will probably not be significant. Factors limiting future discoveries are the maturity of source rocks and a lack of traps.

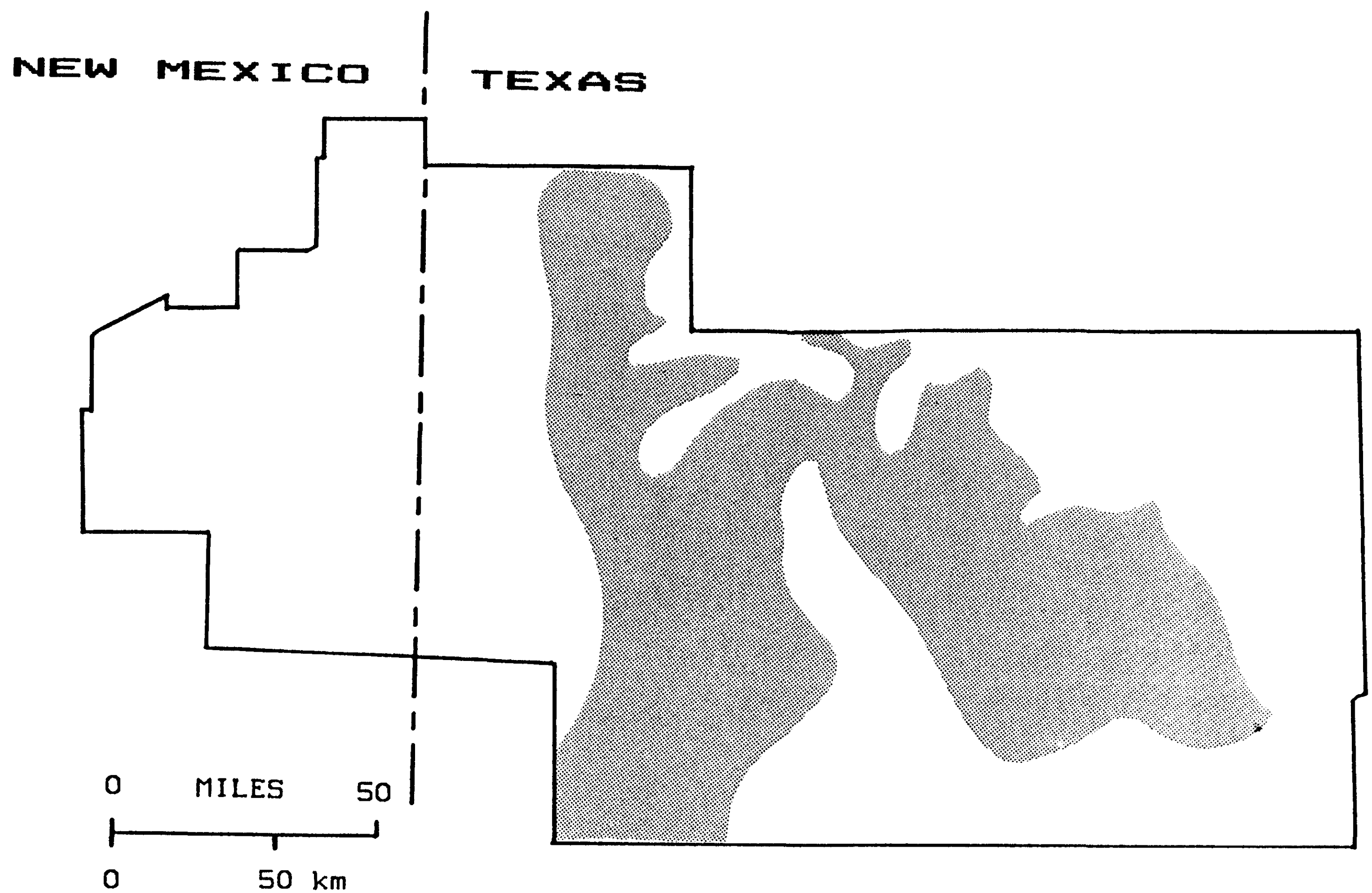

Figure 10. Shaded area indicates the Shelf-Carbonate play.
Distribution of rocks forming this play from Dutton and others(1982).

PEDERNAL UPLIFT

Faulting associated with bounding uplifts are known to exist in the Tucumcari Basin (Petroleum Frontiers, 1986). For this reason, and because any hydrocarbons in this basin would probably have a local source, a single structural play, the Basin Margin Structural Play, is envisioned to surround the deeper parts of the basin. This play corresponds to the Northern Structural and Matador Arch plays of the Palo Duro Basin. A Pennsylvanian-Permian Stratigraphic play similar to the Lower Pennsylvanian Stratigraphic play in the Palo Duro Basin is described for the Tucumcari Basin. A Shelf- Carbonate play may exist in the Tucumcari Basin similar to that identified in the Palo Duro Basin. The final play identified in the Tucumcari Basin is the Triassic-Dockum Play. This play is known to contain significant quantities of heavy oil and tar sands in the area and may be more important as proof that oil does exist in the basin than as a future target.

Basin Margin Structural Play

This hypothetical play consists primarily of Pennsylvanian and Permian rocks that may contain structural traps around the basin margin (Fig. 11). This single play is similar to the Northern Structural Play and the Matador Arch Play in the Palo Duro Basin.

Reservoir rocks are limestones and sandstones that have been involved in known and interpreted faulting around the margin of the basin. Limestone reservoirs are more likely to occur in the southern parts of the basin than in the northern parts (Roberts and others, 1976).

Traps are likely to be formed by high angle faults (Petroleum Frontiers, 1986) sealing porous units against less porous units and by the creation of anticlines.

Potential source rocks and thermal maturity and migration data for this play are the same as for the Shelf Carbonate Play discussed later.

This play exists at depths of from about 2000 feet (606 meters) to about 6500 feet (1970 meters).

Pennsylvanian-Permian Stratigraphic Play

This play is comprised of Pennsylvanian and Permian rocks which were deposited in nearshore marine and continental environments (Fig. 12). They consist of sandstones, some shales, coals and limestones (Roberts and others, 1976).

Traps are likely to be stratigraphic or combination in nature due to rapid facies changes in the play (Foster and others, 1972). Seals are probably interbedded shales and limestones. Source beds for this play are probably the

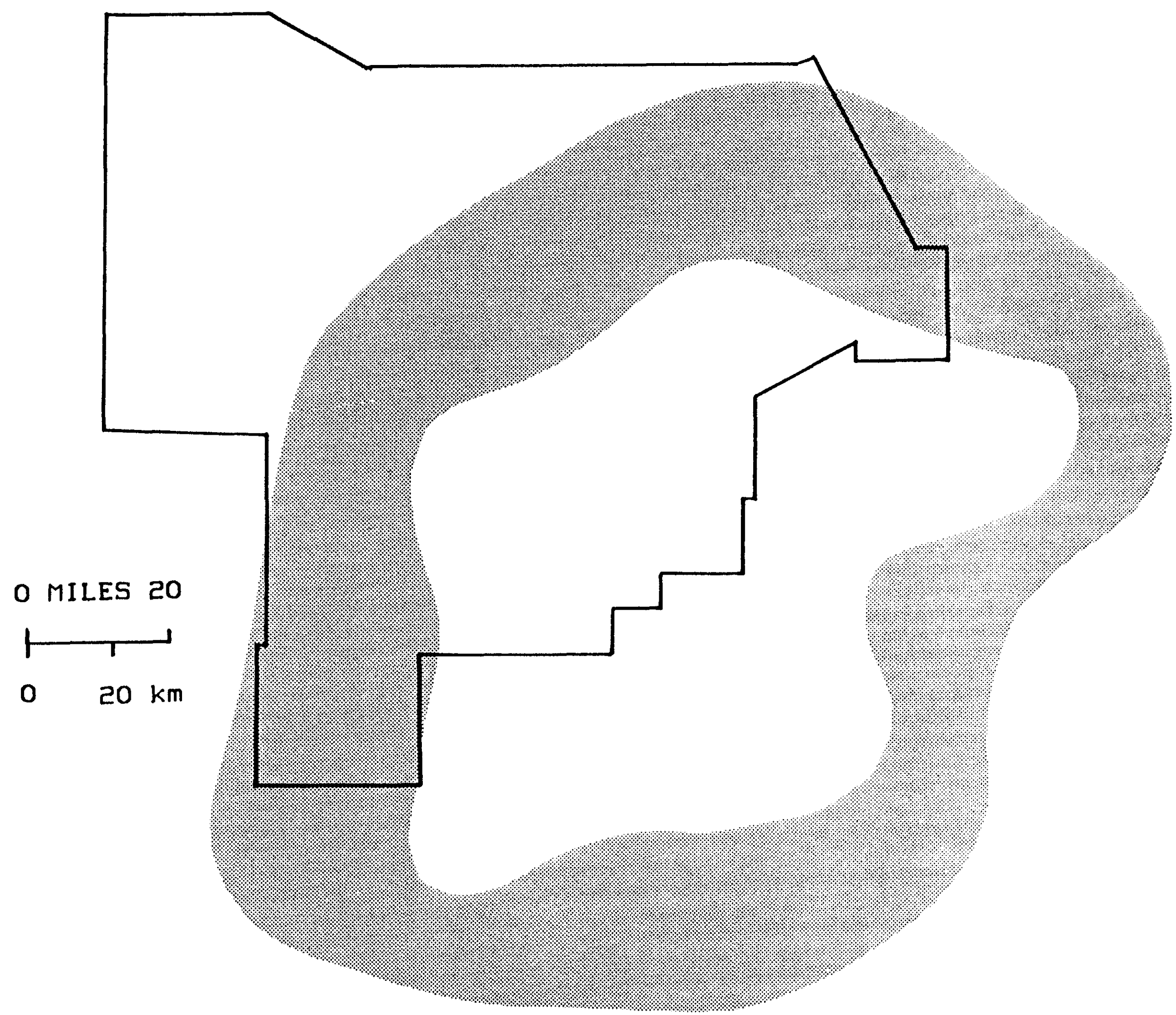

Figure 11. Shaded area indicates the Basin Margin Structural play.

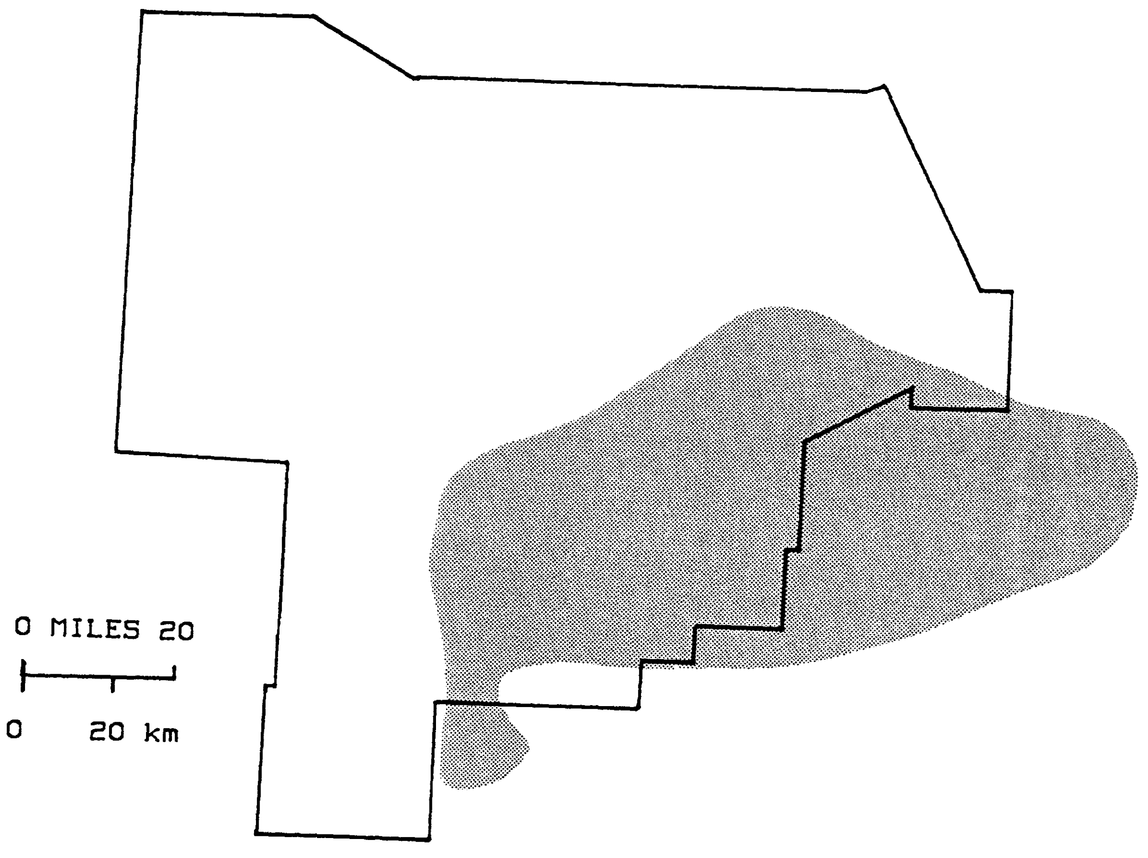

Figure 12. Shaded area indicates the Pennsylvanian-Permian Stratigraphic play. Distribution of rocks forming this play modified from Roberts and others, 1976.

dark basinal shales described by Roberts and others (1976).

Hydrocarbon generation could have begun as early as 210 million years ago based upon present burial depths, an assumed burial history and a geothermal gradient of 1.8 F/100 feet. Migration could limit the existence of petroleum resources in this play. Petroleum entering these porous and permeable beds may have, in many cases, migrated out of them.

Rocks of this play occur at depths of from 1700 feet (515 meters) to 7800 feet (2363 meters). There is no known production from this play in the province. There is, however, tight gas production from the Lower Permian red beds in Chaves County to the south (Broadhead, 1984). This type of trapping may be limited by the lack of adequate seals rather than the lack of reservoirs (Broadhead, 1984).

It is not likely that this play wil contain significant future resources. This conclusion may be largely the result of lack of sufficient borehole data and the possible lack of effective trapping mechanisms.

Shelf-Carbonate Play

The play consists of Pennsylvanian and Permian shelf carbonates. This facies is known to display good reservoir characteristics a few miles to the east in the Palo Duro Basin (Dutton and others, 1982).

Reservoir rocks are limestones, which exist in greater abundance on the southern side of the Basin (Fig. 13), deposited away from clastic sources (Roberts and others, 1976).

Traps are likely to be stratigraphic with seals being formed by tighter limestones in the sequence.

Detailed studies of source rocks in this province are limited. Basinal facies rocks described as dark and fine grained are shown to exist in the deeper parts of the Tucumcari Basin in Lower Pennsylvanian rocks (Roberts and other, 1976).

Potential source rocks in this area are found at about the same depth as they are in the Palo Duro Basin, and similarly may be just entering the petroleum generating zone. Deeper burial or higher paleogeothermal gradients would have enhanced the likelihood of hydrocarbon generation from these source beds. Geothermal gradients from temperature logs from wells drilled in New Mexico indicate a low value of 0.4 F/100 feet in the southeastern part of the state to a high value of 2.6 F/100 feet in the north western part of the state (Summers, 1965). None of these measurements was in the two counties comprising this province. The nearest measurement was in Harding County with a value of 1.8 F/100 feet. If this value is truly representative of the entire province it suggests a higher degree of maturity for the western part of the Tucumcari Basin, than for the eastern part.

Timing between trap formation (late Paleozoic) and hydrocarbon generation (post Triassic?) is favorable for this

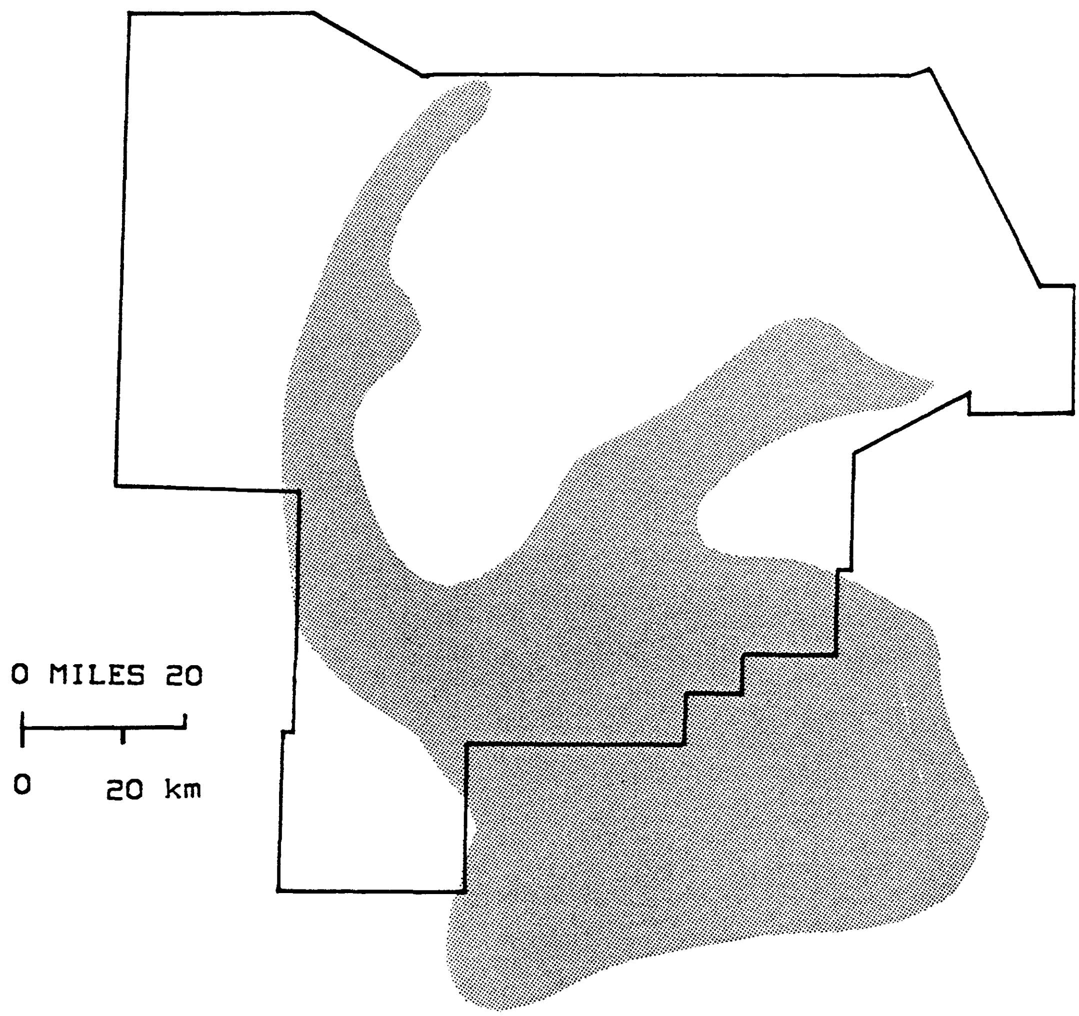

Figure 13. Shaded area indicates the Shelf-Carbonate play. Distribution of rocks forming this play modified from Roberts and others, 1976.

play. Lateral migration from basinal shales could have charged carbonate stratigraphic traps up dip.

Known depths of this play range from about 3000 feet (909 meters) to about 8000 feet (2424 meters).

With only about 200 wells drilled in an area this size (nearly 20,000 square km) it is in an early stage of exploration. Most of the wells were drilled on surface structures and all were dry. No production exists in this play.

If a geothermal gradient of 1.8 F/100 feet is representative for the entire area and if the source rocks contained adequate organic material, hydrocarbons could have been generated and trapped. However, sparce drilling and lack of source rock richness, reservoir potential and subsurface temperature information may limit future hydrocarbon discoveries.

Triassic-Dockum Play

This play consists of the Santa Rosa Sandstone, a medium to coarse grained blanket sandstone located at the base of the Dockum Group (Broadhead, 1984). These rocks were deposited in fluvial, deltaic and lacustrine environments (Fig. 14).

Reservoir rocks are porous and permeable intervals of the upper and lower sandstone units in the Santa Rosa Sandstone. Porosity ranges from 0 to 36 percent for individual wells and averages about 20 percent in the O'Connell Ranch area of the Newkirk oil field (Broadhead, 1984).

Stratigraphic, structural and combination traps may exist in this play. The blanket nature of the sandstone suggest the importance of structure as a trapping mechanism (Broadhead, 1984). Numerous reports of dead oil indicate that large quantities of oil may have accumulated in the Santa Rosa but were either flushed out or migrated out (Broadhead, 1984). Structural or stratigraphic traps farther east of Santa Rosa outcrops may contain oil deposits. The possibility also exists for hydrodynamic trapping in structurally low areas (Broadhead, 1984).

Potential source rocks for the known oil deposits are the San Andres Formation (Gorman and Robeck, 1946; Budding, 1979) or deeper Pennsylvanian rocks (Broadhead, 1984). Geochemical analyses based on stable carbon isotopes by Budding (1979) indicate that Santa Rosa oils were derived from a source which had a delta C value greater than or equal to -26.6. This value is approximately equal to the values reported for Permian oils of the Permian Basin but lighter than those reported for Pennsylvanian oils of the Permian Basin (Broadhead, 1984). Despite this geochemical match it appears that San Andres rocks have not had a time-temperature history sufficient to have caused significant oil generation. A higher paleo-geothermal

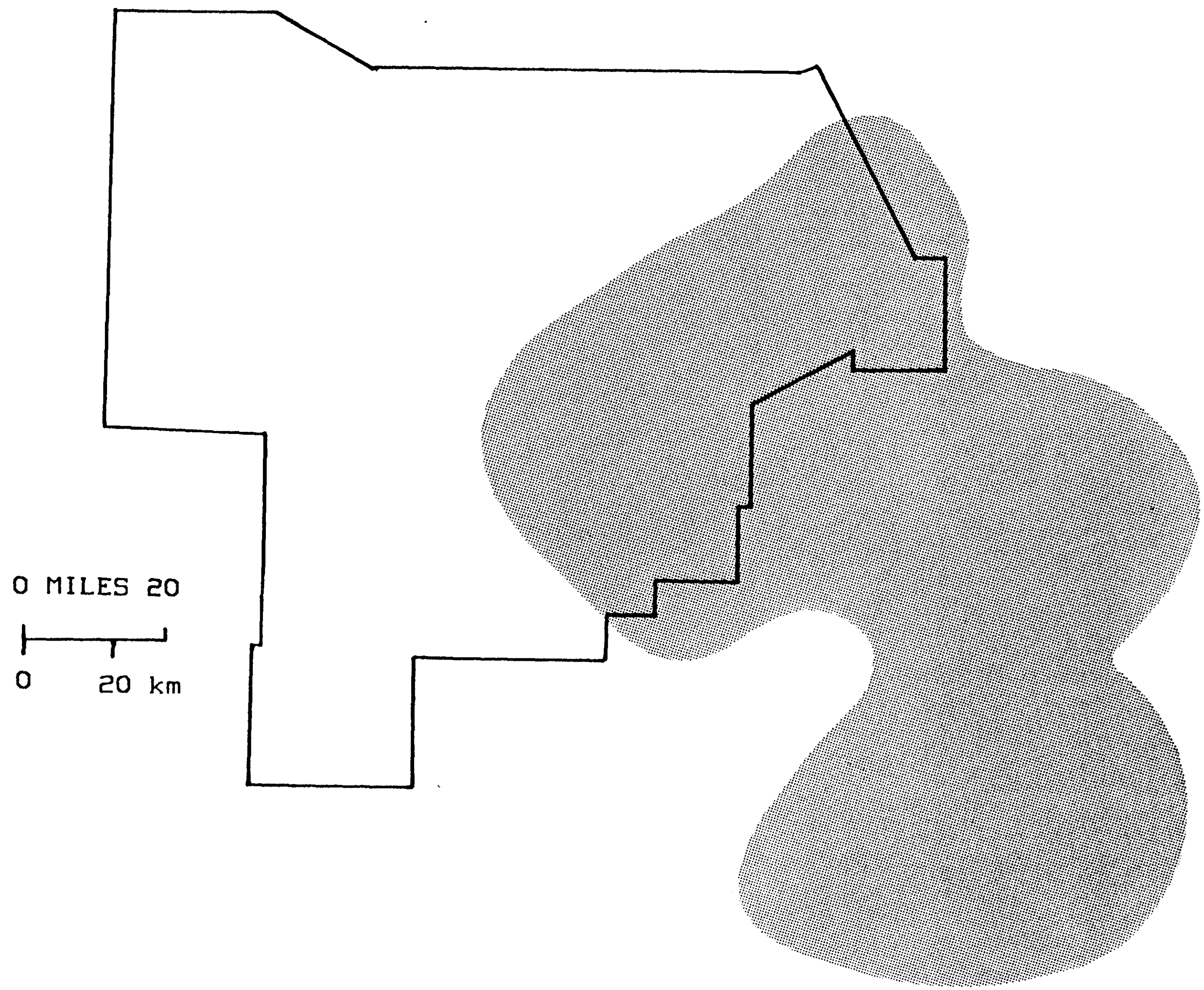

Figure 14. Shaded area indicates the Triassic-Dockum play. Distribution of rocks forming this play modified from Broadhead, 1984.

gradient or deeper burial seems necessary for these rocks to have produced oil. The geothermal gradient is probably higher in the Pedernal Province than it is in the Palo Duro Province (Summers, 1965) but even a gradient of 1.8 F/100 feet does not make the San Andres an attractive source bed.

Timing is difficult to assess without identification of source beds. If San Andres beds supplied the oil, it was probably emplaced quite recently as oil generation may still be occurring. If, however, Pennsylvanian rocks were the source, emplacement may have been as early as the Triassic, 210 million years ago.

Migration pathways were probably faults allowing vertical migration from source beds below.

Reservoir rocks occur at depths of from 0 to about 1600 feet (484 meters) in the area.

Hydrocarbons are known from two areas within the play, the Santa Rosa tar sands and the heavy oil accumulations at the Newkirk oil field (O'Connell Ranch and T-4 Ranch areas). Oil impregnated sandstone was mined from the Santa Rosa tar sands from 1930 to 1939 and about 153,000 tons of material were removed (Gorman and Robeck, 1946). Plans to extract the oil from the sandstone were alive until 1983. An estimated 91 MBO in place exists here (Budding, 1979).

Heavy oil (API gravity 15-17) was discovered at the O'Connell Ranch and T-4 Ranch fields in the early 1960's (Broadhead, 1984). Attempted production by steam flooding at these two locations has been unsuccessful yielding only about 340 barrels of oil.

Although good reservoir rocks and oil accumulations are known to exist, and it is possible that hydrodynamic and other trapping mechanisms also exist, this play is not likely to become an important oil producer. The play is too shallow in parts of the province, there is a potential for water flushing out oil accumulations and known deposits are heavy, immature and biodegraded.

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