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Petroleum Exploration Plays and Resource Estimates, 1989, Onshore United States-- Region 5, West Texas and Eastern New Mexico

By

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PETROLEUM EXPLORATION PLAYS AND RESOURCE ESTIMATES, 1989 ONSHORE UNITED STATES-- REGION 5, WEST TEXAS AND EASTERN NEW MEXICO

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INTRODUCTION

By Richard B. Powers

This report, one of a series, provides brief discussions of the petroleum geology, play descriptions, and resource estimates of 20 individually assessed exploration plays in 5 onshore geologic provinces in assessment Region 5 within the continental United States; these 5 onshore provinces were among 80 provinces, including 220 total plays, that were assessed in connection with the determination of the Nation's estimated undiscovered resources of oil and gas in 1989. The report is an outgrowth of, and is based on, studies that led to the publication of "Estimates of undiscovered conventional oil and gas resources in the United States--A part of the Nation's energy endowment" (Mast and others, 1989). That report, a cooperative effort by the USGS (U.S. Geological Survey) and MMS (Minerals Management Service), presented estimates of undiscovered conventionally recoverable oil and gas for both the onshore and offshore geologic provinces of the Nation. The data sources, assumptions, and methodologies used in the development of these estimates are summarized in Mast and others (1989) and described in more detail in a joint USGS-MMS Working Paper, U.S. Geological Survey Open-File Report 88-373 (1988). The plays discussed in this present report are those that are located exclusively within the onshore United States and where applicable, adjoining State offshore areas, as assessed by the USGS. All estimates of undiscovered oil and gas resources are as of January 1, 1987; additional data received after that date were not incorporated into the assessment.

In the 1989 National appraisal of undiscovered oil and gas resources, plays were the basic unit for quantitative estimates; this report presents not only the play estimates, but also the framework and petroleum geology for each of these basic units. Play discussions here summarize the open-file reports which were prepared by the geologists assigned to each assessment area. We are presenting the resource estimates and narrative descriptions at this basic play level because of the great interest shown by the public, State Geological Surveys, the oil and gas industry, and workers involved in oil and gas appraisal.

Sources of information for province studies included published and purchased data, data from USGS studies in progress, data from previous resource assessments, data from State Geological Surveys, and analysis of geological, geochemical, and geophysical data from various sources utilized in developing and defining plays. Computerized drilling and well completion data from oil and gas exploratory and development wells came from PI WHCS (Petroleum Information Corporation's Well History Control System). In addition, data on oil and gas fields were obtained from the "Significant oil and gas fields of the United States" file of NRG Associates, Inc.,of 1986, and from the PI PDS (Petroleum Data System) computerized file of 1986. Additional statistical information on field production and reserves was obtained from yearly publications of various State oil and gas commissions, or their equivalents.

Uncertainties are inherent in estimating undiscovered quantities of oil and gas. Play estimates presented here are judgmental and are based upon a variety of geologic data, records of exploration successes and failures, production histories, assumptions of economic and technical conditions, and appraisal methods. Methodologies were developed to aid in making decisions under conditions of uncertainty, and the results are presented as ranges of values with associated probabilities of occurrence. The estimates should be viewed as indicators, not absolutes, of the petroleum potential of the plays. The plays range from those in mature, established producing basins, to highly speculative, frontier-type plays in provinces that have experienced scant exploration or wildcat drilling.

COMMODITIES ASSESSED

Commodities assessed in this study are crude oil, natural gas, and natural gas liquids that exist in conventional reservoirs. Terms defined here are standard usage of the the oil and natural gas industry and resource estimation.

Undiscovered recoverable resources.--Resources in undiscovered accumulations analogous to those in existing fields which are producible with current recovery technology and efficiency, but without reference to economic viability. These resources occupy the area of the heavily framed box in figure 1.

Conventional resources.--Resources included in this category are crude oil, natural gas, and natural gas liquids that exist in reservoirs or in a fluid state amenable to extraction techniques employed in traditional development practices. They occur as discrete accumulations. They do not include oil occurring within extremely viscous and intractable heavy oil deposits, tar deposits, or oil shales, or gas from low-permeability "tight" sandstone and fractured shale reservoirs having *in situ* permeabilities to gas of less than 0.1 millidarcy, coal bed methane, gas in geopressured shales and brines, or gas hydrates.

AREAS OF STUDY

The primary organization of this report is by region (fig. 2); the nine regions described in the volume correspond to those in Mast and others (1989). Discussion of provinces in the region follows; the format for each province includes an introduction covering the geologic setting, exploration history, age of sediments, and a generalized stratigraphic chart. (No stratigraphic chart is provided for a province where no individual plays were assessed; a map of the province is substituted, because no specific stratigraphy is given in that province.) Following each province introduction is systematic discussion of its individual plays. The play format includes the play name, narrative discussion and two illustrations, (1) a province map with the area of the play emphasized, and (2) a tabular form showing the original input data for the play appraisal.

Areas of State but not Federal waters are included in the assessment of adjacent onshore regions and provinces. The boundaries of State waters are 3 nautical miles offshore for the Pacific and Atlantic coasts and for the Alabama coast of the Gulf of Mexico. Louisiana and Mississippi have decreed State water boundaries that vary slightly from 3 nautical miles. For the Texas and Florida coasts of the Gulf of Mexico, the boundaries of State waters are 3 marine leagues (10.36 statute miles) offshore. In addition, all maritime boundaries and limits depicted on maps in the report are for initial planning purposes only, and do not prejudice or affect United States jurisdiction in any way.

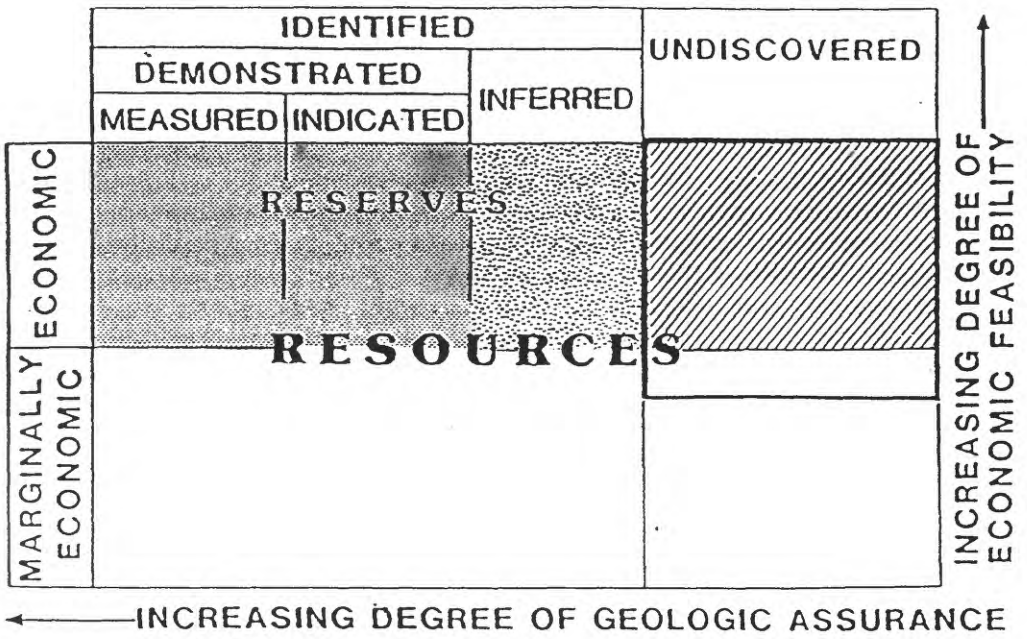

Figure 1. Diagrammatic representation of petroleum resource classification (Mast and others, 1989) representing conventional oil and gas resources. Area with heavy frame on upper right represents undiscovered recoverable resources estimated in this study.

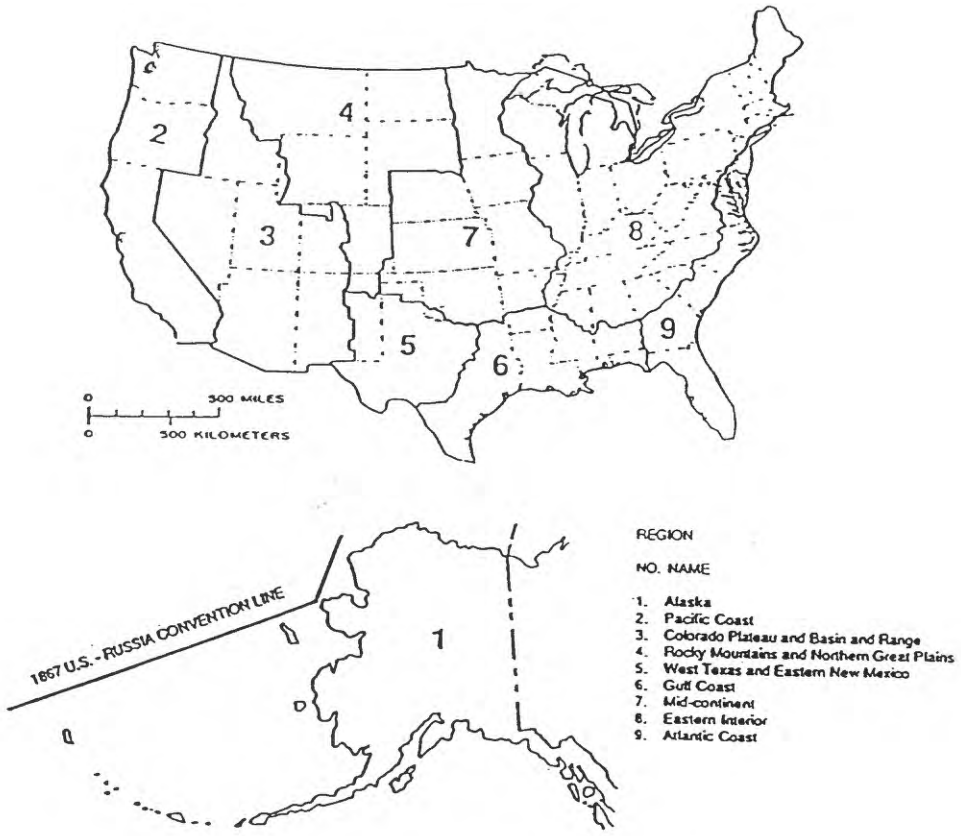

Figure 2. Map showing petroleum regions assessed in this study. Heavy lines are region boundaries, dotted lines are state boundaries.

Regions are basically geographic in character; however, their outlines are an attempt to group individual provinces along broad geologic lines. Provinces are constructed around natural geologic entities and may include a single dominant structural element, or a number of contiguous elements; they are named for structural or geographic features within their boundaries. These boundaries, following State and county lines, wherever possible, facilitate the use of production, reserves, and other reported data. A play is named after the most dominant feature or characteristic of a structural, stratigraphic, or geographic nature that best identifies it. Its name can also apply to a concept. Many plays described herein are recognized from their titles by the petroleum industry, but play titles are in no way formal geologic or stratigraphic names.

PLAY DISCUSSION FORMAT

Individual plays described and assessed in this report include only those that were estimated to have undiscovered accumulations greater than 1 MMBO (million barrels of oil) or 6 BCFG (billion cubic feet of gas). Plays judged to have undiscovered accumulations that fell below that threshold were assessed separately for the provinces as a whole, and are not described in the report . A play is defined as a group of geologically related known or undiscovered accumulations and(or) prospects having similar characteristics of hydrocarbon source, reservoir, trap, and geologic history.

In order to achieve some degree of consistency in narrative discussions of a great number and variety of plays, a topical outline based on the definition of an exploration play has been used. Each play discussion notes the play characteristics, followed by descriptions of (1) reservoirs, (2) source rocks and related geochemistry, (3) timing of generation and migration of hydrocarbons, (4) traps (types, sizes, seals, and drilling depths), (5) exploration status (history, discovered volumes, field sizes, and hydrocarbon types), and (6) qualitative future hydrocarbon potential and factors limiting that potential. Although the discussions adhere to the order of the topical outline, it will be apparent that some inconsistency occurs in the amount of detail and coverage of each topic from one play to another. This is due to the relative abundance or lack of data pertinent to each play and is unavoidable in a report of this scope. Play discussions here are, of necessity, brief summaries. More detailed play information can be found in the province open-file reports, which are listed in the references at the close of each region. The number of individually assessed plays in each province ranges from 1 to as many as 13; however, most provinces contain 3-5 plays. Each play title is followed by a sequence number (for example, Topset Play (020)), and these also appear on the table of resource estimates at the close of each region.

ASSESSMENT PROCEDURES AND METHODS

Assessments of undiscovered recoverable oil and gas in the individual plays in each province, and resources in small (< 1 MMBO or < 6 BCFG) accumulations were based upon review and analysis of the petroleum geology and exploration history of each province that incorporated the most recent geologic and geophysical information available as of January 1, 1987. In the National assessment, 220 plays covering the onshore and State offshore areas were identified, and for each individually assessed play, undiscovered oil and gas resources were estimated. Plays judged to contain more than 1 MMBO or 6 BCFG were individually assessed; plays judged to contain less than those amounts were treated differently, as described following. See Mast and others (1989) and USGS/MMS (1988) for a detailed discussion of this assessment, its assumptions, methods, and results.

In the play analysis method, geologic settings of oil and gas occurrence are modeled. The play is treated as a collection of accumulations (pools, fields) of similar geologic risk sharing common geologic characteristics that include reservoir and source rocks and known or suspected trapping conditions. A team of geoscientists made judgments as to the probability of the occurrence of those geologic factors necessary for the formation of hydrocarbon accumulations, and quantitatively assessed each factor as a geologic attribute of the play; the team then estimated the numbers and sizes of accumulations as probability distributions, conditional on favorable play attributes. All of this information was entered on the play data input form which is included in each play discussion in this report. A computer program then performed the resource calculations on the basis of the assessment information in the input form, employing an analytical method based on probability theory. Final, undiscovered oil and gas estimates for each play, based on this method, are shown on a table of estimates at the end of the discussion for each region.

Probabilistic estimates of recoverable oil and gas in accumulations smaller than the established size cut-off (1 MMBO, 6 BCFG) were made separately. These estimates of small accumulations were based primarily on log-geometric extrapolations of numbers of fields into field-size classes smaller than the cut-offs. Estimates of undiscovered resources for these small fields were made for the province as a whole, rather than for the individual plays. These are shown in the tables of estimates as: Oil < 1 MMB and Gas < 6BCF. In addition, minor plays and very mature, or nearly depleted plays not assessed individually are included in the tables of estimates as: Other Occurrences > 1 MMBO and Other Occurrences >6 BCFG. Ratios of associated-dissolved gas to oil, and NGL (natural gas liquids) to gas, were estimated from historical production data and used for calculation of these components.

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GLOSSARY

Play.--A group of geologically related known or undiscovered accumulations and (or) prospects having similar characteristics of hydrocarbon source, reservoir, trap and geologic history.

Field.--A single pool or multiple pools of hydrocarbons grouped on, or related to, a single structural or stratigraphic feature.

Prospect.--A geologic feature having the potential for trapping and accumulating hydrocarbons.

Crude oil.--A mixture of hydrocarbons present in underground reservoir rocks in a liquid state that remains in a liquid state as it is produced from wells.

Associated gas.--Free natural gas, occurring as a gas cap, in contact with and above an oil accumulation within a reservoir.

Dissolved gas.--Natural gas dissolved in crude oil within a reservoir.

Nonassociated gas. (NA)--Natural gas that is neither associated with nor in contact with crude oil within a reservoir.

Natural gas liquids (NGL).--Those portions of reservoir gas that are liquified at the surface in lease separators, field facilities, or gas processing plants. NGL is reported only in the tables of estimates in this report.

MMBO.--Millions (10^6) of barrels of oil (standard stock tank barrels of crude oil, 42 gallons per barrel).

BBO.--Billions (10^9) of barrels of oil.

BCFG.--Billions (10^9) of cubic feet of gas (standard cubic feet of gas at 14.73 pounds per in^2 and 60°F). Hydrocarbon gases only.

TCFG.--Trillions (10^{12}) of cubic feet of gas.

MMBOE.--Millions of barrels of oil equivalent (conversion factor utilized is 6,000 ft^3 = 1 BOE).

REGION 5--WEST TEXAS AND EASTERN NEW MEXICO

GEOLOGIC FRAMEWORK

By Richard B. Powers

Region 5 is subdivided into five provinces (number 107-111). The total number of individually assessed plays in these provinces is 20. No plays were defined for assessment in the Pedernal Uplift province (109).

The main structural elements of Region 5 include the Permian basin, the Bend arch-Fort Worth basin and, on the south, the Marathon-Ouachita thrust belt Almost the entire Paleozoic section in the Region is productive of hydrocarbons. The Permian basin is a large asymmetric structural depression on the southwestern margin of the North American craton that has been filled with a thick Paleozoic rock sequence. Region 5 is second only to Region 6, the Gulf Coast, in the cumulative production of oil and gas in the United States, and the Permian Basin province is the most prolific part. The Permian basin is also the most important province in the Region for undiscovered hydrocarbon resources; the Bend arch-Fort Worth basin area is a distant second. The Delaware-Val Verde portion of the Permian basin is particularly important for undiscovered gas resources.

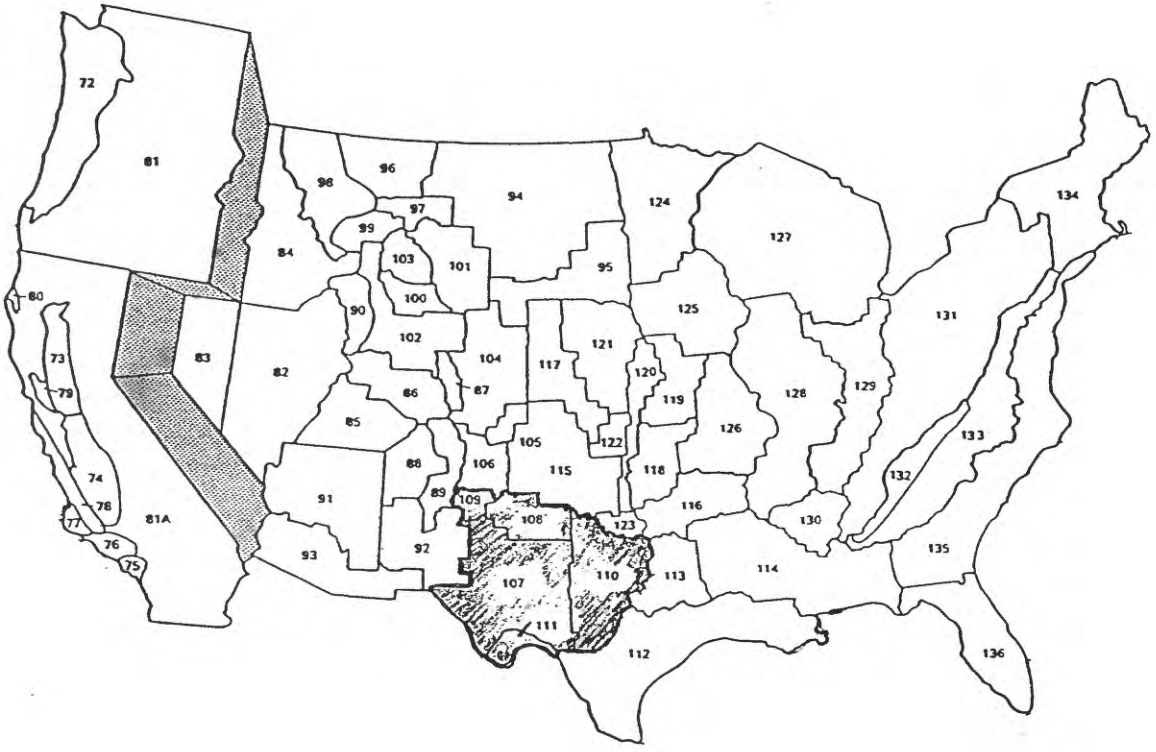

Figure 3. Index map of lower 48 states showing provinces assessed in Region 5 (shaded). Names of provinces are listed by number in the Table of estimates.

PERMIAN BASIN PROVINCE (107)

By Keith Robinson

INTRODUCTION

The Permian basin is one of the largest structural basins in North America. It encompasses a surface area in excess of 86,000 mi^2 and includes all or parts of 52 counties located in West Texas and southeast New Mexico. Structurally, the Permian basin is bounded on the south by the Marathon-Ouachita fold belt, on the west by the Diablo Platform and Pedernal uplift, on the north by the Matador Arch, and on the east by the Eastern Shelf of the Permian (Midland) Basin and west flank of the Bend arch. The basin is approximately 260 by 300 mi in area and is separated into eastern and western halves by a north-south trending central uplift or platform. In cross-section, the basin is an asymmetrical feature, the western half of which contains a thicker and more structurally deformed sequence of sedimentary rock than the eastern half. The Permian basin has been characterized as a large structural depression, formed as a result of downwarp in the Precambrian basement surface located at the southern margin of the North American craton. The basin was filled with Paleozoic and, to a much lesser extent, younger sediments (fig. 4). It acquired its present structural form by Early Permian time and was further accentuated by tectonic activity and down-warping during the Permian and Triassic. The overall basin is divisible into several distinct structural and tectonic elements, these are the Central Basin platform and the Ozona arch, which separate the Delaware and Val Verde basins on the west from the Midland basin on the east, the Northwestern shelf on the southern extremity of the Pedernal uplift and Matador arch, and the Eastern shelf on the western periphery of the Bend arch. Stratigraphic sections of all systems of the Paleozoic are present and reach a maximum thickness in excess of 25,000 ft (fig.4); however, complete vertical sequences of Paleozoic strata are rare. The Permian basin, one of the most prolific petroleum provinces of North America, is now in a mature stage of exploration and development. Oil and gas have been found in rocks ranging from Cambrian to Cretaceous age; however, most hydrocarbons are found in rocks of Paleozoic age. Cumulative production in the province to the end of 1986 is approximately 50 BBO and 38 TCFG.

Ten plays were defined and individually assessed for undiscovered oil and gas resources: Delaware Sandstone (020), Upper Northwestern Shelf (031), Upper Central Basin Platform (032), Upper Eastern Shelf-Midland Basin (033), Spraberry-Dean Sandstone (040), Upper Delaware-Val Verde Basins (050), Horseshoe Atoll (060), Lower Northwestern and Eastern Shelf (071), Lower Central Platform-Midland Basin (072), and Lower Delaware-Val Verde Basins (073).

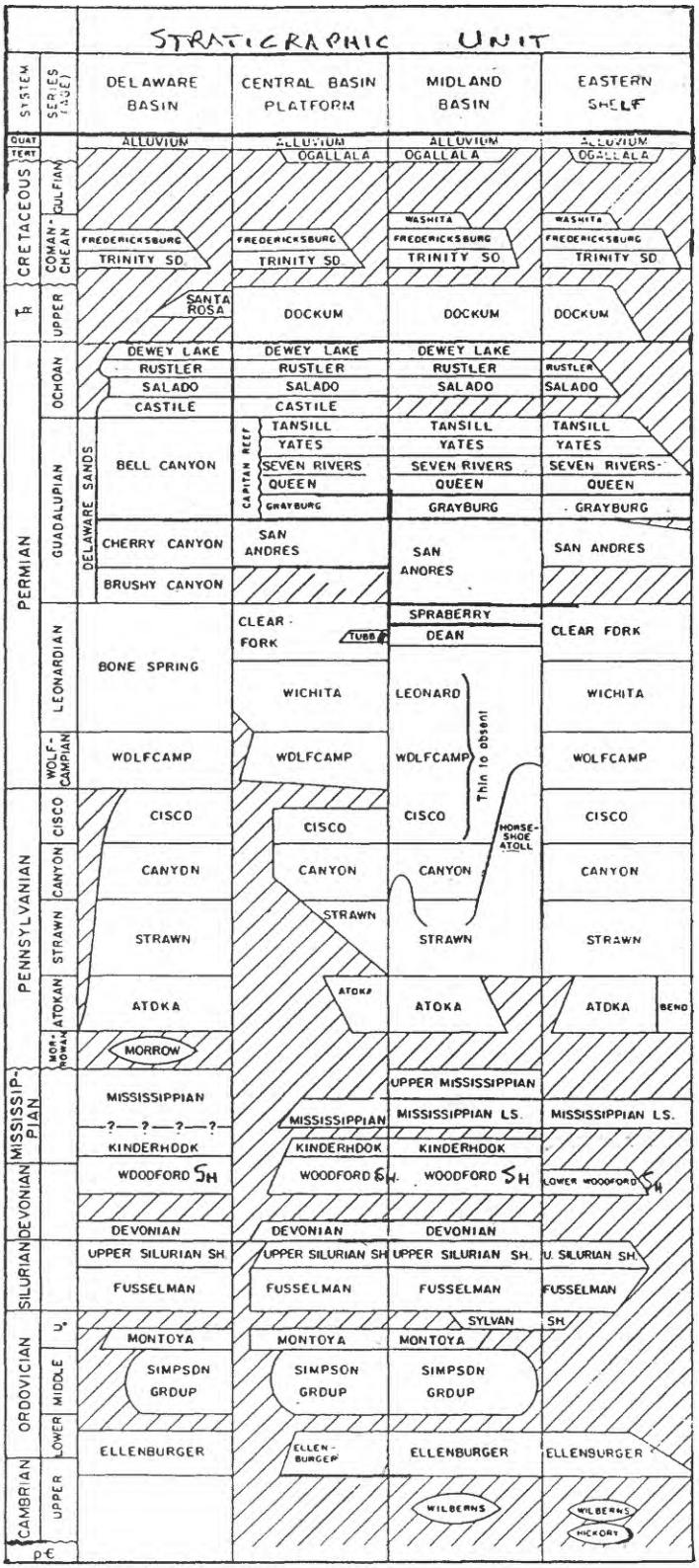

Figure 4. Generalized stratigraphic columns, Permian basin province

DELAWARE SANDSTONE PLAY (020)

The play is defined by oil and gas fields in combination structural and stratigraphic traps, involving anticlines, updip pinch-out, and channel-fill combination traps in clastic reservoirs of Guadalupian-Ochoan age. The play area is arcuate in shape, approximately 265 mi along an arc and varying in width from 7 mi in the southeast to 85 mi in the northwest (fig.5). The play is confined primarily to the Delaware basin but, because of similarities, includes shelf margin sandstone reservoirs in the adjoining Ozona arch area. Maximum thickness of Upper Permian sedimentary rocks is less than 10,000 ft.

Major reservoir rocks consist of fine grained basinal sandstone interbedded with laminated siltstone, organic rich shale, limestone and dolomite. In the Ozona area the reservoirs are open shelf sandstones. Reservoirs are contained in the Permian Rustler Formation of the Ochoan Series, and the Bell Canyon, Yates, Queen and Cherry Canyon formations of the Guadalupian Delaware Sands Series (fig.4). Reservoir thicknesses range up to 50 ft with 20 to 25 percent porosity and moderate to low permeability. Source rocks are considered to be associated organic-rich basinal shales of Permian age. The relatively low permeability of reservoir rocks suggests that hydrocarbons were generated from sources near the reservoirs and that migration distances were short.

Trapping mechanisms are stratigraphic, primarily updip pinch-out of channel-fill sandstone bodies in the Delaware basin. In the Ozona arch area, anticlinal structure and combination structural/stratigraphic traps are present. Seals are generally impervious silty shales and updip facies changes. Stratigraphically and structurally trapped hydrocarbons occur at depth ranges from 1,000 to 7,000 ft and average about 4,000 ft.

The first discoveries in the play were in the 1920's but the majority of large oil discoveries were made during the 1950's. Since the initial discovery to the end of 1986, cumulative recoverable resources were 259 MMBO, 868 BCFG and 30 MMBNGL. Approximately 9 oil and 5 gas fields larger than 1 MMBO and 6 BCFG have been found since 1961, resulting in the discovery of approximately 27 MMBO, 124 BCFG and 4 MMBNGL. The largest size gas field is the Waha field with 126 BCFG. The average field size discovered since 1961 is approximately 14 BCFG. Future resource potential is estimated to be fair to good for the discovery of additional small size fields.

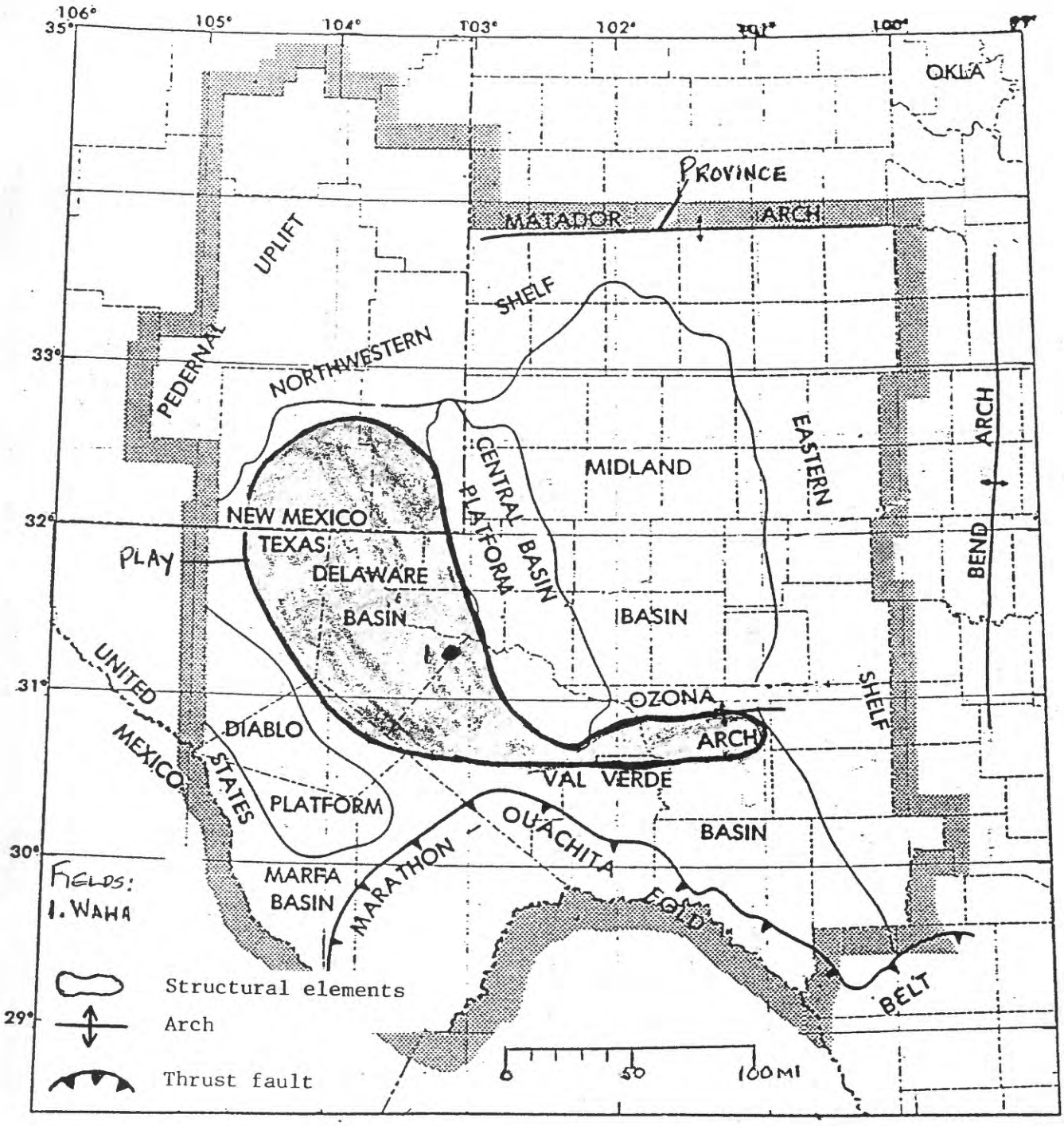

Figure 5. Map of Delaware Sandstone play

OIL AND GAS PLAY DATA

PLAY **DELAWARE SANDSTONE**
PROVINCE **PERMIAN BASIN** CODE **05-107-020**

Play attributes

	Probability of attribute being favorable or present
Hydrocarbon source (S)	**1.00**
Timing (T)	**1.00**
Migration (M)	**1.00**
Potential reservoir-rock facies (R)	**1.00**
Marginal play probability (MP) (S x T x M x R = MP)	**1.00**

Accumulation attribute, conditional on favorable play attributes

Minimum size assessed: oil, 1 x 10^6 BBL; gas, 6 x 10^9 CFG

	Probability of occurrence
At least one undiscovered accumulation of at least minimum size assessed	**1.00**

Character of undiscovered accumulations, conditional on at least one undiscovered accumulation present

Reservoir lithology	Probability of occurrence
Sandstone	X
Carbonate rocks	
Other	
Hydrocarbon type	
Oil	**0.6**
Gas	**0.4**

	Fractiles * (estimated amounts)						
Fractile percentages * ----	*100*	*95*	*75*	*50*	*25*	*5*	*0*
Accumulation size							
Oil (x 10^6 BBL)	**1**	**1.1**	**1.6**	**2.5**	**4.4**	**10**	**25**
Gas (x 10^9 CFG)	**6**	**6.6**	**8.4**	**13**	**20**	**55**	**120**
Reservoir depth (x10^3 ft)							
Oil	**1**			**4**			**6.5**
Gas (non-associated)	**1**			**4**			**7**
Number of accumulations	**4**	**7**	**11**	**15**	**22**	**34**	**50**

Average ratio of associated-dissolved gas to oil (GOR)	**2000**	CFG/BBL
Average ratio of NGL to non-associated gas	**38**	BBL /10^6 CFG
Average ratio of NGL to associated-dissolved gas	**0**	BBL /10^6 CFG

* For example, fractile percentage 95 represents a 19 in 20 chance of the occurrence of at least the fractile tabulated.

UPPER NORTHWESTERN SHELF PLAY (031)

The play is characterized by oil and subordinate gas fields in a combination of stratigraphic, stratigraphic/structural and structural traps, in shelf margin and interior facies carbonate and, to a lesser extent, clastic reservoirs of Pennsylvanian to Permian age. The play area is approximately 180 mi long and 140 mi wide, and covers the whole of the Northwestern shelf area south of the Matador arch, the area southeast of the Pedernal uplift and extends into a small part of the northern Midland basin (fig.6). Maximum thickness of Permian and Pennsylvanian sedimentary rocks in the play is less than 15,000 ft.

Reservoir rocks consist of porous limestone, dolomite, dolomitized mudstone and wackestone, and lesser amounts of fine grained clastics, frequently associated with evaporites, red beds and sabkha facies. These rocks appear to have been deposited in a strandline, intertidal to supratidal and restricted shelf environment associated with reef growth. Reservoirs are contained in the Pennsylvanian Strawn and Cisco Formations and Permian Wolfcampian, Leonardian Bone Spring and Clear Fork Formations, and Guadalupian San Andres, Grayburg, Queen, Seven Rivers and Yates Formations (fig. 4). Gross reservoir thicknesses range up to 1,000 ft, porosities average 10 percent and permeabilities average 6 millidarcies.

Source rocks are indigenous organic-rich calcareous shale and shaly limestone of Permian-Pennsylvanian age; but it is believed that Lower Permian sediments are the primary source beds. Deposited under restricted shelf, intertidal and lagoonal environments, the source beds are probably extremely rich in organic material. Hydrocarbon generation from adjacent organic-rich source rocks probably occurred during Upper Permian time. Hydrocarbons migrated laterally and upward into the present porous reservoir rocks simultaneously with generation.

Primary trapping mechanisms are stratigraphic, structural and combined stratigraphic/structural. Stratigraphic traps in the shelf sequence are formed by lateral facies changes into non-porous and permeable strata. Structural traps are generally simple anticlinal closures which had topographic relief during the Permian. Buried reef traps are also present. Seals consist of anhydrite, salt beds, nonporous dolomites and red beds. Stratigraphically and structurally trapped hydrocarbons occur at depths of 1,000 to 11,000 ft, with an average of 5,100 ft.

The first discovery in the play was in 1923 at the Artesia field, but most discoveries were made during the 1950's and 1960's. To the end of 1986 cumulative recurrable resources totaled 7,390 MMBO, 7,605 BCFG, and 725 MMBNGL. Approximately 55 fields larger than 1 MMBO and 6 BCFG gas have been discovered since 1961 (46 oil and 9 gas); these have a combined ultimate recovery of 228 MMBO, 567 BCFG gas and 12 MMBNGL. One of the largest oil fields discovered is Wasson with approximately 2 BB of recoverable oil. The largest gas field discovered is Pecos Slope (New Mexico) which is 225 BCFG in size. Future resource potential is estimated as relatively good for the discovery of additional small fields and possibly one or more medium size fields.

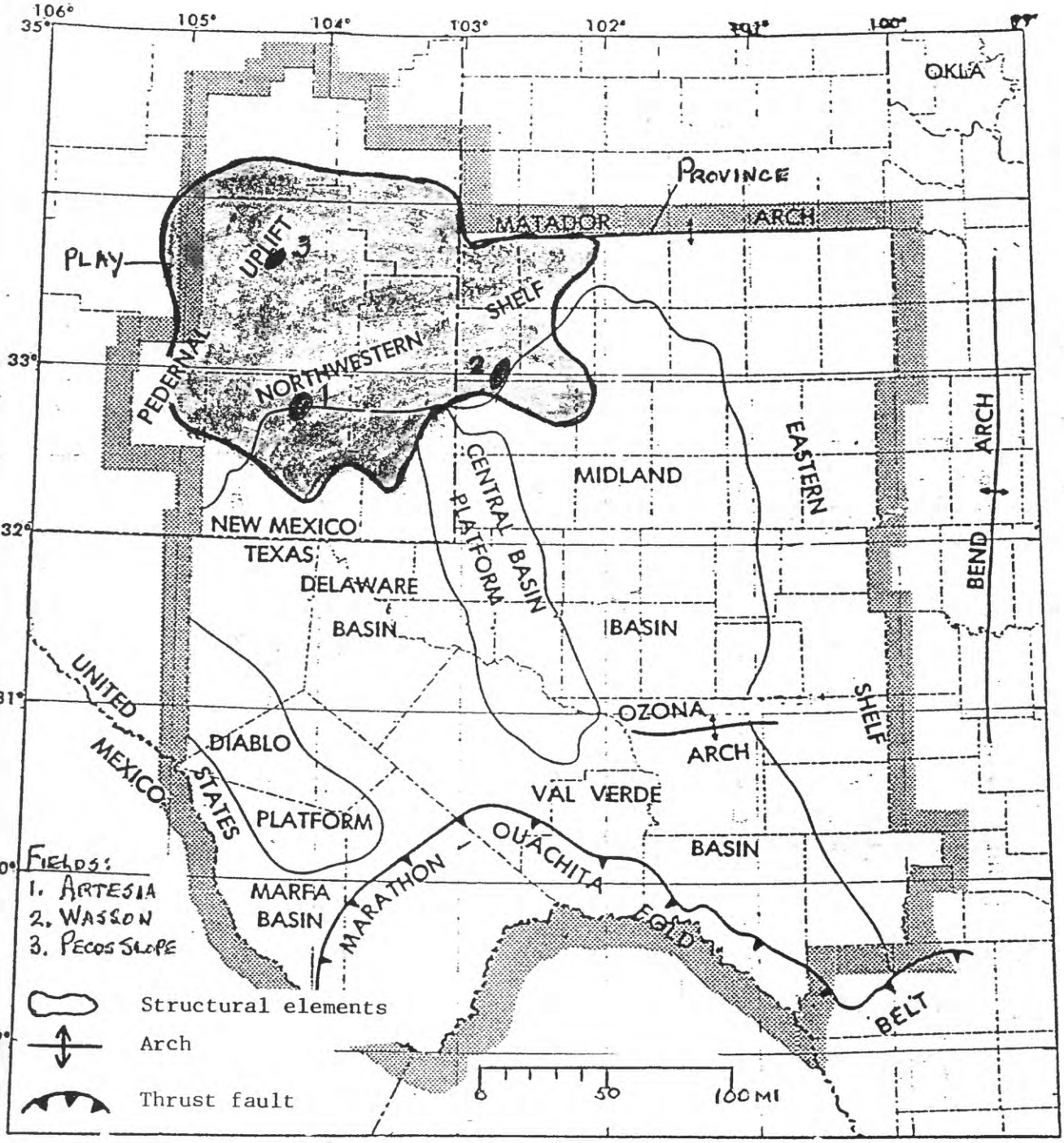

Figure 6. Map of Upper Northwestern Shelf play

OIL AND GAS PLAY DATA

PLAY **UPPER NORTHWESTERN SHELF**
PROVINCE **PERMIAN BASIN** CODE **05-107-031**

Play attributes

	Probability of attribute being favorable or present
Hydrocarbon source (S)	**1.00**
Timing (T)	**1.00**
Migration (M)	**1.00**
Potential reservoir-rock facies (R)	**1.00**
Marginal play probability (MP) (S x T x M x R = MP)	**1.00**

Accumulation attribute, conditional on favorable play attributes

Minimum size assessed: oil, 1 x 10^6 BBL; gas, 6 x 10^9 CFG

	Probability of occurrence
At least one undiscovered accumulation of at least minimum size assessed	**1.00**

Character of undiscovered accumulations, conditional on at least one undiscovered accumulation present

Reservoir lithology	Probability of occurrence
Sandstone	**X**
Carbonate rocks	**X**
Other	
Hydrocarbon type	
Oil	**0.8**
Gas	**0.2**

	Fractiles * (estimated amounts)						
Fractile percentages * ----	*100*	*95*	*75*	*50*	*25*	*5*	*0*
Accumulation size							
Oil (x 10^6 BBL)	**1**	**1.1**	**1.4**	**2**	**4**	**14**	**65**
Gas (x 10^9 CFG)	**6**	**6.6**	**8.4**	**12**	**18.5**	**36**	**50**
Reservoir depth (x10^3 ft)							
Oil	**2**			**5**			**11.5**
Gas (non-associated)	**3**			**9**			**13**
Number of accumulations	**20**	**28**	**40**	**50**	**66**	**90**	**125**

Average ratio of associated-dissolved gas to oil (GOR)	**1000**	CFG/BBL
Average ratio of NGL to non-associated gas	**6**	BBL /10^6 CFG
Average ratio of NGL to associated-dissolved gas	**0**	BBL /10^6 CFG

* For example, fractile percentage 95 represents a 19 in 20 chance of the occurrence of at least the fractile tabulated.

UPPER CENTRAL BASIN PLATFORM PLAY (032)

The play is characterized by oil and subordinate gas accumulations in stratigraphic/structural and structural traps, in a platform sequence of carbonate and, to a lesser extent, fine-grained clastic reservoirs of primarily Lower Permian to Upper Pennsylvanian age. The play area is approximately 200 mi long and 110 mi wide, and covers all of the Central Basin Platform and the Ozona arch; it is bounded on the west and south by the Delaware-Val Verde basins, and on the east by the Midland basin (fig. 7). Maximum thickness of Permian and Pennsylvanian sedimentary rocks is less than 10,000 ft.

Reservoir rocks consist of porous and permeable dolomitized carbonates, limestone and fine-grained sandstone. They include skeletal grainstones, dolomite, limestone, calcareous and silty sandstones, sponge and algal dolomitized limestone, dolomitized mud and wackestone, and vuggy to cavernous carbonate beds. Carbonate rocks were deposited in open to restricted platform and platform margins associated with sea level fluctuations, shelf margin reef development, evaporite, and sabkha deposits. Reservoir quality is enhanced by selective dolomitization, dissolution, fracturing and leaching. Reservoirs are contained in the Permian Guadalupian San Andres, Grayburg, Queen, Seven Rivers, and Yates Formations; they also occur in the Clear Fork and Wolfcamp Formations and in the Pennsylvanian Strawn, Canyon and Cisco Formations (fig.4). Individual reservoir thicknesses may range up to hundreds of ft; overall porosities average 12 percent and permeabilities average 18 millidarcies.

Source rocks are indigenous organic-rich calcareous shale and shaly limestone of Wolfcampian and Leonardian age. Organic-rich shale of Pennsylvanian age is thought to be the source rock for hydrocarbons contained in Pennsylvanian formations. Hydrocarbon generation from adjacent organic-rich source rocks probably occurred during Upper Permian time. Fluids migrated laterally and upward into the present reservoirs.

Primary trapping mechanisms are generally a combination of structural and stratigraphic features, such as anticlinal noses and domes, which are associated with stratigraphic depositional and diagenetic facies changes. Large, simple anticlinal closures also are present. Seals consist of impervious dolomite, shaly carbonate, anhydrite and other evaporite facies. Structurally and stratigraphically trapped hydrocarbons occur at depths of 1,000 to 5,500 ft, and average 4,300 ft in Permian rocks. Pennsylvanian reservoirs produce from depths of 8,500 to 10,000 ft.

The first discovery in the play in Permian rocks was in 1925 at the McCamey field, but most discoveries were made during the late 1920's and up to the 1960's. Pennsylvanian age reservoirs were discovered and developed primarily during the 1950's. Rocks of these ages in the play have been extensively explored and drilled. Cumulative recoverable resources from the first discovery to the end of 1986 were 9,694 MMBO, 25,598 BCFG and 1,490 MMBNGL. Approximately 29 oil and 2 gas fields larger than 1 MMBO and 6 BCFG have been discovered since 1961. The Yates field, discovered in 1926, is the largest field in the play and contains more than 2 BB of ultimately recoverable oil. Since 1961, approximately 102 MMBO, 228 BCFG, and 12 MMBNGL have been discovered. The play has been maturely explored and the future resource potential is limited; however, it is probable that a number of small additional fields may remain to be discovered.

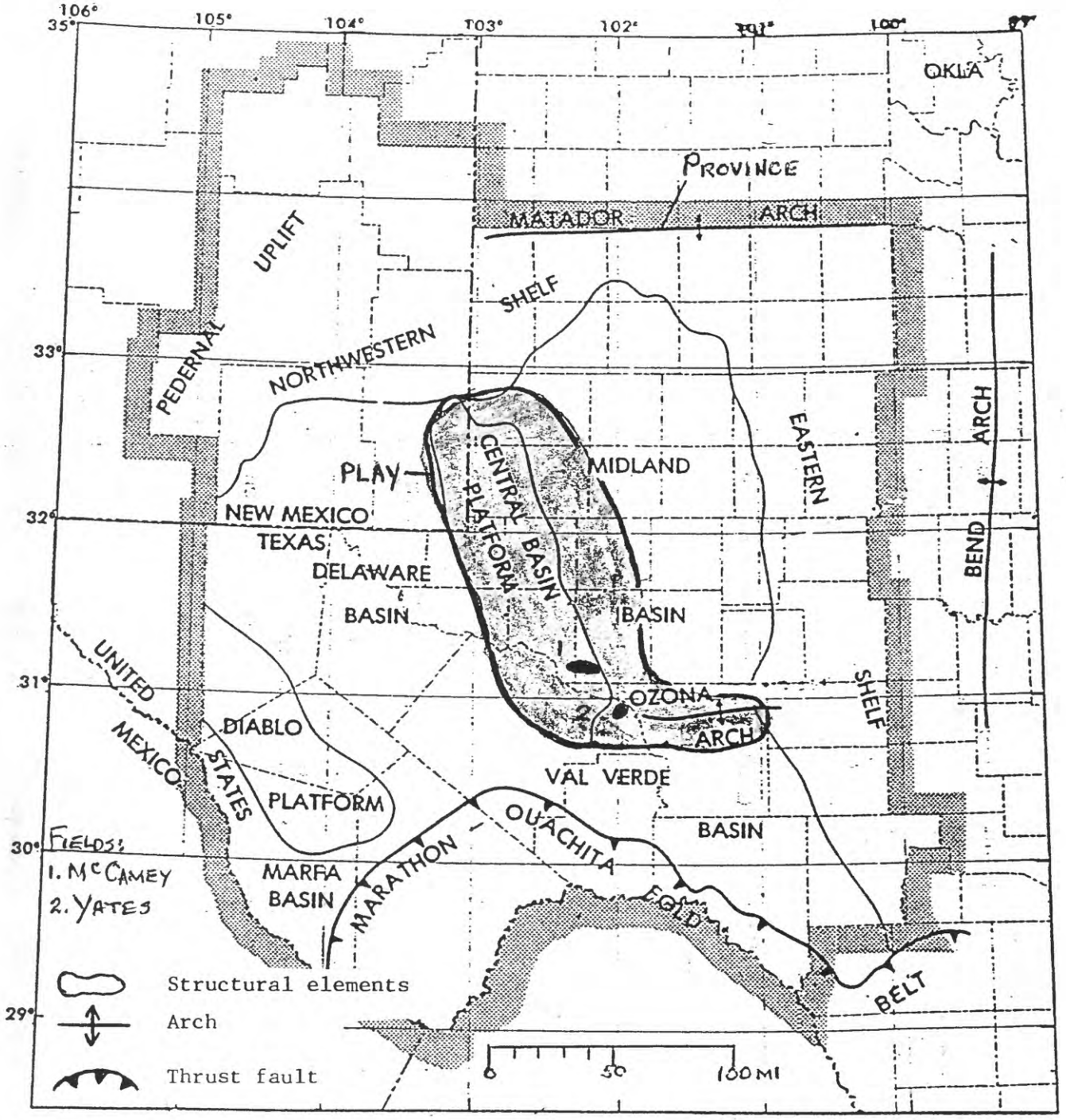

Figure 7. Map of Upper Central Basin Platform play

OIL AND GAS PLAY DATA

PLAY **UPPER CENTRAL BASIN PLATFORM**
PROVINCE **PERMIAN BASIN** CODE **05-107-032**

Play attributes

	Probability of attribute being favorable or present
Hydrocarbon source (S)	**1.00**
Timing (T)	**1.00**
Migration (M)	**1.00**
Potential reservoir-rock facies (R)	**1.00**
Marginal play probability (MP) (S x T x M x R = MP)	**1.00**

Accumulation attribute, conditional on favorable play attributes

Minimum size assessed: oil, 1 x 10^6 BBL; gas, 6 x 10^9 CFG

	Probability of occurrence
At least one undiscovered accumulation of at least minimum size assessed	**1.00**

Character of undiscovered accumulations, conditional on at least one undiscovered accumulation present

Reservoir lithology	Probability of occurrence
Sandstone	**X**
Carbonate rocks	**X**
Other	
Hydrocarbon type	
Oil	**0.9**
Gas	**0.1**

	Fractiles * (estimated amounts)						
Fractile percentages * ----	*100*	*95*	*75*	*50*	*25*	*5*	*0*
Accumulation size							
Oil (x 10^6 BBL)	**1**	**1.1**	**1.4**	**2**	**3.8**	**14**	**65**
Gas (x 10^9 CFG)	**6**	**6.1**	**6.6**	**8**	**11**	**30**	**115**
Reservoir depth (x10^3 ft)							
Oil	**2**			**5**			**11**
Gas (non-associated)	**2**			**5**			**11**
Number of accumulations	**15**	**24**	**36**	**50**	**66**	**90**	**120**

Average ratio of associated-dissolved gas to oil (GOR)	**1900**	CFG/BBL
Average ratio of NGL to non-associated gas	**9**	BBL /10^6 CFG
Average ratio of NGL to associated-dissolved gas	**0**	BBL /10^6 CFG

* For example, fractile percentage 95 represents a 19 in 20 chance of the occurrence of at least the fractile tabulated.

UPPER EASTERN SHELF-MIDLAND BASIN PLAY (033)

The play consists of oil and subordinate gas fields in stratigraphic and structural traps in shelf sequence carbonate and, to a lesser extent, clastic reservoirs of Lower and Upper Permian to Pennsylvanian age. The play area is approximately 250 mi long by 150 mi wide, covers the Eastern Shelf and Midland basin, and is bounded on the east by the Bend arch, on the west by the Central Basin Platform, and on the north by the Northwestern Shelf and Matador arch (fig. 8). Maximum thickness of Permian and Pennsylvanian sedimentary rocks is less than 15,000 ft.

Reservoir rocks consist of porous dolomite, limestone, and sandstone beds, which occur in multiple stacked sequences, and are frequently associated with anhydrite, salt, and siltstone red beds. These facies change and intertongue from east to west due to prograding of the paleo-margin of the Eastern Shelf into the Midland basin. Reservoirs are contained in the Pennsylvanian Atoka (Bend), Strawn, Canyon and Cisco Formations, and in the Permian Wolfcamp, Clear Fork, Yates, Seven Rivers, Queen, Grayburg and San Andres Formations (fig. 4). Cumulative reservoir thicknesses range up to several hundreds of feet; porosities average 12 percent and permeabilities 15 millidarcies.

Source rocks for hydrocarbons in Pennsylvanian and Permian reservoirs are widely distributed indigenous bituminous shale of the same ages. Hydrocarbon generation from the bituminous shale probably occurred during two periods, one in Upper Pennsylvanian, and one in Upper Permian time. Generated oil and gas readily migrated into adjacent reservoirs.

Trapping mechanisms are predominantly a combination of structural and stratigraphic features. Anticlinal and domal structures are areally extensive and of low-relief. Combination structural-stratigraphic traps consist frequently of reef sediments and structural noses which wedge-out updip and are associated with lateral depositional and diagenetic facies-change permeability barriers. Multiple, stacked porous reservoir rocks are separated by non-productive impermeable shale, evaporite rocks and limestone beds which act as effective seals. Trapped hydrocarbons occur at depths of 1,500 to 3,200 ft, with an average of 2,100 ft.

The first discovery in the play was in 1920 at the Westbrook field, but most of the discoveries were made during the 1950's. The largest fields were discovered, typically, during the early stage of exploration in the Permian basin. The play has been extensively explored and drilled. To the end of 1986 cumulative recoverable resources totaled 2,864 MMBO, 3,698 BCFG and 270 MMBNGL. Approximately 40 oil and 12 gas fields have been discovered since 1961. These contain more than 148 BBO, 809 BCFG, and 59 MMBNGL. The average size of the oil fields is 3.1 MMBO. The largest field discovered, Howard-Glasscock, contains 420 MMB of ultimately recoverable oil. Because the play has been maturely explored, the future resource potential is moderate, although it is probable that a number of small and medium-sized fields remain to be discovered.

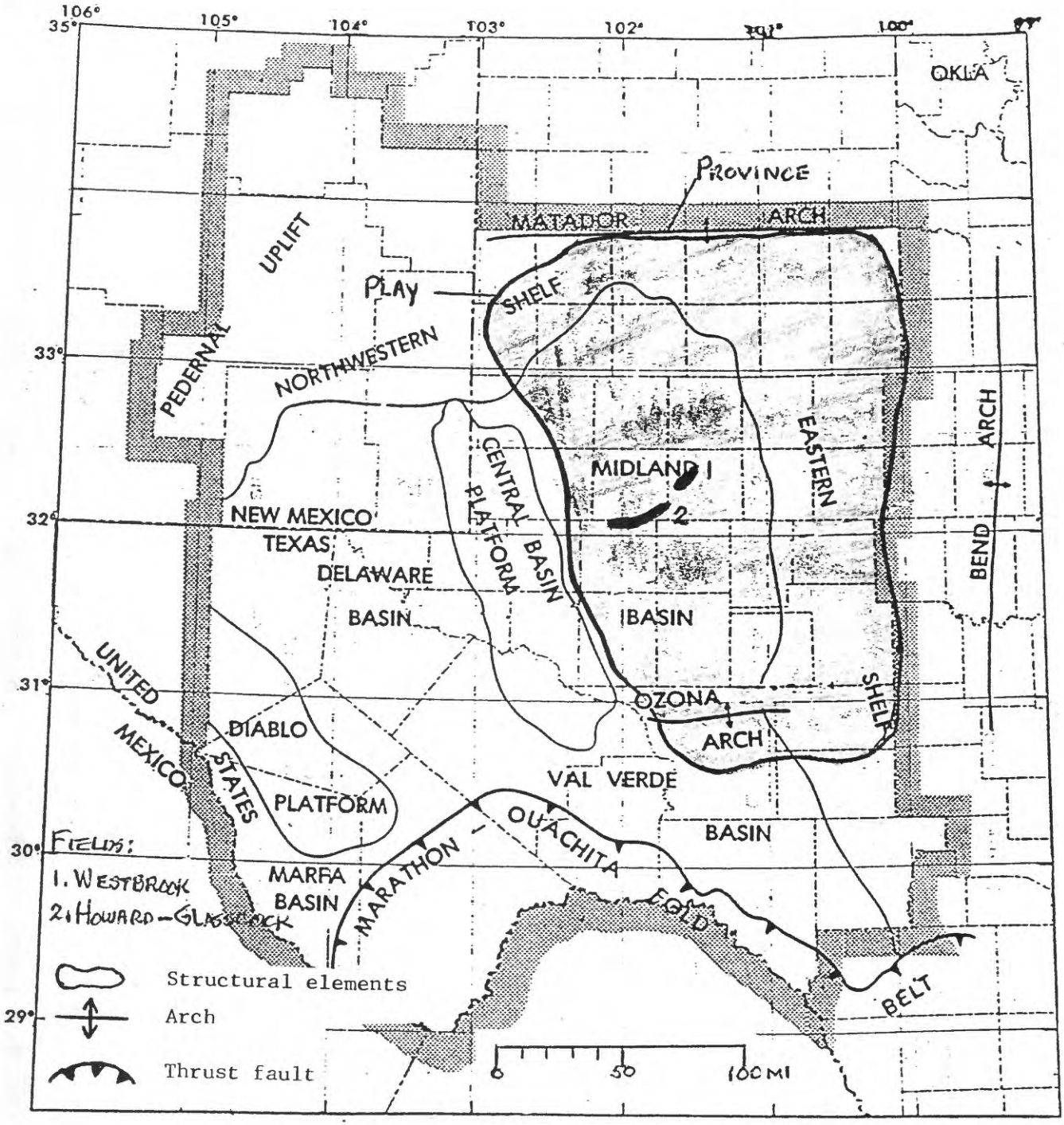

Figure 8. Map of Upper Eastern Shelf-Midland Basin play

OIL AND GAS PLAY DATA

PLAY **UPPER EASTERN SHELF-MIDLAND BASIN**
PROVINCE **PERMIAN BASIN** CODE **05-107-033**

Play attributes

	Probability of attribute being favorable or present
Hydrocarbon source (S)	**1.00**
Timing (T)	**1.00**
Migration (M)	**1.00**
Potential reservoir-rock facies (R)	**1.00**
Marginal play probability (MP) (S x T x M x R = MP)	**1.00**

Accumulation attribute, conditional on favorable play attributes

Minimum size assessed: oil, 1 x 10^6 BBL; gas, 6 x 10^9 CFG

	Probability of occurrence
At least one undiscovered accumulation of at least minimum size assessed	**1.00**

Character of undiscovered accumulations, conditional on at least one undiscovered accumulation present

Reservoir lithology	Probability of occurrence
Sandstone	**X**
Carbonate rocks	**X**
Other	
Hydrocarbon type	
Oil	**0.8**
Gas	**0.2**

	Fractiles * (estimated amounts)						
Fractile percentages * ----	*100*	*95*	*75*	*50*	*25*	*5*	*0*
Accumulation size							
Oil (x 10^6 BBL)	**1**	**1.1**	**1.4**	**2.1**	**3.6**	**9**	**22**
Gas (x 10^9 CFG)	**6**	**6.7**	**10**	**16**	**27**	**52**	**90**
Reservoir depth (x10^3 ft)							
Oil	**1**			**7**			**12**
Gas (non-associated)	**3**			**8**			**12**
Number of accumulations	**50**	**55**	**65**	**75**	**92**	**115**	**150**

Average ratio of associated-dissolved gas to oil (GOR)	**3800**	CFG/BBL
Average ratio of NGL to non-associated gas	**50**	BBL /10^6 CFG
Average ratio of NGL to associated-dissolved gas	**0**	BBL /10^6 CFG

* For example, fractile percentage 95 represents a 19 in 20 chance of the occurrence of at least the fractile tabulated.

SPRABERRY-DEAN SANDSTONE PLAY (040)

The play is defined by oil and associated gas fields in a combination of stratigraphic, stratigraphic-structural and pure structural traps in deep basinal clastic reservoirs of Lower Permian age. The play area is approximately 150 mi long, 40 to 75 mi wide, covers the Midland basin, and is bounded on the west by the Central Basin Platform and on the east by the Eastern Shelf (fig. 9). Maximum thickness of Permian sedimentary rocks is less than 15,000 ft.

Reservoir rocks consist of laminated sandstone, muddy burrowed sandstone, muddy siltstone and mudstone tongues, which are all intercalated and are poor-quality reservoirs. These sediments were deposited as channel fills, channel-margin bars, and as splay-like distal fans in a deep-water system of submarine fans. Reservoirs are contained in the Leonardian Spraberry and Dean Formations (fig. 4), where a great amount of oil-in-place exists. Individual reservoirs may range up to 200 ft or more in thickness, but porosities (11 percent) and especially permeabilities (1 millidarcy) are very low.

Thin, organic-rich black shale beds are widely distributed in the Spraberry-Dean interval. These shales are interbedded with sandstone and siltstone and generally contain 1 to 3 percent total organic carbon. Most of the organic material consists of oil-prone algal and amorphous types, and these shales provide optimum quality source rocks within the system containing the reservoirs. Hydrocarbon generation from the shale beds probably occurred during Upper Permian time. Hydrocarbons are believed to have accumulated in the juxtaposed reservoir sandstones during generation.

Primary trapping mechanisms are stratigraphic, with some associated structural traps, and in combination traps. Up-dip thinning and pinch-out of sandstone on the marginal slope of the Eastern Shelf are prevalent. A few simple anticlinal traps also exist and some fields are contained within a single isolated, and elongate, sandstone lens. The organic-rich black shales, in addition to being high quality source rocks, also act as effective seals. Other seals consist of non-porous interbedded shale, dolomitic and impure limestone, as well as porosity and permeability barriers within the interlaminated reservoir sequences. Trapped hydrocarbons occur at depths of 4,500 to 9,500 ft, with an average of approximately 7,500 ft.

The first discovery in the play was in 1949 at the Spraberry trend field, but most discoveries were made in the 1950's and 1960's. Cumulative recoverable resources to the end of 1986 were 1,008 MMBO, 2,455 BCFG and 307 MMBNGL. Since 1961, approximately 13 fields larger than 1 MMBO have been discovered, containing greater than 90 MMBO, 282 BCF of associated gas, and 36 MMBNGL. Original oil-in-place in the play has been estimated to be in excess of 10 BB. Although the play has been extensively drilled and explored, the future potential for undiscovered hydrocarbon resources is considered to be moderate to good. However, because of the deterrent of low porosity and permeability of the reservoirs, the current primary oil recovery factor for hydrocarbons is low. Recovery factors for in-place oil in the play rarely exceed 15 percent and average about 6 percent.

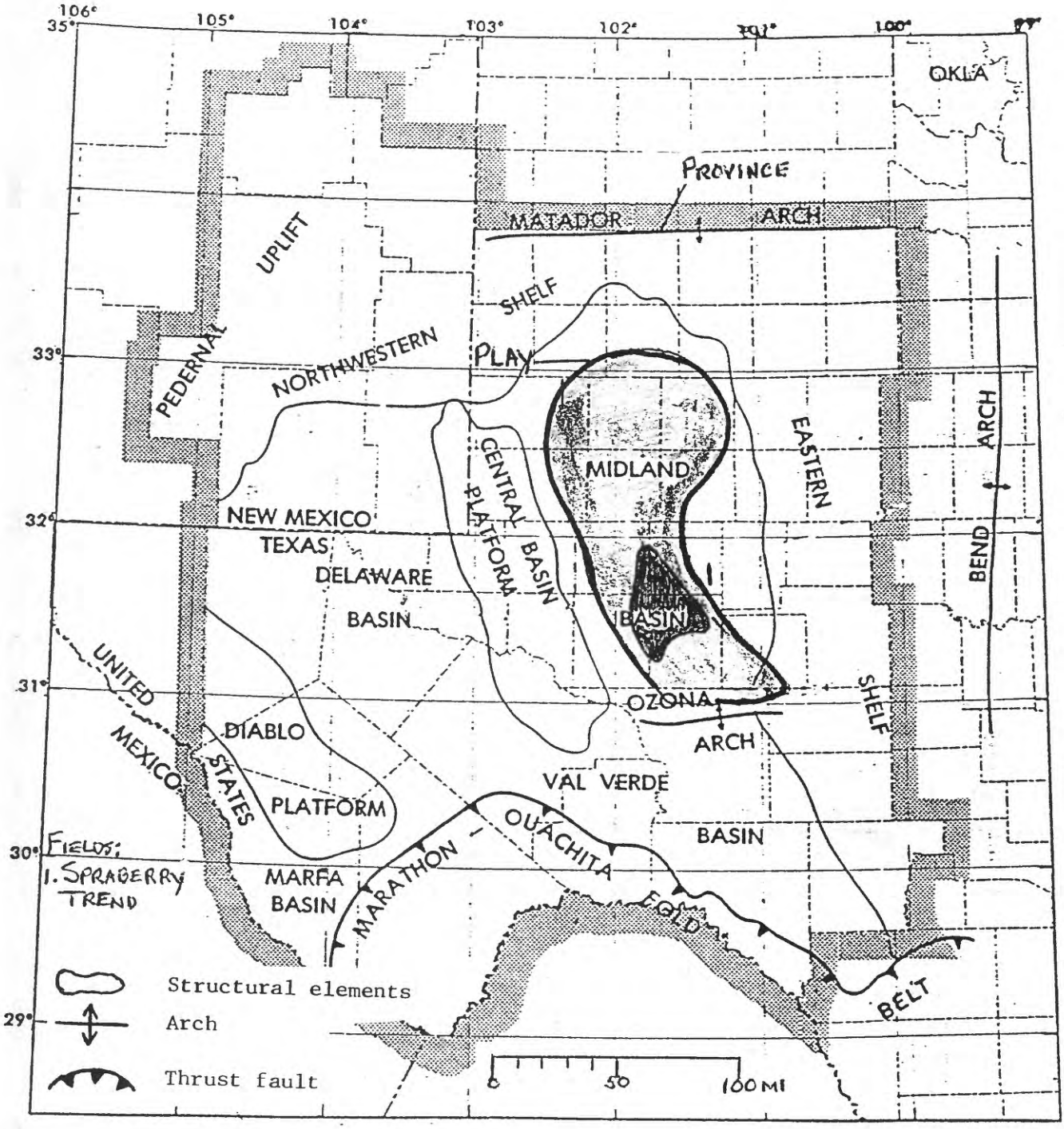

Figure 9. Map of Spraberry-Dean Sandstone play

OIL AND GAS PLAY DATA

PLAY **SPRABERRY-DEAN SANDSTONE**
PROVINCE **PERMIAN BASIN** CODE **05-107-040**

Play attributes

	Probability of attribute being favorable or present
Hydrocarbon source (S)	**1.00**
Timing (T)	**1.00**
Migration (M)	**1.00**
Potential reservoir-rock facies (R)	**1.00**
Marginal play probability (MP) (S x T x M x R = MP)	**1.00**

Accumulation attribute, conditional on favorable play attributes

Minimum size assessed: oil, 1 x 10^6 BBL; gas, 6 x 10^9 CFG

	Probability of occurrence
At least one undiscovered accumulation of at least minimum size assessed	**1.00**

Character of undiscovered accumulations, conditional on at least one undiscovered accumulation present

Reservoir lithology	Probability of occurrence
Sandstone	**X**
Carbonate rocks	
Other	
Hydrocarbon type	
Oil	**1**
Gas	**0**

	Fractiles * (estimated amounts)						
Fractile percentages * ----	*100*	*95*	*75*	*50*	*25*	*5*	*0*
Accumulation size							
Oil (x 10^6 BBL)	**1**	**1.1**	**1.7**	**3**	**6.5**	**25**	**125**
Gas (x 10^9 CFG)	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Reservoir depth (x10^3 ft)							
Oil	**5**			**7**			**8.5**
Gas (non-associated)	**0**			**0**			**0**
Number of accumulations	**20**	**22**	**26**	**30**	**35**	**43**	**50**

Average ratio of associated-dissolved gas to oil (GOR)	**3000**	CFG/BBL
Average ratio of NGL to non-associated gas	**0**	BBL /10^6 CFG
Average ratio of NGL to associated-dissolved gas	**0**	BBL /10^6 CFG

* For example, fractile percentage 95 represents a 19 in 20 chance of the occurrence of at least the fractile tabulated.

UPPER DELAWARE-VAL VERDE BASINS PLAY (050)

The play involves mainly gas accumulations in a combination of stratigraphic-structural, stratigraphic and to a lesser extent, pure structural traps in clastic and subordinate carbonate reservoirs of primarily Pennsylvanian and Lower Permian age. The play area is arcuate in shape, extending approximately 300 mi along an arc and varying in width from 90 to 20 mi; it covers most of the Delaware and Val Verde basins and extends onto the Northwestern Shelf. It is bounded on the east by the Central Basin Platform, and on the south, west, and northwest by the Marathon-Ouachita fold belt, the Diablo Platform, and the Pedernal uplift, respectively (fig. 10). Maximum thickness of Permian and Pennsylvanian sedimentary rocks is less than 20,000 ft.

Reservoir rocks consist of porous and permeable sandstone, coarse-grained to conglomeratic, locally, together with subordinate dolomite and limestone beds. The most important reservoirs occur in clastic sediments of the Pennsylvanian Morrow, Atoka, Strawn, Canyon and Cisco Formations, and in sandstone and carbonate rocks of the Lower Permian Leonardian Wichita Formation (fig. 4). Reservoir rocks on the southern part of the Northwestern Shelf are primarily carbonate. Canyon Formation reservoirs are sandstone interbedded with shale. The Wolfcamp Formation in the western part of the Val Verde basin contains clean, porous and permeable, medium to coarse-grained sandstone reservoir beds that are draped over older structural features. Reservoirs are a succession of sandstone beds, 5 to 10 ft in thickness, scattered through a vertical sequence of 600 ft. Total net pay varies from 20 to 100 ft.

Source rocks are associated dark shale and argillaceous limestone in the Lower Pennsylvanian Atokan Series. Shale of the Leonardian Bone Springs Formation is thought to be the source rock for gas in reservoirs of Lower Permian age. Hydrocarbon generation from organic shale and argillaceous limestone source rocks occurred possibly during two periods, one in Middle Pennsylvanian, and one in Early Permian times, with hydrocarbons migrating into adjacent reservoirs.

Trapping mechanisms are predominantly a combination of structural and stratigraphic features. Anticlinal structures are generally associated with lateral facies changes, together with structural nosing and up-dip lensing. Lenticular sandstone bodies are numerous. Seals are overlying shale and dense carbonate rocks, updip pinchouts, and facies-change permeability barriers. Drilling depths to the Wolfcamp Formation vary from 5,500 to 6,500 ft; depths to the Pennsylvanian Canyon Formation vary from 6,100 to 7,000 ft, and to the Morrow Formation from 9,000 to 13,000 ft.

The first gas field discovered in the play was the Miers field in 1946, but the majority of gas fields were discovered during the 1960's and 1970's. To the end of 1986 cumulative recoverable resources totaled 40 MMBO, 8,096 BCFG, and 180 MMBNGL. Since 1961, approximately 6 oil and 101 gas fields (>1 MMBO and 6 BCFG in size) have been discovered. These contain more than 27 MMBO, 5,894 BCFG, and 123 MMBNGL. The average size of oil fields is 5 MMBO, the largest being 16 MMBO. The average size of gas fields is 60 BCFG, the largest being greater than 1.3 TCFG. The future gas potential of the play is estimated to be excellent.

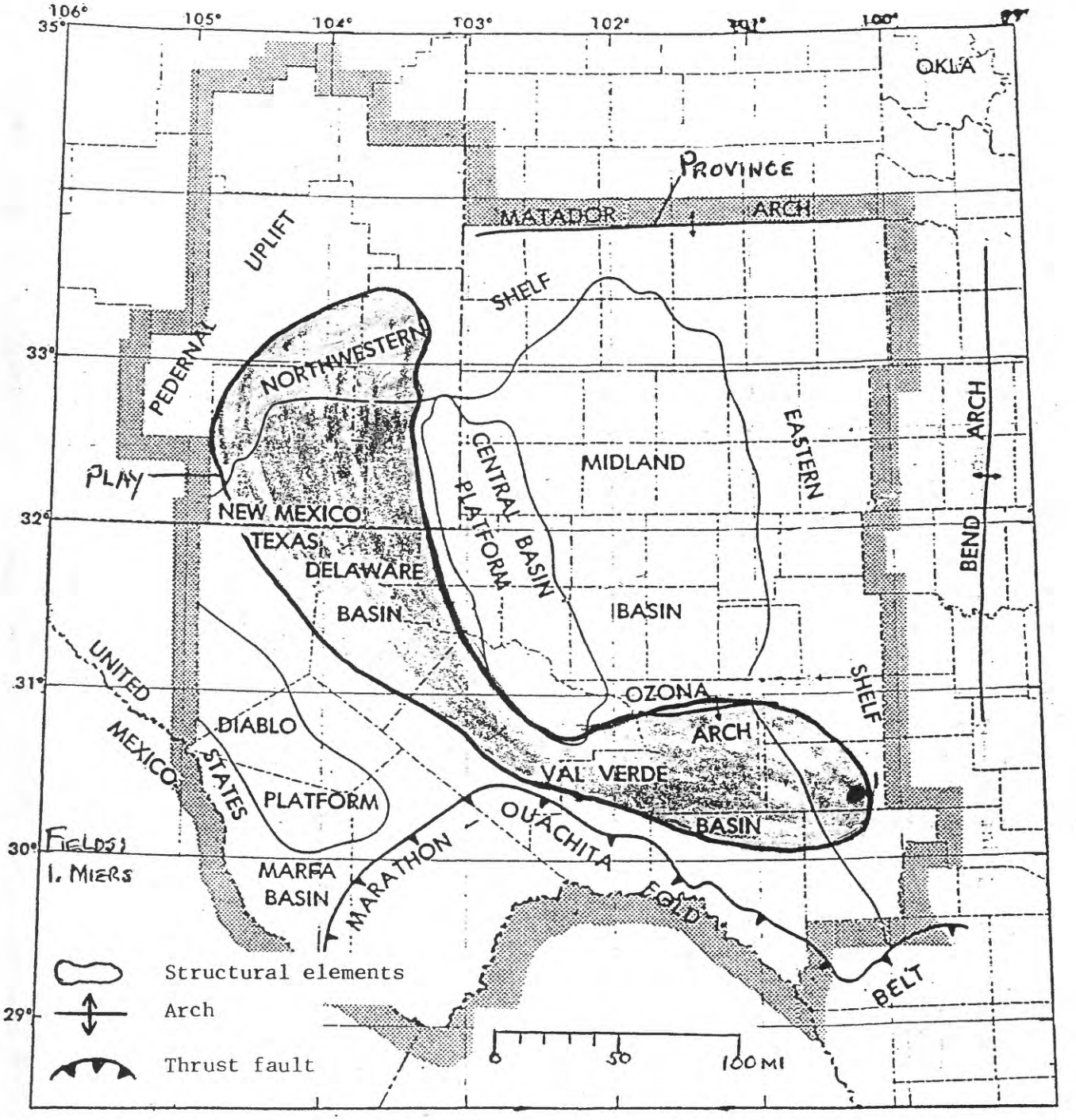

Figure 10. Map of Upper Delaware-Val Verde Basins

OIL AND GAS PLAY DATA

PLAY **UPPER DELAWARE-VAL VERDE BASINS**
PROVINCE **PERMIAN BASIN** CODE **05-107-050**

Play attributes

	Probability of attribute being favorable or present
Hydrocarbon source (S)	**1.00**
Timing (T)	**1.00**
Migration (M)	**1.00**
Potential reservoir-rock facies (R)	**1.00**
Marginal play probability (MP) (S x T x M x R = MP)	**1.00**

Accumulation attribute, conditional on favorable play attributes

Minimum size assessed: oil, 1 x 10^6 BBL; gas, 6 x 10^9 CFG

	Probability of occurrence
At least one undiscovered accumulation of at least minimum size assessed	**1.00**

Character of undiscovered accumulations, conditional on at least one undiscovered accumulation present

Reservoir lithology	Probability of occurrence
Sandstone	**X**
Carbonate rocks	**X**
Other	
Hydrocarbon type	
Oil	**0.03**
Gas	**0.97**

	Fractiles * (estimated amounts)						
Fractile percentages * ----	*100*	*95*	*75*	*50*	*25*	*5*	*0*
Accumulation size							
Oil (x 10^6 BBL)	**1**	**1.1**	**1.4**	**2**	**3.4**	**9.2**	**26**
Gas (x 10^9 CFG)	**6**	**6.7**	**11**	**19**	**40**	**125**	**420**
Reservoir depth (x10^3 ft)							
Oil	**3**			**9**			**11**
Gas (non-associated)	**3**			**10**			**15**
Number of accumulations	**50**	**55**	**65**	**75**	**92**	**115**	**150**

Average ratio of associated-dissolved gas to oil (GOR)	**5000**	CFG/BBL
Average ratio of NGL to non-associated gas	**20**	BBL /10^6 CFG
Average ratio of NGL to associated-dissolved gas	**0**	BBL /10^6 CFG

* For example, fractile percentage 95 represents a 19 in 20 chance of the occurrence of at least the fractile tabulated.

HORSESHOE ATOLL PLAY (060)

The play is characterized by oil and associated gas accumulations trapped in stacked carbonate beds, growth reef and organic-rich carbonate mound reservoirs of a massive reef bank of Pennsylvanian to Lower Permian age. As its name implies, the play area is an arcuate, horseshoe-shaped reef bank, approximately 150 mi long and 20 to 25 mi wide, located in the northwestern part of the Eastern Shelf and the northern part of the Midland basin (fig. 11). Maximum thickness of the reef complex is approximately 3,000 ft; it is buried to a depth of less than 10,000 ft.

Reservoir rocks consist of porous grainstone, algal-mound wackestone and boundstone contained within stacked, massive limestone and dolomitic limestone beds. Carbonate rocks in the massive reef consist of numerous fossil organisms, including shell debris, algal, sponge, bryozoan and crinoidal growths. Reservoirs are contained in the Pennsylvanian Strawn, Canyon and Cisco Formations (fig. 4). Cumulative reservoir thicknesses may range up to 1,500 ft, and porosities average 9 percent and permeabilities 28 millidarcies.

Source rocks for the Pennsylvanian reef reservoirs are adjacent organic-rich shale and shaly limestone deposited in the sediment-starved Midland basin. Hydrocarbon generation in these organic-rich shale and shaly limestone beds probably occurred during Upper Permian time, with the hydrocarbons readily migrating into porous atoll limestones. Trapping mechanisms are stacked reefoidal carbonates, stratigraphic reef growth features and associated organic-rich carbonate rocks. Seals consist of thick sequences of impervious mudstone and shale, which surround and cover the former reef. Trapped hydrocarbons occur at depths of 5,000 to 10,000 ft, and average about 7,400 ft.

The first series of discoveries were in 1948 at the Scurry and Vealmoor fields, but most discoveries were made during the 1950's. The play has been extensively explored and drilled. Since these initial discoveries in 1948 to the end of 1986 the cumulative recoverable resources were 2,739 MMBO, 1,808 BCFG and 522 MMBNGL. Approximately 8 fields larger than 1 MMBO have been discovered since 1961; these contain approximately 14 MMBO, 10 BCF of associated gas, and 0.1 MMBNGL. The average size of the oil fields is 1.7 MMBO, and the largest is the Scurry field with greater than 1.6 BB of ultimately recoverable oil. The play is in a mature stage of exploration, and the future resource potential is probably limited to small-size fields.

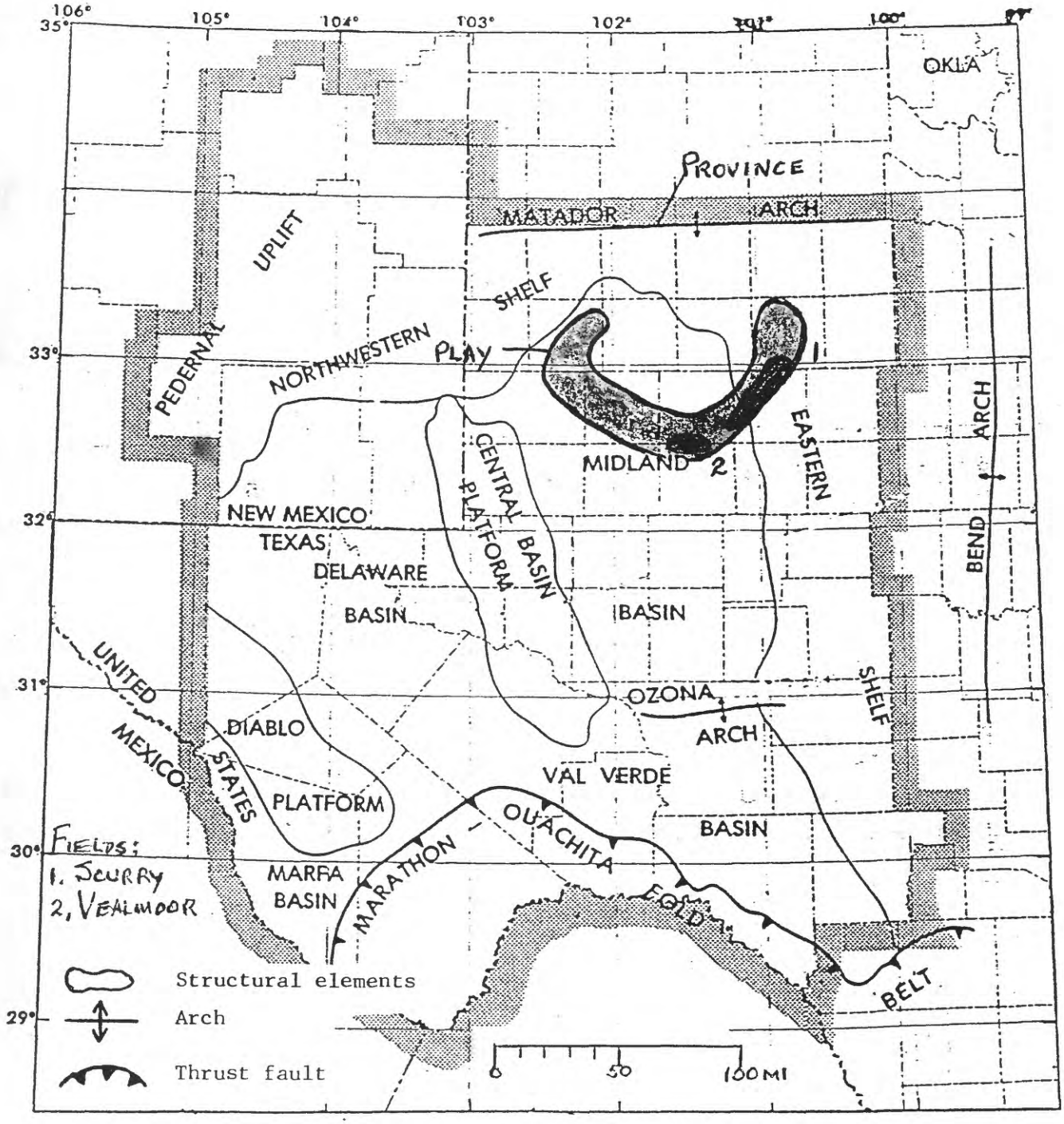

Figure 11. Map of Horseshoe Atoll play

OIL AND GAS PLAY DATA

PLAY **HORSESHOE ATOLL**
PROVINCE **PERMIAN BASIN** CODE **05-107-060**

Play attributes

	Probability of attribute being favorable or present
Hydrocarbon source (S)	**1.00**
Timing (T)	**1.00**
Migration (M)	**1.00**
Potential reservoir-rock facies (R)	**1.00**
Marginal play probability (MP) (S x T x M x R = MP)	**1.00**

Accumulation attribute, conditional on favorable play attributes

Minimum size assessed: oil, 1 x 10^6 BBL; gas, 6 x 10^9 CFG

	Probability of occurrence
At least one undiscovered accumulation of at least minimum size assessed	**1.00**

Character of undiscovered accumulations, conditional on at least one undiscovered accumulation present

Reservoir lithology	Probability of occurrence
Sandstone	
Carbonate rocks	**X**
Other	
Hydrocarbon type	
Oil	**1**
Gas	**0**

	Fractiles * (estimated amounts)						
Fractile percentages * ----	*100*	*95*	*75*	*50*	*25*	*5*	*0*
Accumulation size							
Oil (x 10^6 BBL)	**1**	**1.01**	**1.1**	**1.3**	**1.8**	**5.5**	**29**
Gas (x 10^9 CFG)	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Reservoir depth (x10^3 ft)							
Oil	**5**			**7.5**			**10**
Gas (non-associated)	**0**			**0**			**0**
Number of accumulations	**4**	**5**	**7**	**8**	**10**	**13**	**16**

Average ratio of associated-dissolved gas to oil (GOR)	**700**	CFG/BBL
Average ratio of NGL to non-associated gas	**0**	BBL /10^6 CFG
Average ratio of NGL to associated-dissolved gas	**0**	BBL /10^6 CFG

* For example, fractile percentage 95 represents a 19 in 20 chance of the occurrence of at least the fractile tabulated.

LOWER NORTHWESTERN AND EASTERN SHELF PLAY (071)

The play consists of oil and associated gas accumulations in structural-stratigraphic, structural and, to a lesser extent, stratigraphic traps, in carbonate and subordinate clastic reservoirs of Lower Mississippian through Cambrian age. The play area is triangular in shape and covers a large part of the province. It encompasses most of the Eastern Shelf, the northern part of the Midland basin, and a large part of the Northwestern Shelf. The sides of this triangular area are approximately 235 and 220 mi in length (fig. 12). The thickness of lower Paleozoic sedimentary rocks is less than 5,000 ft.

Reservoir rocks consist of Ordovician to Mississippian age limestone and dolomite, together with a few Ordovician age sandstone beds (fig. 4). Interbedded limestone and dolomite were deposited in the ancestral Tobosa basin, on platform, strandline, and deeper environments associated with evaporitic tidal flat sabkha facies, and mudstone, algal boundstone, wackestone, and oolitic grainstone. The most significant reservoirs are in the Ordovician Ellenburger Formation, Simpson Group, Montoya Formation, Silurian Fusselman and Upper Silurian Shale Formations, and also in other Devonian and Mississippian carbonate rocks. Individual reservoir thicknesses are generally less than 100 ft; porosities average 8 percent and permeabilities 60 millidarcies, the latter being extremely variable.

Source rocks in the lower Paleozoic are considered to be indigenous, organic-rich shales, argillaceous limestone and mudstone. However, a large portion of the generated hydrocarbons may have migrated considerable distances along extensive fault and fracture systems from over- and underlying source beds. Source rocks for hydrocarbons in Ordovician reservoirs are thought to be shale in the Simpson Group. Source rocks for hydrocarbons in Ordovician-Mississippian reservoirs are considered to be primarily shale in the Woodford and Simpson, and associated organic-rich shale beds. Hydrocarbon generation in lower Paleozoic source rocks probably occurred during Permian time, with generated hydrocarbons readily migrating into adjacent reservoirs.

Trapping is by a combination of structural and stratigraphic mechanisms. Simple and faulted anticlines exist, together with stratigraphic updip pinch-out, reservoir truncation, porosity barriers, and lateral facies changes. Interbedded shale, impervious crystalline and argillaceous carbonate, updip pinchout, truncation, facies changes, and permeability barriers act as effective seals. Depths to trapped hydrocarbons are variable and range from 5,000 to 13,000 ft, depending on the location within the play.

The first discovery in the play was in 1927, but most discoveries were made during the 1950's and 1960's. Cumulative recoverable resources to the end of 1986 totaled 964 MMBO, 525 BCFG and 30 MMBNGL. Since 1961, 20 oil and 3 gas fields have been discovered; these contain greater than 112 MMBO, 90 BCFG and 5 MMBNGL. Average size of oil fields is 5.1 MMB, and the average size of gas fields is 9.7 BCFG. The future resource potential of the play is fair to good, but probably limited to small- and medium-sized fields.

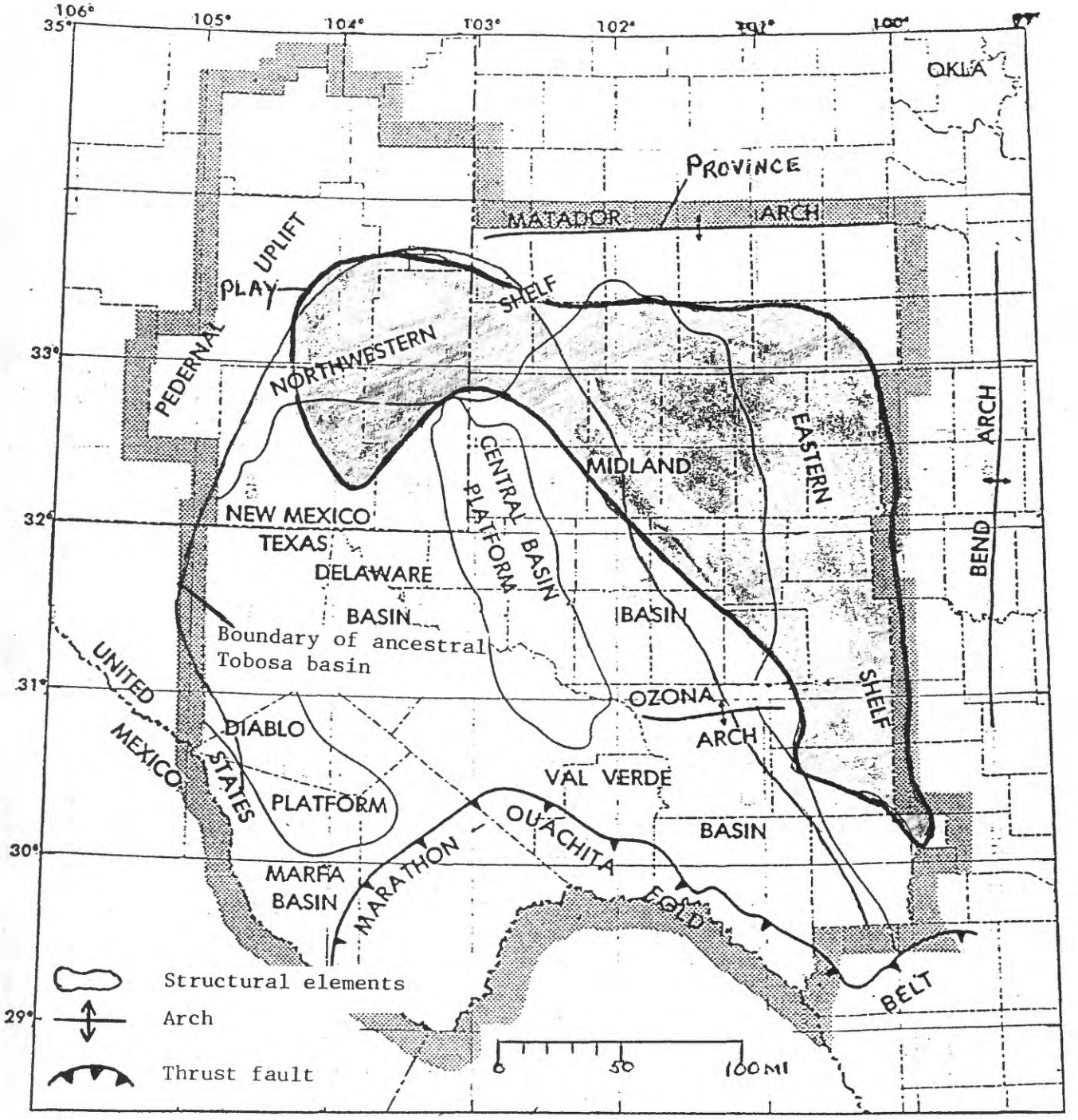

Figure 12. Map of Lower Northwestern and Eastern Shelf play

OIL AND GAS PLAY DATA

PLAY **LOWER NORTHWESTERN AND EASTERN SHELF**
PROVINCE **PERMIAN BASIN** CODE **05-107-071**

Play attributes

	Probability of attribute being favorable or present
Hydrocarbon source (S)	**1.00**
Timing (T)	**1.00**
Migration (M)	**1.00**
Potential reservoir-rock facies (R)	**1.00**
Marginal play probability (MP) (S x T x M x R = MP)	**1.00**

Accumulation attribute, conditional on favorable play attributes

Minimum size assessed: oil, 1 x 10^6 BBL; gas, 6 x 10^9 CFG

	Probability of occurrence
At least one undiscovered accumulation of at least minimum size assessed	**1.00**

Character of undiscovered accumulations, conditional on at least one undiscovered accumulation present

Reservoir lithology	Probability of occurrence
Sandstone	**X**
Carbonate rocks	**X**
Other	
Hydrocarbon type	
Oil	**0.95**
Gas	**0.05**

	Fractiles * (estimated amounts)						
Fractile percentages * ----	*100*	*95*	*75*	*50*	*25*	*5*	*0*
Accumulation size							
Oil (x 10^6 BBL)	**1**	**1.1**	**1.5**	**2.4**	**4.6**	**16**	**60**
Gas (x 10^9 CFG)	**6**	**6.6**	**9**	**16**	**24**	**45**	**72**
Reservoir depth (x10^3 ft)							
Oil	**6**			**8.5**			**13**
Gas (non-associated)	**6**			**8.5**			**13**
Number of accumulations	**20**	**24**	**32**	**40**	**52**	**70**	**100**

Average ratio of associated-dissolved gas to oil (GOR)	**550**	CFG/BBL
Average ratio of NGL to non-associated gas	**30**	BBL /10^6 CFG
Average ratio of NGL to associated-dissolved gas	**0**	BBL /10^6 CFG

* For example, fractile percentage 95 represents a 19 in 20 chance of the occurrence of at least the fractile tabulated.

LOWER CENTRAL PLATFORM-MIDLAND BASIN PLAY (072)

The play is defined by oil and subordinate gas accumulations in combination structural-stratigraphic and highly faulted structural traps below a major unconformity in reservoir rocks of primarily Lower Ordovician to Devonian age, and secondarily of Pennsylvanian age. The play area is approximately 210 mi long by 80 mi wide, covering the Central basin platform, the western part of the Midland basin, and the Ozona arch (fig. 13). It is bounded on the west and south by the Delaware and Val Verde basins and on the east by the Eastern Shelf. The thickness of lower Paleozoic sedimentary rocks is less than 7,500 ft.

Reservoir rocks consist of Ordovician to Mississippian weathered carbonate, chert, and sandstone located below the major unconformity. Lower Paleozoic rocks were deposited in the ancestral Tobosa basin, under various environmental settings, ranging from shallow open-shelf, ramp and deep basin, to restricted shallow-water platform. Principal reservoirs are Devonian in age; reservoirs also occur in the Ordovician Ellenburger Formation, Simpson Group, Montoya Formation, Silurian Fusselman Formation and in the Pennsylvanian Strawn Formation (fig. 4). Individual thicknesses of Devonian reservoirs are generally less than 150 ft. Porosities average 10 percent and permeabilities 55 millidarcies.

Associated organic-rich beds in the Devonian-Mississippian Woodford Shale are prolific source rocks. Hydrocarbon generation from this unit probably occurred during Lower and Upper Permian time. Generated hydrocarbons were trapped below the unconformity and migrated into nearby weathered reservoir rocks. Trapping is by a combination of both structural and stratigraphic mechanisms. Structural traps are anticlines, fault blocks, and domes. Stratigraphic traps, prevalent on the Central Basin Platform, are pinch-out and eroded updip truncation types controlled by facies changes. Seals are provided by the Woodford Shale, and in, impervious Upper Pennsylvanian carbonate strata, Lower Permian shale and carbonate, updip pinch-out and facies change permeability barriers. Trapped hydrocarbons occur at depths ranging from 4,500 to 12,000 ft, with an average depth of approximately 9,500 ft.

The first discovery in the play occurred in the Ozona arch area in the 1920's, but most discoveries were made during the 1940's and 1950's. Cumulative recoverable resources to the end of 1986 were 2,558 MMBO, 7,876 BCFG and 756 MMBNGL. Since 1961, approximately 21 oil and 6 gas fields have been discovered. These fields contain greater than 73 MMBO, 200 BCFG and 7 MMBNGL. Average size of oil fields is 3.3 MMBO, and the average size of gas fields is 15.5 BCFG. Future resource potential is fair to good, but limited to smaller fields.

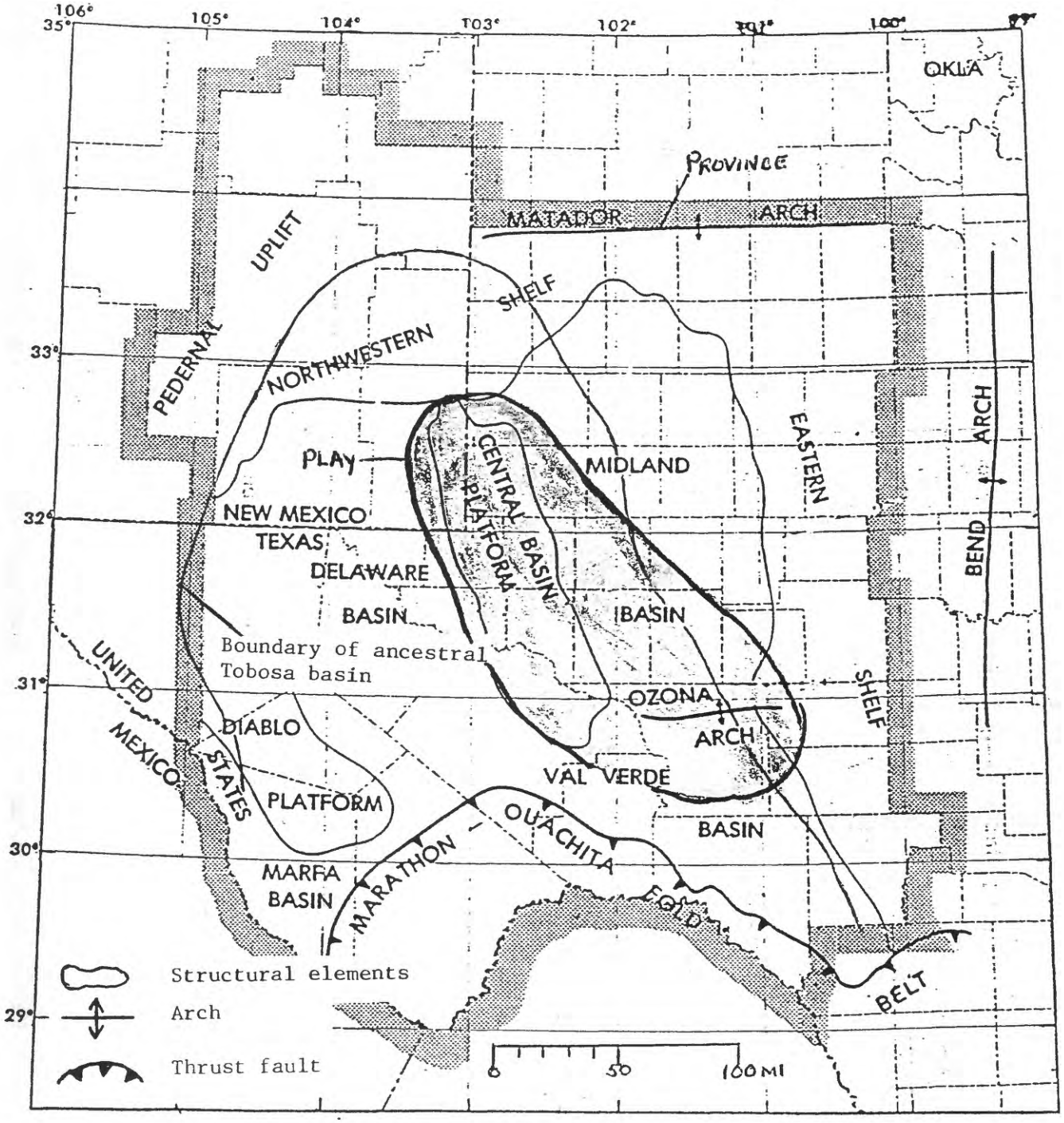

Figure 13. Map of Lower Central Platform-Midland Basin play

OIL AND GAS PLAY DATA

PLAY **LOWER CENTRAL PLATFORM-MIDLAND BASIN**
PROVINCE **PERMIAN BASIN** CODE **05-107-072**

Play attributes

	Probability of attribute being favorable or present
Hydrocarbon source (S)	**1.00**
Timing (T)	**1.00**
Migration (M)	**1.00**
Potential reservoir-rock facies (R)	**1.00**
Marginal play probability (MP) (S x T x M x R = MP)	**1.00**

Accumulation attribute, conditional on favorable play attributes

Minimum size assessed: oil, 1 x 10^6 BBL; gas, 6 x 10^9 CFG

	Probability of occurrence
At least one undiscovered accumulation of at least minimum size assessed	**1.00**

Character of undiscovered accumulations, conditional on at least one undiscovered accumulation present

Reservoir lithology	Probability of occurrence
Sandstone	**X**
Carbonate rocks	**X**
Other	
Hydrocarbon type	
Oil	**0.75**
Gas	**0.25**

	Fractiles * (estimated amounts)						
Fractile percentages * ----	*100*	*95*	*75*	*50*	*25*	*5*	*0*
Accumulation size							
Oil (x 10^6 BBL)	**1**	**1.05**	**1.4**	**2**	**4**	**17**	**90**
Gas (x 10^9 CFG)	**6**	**6.3**	**7.6**	**10**	**17**	**44**	**130**
Reservoir depth (x10^3 ft)							
Oil	**5**			**9.5**			**13.5**
Gas (non-associated)	**8**			**11**			**14**
Number of accumulations	**15**	**18**	**24**	**30**	**40**	**56**	**80**

Average ratio of associated-dissolved gas to oil (GOR)	**1500**	CFG/BBL
Average ratio of NGL to non-associated gas	**35**	BBL /10^6 CFG
Average ratio of NGL to associated-dissolved gas	**0**	BBL /10^6 CFG

* For example, fractile percentage 95 represents a 19 in 20 chance of the occurrence of at least the fractile tabulated.

LOWER DELAWARE-VAL VERDE BASINS PLAY (073)

This gas play is defined by deep accumulations in structural and, to a lesser extent, structural-stratigraphic, anticlinal traps in carbonate reservoirs of Lower Ordovician to Silurian age. The play area is arcuate in shape, approximately 275 mi long and 70 mi at maximum width, and covers the Delaware and Val Verde basins. It is bounded on the west and south by the Diablo platform and the Marathon-Ouachita fold belt, and on the east by the Central basin platform and Ozona arch (fig. 14). The thickness of Lower Paleozoic sedimentary rocks is less than 8,000 ft.

Reservoir rocks are mainly crystalline cherty dolomite and limestone of Ordovician to Silurian age, which have solution and vuggy porosity and are fractured and faulted. Lower Paleozoic rocks were deposited in a shallow marine environment in the gently subsiding ancestral Tobosa basin, which covered all of the province, including the surrounding shelves. Carbonate reservoirs are in the Lower Ordovician Ellenburger Formation, Upper Ordovician Montoya and Silurian Fusselman Formations; clastic reservoirs are in the Ordovician Simpson Group (fig. 4). Fractures and joints in the carbonate rocks form adequate porosity and permeability conduits for migration of gas. Individual reservoir thicknesses are in excess of 500 ft.

Three chief sources of hydrocarbons in the two basins may be: (1) Middle Ordovician shale and limestone; (2) Upper Devonian and Mississippian shale and shaly limestone (Woodford); and (3) Pennsylvanian and Permian basinal shale facies. Major hydrocarbon generation probably occurred in Permian time. Generated hydrocarbons migrated, probably long distances, into porous fractures and joints in lower Paleozoic carbonates. Trapping mechanisms are mostly structural, in faulted, fractured, and jointed anticlinal features. Seals are overlying impermeable carbonate and shale which are not fractured or jointed. Trapped hydrocarbons occur at depths of 10,000 to 22,000 ft in Ordovician rocks, and at depths greater than 8,000 ft in Silurian rocks.

The first significant discovery in the play was in 1952 at the Puckett field, but most discoveries were made during the 1960's and 1970's. Cumulative recoverable resources to the end of 1986 were 20 MMBO, 20,765 BCFG and 182 MMBNGL. Since 1961, 55 gas fields have been discovered which contain more than 15 TCFG. The Gomez field in Texas, discovered in 1963, contains 5.5 TCFG. The average size of fields discovered, since 1961, is 273 BCFG. Future potential for significant, major gas field discoveries is excellent.

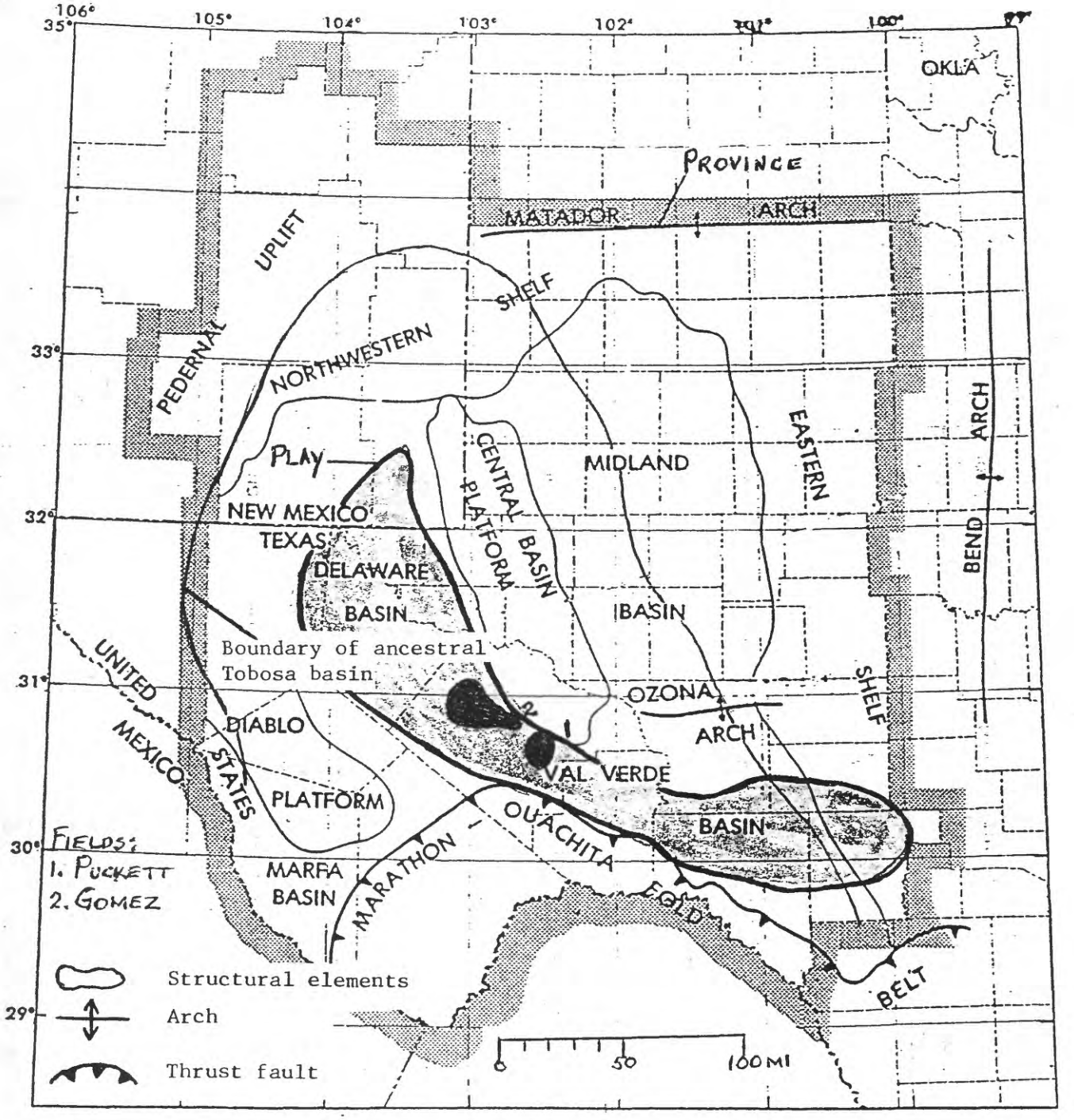

Figure 14. Map of Lower Delaware-Val Verde Basins play

OIL AND GAS PLAY DATA

PLAY **LOWER DELAWARE-VAL VERDE BASINS**
PROVINCE **PERMIAN BASIN** CODE **05-107-073**

Play attributes

	Probability of attribute being favorable or present
Hydrocarbon source (S)	**1.00**
Timing (T)	**1.00**
Migration (M)	**1.00**
Potential reservoir-rock facies (R)	**1.00**
Marginal play probability (MP) (S x T x M x R = MP)	**1.00**

Accumulation attribute, conditional on favorable play attributes

Minimum size assessed: oil, 1 x 10^6 BBL; gas, 6 x 10^9 CFG

	Probability of occurrence
At least one undiscovered accumulation of at least minimum size assessed	**1.00**

Character of undiscovered accumulations, conditional on at least one undiscovered accumulation present

Reservoir lithology	Probability of occurrence
Sandstone	**X**
Carbonate rocks	**X**
Other	
Hydrocarbon type	
Oil	**0**
Gas	**1**

	Fractiles * (estimated amounts)						
Fractile percentages * ----	*100*	*95*	*75*	*50*	*25*	*5*	*0*
Accumulation size							
Oil (x 10^6 BBL)	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Gas (x 10^9 CFG)	**6**	**7.8**	**18**	**36**	**90**	**390**	**1900**
Reservoir depth (x10^3 ft)							
Oil	**0**			**0**			**0**
Gas (non-associated)	**8**			**15**			**22**
Number of accumulations	**40**	**44**	**52**	**60**	**70**	**86**	**100**

Average ratio of associated-dissolved gas to oil (GOR)	**0**	CFG/BBL
Average ratio of NGL to non-associated gas	**10**	BBL /10^6 CFG
Average ratio of NGL to associated-dissolved gas	**0**	BBL /10^6 CFG

* For example, fractile percentage 95 represents a 19 in 20 chance of the occurrence of at least the fractile tabulated.

PALO DURO BASIN PROVINCE (108)

By Mitchell E. Henry

INTRODUCTION

The Palo Duro basin province is located in the Texas Panhandle and eastern New Mexico and covers an area of about 22,700 mi^2 in 19 Texas counties and 2 counties in New Mexico. The largest geologic feature in the province is the Palo Duro basin which is bounded at the north by the Amarillo uplift, at the south by the Matador arch, and to the east, and west by minor structural highs that separate it from the Hardeman and Tucumcari basins.

The Palo Duro basin, which contains approximately 10,000 ft of sedimentary rocks ranging from Precambrian to Tertiary, deepens generally from north to south (fig. 15); however, some of the more deeply buried rocks occur in a down-dropped block south of the Amarillo uplift. The central portion of the province does not currently produce oil or gas, but production does exist along the southern border (Matador Arch) and along the northern border, south of the Amarillo uplift in rocks of Mississippian, Pennsylvanian and Permian age. Four plays were defined and individually assessed in the province: Pennsylvanian Stratigraphic (020), Shelf Margin (030), Matador arch (040), and Northern Basin (050).

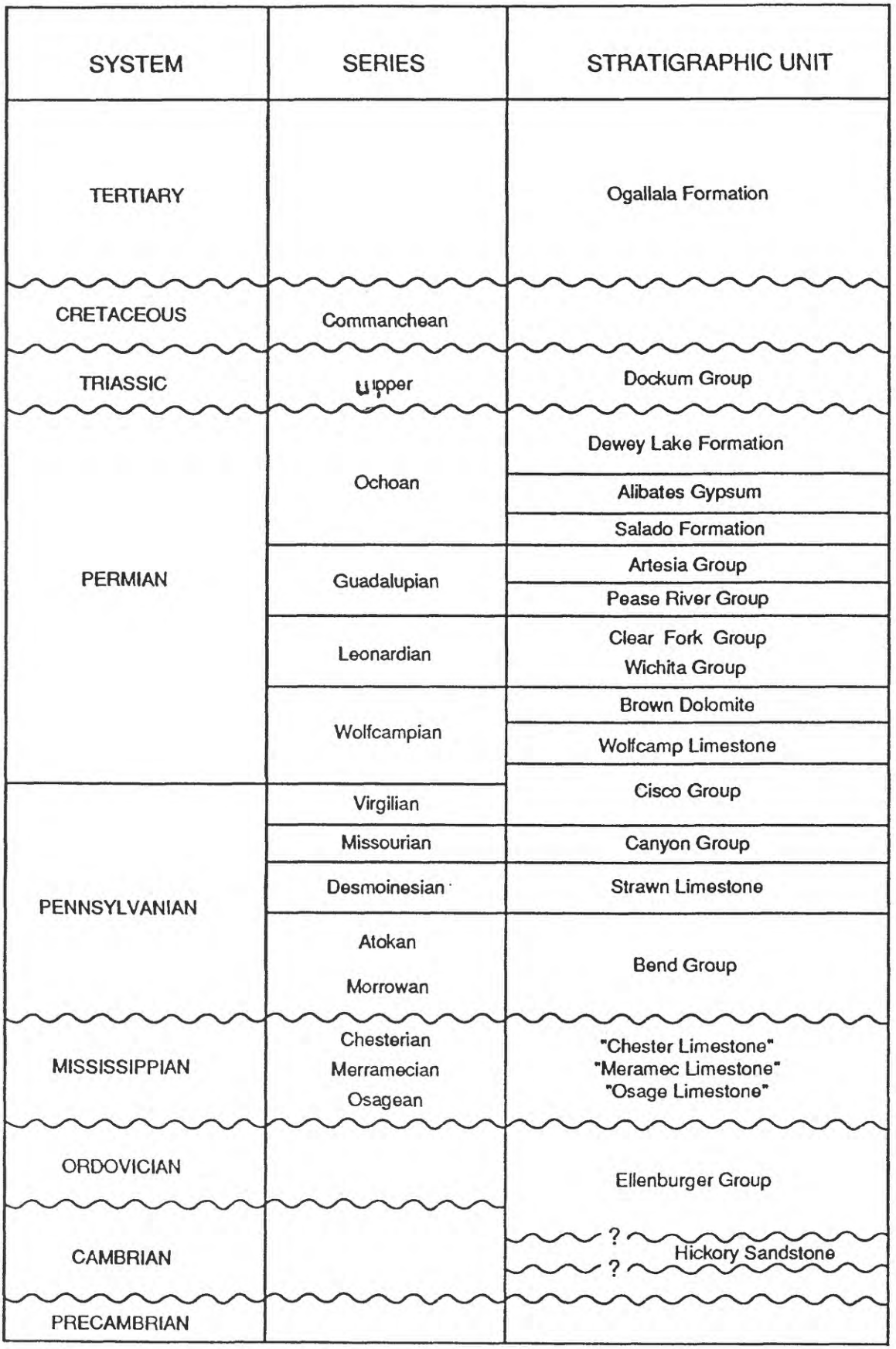

Figure 15. Generalized stratigraphic column, Palo Duro Basin province

PENNSYLVANIAN STRATIGRAPHIC PLAY (020)

This speculative play consists of potential stratigraphically trapped oil and gas in Pennsylvanian clastic reservoir rocks that were deposited south of Bravo dome and the Amarillo uplift. The play is composed of two, irregular eastern and western segments that correspond to the distribution of Pennsylvanian fan-delta deposits. The eastern area is about 90 mi long and 145 mi wide, and the western area is about 60 mi long and 50 mi wide. (fig. 16)

Potential reservoirs are in clastic rocks of the Lower to Middle Pennsylvanian Bend Group, Strawn Limestone and Canyon Group (fig. 15) that were deposited by fan-delta complexes. These sandstone beds are arkosic near the Amarillo uplift and Bravo dome and become generally more quartz-rich and fine-grained toward the south, and include interbedded shale and limestone in the fan-delta sequences. Total combined thicknesses of the Bend, Strawn and Canyon units range from less than 700 to over 2,000 ft. Porosity values calculated from porosity logs range from 3 to 21 percent and average about 14 percent.

Source rocks are probably shale in the Pennsylvanian Cisco Group and marine basinal shales of Permian Wolfcampian age. These rocks display a range of total organic carbon (TOC) from 0.01 to 6.9 percent with about one-third of the analyzed samples containing greater than 0.5 percent TOC. Thermal maturity analyses indicate that the source rocks range from transitional to immature and probably never reached the main stage of oil generation. Thermal maturity studies also suggest that these source rocks are presently entering the early stage of oil generation.

A favorable relationship exists between the formation of traps during deposition of reservoir rocks and generation of hydrocarbons. Traps were available prior to and during the time of hydrocarbon generation; migration pathways are probably lateral and updip from basinal shale source rocks to the reservoir rocks. Anticipated traps are formed by sandstone and arkosic sandstone units that pinch out up-dip into shale or non-porous limestone. Drilling depths range from about 3,000 to 9,000 ft.

Approximately 84 wells have been drilled in the play with no discovered fields to date. Because of the poor quality of source rocks and their low level of thermal maturity, the future potential of the play is expected to be poor to fair.

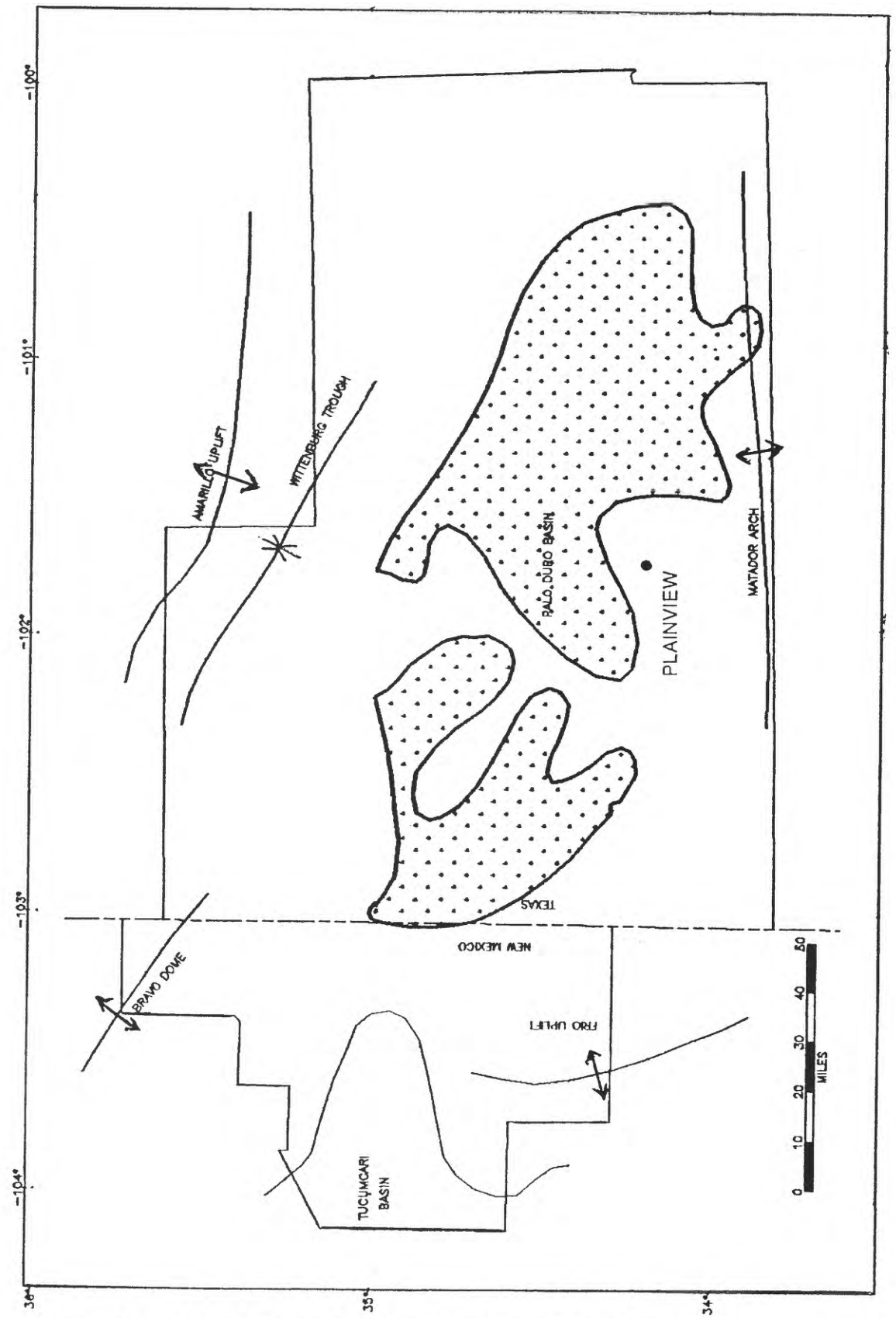

Figure 16. Map of Pennsylvanian Stratigraphic play

OIL AND GAS PLAY DATA

PLAY **PENNSYLVANIAN STRATIGRAPHIC**
PROVINCE **PALO DURO BASIN** CODE **05-108-020**

Play attributes

	Probability of attribute being favorable or present
Hydrocarbon source (S)	**1.00**
Timing (T)	**1.00**
Migration (M)	**1.00**
Potential reservoir-rock facies (R)	**1.00**
Marginal play probability (MP) (S x T x M x R = MP)	**1.00**

Accumulation attribute, conditional on favorable play attributes

Minimum size assessed: oil, 1 x 10^6 BBL; gas, 6 x 10^9 CFG

	Probability of occurrence
At least one undiscovered accumulation of at least minimum size assessed	**1.00**

Character of undiscovered accumulations, conditional on at least one undiscovered accumulation present

Reservoir lithology	Probability of occurrence
Sandstone	**X**
Carbonate rocks	**X**
Other	
Hydrocarbon type	
Oil	**1**
Gas	**0**

	Fractiles * (estimated amounts)						
Fractile percentages * ----	*100*	*95*	*75*	*50*	*25*	*5*	*0*
Accumulation size							
Oil (x 10^6 BBL)	**1**	**1.03**	**1.2**	**1.5**	**2.2**	**5.1**	**14**
Gas (x 10^9 CFG)	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Reservoir depth (x10^3 ft)							
Oil	**5.5**			**7.5**			**8.5**
Gas (non-associated)	**0**			**0**			**0**
Number of accumulations	**3**	**4**	**5**	**6**	**8**	**12**	**15**

Average ratio of associated-dissolved gas to oil (GOR)	**100**	CFG/BBL
Average ratio of NGL to non-associated gas	**0**	BBL /10^6 CFG
Average ratio of NGL to associated-dissolved gas	**0**	BBL /10^6 CFG

* For example, fractile percentage 95 represents a 19 in 20 chance of the occurrence of at least the fractile tabulated.

SHELF MARGIN PLAY (030)

The play is defined by stratigraphic accumulations involving Pennsylvanian and Permian shelf and shelf-margin carbonate rocks in the Palo Duro basin. The play boundary encloses an irregular area generally coincident with the presence of porous units in the Pennsylvanian Strawn Limestone and Canyon Group, and in Permian Wolfcampian and Leonardian carbonate rocks (fig. 15). The play area in the central part of the basin is nearly separated into two subequal parts by a narrow north-south trending basinal shale facies, and extends for about 130 mi in an east-west and a north-south direction. A portion of the play area extends a short distance south into the Permian Basin province (107); however, all undiscovered resources in the play were assessed entirely within the Palo Duro Basin province (fig. 17).

Known reservoir rocks are primarily dolomitic limestone in the Strawn, Canyon, Wolfcamp and Leonard and secondarily in thin sandstones of the Pennsylvanian Cisco Group. These rocks have porosities ranging locally from 6 to 20 percent, but in general, they are mainly tight. Porosity is best developed in and near the shelf margin areas of shelf limestones where dolomitization has enhanced porosity. Wolfcampain reservoirs are not as prospective because the upper part of the Wolfcampain sequence, which contains the greatest porosity, is known to be a regional saline aquifer. Total thickness of carbonate rocks in the play ranges from 1,300 to about 4,000 ft.

Probable source rocks are basinal shales in the Pennsylvanian Cisco Group and Permian Wolfcampian that contain greater than 0.5 percent TOC; however, these rocks are not fully mature with respect to hydrocarbon generation. Timing of migration is not a limiting factor for present-day traps formed by dolomitization-enhanced porosity. Migration pathways are postulated which indicate that hydrocarbons moved generally northward and eastward from source rocks in the central part of the basin. Additional, minor pathways are also suggested toward the south and west in the northern part of the basin.

Traps are mainly stratigraphic; however, minor production is present from Wolfcampain rocks outside of the play area in small, structurally controlled accumulations near the Amarillo uplift and Matador arch (Cruz Creek and Wilie fields; cumulative production is 2,200 and 74,000 BO, respectively). Drilling depths range from 4,000 to 8,000 ft.

The CeeVee and Silverton fields (now abandoned) located in the southeastern and east-central part of the play have produced a combined total of about 900,000 BO as of December, 1986 (fig. 17). The CeeVee field was discovered in 1975 and the Silverton field in 1982. Approximately 266 wildcat wells have been drilled in the play with generally negative results. The future potential of the play is poor and limiting factors are the low level of thermal maturity of source rocks and difficulty in locating potential stratigraphic traps.

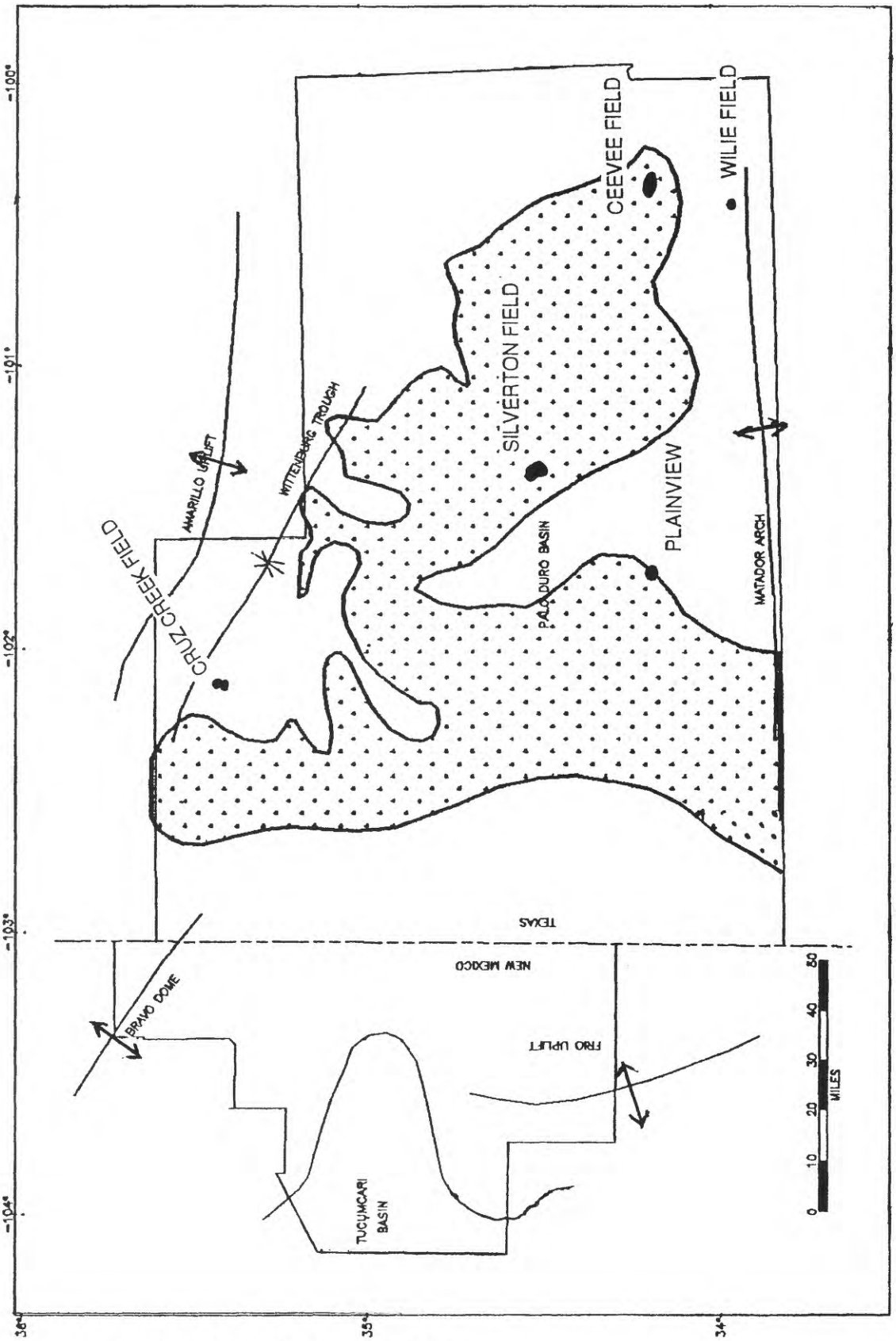

Figure 17. Map of Shelf Margin play

OIL AND GAS PLAY DATA

PLAY **SHELF MARGIN**
PROVINCE **PALO DURO BASIN** CODE **05-108-030**

Play attributes

	Probability of attribute being favorable or present
Hydrocarbon source (S)	**1.00**
Timing (T)	**1.00**
Migration (M)	**1.00**
Potential reservoir-rock facies (R)	**1.00**
Marginal play probability (MP) (S x T x M x R = MP)	**1.00**

Accumulation attribute, conditional on favorable play attributes

Minimum size assessed: oil, 1 x 10^6 BBL; gas, 6 x 10^9 CFG

	Probability of occurrence
At least one undiscovered accumulation of at least minimum size assessed	**1.00**

Character of undiscovered accumulations, conditional on at least one undiscovered accumulation present

Reservoir lithology	Probability of occurrence
Sandstone	
Carbonate rocks	**X**
Other	
Hydrocarbon type	
Oil	**1**
Gas	**0**

	Fractiles * (estimated amounts)						
Fractile percentages * ----	*100*	*95*	*75*	*50*	*25*	*5*	*0*
Accumulation size							
Oil (x 10^6 BBL)	**1**	**1.03**	**1.2**	**1.5**	**2.4**	**7.4**	**32**
Gas (x 10^9 CFG)	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Reservoir depth (x10^3 ft)							
Oil	**4**			**6**			**8**
Gas (non-associated)	**0**			**0**			**0**
Number of accumulations	**5**	**7**	**11**	**14**	**18**	**24**	**30**

Average ratio of associated-dissolved gas to oil (GOR)	**100**	CFG/BBL
Average ratio of NGL to non-associated gas	**0**	BBL /10^6 CFG
Average ratio of NGL to associated-dissolved gas	**0**	BBL /10^6 CFG

* For example, fractile percentage 95 represents a 19 in 20 chance of the occurrence of at least the fractile tabulated.

MATADOR ARCH PLAY (040)

This play is characterized by the presence of oil and gas fields in predominately structural traps, some with stratigraphic control, in Pennsylvanian and Permian carbonate reservoirs on the Matador arch. The play area extends for about 150 mi in an east-west direction and about 12 mi in a north-south direction. The southern, eastern and western boundaries are the province boundaries and the northern boundary is approximately the northern limit of the structural influence of the Matador arch (fig. 18). Although part of the play extends into the northern portion of the Permian Basin province (107), all undiscovered resources in the play were assessed within the Palo Duro Basin province.

Known producing reservoirs are exclusively carbonate rocks and with the exception of the NRM field, which produces from Mississippian age rocks, all are of Pennsylvanian or Permian age. Total thickness of these rocks is about 3,800 ft.

Organic matter in probable source rocks is relatively lean and immature, and the rather large volume of oil production from this hydrocarbon-poor area is due to migration from the hydrocarbon-rich Midland basin (Permian basin) to the south. If this explanation is correct, the presence of large volumes of oil along the Matador arch is not viewed as encouragement as to the presence of large undiscovered accumulations in other plays adjacent to and northward of the Matador Arch play.

Known traps are all primarily structural, but the majority of these have some stratigraphic control that is probably the result of dolomitization-enhanced porosity, as in the Anton-Irish field. Drilling depths range from 3,200 to 10,000 ft.

Approximately 211 wildcat wells have been drilled in this mature play; the first field discovery was in 1945 and the most recent discovery was in 1977. Cumulative production from 21 fields is 168 MMBO at the end of 1986, with greater than 150 MMBO being derived from the Anton-Irish field alone. Of the total fields in the play, only six have produced more than 1 MMBO. The future potential of the play is minor and additional discoveries will probably occur in traps similar to those already found; however, future stratigraphic traps of smaller size may be more common.

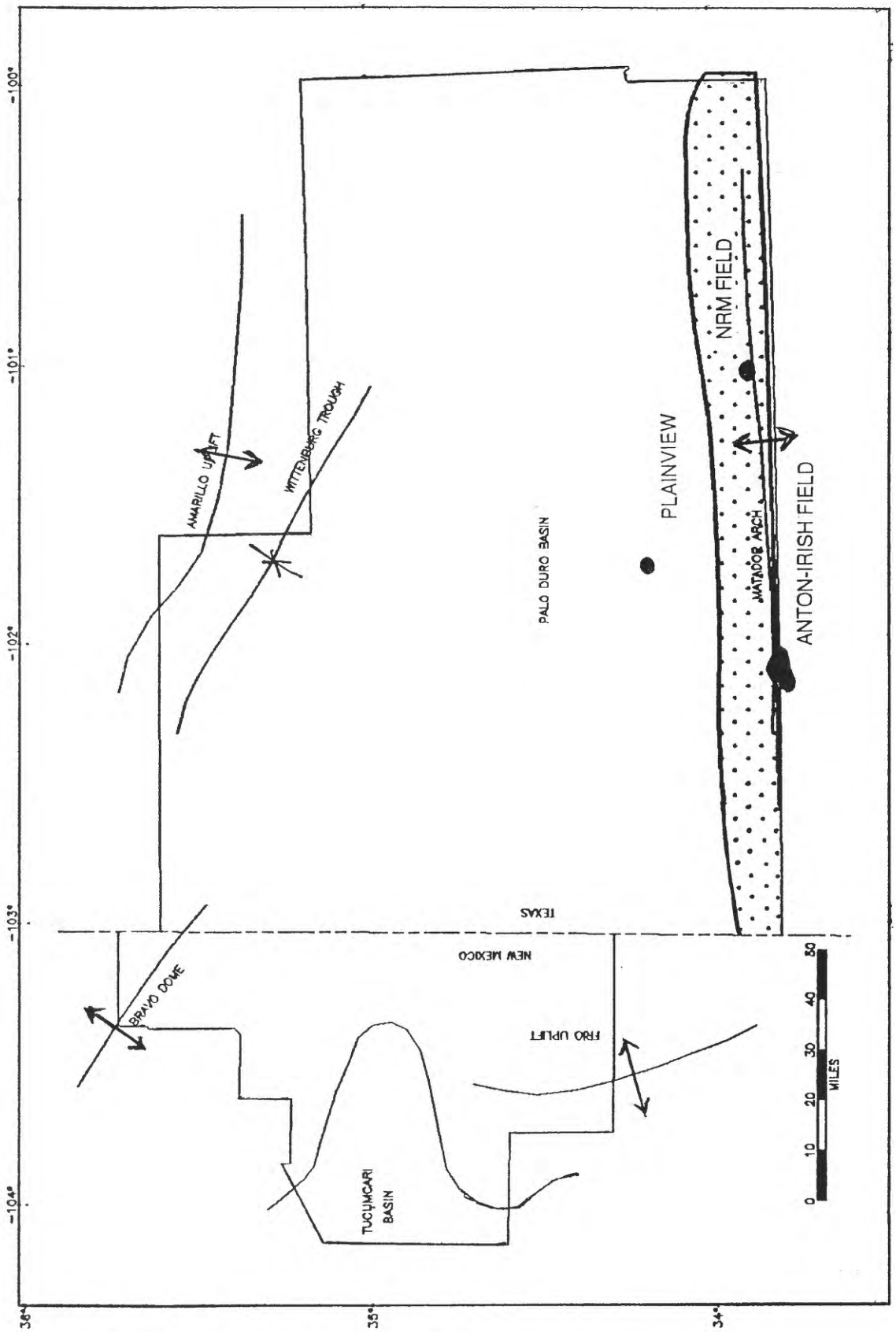

Figure 18. Map of Matador Arch play

OIL AND GAS PLAY DATA

PLAY **MATADOR ARCH**
PROVINCE **PALO DURO BASIN** CODE **05-108-040**

Play attributes

	Probability of attribute being favorable or present
Hydrocarbon source (S)	**1.00**
Timing (T)	**1.00**
Migration (M)	**1.00**
Potential reservoir-rock facies (R)	**1.00**
Marginal play probability (MP) (S x T x M x R = MP)	**1.00**

Accumulation attribute, conditional on favorable play attributes

Minimum size assessed: oil, 1 x 10^6 BBL; gas, 6 x 10^9 CFG

	Probability of occurrence
At least one undiscovered accumulation of at least minimum size assessed	**1.00**

Character of undiscovered accumulations, conditional on at least one undiscovered accumulation present

Reservoir lithology	Probability of occurrence
Sandstone	
Carbonate rocks	**X**
Other	
Hydrocarbon type	
Oil	**1**
Gas	**0**

	Fractiles * (estimated amounts)						
Fractile percentages * ----	*100*	*95*	*75*	*50*	*25*	*5*	*0*
Accumulation size							
Oil (x 10^6 BBL)	**1**	**1.07**	**1.4**	**2**	**3**	**5**	**6**
Gas (x 10^9 CFG)	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Reservoir depth (x10^3 ft)							
Oil	**3**			**7**			**10**
Gas (non-associated)	**0**			**0**			**0**
Number of accumulations	**1**	**1**	**2**	**3**	**4**	**5**	**5**

Average ratio of associated-dissolved gas to oil (GOR)	**200**	CFG/BBL
Average ratio of NGL to non-associated gas	**0**	BBL /10^6 CFG
Average ratio of NGL to associated-dissolved gas	**0**	BBL /10^6 CFG

* For example, fractile percentage 95 represents a 19 in 20 chance of the occurrence of at least the fractile tabulated.

NORTHERN BASIN PLAY (050)

The play involves oil and gas accumulations in carbonate and clastic reservoirs of Pennsylvanian and Permian age in structural traps, but combination structural-stratigraphic traps are probably also present. The play is the only one in the province that contains significant quantities of hydrocarbons that are believed to be indigenous to the Palo Duro basin. The play extends for about 170 mi in an east-west direction and ranges from about 25 to 50 mi in a north-south direction (fig. 19). The northern and eastern boundaries coincide with the northern and eastern province boundaries, the western boundary is near the Texas-New Mexico border, and the southern boundary is drawn to include rocks that were probably affected by movement along the Amarillo uplift and Bravo dome.

Known reservoir rocks include Pennsylvanian and Permian carbonate, sandstone and "granite wash". Porosities range from 3 to 21 percent and average about 14 percent. Total reservoir thicknesses range from about 1,400 to 3,700 ft.

Source rocks are probably shale in the Pennsylvanian Cisco Group and basinal shales in the Permian Wolfcampian series that are down-faulted in the Wittenburg trough area and are more thermally mature than those less deeply buried. An elevated geothermal gradient (1.6°F/100 ft) is known to exist about 25 mi southwest of the Wittenburg trough; this location is also coincident with an area of elevated (180°F) subsurface temperatures. Both of these thermal anomalies occur in an area containing from 500 to 1,000 ft of probable source rocks and may explain the presence of some of the hydrocarbon accumulations in the play. Locations of known hydrocarbon accumulations correlate well with proposed migration pathways from these two more thermally mature areas. In general, source beds range from poor to good in quality but the actual volume of these rocks that have generated hydrocarbons may be small. Favorability of the relationship between hydrocarbon generation, migration and trap formation is apparent from known production in the play. Known traps all display dominant structural control with secondary stratigraphic control resulting from porosity variations in limestone, and pinchouts of sandstone into interbedded shale or tight limestone zones.

Structural traps are low amplitude anticlines related to en echelon faulting near Bravo dome and the Amarillo uplift. Shale and dense limestone are probable seals; drilling depths range from 2,500 to 10,000 ft.

Hydrocarbons were first discovered in 1924 at the Cliffside gas field, and oil was discovered in 1957 at the Alamosa field (fig. 19). The most recent discoveries were made in 1983 at the Brandi and Lambert-Twell fields. About 7.5 MMBO and 100 BCFG have been produced from 20 fields in the play to the end of 1986. About 99 percent of the produced gas is from the Cliffside field; only two oil fields have each produced more than 1 MMBO. Approximately 210 wildcat wells have been drilled in the play, and the future potential of the play is estimated to be poor to fair.

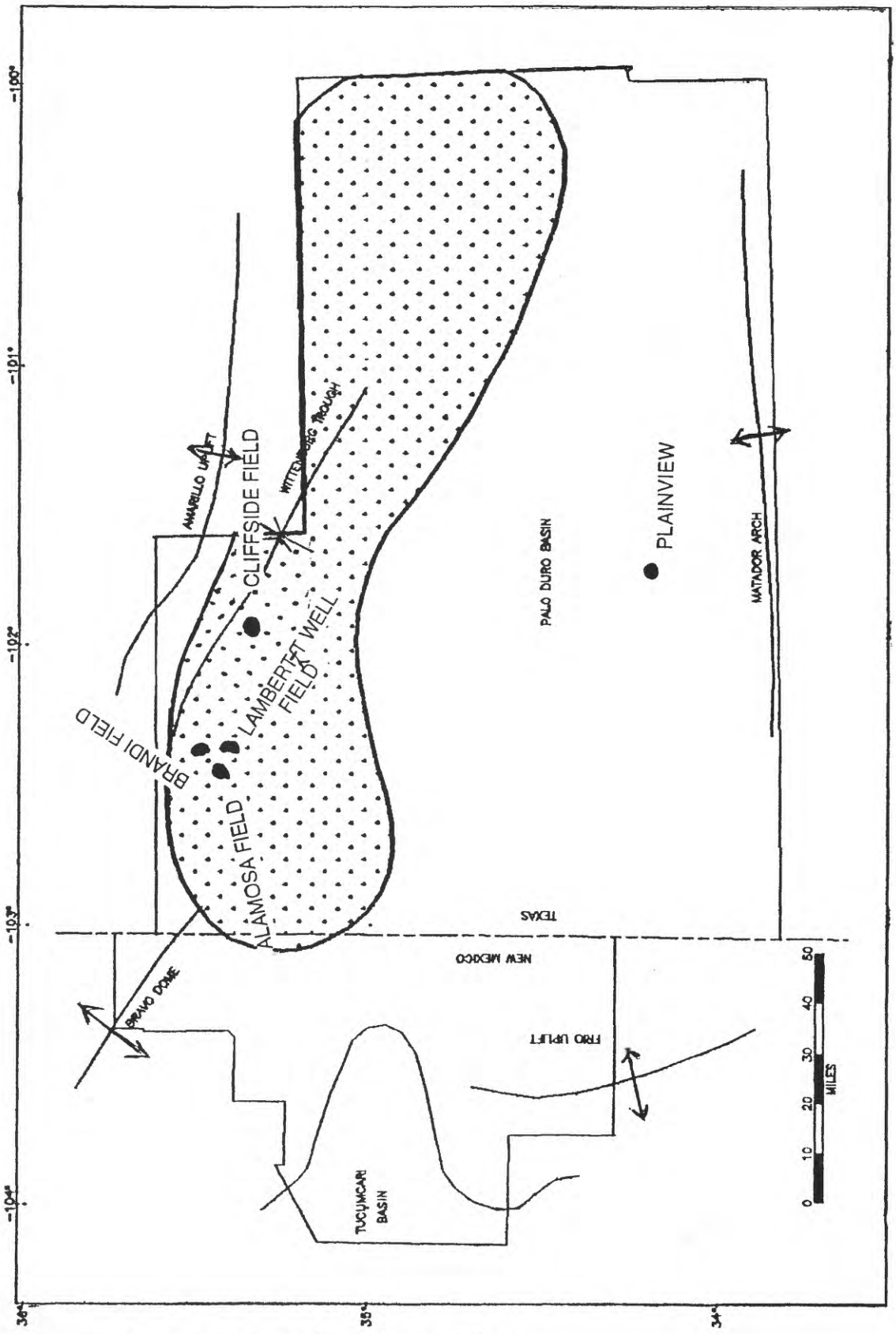

Figure 19. Map of Northern Basin play

OIL AND GAS PLAY DATA

PLAY **NORTHERN BASIN**
PROVINCE **PALO DURO BASIN** CODE **05-108-050**

Play attributes

	Probability of attribute being favorable or present
Hydrocarbon source (S)	**1.00**
Timing (T)	**1.00**
Migration (M)	**1.00**
Potential reservoir-rock facies (R)	**1.00**
Marginal play probability (MP) (S x T x M x R = MP)	**1.00**

Accumulation attribute, conditional on favorable play attributes

Minimum size assessed: oil, 1 x 10^6 BBL; gas, 6 x 10^9 CFG

	Probability of occurrence
At least one undiscovered accumulation of at least minimum size assessed	**1.00**

Character of undiscovered accumulations, conditional on at least one undiscovered accumulation present

Reservoir lithology	Probability of occurrence
Sandstone	**X**
Carbonate rocks	**X**
Other	
Hydrocarbon type	
Oil	**0.9**
Gas	**0.1**

	Fractiles * (estimated amounts)						
Fractile percentages * ----	*100*	*95*	*75*	*50*	*25*	*5*	*0*
Accumulation size							
Oil (x 10^6 BBL)	**1**	**1.03**	**1.2**	**1.5**	**2.4**	**7.4**	**32**
Gas (x 10^9 CFG)	**6**	**6.2**	**7.2**	**9**	**13**	**30**	**84**
Reservoir depth (x10^3 ft)							
Oil	**2.5**			**7**			**10**
Gas (non-associated)	**2.5**			**7**			**10**
Number of accumulations	**6**	**7**	**9**	**10**	**14**	**22**	**30**

Average ratio of associated-dissolved gas to oil (GOR)	**200**	CFG/BBL
Average ratio of NGL to non-associated gas	**5**	BBL /10^6 CFG
Average ratio of NGL to associated-dissolved gas	**0**	BBL /10^6 CFG

* For example, fractile percentage 95 represents a 19 in 20 chance of the occurrence of at least the fractile tabulated.

PEDERNAL UPLIFT PROVINCE (109)

By Mitchell E. Henry

The province covers about 7,700 mi^2 in east-central New Mexico and is composed principally of the Tucumcari basin and its bounding positive features, the Pedernal uplift, Bravo dome and Frio uplift (fig. 20). Major faulting in the province probably occurred in Late Precambrian to Early Cambrian time; reactivation of these faults during Late Mississippian to Early Permian time created the present-day Tucumcari basin, the most important geologic feature in the province relative to the presence of hydrocarbons. A minor basement high between Bravo dome and the Frio uplift separates the Tucumcari from the Palo Duro basin to the east. Sedimentary rocks ranging from Ordovician (?) to Quaternary in age reach a maximum thickness of about 9,000 ft in the Tucumcari Basin.

No commercial oil or gas production has been established in the province; however, heavy oil (tar) sands in the Triassic Dockum Group (see province 108) exposed at and near the surface near Santa Rosa, New Mexico, were mined in the 1930's for road surfacing material. It has been estimated that over 90 MMBO-in-place exists in these tar sands. Attempts begun in 1981 to lower the viscosity of this heavy oil (5-17° gravity API) with steam injection at the Newkirk field, about 20 mi northeast of Santa Rosa resulted in the production about 340 BO; the attempts were abandoned in 1984. Although approximately 200 wells have been drilled in two counties in the province, no production has been achieved. This number of wells equates to a drilling density of about 1 well per 40 mi^2. Although the province is sparsely drilled, the lack of success in establishing production from exploratory wells, most of which were drilled on mapped structures, is not encouraging. No plays were defined or assessed in the province.

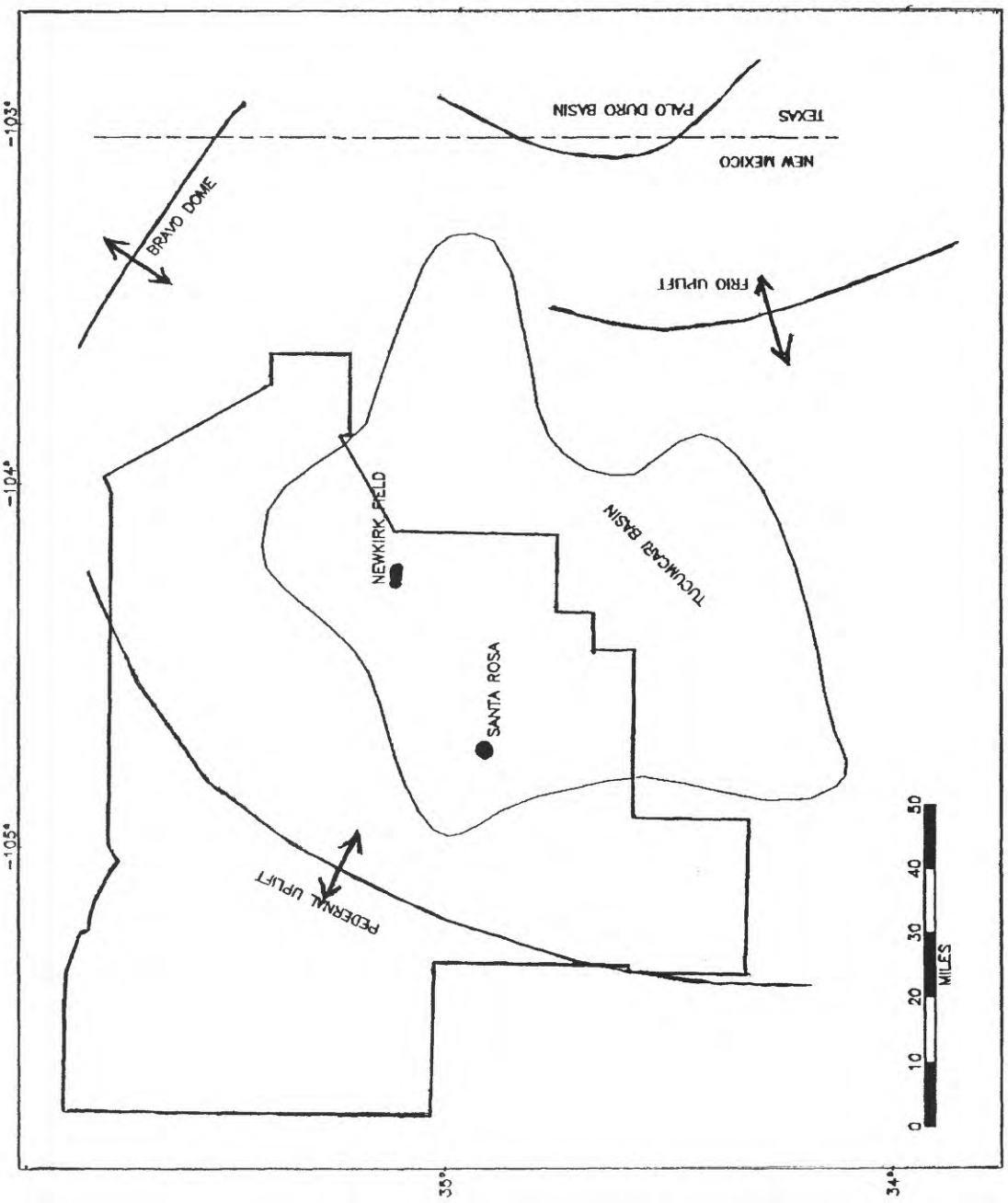

Figure 20. Map of Pedernal Uplift province

BEND ARCH-FORT WORTH BASIN PROVINCE (110)

By Mahlon M. Ball

INTRODUCTION

With the exception of the southwesternmost corner of Oklahoma, the province lies entirely within north central Texas and covers an area of 54,000 mi^2. The southern and eastern province boundaries are defined by county lines that generally follow the Ouachita structural front, although a substantial portion of this structural feature is included in the province in the vicinity of the city of Dallas, Texas. The northern boundary follows the Texas-Oklahoma State line (the Red River) in the east, where the province includes parts of the Sherman (Marietta) basin and Muenster arch. In the west, the northern boundary follows the northern and eastern county lines of Oklahoma's three southwesternmost counties which include the south flank of the Wichita Mountains and the Hollis (Hardeman) basin. The western boundary trends north-south along county lines that defines the province junction with the Permian basin (107), where part of the eastern shelf of the Permian basin lies in this province (110). The first indication of hydrocarbons in the province were shows of oil and gas in wells drilled for water during the mid-nineteenth century. Sporadic exploration for petroleum began at the conclusion of the Civil War and the first commercial oil accumulations were found in the early 1900's. The province reached a mature stage of exploration and development in the 1960's. Oil and lesser amounts of gas are found throughout the Paleozoic section, but the preponderance of hydrocarbons consists of oil in Pennsylvanian-age reservoirs, (fig. 21). Cumulative production in the province through 1986 is approximately 6 BBO (includes 600 MMBNGL and 9 TCFG including 4 TCF of non-associated gas). Five plays defined by geologic age were individually assessed: Morrowan-Atokan (020), Desmoinesian (030), Post-Desmoinesian (040),) Mississippian (060), and 5) Pre-Mississippian (070).

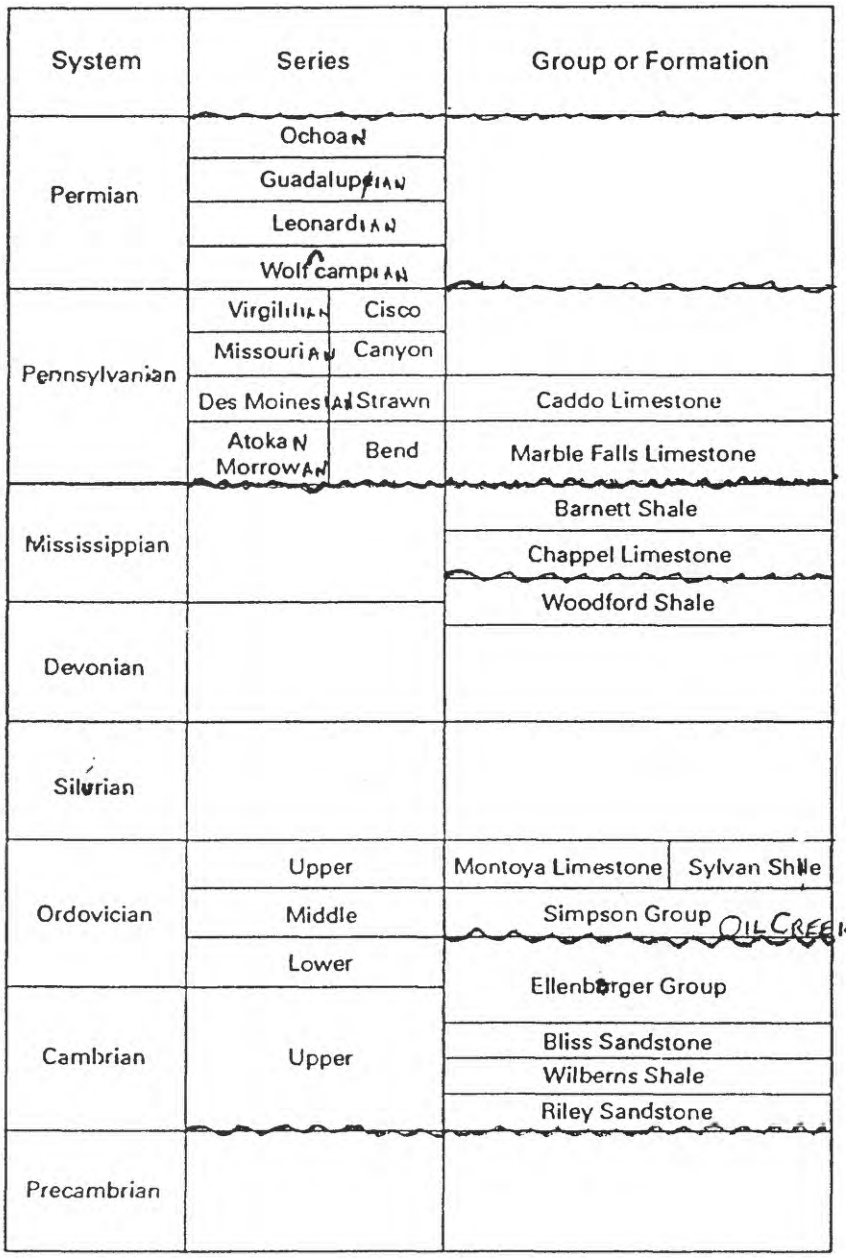

Figure 21. Generalized stratigraphic column, Bend Arch-Fort Worth Basin province

MORROWAN-ATOKAN PLAY (020)

The play is characterized by gas and minor oil accumulations in stratigraphic and structural traps associated with predominantly Early Pennsylvanian (Morrowan and Atokan Series) quartz sandstone and conglomerate reservoirs. These units were derived from highlands uplifted during the late Paleozoic collision of the ancestral North American plate with South America and Africa. This collision gave rise to the present configurations of the Ouachita structural front, Wichita Mountains, Sherman and Hollis basins, and the Muenster and Red River arches (fig. 22). The play limits on the north are the Red River and Muenster arches. On the east the play boundary is the province boundary, modified by the downdip extent of the Morrowan-Atokan section under the overhang of the Ouachita structural front. The pinchout of reservoir facies on the eastern shelf and Llano uplift limits the play to the south and southwest. Maximum thickness of clastic wedges in this section exceeds 5,000 ft on the east, where the section disappears beneath the Ouachita structural front.

The distal, Marble Falls Limestone (Morrowan) is the only noteworthy carbonate reservoir in the play. Production from carbonate reservoirs occurs in two belts bordering the ancestral Bend arch crest where post-Atokan erosion has cut out the upper Marble Falls platform carbonate reservoir facies. Later subsidence of the Fort Worth basin shifted the present Bend arch crest some thirty miles westward from its position at the end of Atokan time. This subsidence imparted a slight eastward dip to the Morrowan-Atokan section, so that hydrocarbons in the section are locked in the predominantly clastic reservoirs that pinch out toward the west. Morrowan and Atokan sandstone reservoirs are lithologically complex and vary in thickness and areal extent with variations in sandbody facies, geometry, and diagenetic influences. Conglomeratic (Bend) and clean sandstone facies have porosities as high as 20 percent and permeabilities as great as 100 millidarcies. Most pay thicknesses are in the 20 to 25 ft range. Lower quality gas-bearing reservoirs have effective porosities of less than 10 percent and permeabilities of less than 1 millidarcy.

Most of the production in the play is on the east flank of the Bend arch and it is possible that the gas simply migrated westward into traps on the arch from Morrowan and Atokan source shales deeper in the Fort Worth basin. This migration may have continued from post-Middle Pennsylvanian to the present. Most of the oil in the play occurs on the crest and western flank of the Bend arch. Oil on the western flank of the Bend arch may have originated in organic-rich Permian shale source rocks in the Midland basin to the west, and oil on the crest of the arch may have originated in source rocks in either the Midland or Fort Worth basins.

Traps consist of simple anticlines, fault bounded anticlines, and stratigraphic traps with both facies controlled and truncation pinchouts. Shale beds in the section provide numerous seals. Drilling depths range from 3,500 to 6,000 ft.

Thirty-nine gas fields were discovered in the play between 1920 and 1978, each with a cumulative production exceeding 10 BCFG. Drilling depths in these fields range from 1,050 to 8,900 ft. The largest gas field in the play, Boonsville, with a cumulative production of 2.3 TCF, 266 MMBNGL and 6 MMBO to the end of 1986, was discovered in 1945 at a depth of 6,000 ft; this constitutes 70 percent of the play's total gas production. Only two other fields have produced in excess of 100 BCFG. Six oil fields in the play were found between 1917 and 1951. The largest of these is Ranger, with a cumulative production of 78 MMBO; this field accounts for 45 percent of the play's total oil production. The play has been heavily drilled over a long period of time, and its

potential for discovery of large oil accumulations is limited; however the future potential for gas is fair to good.

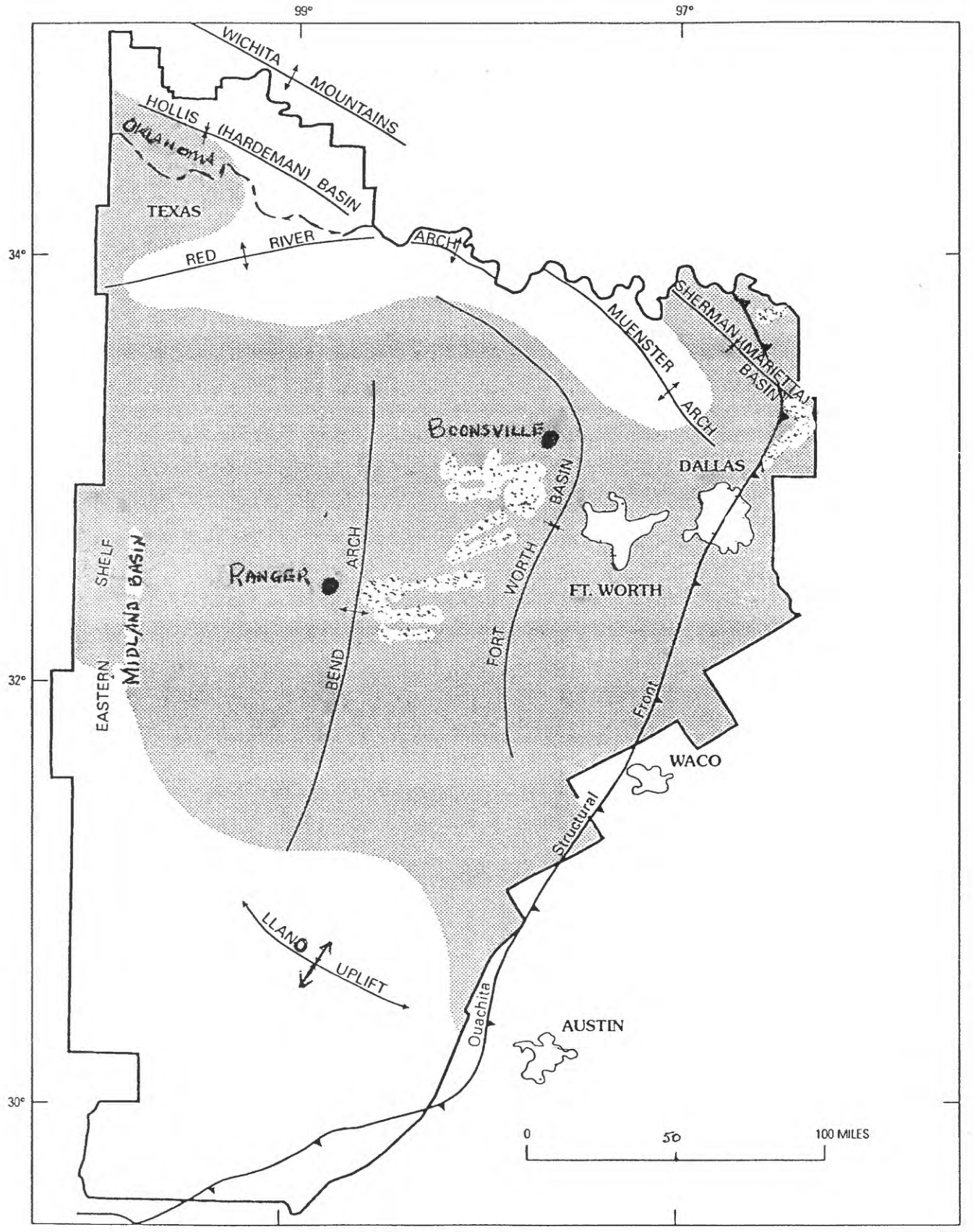

Figure 22. Map of Morrowan-Atokan play

OIL AND GAS PLAY DATA

PLAY **MORROWAN-ATOKAN**
PROVINCE **BEND ARCH-FORT WORTH BASIN** CODE **05-110-020**

Play attributes

	Probability of attribute being favorable or present
Hydrocarbon source (S)	**1.00**
Timing (T)	**1.00**
Migration (M)	**1.00**
Potential reservoir-rock facies (R)	**1.00**
Marginal play probability (MP) (S x T x M x R = MP)	**1.00**

Accumulation attribute, conditional on favorable play attributes

Minimum size assessed: oil, 1 x 10^6 BBL; gas, 6 x 10^9 CFG

	Probability of occurrence
At least one undiscovered accumulation of at least minimum size assessed	**1.00**

Character of undiscovered accumulations, conditional on at least one undiscovered accumulation present

Reservoir lithology	Probability of occurrence
Sandstone	**X**
Carbonate rocks	
Other	
Hydrocarbon type	
Oil	**0.2**
Gas	**0.8**

	Fractiles * (estimated amounts)						
Fractile percentages * ----	*100*	*95*	*75*	*50*	*25*	*5*	*0*
Accumulation size							
Oil (x 10^6 BBL)	**1**	**1.05**	**1.3**	**1.8**	**2.5**	**4.6**	**8**
Gas (x 10^9 CFG)	**6**	**6.2**	**7.5**	**10**	**13**	**19**	**25**
Reservoir depth (x10^3 ft)							
Oil	**3.5**			**5**			**6**
Gas (non-associated)	**3.5**			**5**			**6**
Number of accumulations	**13**	**17**	**22**	**27**	**34**	**44**	**53**

Average ratio of associated-dissolved gas to oil (GOR)	**800**	CFG/BBL
Average ratio of NGL to non-associated gas	**45**	BBL /10^6 CFG
Average ratio of NGL to associated-dissolved gas	**0**	BBL /10^6 CFG

* For example, fractile percentage 95 represents a 19 in 20 chance of the occurrence of at least the fractile tabulated.

DESMOINESIAN PLAY (030)

The play consists of oil accumulations in combination traps in predominantly Pennsylvanian (Desmoinesian) quartz sandstone reservoirs. The sandstones were deposited in a fluvial-deltaic environment and are referred to locally as the Strawn Series; the Strawn is thickest in the northeast corner of the play, in the Sherman (Marietta) basin, where it exceeds 5,000 ft and decreases to about 1,000 ft in the western margin of the play. The Strawn is truncated on the north and east and onlapped by Cretaceous rocks. The play area is approximately 42,500 mi^2 (fig. 23).

The sandstone reservoir facies interfingers basinward and shelfward with prodelta mudstone and shale beds. The Desmoinesian Caddo Limestone is the only important carbonate reservoir in the play and has a maximum thickness of 800 ft. Sandstone reservoirs tend to have complex geometries and depositional topographies with internal variations due to shale interbeds. Porosities range from 14 to 23 percent, permeabilities average more than 100 millidarcies, and oil columns range from 65 to 400 ft. In the Caddo carbonate reservoir, porosities range from 7 to 14 percent, permeabilities range from 3 to 15 millidarcies, and oil columns range from 80 to 174 ft.

Trapping consists of porosity pinchouts on structural noses, simple anticlines and faulted anticlines; combination structural and stratigraphic traps are common. Isolated porosity lenses control reservoir distribution in the Caddo platform carbonates. Source rocks in the play are probably Pennsylvanian and Permian organic-rich shale in the Midland basin to the west. Drilling depths range from 3,100 to 6,100 ft to the Caddo Limestone and from 1,600 to 6,700 ft to Strawn sandstone production.

Discoveries in Caddo Limestone reservoirs occurred between 1918 and 1955, and discoveries in Strawn reservoirs occurred between 1919 and 1951. Of the total of 17 fields discovered in these and in other minor reservoirs, each with cumulative production in excess of 10 MMBO, four produce from carbonate reservoirs, including one of the play's largest fields, Breckenridge. This field has a cumulative production of 147 MMBO, which accounts for 21 percent of the play's total, and 75 percent of the total production from all carbonate reservoirs. Sandstone reservoirs account for 71 percent of the play's total production. The largest field in the play, KMA, produced 200 MMBO before being abandoned.

The play has been extensively drilled over a period of nearly 70 years, and it is estimated that the potential for the discovery of large accumulations is very limited; the future potential for medium-size oil and gas fields is fair.

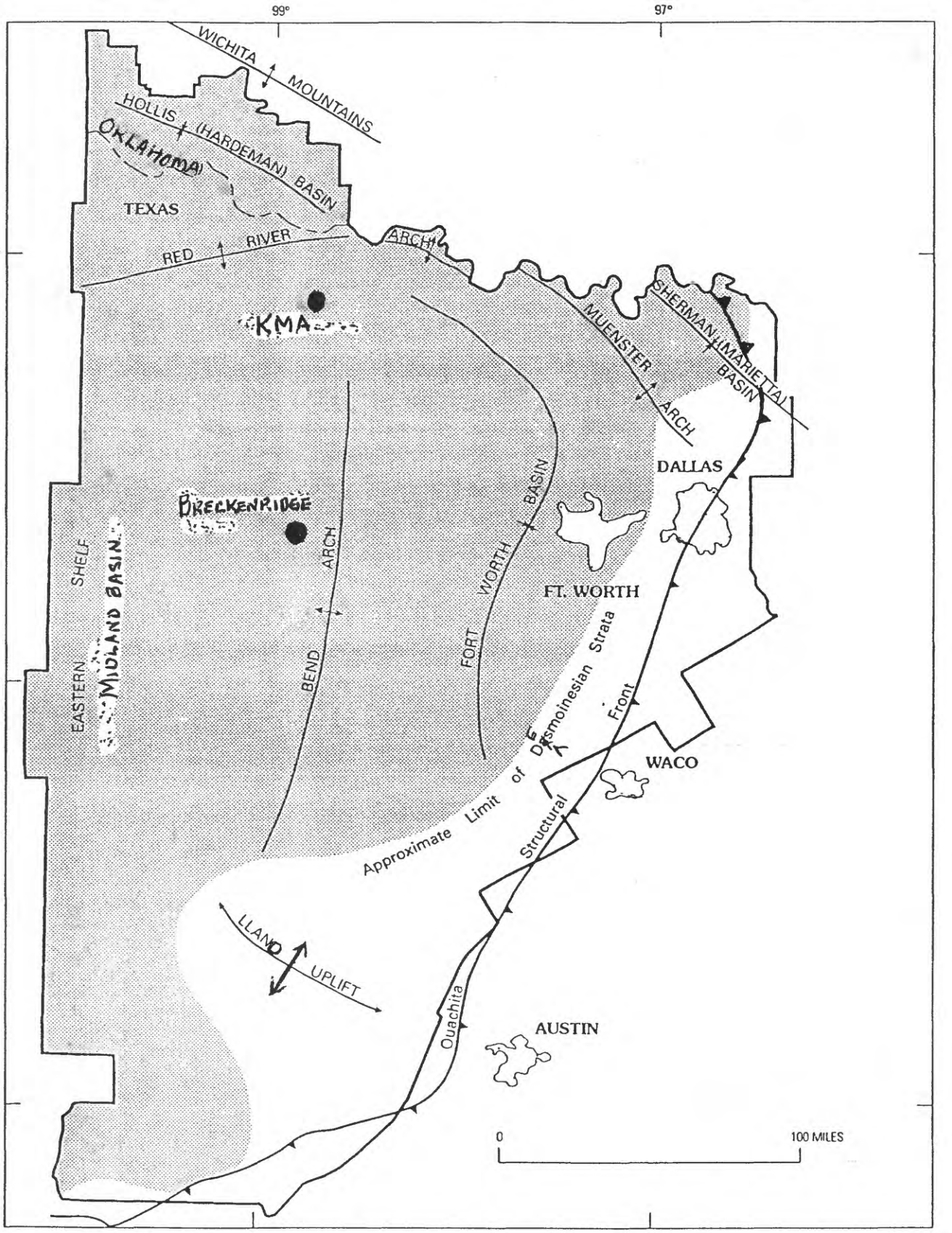

Figure 23. Map of Desmoinesian play

OIL AND GAS PLAY DATA

PLAY **DESMOINESIAN**
PROVINCE **BEND ARCH-FORT WORTH BASIN** CODE **05-110-030**

Play attributes

	Probability of attribute being favorable or present
Hydrocarbon source (S)	**1.00**
Timing (T)	**1.00**
Migration (M)	**1.00**
Potential reservoir-rock facies (R)	**1.00**
Marginal play probability (MP) (S x T x M x R = MP)	**1.00**

Accumulation attribute, conditional on favorable play attributes

Minimum size assessed: oil, 1 x 10^6 BBL; gas, 6 x 10^9 CFG

	Probability of occurrence
At least one undiscovered accumulation of at least minimum size assessed	**1.00**

Character of undiscovered accumulations, conditional on at least one undiscovered accumulation present

Reservoir lithology	Probability of occurrence
Sandstone	**X**
Carbonate rocks	**X**
Other	
Hydrocarbon type	
Oil	**0.65**
Gas	**0.35**

	Fractiles * (estimated amounts)						
Fractile percentages * ----	*100*	*95*	*75*	*50*	*25*	*5*	*0*
Accumulation size							
Oil (x 10^6 BBL)	**1**	**1.1**	**1.6**	**2.4**	**3.8**	**7.1**	**11.5**
Gas (x 10^9 CFG)	**6**	**6.2**	**7.5**	**9.6**	**13**	**19**	**24**
Reservoir depth (x10^3 ft)							
Oil	**1**			**2.5**			**4.5**
Gas (non-associated)	**1**			**2.5**			**4.5**
Number of accumulations	**20**	**23**	**27**	**30**	**33**	**37**	**40**

Average ratio of associated-dissolved gas to oil (GOR)	**900**	CFG/BBL
Average ratio of NGL to non-associated gas	**40**	BBL /10^6 CFG
Average ratio of NGL to associated-dissolved gas	**0**	BBL /10^6 CFG

* For example, fractile percentage 95 represents a 19 in 20 chance of the occurrence of at least the fractile tabulated.

POST-DESMOINESIAN PLAY (040)

This play is characterized by oil accumulations in combination traps in Pennsylvanian (Missourian-Virgilian) shelf sandstone, Permian (Wolfcampian) sandstone, and Pennsylvanian local shelf-edge carbonate buildup reservoirs on the eastern shelf of the Midland basin (fig. 24).

Reservoirs include prodelta-front bar and blanket sandstones, channel mouth bars and distributary channel sandstone. Slope-derived sandstone reservoirs include submarine channel fills and submarine fan lobes. Reservoirs in platform carbonate buildups consist of packstone, wackestone, and grainstone with moldic and intercrystalline porosity. Reservoir units range in age from Pennsylvanian (Virgilian and Missourian) for shelf sandstone and platform edge-interior carbonate rocks, to Permian (Wolfcampian) for slope derived sandstone. Maximum aggregate thickness of all units is 5,000 ft in the southwestern Oklahoma portion of the play; however, erosion of these units limits the play to the northwestern half of the province. Shelf sandstone reservoirs have a porosity range of 14 to 25 percent, permeabilities range from 10 to 380 millidarcies, and oil columns range from 55 to 215 ft. Carbonate reservoirs in the play have porosities that range from 5 to 20 percent; permeability averages about 10 millidarcies.

Traps are related to the configuration of sandstone bodies and to structure in the case of shelf and slope derived sandstone reservoirs. The former include pinch-outs on low relief anticlines and other combination stratigraphic, and structural traps. The latter shelf and slope sandstones tend to be predominantly stratigraphic in the form of updip pinch-outs of fan and submarine channel sandstone. Traps in carbonate rocks are low relief, paleotopographic highs, and purely stratigraphic updip pinch-outs of facies and diagenetically controlled porosity zones. Shale in the overall section provides numerous seals; source rocks probably lie to the west in the Midland basin. Drilling depths range from 3,000 to 5,000 ft.

A total of six oil fields have been found in the play since the initial discovery at Cook Ranch in 1926. The two largest fields are Fargo and Knox City with cumulative production of 36 MMBO and 15 MMBO, respectively. The play covers a limited area of the province and is maturely explored; it has a minor future potential for small-size accumulations.

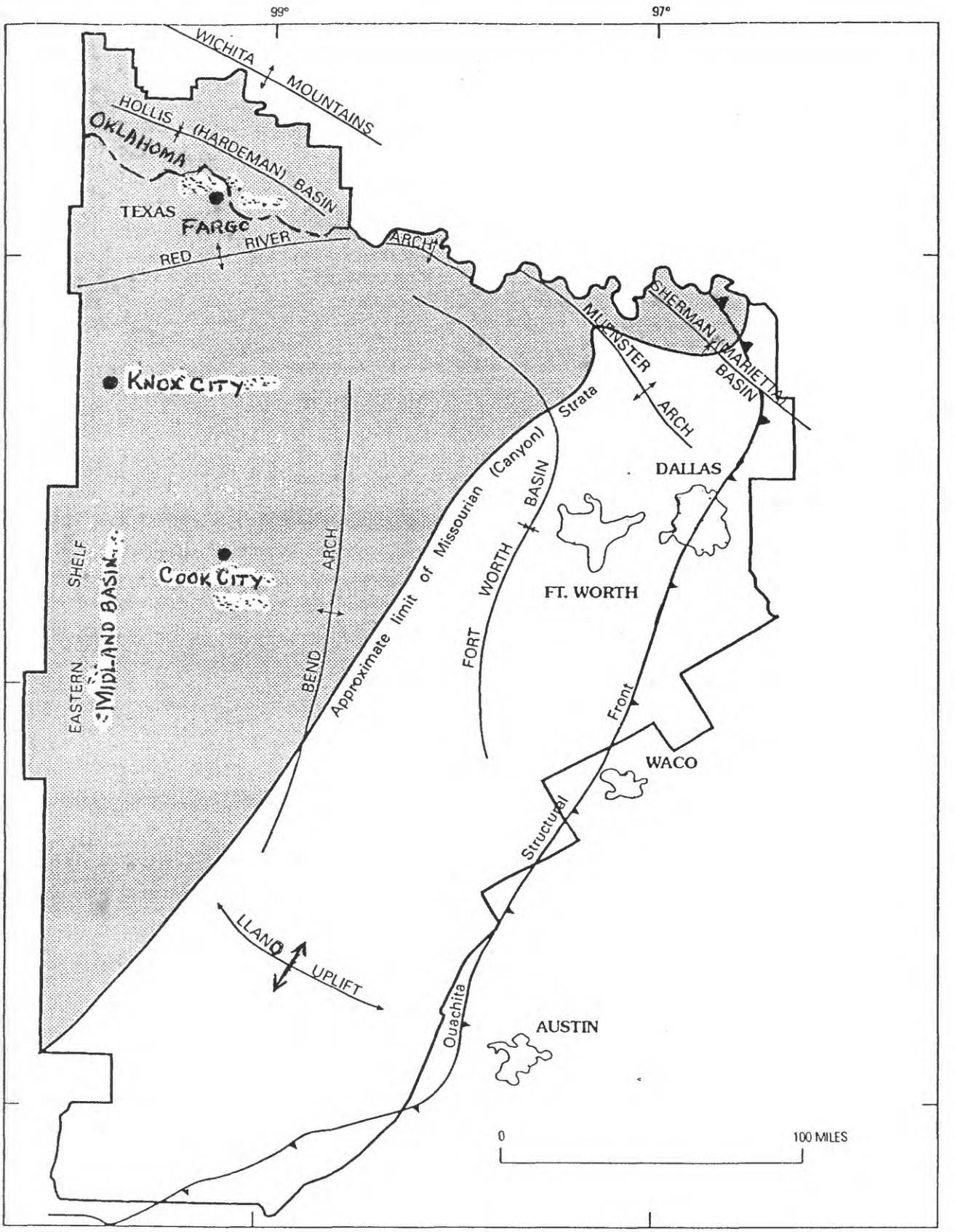

Figure 24. Map of Post-Desmoinesian play

OIL AND GAS PLAY DATA

PLAY **POST-DESMOINESIAN**
PROVINCE **BEND ARCH-FORT WORTH BASIN** CODE **05-110-040**

Play attributes

	Probability of attribute being favorable or present
Hydrocarbon source (S)	**1.00**
Timing (T)	**1.00**
Migration (M)	**1.00**
Potential reservoir-rock facies (R)	**1.00**
Marginal play probability (MP) (S x T x M x R = MP)	**1.00**

Accumulation attribute, conditional on favorable play attributes

Minimum size assessed: oil, 1 x 10^6 BBL; gas, 6 x 10^9 CFG

	Probability of occurrence
At least one undiscovered accumulation of at least minimum size assessed	**1.00**

Character of undiscovered accumulations, conditional on at least one undiscovered accumulation present

Reservoir lithology	Probability of occurrence
Sandstone	**X**
Carbonate rocks	**X**
Other	
Hydrocarbon type	
Oil	**1**
Gas	**0**

	Fractiles * (estimated amounts)						
Fractile percentages * ----	*100*	*95*	*75*	*50*	*25*	*5*	*0*
Accumulation size							
Oil (x 10^6 BBL)	**1**	**1.04**	**1.2**	**1.5**	**2**	**3**	**3.6**
Gas (x 10^9 CFG)	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Reservoir depth (x10^3 ft)							
Oil	**1.3**			**2**			**4.2**
Gas (non-associated)	**0**			**0**			**0**
Number of accumulations	**2**	**3**	**4**	**5**	**7**	**12**	**20**

Average ratio of associated-dissolved gas to oil (GOR)	**350**	CFG/BBL
Average ratio of NGL to non-associated gas	**0**	BBL /10^6 CFG
Average ratio of NGL to associated-dissolved gas	**0**	BBL /10^6 CFG

* For example, fractile percentage 95 represents a 19 in 20 chance of the occurrence of at least the fractile tabulated.

MISSISSIPPIAN PLAY (060)

This play is defined by mainly gas and minor oil accumulations in carbonate reservoirs in the Mississippian Chappel Limestone in stratigraphic traps on localized, low-relief erosional highs of the underlying Ordovician Ellenberger Group. The play is limited by the province boundaries on the northwest and southeast, and by a line indicating erosion of Mississippian rocks on the southwest and north of the Llano uplift (fig. 25). Mississippian rocks are also absent along the crests of the Red River and Muenster arches.

Reservoirs are termed pinnacle reefs, and hydrocarbons contained in the reservoirs are typically gas and condensate. Reservoir porosity and permeability are generally less than 10 percent and range from 100 to tenths of a millidarcy, respectively. Pay thicknesses as much as 350 ft have been encountered in the reservoirs.

Traps are purely stratigraphic, resulting from a combination of depositional topography and erosion. Local porous zones of grainstone and packstone in the Chappel Limestone, for instance, are restricted to reefal highs. Reefs are sealed within the Mississippian Barnett Shale, which is also the probable source of the hydrocarbons. The reefs tend to occur in trends, and although they are typically small, compactional drape of beds overlying the carbonate highs make these features detectable using seismic methods. Drilling depths range from 4,300 to more than 5,000 ft.

Only two fields in the play have produced in excess of 10 BCFG. The largest field, Shackleford, was discovered in 1973 and has produced 44 BCFG to the end of 1986. The past production history and small areal size of Mississippian pinnacle reefs fields appears to limit the future potential of the play to small-size oil and medium-size gas fields.

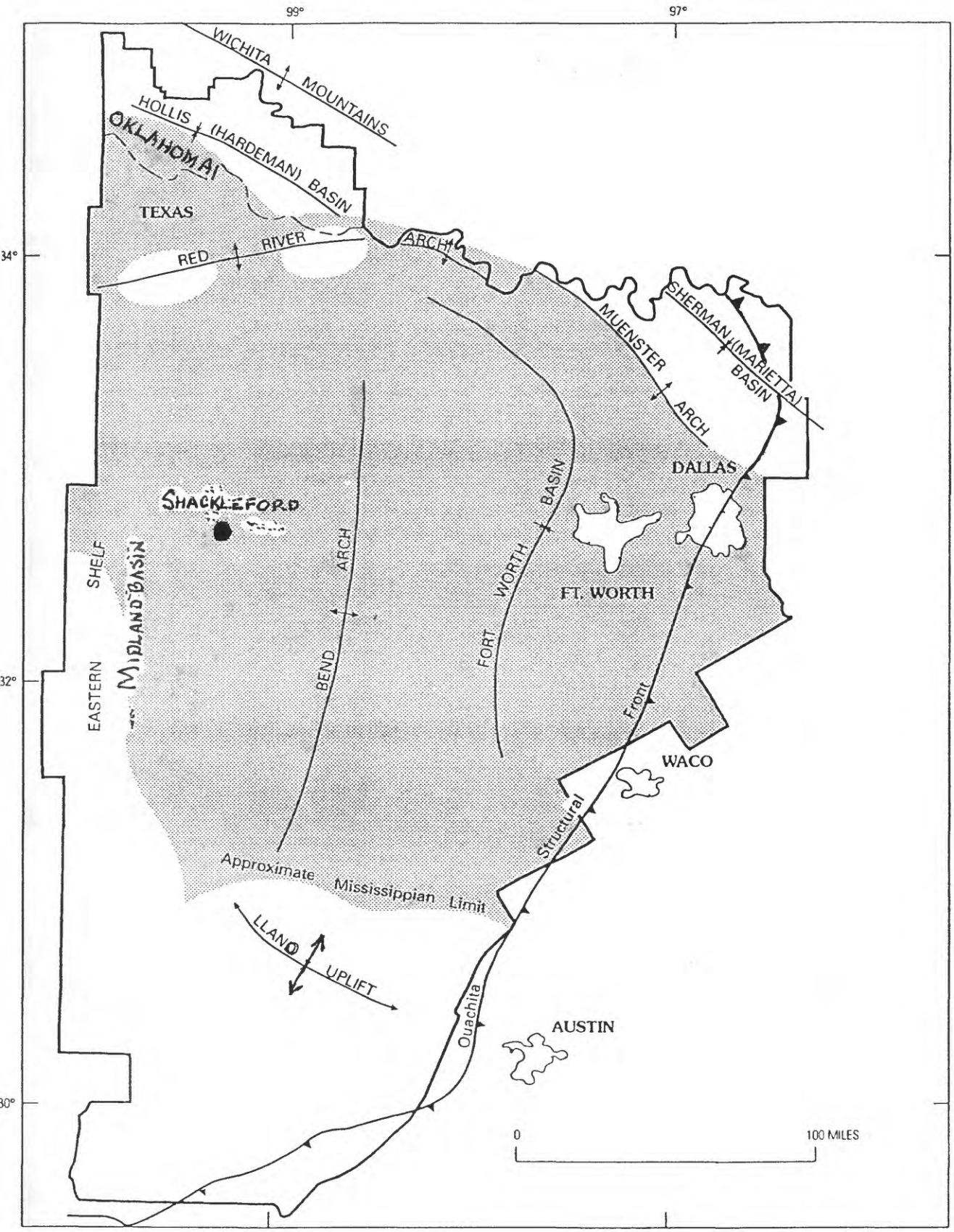

Figure 25. Map of Mississippian play

OIL AND GAS PLAY DATA

PLAY **MISSISSIPPIAN**
PROVINCE **BEND ARCH-FORT WORTH BASIN** CODE **05-110-060**

Play attributes

	Probability of attribute being favorable or present
Hydrocarbon source (S)	**1.00**
Timing (T)	**1.00**
Migration (M)	**1.00**
Potential reservoir-rock facies (R)	**1.00**
Marginal play probability (MP) (S x T x M x R = MP)	**1.00**

Accumulation attribute, conditional on favorable play attributes

Minimum size assessed: oil, 1 x 10^6 BBL; gas, 6 x 10^9 CFG

	Probability of occurrence
At least one undiscovered accumulation of at least minimum size assessed	**1.00**

Character of undiscovered accumulations, conditional on at least one undiscovered accumulation present

Reservoir lithology	Probability of occurrence
Sandstone	
Carbonate rocks	X
Other	
Hydrocarbon type	
Oil	**0.2**
Gas	**0.8**

	Fractiles * (estimated amounts)						
Fractile percentages * ----	*100*	*95*	*75*	*50*	*25*	*5*	*0*
Accumulation size							
Oil (x 10^6 BBL)	**1**	**1.02**	**1.1**	**1.2**	**1.4**	**1.8**	**2**
Gas (x 10^9 CFG)	**6**	**6.1**	**6.6**	**7.2**	**8.4**	**11**	**12**
Reservoir depth (x10^3 ft)							
Oil	**3**			**4**			**5**
Gas (non-associated)	**3**			**4**			**5**
Number of accumulations	**10**	**12**	**16**	**20**	**25**	**33**	**40**

Average ratio of associated-dissolved gas to oil (GOR)	**1700**	CFG/BBL
Average ratio of NGL to non-associated gas	**35**	BBL /10^6 CFG
Average ratio of NGL to associated-dissolved gas	**0**	BBL /10^6 CFG

* For example, fractile percentage 95 represents a 19 in 20 chance of the occurrence of at least the fractile tabulated.

PRE-MISSISSIPPIAN PLAY (070)

The play is characterized by mainly oil accumulations in Cambrian-Ordovician predominantly carbonate reservoirs in anticlines and combination traps. These rocks are present over the entire area of the province with the exception of local absences on the crests of the Red River and Muenster arches, and a regional absence on the Llano uplift. The province boundaries are the boundary limits for the play (fig.26).

The Ellenburger Group is the most important reservoir unit and attains thicknesses up to 5,000 ft in the Marietta basin in the northeasternmost corner of the play and thins to less than 500 ft only in the vicinity of the described arches and on the Llano uplift. The Ellenburger Group is underlain by the Cambrian Bliss Sandstone, Wilberns Shale, and Riley Sandstone, formations that are rarely drilled. There are fewer than 50 wells drilled below these units and into the Precambrian in the entire play. Reservoirs in the Ordovician Simpson Group and Montoya Limestone are present only in the Marietta and Hardeman basins, and on the southwestern, downthrown flank of the Muenster arch. Maximum thickness for the Simpson is 1,500 ft and 500 ft for the Montoya. Simpson reservoirs range in thickness from tens of feet to more than 200 ft. Porosities average in the high teens and permeabilities are measured in hundreds of millidarcies. Negligible amounts of hydrocarbons occur in the Montoya. The Simpson Group is the exception to the dominance of carbonate reservoirs in this play, in that it contains a productive basal strandplain sandstone reservoir, the Oil Creek. Individual reservoir thicknesses in the Ellenburger range from 10 to over 100 ft, and porosities and permeabilities tend to be low; the former averages around 10 percent and the latter only a few millidarcies.

Identity of source rocks is controversial. Permian shale in the Midland basin to the west, and Pennsylvanian shale in the Fort Worth basin to the east are both down-dip from the pre-Mississippian section on the Bend arch. There are ample regional unconformities in the section in addition to faults that could have provided avenues for generated hydrocarbon to migrate from these particular shale source beds into the structurally higher pre-Mississippian section. Trapping configurations are in simple and complex, faulted anticlines in 50 percent of the known fields in the play. Other fields are in combination structural and stratigraphic traps. Drilling depths range from 3,500 to more than 6,000 ft.

Most oil and gas discoveries occurred in the 1940's and 1950's, but there was a resurgence in exploratory drilling and consequent field discoveries in the early 1980's. One discovery in the Sherman (Marietta) basin area, the New Mag field, has produced greater than 50 BCFG from a sandstone reservoir in the Oil Creek Formation of the Ordovician Simpson Group. An encouraging aspect of the play is the relative success of new discoveries from tests drilled during the early eighties period, although the sizes of the accumulations are small. The potential for both oil and gas is fair.

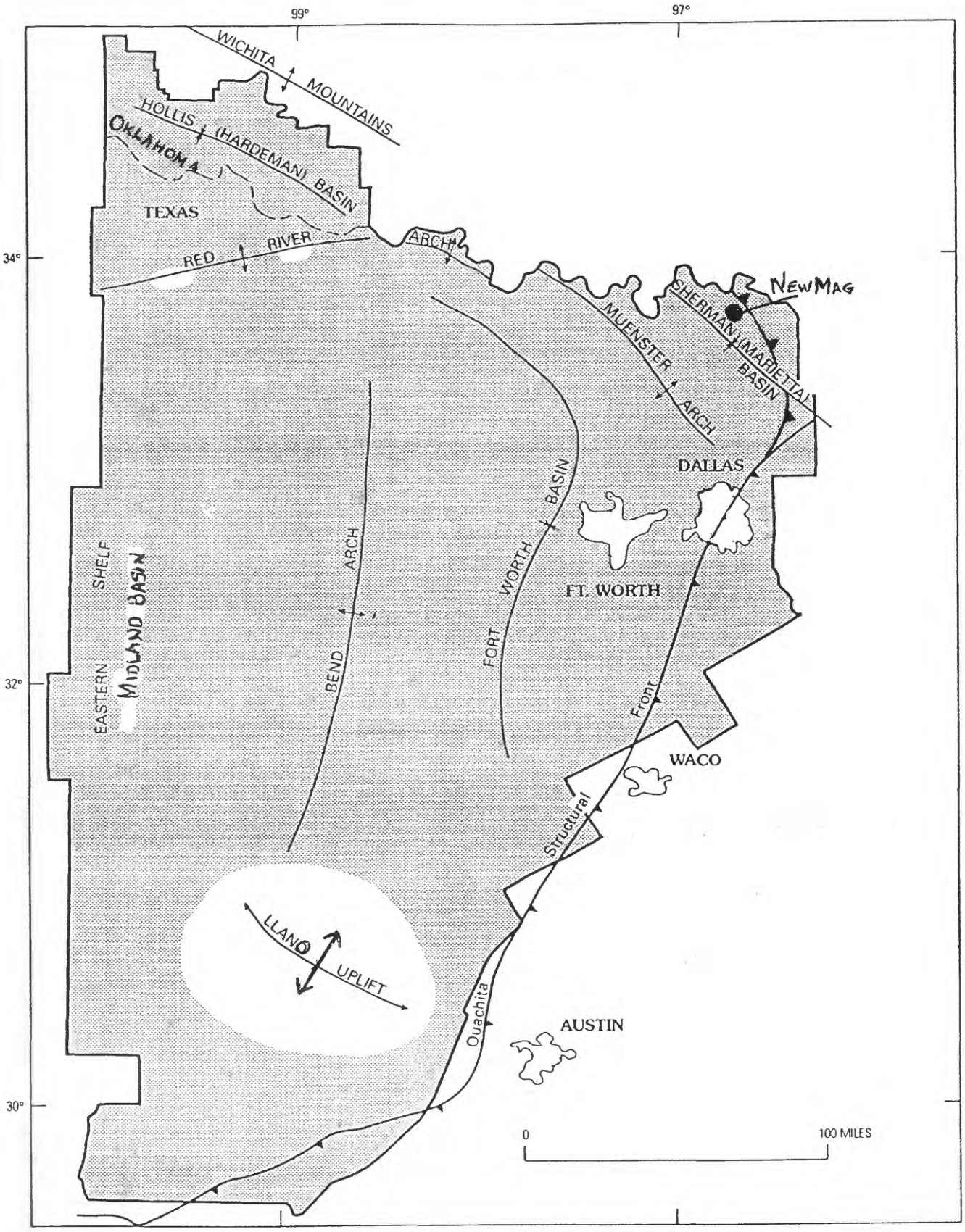

Figure 26. Map of Pre-Mississippian play

OIL AND GAS PLAY DATA

PLAY **PRE-MISSISSIPPIAN**
PROVINCE **BEND ARCH-FORT WORTH BASIN** CODE **05-110-070**

Play attributes

	Probability of attribute being favorable or present
Hydrocarbon source (S)	**1.00**
Timing (T)	**1.00**
Migration (M)	**1.00**
Potential reservoir-rock facies (R)	**1.00**
Marginal play probability (MP) (S x T x M x R = MP)	**1.00**

Accumulation attribute, conditional on favorable play attributes

Minimum size assessed: oil, 1×10^{6} BBL; gas, 6×10^{9} CFG

	Probability of occurrence
At least one undiscovered accumulation of at least minimum size assessed	**1.00**

Character of undiscovered accumulations, conditional on at least one undiscovered accumulation present

Reservoir lithology	Probability of occurrence
Sandstone	**X**
Carbonate rocks	**X**
Other	
Hydrocarbon type	
Oil	**0.75**
Gas	**0.25**

	Fractiles * (estimated amounts)						
Fractile percentages * ----	*100*	*95*	*75*	*50*	*25*	*5*	*0*
Accumulation size							
Oil (x 10^{6} BBL)	**1**	**1.1**	**1.4**	**1.9**	**2.8**	**4.4**	**5.4**
Gas (x 10^{9} CFG)	**6**	**6.6**	**8.4**	**11**	**16**	**24**	**30**
Reservoir depth (x10^{3} ft)							
Oil	**3.5**			**5**			**6**
Gas (non-associated)	**3.5**			**5**			**6**
Number of accumulations	**20**	**24**	**32**	**40**	**50**	**66**	**80**

Average ratio of associated-dissolved gas to oil (GOR)	**700**	CFG/BBL
Average ratio of NGL to non-associated gas	**40**	BBL /10^{6} CFG
Average ratio of NGL to associated-dissolved gas	**0**	BBL /10^{6} CFG

* For example, fractile percentage 95 represents a 19 in 20 chance of the occurrence of at least the fractile tabulated.

MARATHON FOLD BELT PROVINCE (111)

By Mitchell E. Henry

INTRODUCTION

The province comprises four counties in southwestern Texas and covers an area of about 8,000 mi^2. It has been the site of large scale subsidence, thick sedimentary accumulations, and intense folding and faulting associated with thrusting. Much of what is known about the geology is interpreted from outcropping rocks present in the Marathon basin, a topographic basin located on the Marathon uplift. The Marathon basin extends for about 30 mi in an east-west direction and about 30 mi in a north-south direction.

Sedimentary rocks range in age from Cambrian to Holocene (fig. 27) and attain thicknesses of greater than 20,000 ft. The province has not been heavily explored for oil and gas. The degree of metamorphism and the effects of structural deformation displayed in surface rocks and inferred from well data in the Marathon basin do not indicate the presence of favorable traps in Paleozoic rocks. South of the Marathon basin, in the Big Bend area of the province, there is a much thicker sequence of Cretaceous rocks that have not been subjected to the degree of structural deformation or metamorphism that Paleozoic rocks of the Marathon basin have undergone. Cenozoic rocks in the Big Bend area do not appear to be prospective because they do not contain known source beds, and have never been deeply buried. One play was individually assessed in the province, the Frontal Zone play (020).

GEOLOGIC AGE	GROUP	STRATIGRAPHIC UNIT
Recent and Pleistocene		
Oligocene or younger	Big Bend Park	South Rim Formation
		Chisos Formation
Eocene		Canoe Formation
Paleocene	Tornillo	Hannold Hill Formation
		Black Peaks Formation
		Javelina Formation
		Aquja Formation
Cretaceous (Gulfian)	Terlingua	Pen Formation
		Boquillas Formation
Cretaceous (Comanchean)		Buda Limestone
		Del Rio Clay
		Santa Elena Limestone
		Sue Peaks Formation
		Del Carmen Limestone
		Telephone Canyon Formation
		Maxon Sandstone
		Glen Rose Formation
Permian		Tessey Limestone
		Captian Limestone
		Word Formation
		Leonard Formation
		Wolfcamp Formation
Pennsylvanian		Gaptank Formation
		Haymond Formation
		Dimple Limestone
		Tesnus Formation
Devonian(?)		Caballos Novaculite
Ordovician		Maravillas Chert
		Woods Hollow Shale
		Fort Pena Formation
		Alsate Shale
		Marathon Limestone
Cambrian		Daggar Flat Sandstone

Figure 27. Generalized stratigraphic column, Marathon Fold Belt province

FRONTAL ZONE PLAY (020)

The play is defined by potential gas accumulations in open folds or large anticlines and possibly fault block traps in mainly clastic, carbonate and chert reservoirs of Devonian to Pennsylvanian age. The play is an irregularly shaped area and forms a broad, elongated band extending for about 150 mi in an east-west direction, and from 12 mi in the eastern part to about 100 mi in the western part in a north-south direction (fig. 28). The northern play boundary is coincident with the province boundary and the southern boundary is the approximate northern boundary of the interior structural zone, in which rocks display a more highly metamorphosed nature than rocks within the play. The western play boundary is the western province boundary and the eastern limit is formed by the Devil's River uplift. Maximum sedimentary thickness is greater than 20,000 ft, and rocks range in age from Cambrian to Holocene.

Known reservoir rocks include the Devonian(?) Caballos Novaculite, the Pennsylvanian Tesnus Formation, and the Pennsylvanian Dimple Limestone (fig. 27). Reservoirs in the Caballos are probably the result of fracture porosity. Specific values of porosity are not available for the Tesnus or Dimple; however, the Tesnus is a friable, fine to coarse-grained sandstone, or arkose, and the Dimple locally contains layers of coarse-grained fossil debris. The Caballos Novaculite ranges from 200 to 600 ft in thickness, the Tesnus Formation exceeds 6,500 ft in thickness, and the Dimple Limestone reaches a maximum thickness of 1,000 ft.

Source rocks are probably black shale, bituminous limestone and black chert of the Caballos Novaculite and the underlying Ordovician Maravillas Chert. Assuming an average geothermal gradient of 1.6°F per 100 ft and present burial depths (as deep as 9,700 ft), Devonian rocks could have experienced a thermal history sufficient to have generated hydrocarbons as early as Upper Pennsylvanian time. Numerous faults present in the play could have provided avenues of migration for hydrocarbons. However, if hydrocarbons were generated that long ago, subsequent faulting may have destroyed hydrocarbon-filled traps.

Anticipated traps are open folds involving the Tesnus Formation and fault blocks that place reservoir beds adjacent to seals. Adequate seals are present in thick shale beds of the Tesnus Formation, and in relatively impermeable carbonate beds of the Dimple Limestone. These rocks range in depth from the surface to over 20,000 ft.

Approximately 100 wildcat wells have been drilled in the play since 1919 resulting in one producing gas field at the northern play boundary, the Pinon field, discovered in 1982. The future gas potential of the play is estimated to be fair to good.

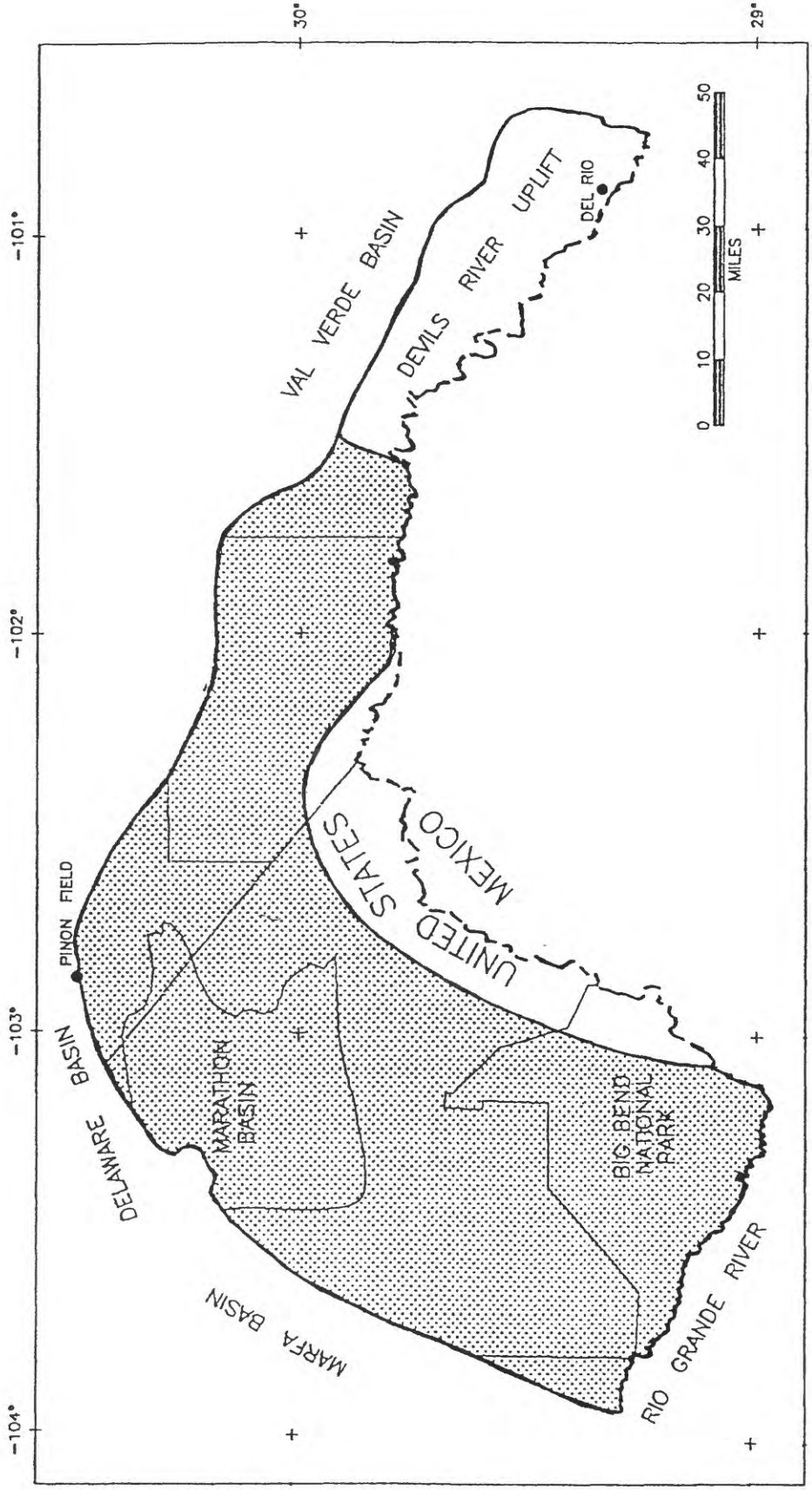

Figure 28. Map of Frontal Zone play

OIL AND GAS PLAY DATA

PLAY **FRONTAL ZONE**
PROVINCE **MARATHON FOLD BELT** CODE **05-111-020**

Play attributes

	Probability of attribute being favorable or present
Hydrocarbon source (S)	**1.00**
Timing (T)	**1.00**
Migration (M)	**1.00**
Potential reservoir-rock facies (R)	**1.00**
Marginal play probability (MP) (S x T x M x R = MP)	**1.00**

Accumulation attribute, conditional on favorable play attributes

Minimum size assessed: oil, 1 x 10^6 BBL; gas, 6 x 10^9 CFG

	Probability of occurrence
At least one undiscovered accumulation of at least minimum size assessed	**1.00**

Character of undiscovered accumulations, conditional on at least one undiscovered accumulation present

Reservoir lithology	Probability of occurrence
Sandstone	**X**
Carbonate rocks	**X**
Other	
Hydrocarbon type	
Oil	**0**
Gas	**1**

	Fractiles * (estimated amounts)						
Fractile percentages * ----	*100*	*95*	*75*	*50*	*25*	*5*	*0*
Accumulation size							
Oil (x 10^6 BBL)	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Gas (x 10^9 CFG)	**6**	**7**	**8**	**10**	**18**	**35**	**60**
Reservoir depth (x10^3 ft)							
Oil	**0**			**0**			**0**
Gas (non-associated)	**0.1**			**5**			**15**
Number of accumulations	**20**	**22**	**26**	**30**	**38**	**60**	**200**

Average ratio of associated-dissolved gas to oil (GOR)	**0**	CFG/BBL
Average ratio of NGL to non-associated gas	**3**	BBL /10^6 CFG
Average ratio of NGL to associated-dissolved gas	**0**	BBL /10^6 CFG

* For example, fractile percentage 95 represents a 19 in 20 chance of the occurrence of at least the fractile tabulated.

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(111) Marathon fold belt
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TABLE 1.--REGION 5 - West Texas and Eastern New Mexico; estimates of undiscovered recoverable conventional oil, gas, and natural gas liquids (NGL)in onshore provinces by play. Province and region totals are given

[Mean value totals may not be equal to the sums of the component means because numbers have been independently rounded. Fractile values (F95, F5) are not additive and represent estimates with a 19 in 20 chance and a 1 in 20 chance, respectively, of at least these tabulated estimates. Gas includes both nonassociated and associated-dissolved gas. Negl., negligible quantity; -, no estimate.]

		Crude Oil (Millions of Barrels)			Total Gas (Billions of Cubic Feet)			NGL (Millions of Barrels)		
		F95	F5	Mean	F95	F5	Mean	F95	F5	Mean
107	Permian Basin									
020	Delaware Sandstone	13.1	91.8	41.3	76.2	478.3	223.1	2.3	15.5	7.1
031	Upper Northwestern Shelf	99.0	429.8	227.9	187.3	719.0	399.0	4.7	19.6	10.6
032	Upper Central Basin Platform	103.2	474.4	246.4	231.5	1,023.6	539.1	12.1	55.1	28.7
033	Upper Eastern Shelf-Midland Basin	133.9	341.6	222.7	737.6	1,808.1	1,198.5	52.5	128.7	85.3
040	Spraberry-Dean Sandstone	132.6	489.4	275.6	397.9	1,468.1	826.9	49.7	183.5	103.4
050	Upper Delaware-Val Verde Basins	0.0	23.8	8.5	1,993.3	5,302.6	3,398.1	40.8	108.2	69.4
060	Horseshoe Atoll	6.9	44.4	20.5	4.8	31.1	14.4	Negl.	0.2	0.1
071	Lower Northwestern and Eastern Shelf	105.9	422.3	231.0	76.8	312.9	169.8	4.2	16.1	8.9
072	Lower Central Platform-Midland Basin	56.2	321.5	154.7	158.7	728.0	378.4	5.6	25.5	13.2
073	Lower Delaware-Val Verde Basins	0.0	0.0	0.0	4,429.4	13,154.0	8,062.7	44.3	131.5	80.6
320	Oil <1 MMB	379.9	547.8	459.0	759.7	1,095.6	918.0	0.0	0.0	0.0
330	Gas <6 BCF	0.0	0.0	0.0	1,262.6	2,009.3	1,608.8	41.7	66.3	53.1
	Province Total	985.4	3,184.3	1,887.6	10,174.0	28,108.0	17,736.7	253.7	750.0	460.5

TABLE 1.--REGION 5 - West Texas and Eastern New Mexico; estimates of undiscovered recoverable conventional oil, gas, and natural gas liquids (NGL)in onshore provinces by play. Province and region totals are given--continued

		Crude Oil (Millions of Barrels)			Total Gas (Billions of Cubic Feet)			NGL (Millions of Barrels)		
		F95	F5	Mean	F95	F5	Mean	F95	F5	Mean
108	Palo Duro Basin									
020	Pennsylvanian Stratigraphic	5.6	29.3	14.5	0.6	2.9	1.5	0.0	0.0	0.0
030	Shelf Margin	16.9	88.1	43.7	1.7	8.8	4.4	0.0	0.0	0.0
040	Matador Arch	2.2	12.9	6.2	0.4	2.6	1.2	0.0	0.0	0.0
050	Northern Basin	10.7	70.4	32.3	4.4	60.4	22.3	0.0	0.3	0.1
320	Oil <1 MMB	21.4	43.2	31.1	3.0	6.0	4.4	0.0	0.0	0.0
330	Gas <6 BCF	0.0	0.0	0.0	10.7	22.1	15.7	Negl.	Negl.	Negl.
	Province Total	54.3	244.2	127.8	17.2	105.1	49.5	Negl.	0.3	Negl.
109	Pedernal Uplift	-	-	-	-	-	-	-	-	-
110	Bend Arch-Ft. Worth Basin									
020	Morrowan-Atokan	4.7	25.6	12.6	144.8	416.1	258.4	6.5	18.8	11.7
030	Desmoinesian	38.9	88.2	60.4	114.8	232.2	167.1	5.1	9.9	7.2
040	Post-Desmoinesian	3.4	20.6	9.7	1.2	7.2	3.4	0.1	0.4	0.2
060	Mississippian	1.9	10.8	5.3	75.8	222.4	137.0	2.7	8.0	4.9
070	Pre-Mississippian	38.7	116.2	70.9	94.7	315.5	184.8	4.1	13.3	7.9
320	Oil <1 MMB	282.8	497.2	380.5	231.9	407.7	312.0	11.6	20.4	15.6
330	Gas <6 BCF	0.0	0.0	0.0	342.1	714.4	506.9	15.4	32.1	22.8
	Province Total	365.6	757.9	539.4	997.4	2,313.5	1,569.5	45.2	102.8	70.3
111	Marathon Fold Belt									
020	Frontal Zone	0.0	0.0	0.0	169.7	1,292.3	566.5	0.5	3.9	1.7
330	Gas <6 BCF	0.0	0.0	0.0	120.8	334.8	211.0	0.4	1.0	0.6
	Province Total	0.0	0.0	0.0	276.4	1,634.0	777.5	0.8	4.9	2.3
	REGION TOTAL	1,481.8	4,018.1	2,554.9	11,862.0	31,321.0	20,133.2	308.6	839.9	533.2