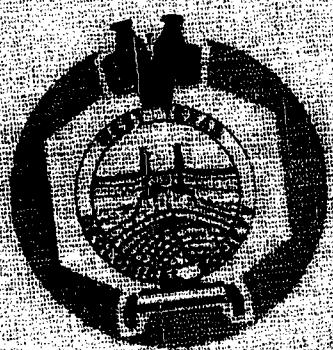
PETROLEUM GEOLOGY

OF

THE PERMIAN BASIN



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• WEST TEXAS GEOLOGICAL SOCIETY

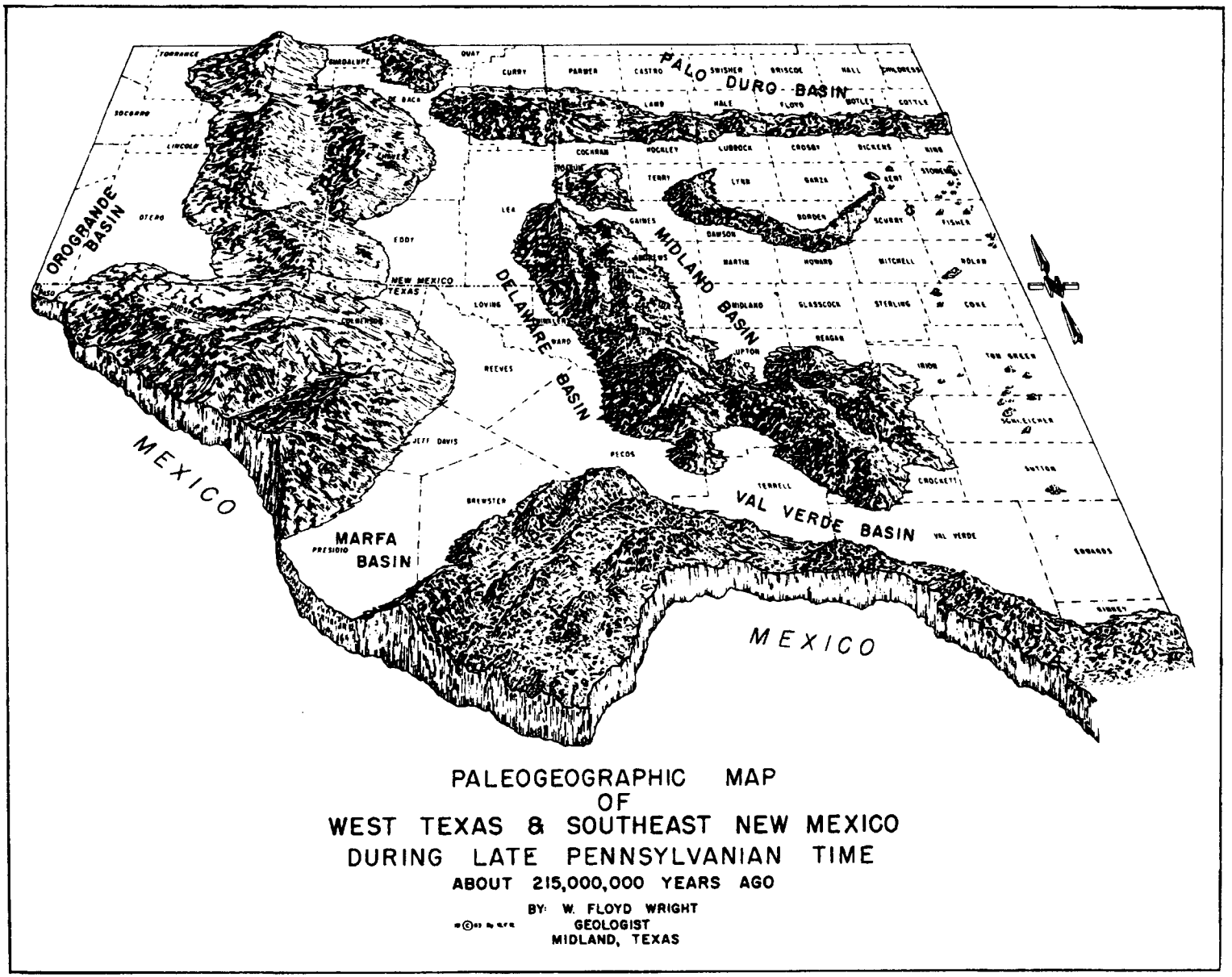
PALO DURO BASIN
OROGRANDE BASIN
MIDLAND BASIN
DELAWARE BASIN
MARFA BASIN
VAL VERDE BASIN
MEXICO
MEXICO
NEW MEXICO
TEXAS
PALEOGEOGRAPHIC MAP
OF
WEST TEXAS & SOUTHEAST NEW MEXICO
DURING LATE PENNSYLVANIAN TIME
ABOUT 215,000,000 YEARS AGO
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Figure 14.

PENNSYLVANIAN

INTRODUCTION

The most spectacular and probably the most significant oil developments in the Permian Basin province the past fifteen years, both from the standpoint of geology and economics, have been made from Pennsylvanian reservoirs. Such prolific reef discoveries as in the Kelly Snyder and Diamond "M" fields in Scurry County, Texas, during the late 1940's expanded a major geologic system for exploration.

In addition to reef reservoirs, lenticular sand bodies which drape over and flank reef masses, porous biostromal and bedded limestones developed over large pre-Pennsylvanian structures, porosity-permeability barriers in sloping carbonate beds and stratigraphic traps associated with detrital facies on the margins and flanks of the Central Basin Platform, have contributed major quantities of Pennsylvanian oil. Many other such reservoirs are waiting to be located by the drill.

FIRST PENNSYLVANIAN FIELDS

Early records indicate that the Royston field in Fisher County, discovered in 1928, yielded the first Pennsylvanian oil in West Texas. Other early Pennsylvanian fields are the Page field, Schleicher County, discovered in 1935; the Rotan field, Fisher County, discovered in 1936; and the Todd field, Crockett County, discovered in 1940. In 1944 the Cass field in Lea County, produced the first Pennsylvanian oil in southeast New Mexico.

Field	County	Discovery Date
Kelly Snyder	Scurry	1948
Diamond M	Scurry	1949
Cogdell Area	Kent-Scurry	1949
Fort Chadbourne	Coke - Runnels	1949
Salt Creek	Kent	1950
Jameson	Coke	1946
Jameson	Coke	1952
Reinecke	Borden	1950
East Vealmoor	Borden Howard	1950
Round Top	Fisher	1947

FIELDS AND CUMULATIVE PRODUCTION

To January 1, 1961, 982 fields had produced Pennsylvanian oil in 45 counties in West Texas and 3 counties in Southeast New Mexzico. Forty fields produced gas-condensate and 12 fields yielded only gas. Over 1,100,000,000 barrels of crude oil had been produced to that date, nearly 26,000,000 barrels of which had been produced in southeast New Mexico. Condensate production totaled 3,397,000 barrels. These figures do not include the so-called "Permo-Pennsylvanian" fields.

Of the 982 oil fields, 110 fields had produced over one million barrels of crude oil each. Thirty-one fields had yielded almost three-fourths of all the Pennsylvanian oil produced in West Texas and southeast New Mexico, each field having produced in excess of five million barrels. Data for the fields are shown in the accompanying table.

Reservoir	Trap	Cum. Prod. to January 1, 1961
Canyon reef lime	Reef	242,786,000 bbls
Canyon reef lime	Reef	94,397,000 bbls
Canyon reef lime	Reef	67,415,000 bbls
Strawn lime	Fault block	35,730,000 bbls
Canyon lime	Reef	33,794,000 bbls
Strawn reef lime	Reef	25,669,000 bbls
Strawn sand	Sand on reef flank	22,642,000 bbls
Cisco reef lime	Reef	18,947,000 bbls
Canyon reef lime	Reef	18,821,000 bbls
Canyon reef lime	Reef	17,876,000 bbls

lime

Vealmoor	Howard	1948	Canyon reef lime	Reef	16,295,000 bbls
Katz	Stonewall	1951	Strawn sand	Anti-cline	16,206,000 bbls
Royston	Fisher	1928	Penn. lime	Anti-cline	14,525,000 bbls
Good	Borden	1949	Canyon reef lime	Reef	14,503,000 bbls
Hulldale	Schleicher	1950	Strawn reef lime	Reef	13,886,000 bbls
Cree Sykes	Runnels	1950	Strawn sand	Reef	11,550,000 bbls
Todd	Crockett	1940	Strawn reef lime	Reef	9,085,000 bbls
Pegasus	Upton-Midland	1951	Bend lime	Anti-cline	8,398,000 bbls
Susan Peak	Tom Green	1948	Strawn lime	Anti-cline	8,333,000 bbls
Boyd	Stonewall	1951	Bend cong.	Anti-cline	7,837,000 bbls
Kelly Snyder	Scurry	1952	Cisco sand	Sd. draped over reef	7,770,000 bbls
Nena Lucia	Nolan	1955	Strawn reef lime	Reef	7,265,000 bbls
Claytonville	Fisher	1952	Canyon reef lime	Reef	7,240,000 bbls
Old Glory	Stonewall	1950	Bend cong.	Anti-cline	7,096,000 bbls
Oceanic	Howard	1953	Strawn reef lime	Reef	6,697,000 bbls
Von Roeder	Borden	1949	Canyon & Cisco reef lime	Reef	6,605,000 bbls
Millican	Coke	1948	Strawn reef lime	Reef	5,779,000 bbls
Andrews	Andrews	1954	Penn. lime	Anti-cline	5,531,000 bbls
S M S	Kent	1954	Canyon sand	Sand on reef flank	5,426,000 bbls
Ropes	Hockley	1950	Canyon reef lime	Reef	5,397,000 bbls
Neva West	Schleicher	1951	Strawn reef lime	Reef	5,383,000 bbls

Table 1

It is significant to note that the 31 fields which yielded over five million barrels of crude oil each, reef limestone provided the reservoir rock for twenty of the fields. Reservoirs for three of the fields consisted of sand draped over and-or lying on the flanks of reefs. Reservoirs for only eight fields were controlled exclusively by structural anomalies.

Of the 38 gas-condensate fields, only two fields yielded in excess of one million barrels of condensate each. They are the Azalea Strawn field in Midland County, which produced 1,356,000 barrels; and the North Branch Strawn field in Sutton County, which produced 1,226,000 barrels.

In-hole drilling depths to top of pay ranged from 1,925 feet in the Love field in Runnels County to 15,040 feet in the Rojo Caballos field in Pecos County.

Gravity of oil ranged from 30 to 47 degrees.

RESERVOIRS AND TRAPS

Pennsylvanian production is controlled both by structural and stratigraphic traps. The two most prevalent types of traps are reefs and anticlines.

Examples of anticlines are the Katz field, Stonewall County; Pegasus field, Upton-Midland Counties; and the Crossroads field, Lea. County. The Doss field, Gaines County, is associated with a domal fold. An example of a monocline is the Cree Syke field, Runnels County.

Examples of stratigraphic traps are the Jameson (Strawn sand) field, Coke County,

where the sandstone wedges out updip on the flanks of a reef; Page field, Schleicher County, where zones of porosity in limestone disappear updip on a broad terrace; and the Arledge field, Coke County, where porosity decreases updip on a structural nose.

Examples of isolated reef limestone build-ups are the Salt Creek field, Kent County; Reinecke field, Borden County; Vealmoor field, Howard County; and Todd field, Crockett County. Most reef build-ups are overlain by confining beds of compacted shale.

OUTCROPS

Pennsylvanian strata discussed in this report outcrop in the Llano Uplift of Central Texas; Marathon region, Solitario Uplift, Marfa Basin, Sierra Diablo, Hueco Mountains and Franklin Mountains in West Texas; and, in the Sacramento Mountains and San Andres Mountains in New Mexico.

THICKNESS

Rocks of the Pennsylvanian system of West Texas and Southeast New Mexico range from a feather edge along truncation lines and near areas of non-deposition to over 2,000 feet in the Midland, Delaware and Palo Duro basins; 2,500 feet on the Eastern Shelf; to aggregate thicknesses of more than 3,600 feet in the Orogrande Basin of New Mexico; and 12,000 feet in the Marathon Basin.

DISTRIBUTION

Pennsylvanian strata overlie rocks ranging in age from Pre-Cambrian to Mississippian. In most areas they are overlain by beds of lower Permian age. Except in restricted areas of truncation or non-deposition, Pennsylvanian rocks cover the entire West Texas and Southeast New Mexico province.

GEOLOGICAL HISTORY

From the beginning of the Cambrian period to late Mississippian time, West Texas and Southeast New Mexico had been a region of mild structural relief and uniform sedimentation. Broad regional arches modified relatively flat, expansive landmasses and shallow depositional basins and troughs.

Near the close of the Mississippian period, tectonic readjustment produced regional warping which destroyed the Tobosa Basin as a distinct structural entity, giving rise to several new regional structural subdivisions which were accentuated into high relief structural provinces during Pennsylvanian time. The broad, low-relief upwarps were the Pedernal Arch, which extended south to north from Trans-Pecos Texas to North Central New Mexico; the Central Basin Platform, which extended northwest to southeast from Southeast New Mexico to eastern Pecos County, Texas; the Matador-Red River Uplift, oriented west to east from Easten New Mexico to North Texas. The Texas Peninsula, which was the exposed crest of the Texas Arch, sank slightly below sea-level.

Compressive orogenic forces from the southeast uplifted the Llanoria Landmass progressively in lower Mississippian and early Pennsylvanian time, raising the west to east Ouachita-Maraton mountain ranges along the cratonic border. Contemporaneous with these positive movements, cratonic-edge downbending depressed an extensive geosyncline which lay in front of and parallel to the north rim of the mobile belt, embracing the whole Marathon region. Clastic debris, stripped from the uplifted blocks of the mountain ranges, was deposited into the newly formed Llanoria Geosyncline, being the source material of the Tesnus formation, which evidently crosses the late Mississippian and early Pennsylvanian time boundary. The lowermost member of the Tesnus formation is considered to be of upper Mississippian age. The middle and uppermost members of the formation have been classified as Springer and Morrow, which are of lower Pennsylvanian age. Strata of Springer age are not known in the region beyond the boundaries of the Llanoria Geosyncline.

The pronounced late Mississippian - early Pennsylvanian uplift caused a general withdrawal of the sea, which subjected the exhumed region previously occupied by the Tobosa Basin to erosion. Subsidence at the close of Springer time permitted the sea to encroach northward from the Llanoria Geosyncline. Landward expansion of the sea, initiated by regional subsidence, continued throughout most of the Pennsylvanian period, gradually filling a broad regional embayment which extends east to west from the Texas Arch to the Pedernal Arch and which extended from south to north from the Ouachita - Marathon mobile belt to the Amarillo Uplift. Crests of the intra-embayment upwarps such as the Central Basin Platform and the Matador-Red River Uplift were exposed as chains of islands.

Broad, shallow structural depressions separating upwarps occupied regional positions which evolved eventually into the Delaware, Midland, Marfa and Palo Duro basins. The Midland Basin and the north part of the Delaware Basin sagged rapidly during the Morrow and Bend epochs.

The expanding early Pennsylvanian sea advanced northward from the Llanoria Geosyncline during the Morrow epoch, entering into and filling the northern part of the Delaware Basin. Clastics derived from the rising New Mexico highlands, rejuvenated by early Pennsylvanian orogenies, were deposited in and near the basin north of thicker shale and limestone deposits.

The expanding sea entered the northern part of the Midland Basin by way of a depression at the north edge of the Central Basin Platform, thence through structural lows of the Matador Uplift into the southern part of the Palo Duro Basin.

Principal elevation of the Matador Uplift occurred at the close of Morrow time. Emerging peaks contributed sand, arkose and gravel which mixed with detritus swept from the New Mexico highlands and deposited on the north flanks of the Midland Basin and the south flank of the Palo Duro Basin. The sea continued to encroach during Bend time until it had filled most of the Delaware Basin and all of the Midland Basin except the eastern flank. Bend strata in the Delaware Basin consist principally of shale and sandstone in its lower part, grading upward into limestone. Sandstone at the base of the section thickens northward into southeast New Mexico. The Bend section is predominantly limestone on its western and eastern margins. In the Midland Basin shale is less common than limestone, which is cleanest over local highs in the basin and on the east flank of the Central Basin Platform.

Deposition of the Dimple limestone in the Llanoria Geosyncline represents a period of quiescence in the adjacent Ouachita-Marathon orogenic belt during the Bend epoch.

Uplift and structural deformation occurred in late Bend time. The Ouachita-Marathon region was re-elevated, pushing its northern rim and the Llanoria Geosyncline northwestward toward the foreland. Strong compressive forces from the south and west mildly downwarped the asymetrical Delaware and Midland basins, uplifted and deformed the elongate Central Basin Platform, and flexed trends of local structures between the Midland Basin and the Lanoria Geosyncline known as the Regan Uplift.

The Fort Stockton High in northern Pecos County stood at the south end of the Central Basin Platform as the highest and most pronounced element of the structural province. Milder upwarps in the basins lay as an echelon trend studded with local tectonic displacements, some of which projected above sea-level as fault blocks that formed isolated islands. Axes of the trends generally paralleled regional structural grain. Erosion stripped sedimentary covers from the crests of exposed high-relief fold and fault blocks. Residual detrital sediments accumulated on the flanks of structure.

Regional subsidence spread early Strawn seas beyond the boundaries of structural basins of the embayment. Thin beds of limestone covered shallow embayment shelves and basin floors except where water was too deep for limestone deposition, such as in the southern sectors of the Delaware and Midland basins.

During the mid-Strawn epoch, structural deformation with renewed vigor rejuvenated local and regional tectonic elements. Intensity of deformation was greatest in the southern part of the embayment. Compressive forces thrust the Ouachita-Marathon mobile belt farther northwest. The Llanoria Geosyncline migrated further toward the foreland. The Central Basin Platform, Matador Uplift, and possibly the Pedernal Arch, were compressed, re-elevated and modified with trends of high-relief localized structures. Enchelon structural trends flanking major positive and negative tectonic provinces were reaccentuated by higher vertical relief and interrupted by well-defined local anomalies. The intricate pattern of the Reagan Uplift was modified by re-elevation of local structures which were sharply folded and faulted.

These positive regional and local tectonic events were accompanied by contemporaneous deepening of the structural basins.

The close of the mid-Strawn epoch initiated a period of stability and gentle subsidence which characterized West Texas and Southeast New Mexico until near the close of the Pennsylvanian period.

During late Strawn time, the expanding sea encroached upon the eroded flanks of regional and local structures, depositing carbonates over detrital sediments which accumulated along shoreward margins as the waste products of denudation.

Widespread deposits of bedded and biostromal limestones were distributed over the floors of shallow shelves and along the flanks of positive

regional structural elements. Broad reef mounds developed along the southern edge of an early Strawn limestone platform situated in the north part of the Midland Basin and overlapping onto the Eastern Shelf, initiating the growth of the Horseshoe Reef Atoll.

Isolated reefs grew around the edges of intrabasin islands and over the crests of shallow submerged local structures. Shale, sandstone and large boulders of the Haymond formation, which possibly crosses the Bend-Strawn time boundary in the Marathon region, and the overlying conglomerate, sandstones and shale of the lower part of the Gaptank formation, were deposited in the Llanoria Geosyncline. Overflow sands from the slowly sinking depression were carried northward, sweeping over the southern part of the developing Eastern Shelf, which lies east of the Midland Basin and the Reagan Uplift. Well developed lenticular sandstone lenses flanked Strawn reefs. Coarse conglomerate and thick sand bodies in the Sacramento Mountains and sand deposits along the north and east margins of the New Mexico segment of the Pedernal Arch is evidence of clastic-source highlands in that region.

Continued subsidence of the West Texas and Southeast New Mexico embayment characterized both the Canyon and Cisco epochs. Deepening of the Delaware and Midland basins by continuing downwarping produced profound effects upon regional sedimentation. Depth of water and distance from clastic source precluded thick sedimentary deposits in the deeper parts of the basins comparable to earlier Pennsylvanian epochs. Widespread thin shale deposits covered basin floors, grading into limestone shelfward.

Isolated reefs over the crests and along the margins of local structures in basins and on the Reagan Uplift sank below sea-level and were drowned. A variety of upper Pennsylvanian ridge, round, chain or cluster reefs, and systems of composite reefs, grew on the Eastern Shelf. During both the Canyon and Cisco epochs extensive bedded and biostromal limestone deposits accumulated over the Northwestern Shelf. Limestone "shoulders" marked the upper flanks of the Central Basin Platform. Masses of limestone were erected over the Matador Uplift, completely covering the alignment of peaks during the Cisco epoch. Numerous Cisco reefs grew locally in the areas now occupied by the Hueco Mountains and the Sacramento Mountains. The exposed crests of the Central Basin Platform and Pedernal Arch shrank as the sea advanced landward and covered clastic deposits which had accumulated along shoreward margins.

The Horseshoe Reef Atoll grew dominantly vertically, gradually reducing in lateral extent as basinal subsidence increased water depth. The feature is considered to be a shell bank consisting of lithified organic debris. During its development, several periods of erosion occurred as sea-level fluctuated. The entire reef trend finally was submerged completely in early Permian time. Its curved shape is believed to be the result of the action of winds and currents.

In the northwestward migrating Llanoria Geosyncline, deposition of clastic sediments from the advancing Ouachita-Marathon highlands was interrupted by intervals of quiescence during which time thick beds of limestone were deposited. These strata represent the upper members of the Gaptank formation in the Marathon region. Canyon and Cisco sands derived from the highlands spread widely over the southern part of the Eastern Shelf, gradually decreasing in volume northward.

Sinking of the Llanoria Geosyncline during Pennsylvanian time is believed to have been accompanied by rapid filling of the depression as many thousands of feet of predominant clastic sediments accumulated in that region. The foreland to the north, in contrast, is characterized by slower subsidence of the embayment, predominant carbonate and shale deposition, and a thinner total Pennsylvanian section.

Limited outcrops and sparse subsurface control in the Marfa Basin demonstrate that Pennsylvanian sediments were deposited in that province. Strata are believed to be composed predominantly of shale, but contain limestone and some sandstone. Pennsylvanian sediments in the Orogrande Basin of New Mexico are mostly of upper Pennsylvanian age. Several thousand of feet of Cisco deltaic and basinal strata occupy the basin. Upper Pennsylvanian reefs, like those exposed in the Sacramento Mountains, are believed to have rimmed the north part of the basin.

The late Pennsylvanian and early Permian time boundary is marked by mountain-making movements with faulting and intense folding in West Texas and Southeast New Mexico. The greatest orogeny occurred in the Ouachita - Marathon mobile belt, where tightly-compressed northeast trending folds and overthrust sheets

from the southeast raised the Llanoria Geosyncline. Associated downwarping to the north formed the deep, linear Val Verde Basin, which was filled by many thousands of feet of clastic material derived from the adjacent areas during the Wolfcamp epoch of the early Permian period.

Compressive forces uplifted the Central Basin Platform to its highest elevations. Highly deformed local structures formed ranges of mountains oriented generally parallel to the main axis of the platform. The Fort Stockton High in north Pecos County, Texas and the Eunice Uplift in southeast Lea County, New Mexico, terminated the south and north edges of the platform, standing at greater heights than intervening structures.

Local folds and fault blocks of the Reagan Uplift and the crests of en echelon trends in the basins were rejuvenated. Some were elevated above sea-level. The Pedernal Arch again became structurally active.

The epoch of intense deformation was followed by a long period of erosion which reduced the mountains of the Ouachita-Marathon mobile belt to low undulating topography and stripped the Central Basin Platform and structures of the Reagan Uplift and the basins to near base-level. Erosion completely unroofed the sedimentary cover from the crest of the Fort Stockton High, cutting hundreds of feet into the Pre-Cambrian core.

The expanding sea gradually encroached over broad eroded surfaces, truncated edges of sedimentary strata and new layers of arkose, sand, chert pebble and shale deposits, which had accumulated along the edges and on the flanks of both regional and local structures as the products of erosion.

The basic architecture of West Texas and Southeast New Mexico, established in Pennsylvanian time, persisted throughout the Permian period.

Life

The Pennsylvanian period is noted for the abundant coal deposits found in the eastern interior of the United States, where humid climatic conditions prevailed over vast regions. Such coal-forming plants as ferns, scouring rushes and scale trees, grew profusely in widespread swamps. Insects were numerous. Limited coal seams also are present on the Eastern Shelf in Texas.

In the seas, brachiopods and bryozoans grew abundantly; pelecypods and gastropods were common. Cephlapods were present but less numerous than in earlier geological periods.

The most useful Pennsylvanian fossils for correlation purposes in West Texas and southeast New Mexico are the fusulinids, a group of spindle-shaped foraminifera which commonly resemble grains of wheat. They are particularly useful in separating the various stratigraphic zones of the Pennsylvanian system.

Bend fusulinids are the Fusiella, Fusulinella and Eoschubertella; Strawn, Fusulina and Wedekindellina; Canyon, Triticites; Cisco fusulinids are Dunbarinella, Waeringella and advanced forms of Triticites.

PROSPECTS AND RECOMMENDATIONS

Many additional drillable Pennsylvanian prospects are expected to develop in West Texas and Southeast New Mexico. The Pennsylvanian system in the various geological provinces which merit further examination are herein briefly reviewed.

EASTERN SHELF

Pennsylvanian sandstones and reefs are significant producing horizons on the Eastern Shelf, requiring the definition of local reef highs and structural trends and the outlining of maximum sand deposition. Most Pennsylvanian wells are completely from sandstone reservoirs.

The search for reefs and bedded limestones draped over deep structures on the Eastern Shelf should uncover new prospects. Geologists have found that a reef trend on the shelf may follow a definite contour line, except where local and regional tilting has occurred after termination of reef growth. Such contour lines can narrow the margin of error in extrapolation between mapped reefs during the search for reef trends.

Discovery and development of lenticular sandstones flanking the Jameson reef field in Coke County several years ago initiated a brisk search for similar reservoirs along the north-

south tier of counties of the Eastern Shelf. The region offers additional substantial sand reservoir prospects. In the Jameson area production is controlled by stratigraphic pinchout or non-deposition of sand bodies updip on reef flanks. Cross-sections are useful in comparing the downdip sand development against sand sections near the crests of reefs. Isopach maps are of value in defining maximum sand development.

The wildcatter can continue to find Runnels County an especiallly attractive area for testing several relatively shallow potential pay zones per hole.

Exploratory efforts to uncover Pennsylvanian pays in Concho and Menard Counties are expected to remain active for some time.

EDWARDS ARCH AND REAL SHELF

The Edwards Arch and Real Shelf, which form the southern extension of the Eastern Shelf, lie adjacent to the Kerr Basin. Pennsylvanian reefs and lenticular sandstones are predicted for the area.

MIDLAND BASIN

The most conspicuous and best known Pennsylvanian feature in West Texas is the spectacular Horseshoe Reef trend, which is an upper Pennsylvanian atoll situated mainly in the north part of the Midland Basin, but covering part of the Eastern Shelf. The Pennsylvanian horizon in such fields along the trend as Good, Vealmoor and Reinecke probably has yielded higher per-acre oil recoveries than any other horizon in the basin.

Many explorers favor reef reservoirs because their environmental position usually is located in the richest zone of marine organic growth, primary and secondary porosity is generally well-developed and steep depositional slopes act as gathering lines for oil.

Exploration on the Horseshoe Reef Atoll reached its peak over a decade ago. Operators now are focusing increasing attention to less extensive reef trends and local buildups near the atoll. One such area which has spurred an active search is in east Gaines County, where a possible trend of important dimensions could be present.

A considerable number of pre-Pennsylvanian structures in the Midland Basin are capped by productive Strawn biostromal and bedded limestone reservoirs. Several fields produce from Bend limestones which are draped over deep structures in the south part of the basin. Additional Strawn and Bend limestone reservoirs are being sought, especially as new developments in oil fields.

Morrow and Atoka coarse clastics which were derived from the Matador Uplift and the New Mexico highlands offer prospective reservoir possibilities in the extreme north part of the basin.

CENTRAL BASIN PLATFORM

The Central Basin Platform is one of the most prolific oil-producing areas in the world, and offers a variety of prospects from the Pennsylvanian system.

Upper Pennsylvanian limestones were deposited over local structures and as thick shoulders adjacent to the more positive areas, paralleling the trend of the structural province. Prospectors should consider potential future pays from Pennsylvanian limestones draped over deep structures underlying shallow Permian fields. Several such discoveries of significance have been made the last few years. Porosity-permeability barriers in limestones flanking the platform are expected.

Marginal clastics around the periphery of the Fort Stockton High in north Pecos County contain chert pebble, quartz sand and arkose, which could act as reservoirs associated with stratigraphic traps. Other detrital facies are present on the margins of the platform and around the edges of local structures which could contain reservoir beds.

DELAWARE BASIN

The Delaware Basin is expected to attract attention as the center of exploratory activity for the next several years. Noteworthy discoveries from lower Pennsylvanian clastics and Strawn carbonates are predicted. Excellent gas wells which produce from the Morrow sandstone rank very high, particularly in southeast New Mexico, where good reserves of considerable importance have been found. Thin beds of Atoka sandstone act as gas and distillate reservoirs. Production has extended into the Texas sector of the Basin.

Strawn limestones are present on the east, north and west flanks and margins of the basin, where a wide variety of oil and gas prospects are

expected to be found. Additional Strawn reefs are postulated. Stratigraphic traps could be of special geological significance.

NORTHWESTERN SHELF

The Pennsylvanian system on the Northwestern Shelf is one of the better reservoir horizons in that province. Upper Pennsylvanian limestone sections are widely distributed over the shelf except along the extreme southern margins in southeast New Mexico. Lower Pennsylvanian clastics are well-developed in the southern part of the region where they are continuous into the Delaware Basin.

Additional Pennsylvanian oil reserves should be encountered in limestone reservoirs draped over pre-Pennsylvanian highs or developed as porosity-permeability barriers on their flanks. Significant gas and distillate discoveries from Morrow and Bend sandstones should show increasing potential. New Morrow gas prospects on the upthrown side of the large Huapache fault can be expected.

MATADOR UPLIFT

Productive possibilities are believed to exist principally from stratigraphic traps associated with the east-west trending alignment of peaks of the uplift. Prospective future development is expected from Permo-Pennsylvanian reefs on and near the crests of local structures of the uplift; domal limestone masses erected over shoals; and Morrow and Atoka sandstone, arkose and gravel on the flanks of local highs.

PALO DURO BASIN

The Palo Duro Basin, situated north of the Matador Uplift, has been referred to as a Pennsylvanian shale basin. However, limestone constitutes a large part of the total Pennsylvanian section. Clastics derived from the Matador Uplift to the south, the New Mexico highlands to the west, and the Amarillo Uplift to the north, are widely distributed in the basin. The region is relatively unexplored in comparison with other structural provinces in West Texas and Southeast New Mexico and has yielded little oil to date.

Pennsylvanian reefs along hinge lines near basin margins are expected to be the primary productive horizons. Facies changes in beds of limestone provide porosity - permeability barriers. Sandstones and arkoses lying on the flanks of regional and local structures and reefs are expected to act as reservoir beds, particularly in association with stratigraphic traps. The basin possibly could develop into one of the large Pennsylvanian oil producing provinces of the future.

VAL VERDE BASIN

Operators who have explored for Pennsylvanian production in the Val Verde Basin classify the Strawn limestone the best-developed reservoir rock in the Pennsylvanian system. The horizon has yielded mostly gas, but condensate and some oil have been produced.

Gas production in the Vinegarone field is reportedly from a reef facies. Strawn gas, condensate and oil in the Puckett field are entrapped in reservoirs associated with a major complex structure. Gas and condensate are produced from Pennsylvanian detrital along the north margin of the basin.

Strawn limestones are associated with structural and stratigraphic traps and reefs, and Pennsylvanian detrital facies near the south edge of the Central Basin Platform could spur exploration for years to come.

In his search for Pennsylvanian prospects, the explorer should study the Devil's River Uplift, which lies between the axis of the Val Verde Basin to the north and the highly-deformed Ouachita mobile belt to the south. The north and east flanks of the uplift feature, which cover parts of Val Verde, Kinney and Edwards Counties, are areas of interest. Major structures are expected to be present. Pennsylvanian lenticular sandstones and possible bedded limestones and reefs may offer favorable reservoirs but are undefined because of sparse subsurface control.

REAGAN UPLIFT

The Reagan Uplift is a pre-Permian structural province which separates the Midland Basin to the north from the Val Verde Basin to the south. Several deep structures are capped by Strawn reefs and Bend non-reef limestones which produce oil. The best Strawn reef fields are the Todd field and the West World field, both in Crockett County. Explorers should search for other such fields. Additional Bend non-reef limestone reservoirs draped over deep structures can be expected to produce in the north part of the province.

MARATHON BASIN

Pennsylvanian rocks in the Marathon Basin in Brewster County are present in a thrust salient found at the surface. Generally, these rocks are not considered favorable as oil or gas reservoirs. However, there is the possibility that the fault has overridden Pennsylvanian foreland rocks near the north margin of the basin. Such underlying beds probably would consist principally of undisturbed Strawn limestones which could contain satisfactory reservoirs. Both structural and stratigraphic traps may be present.

MARFA BASIN

Exploration efforts in the Marfa Basin are hampered by widespread Tertiary lavas. Recent interest in exploration has lagged because of the encountering of relatively fresh water in potential reservoir beds.

OROGRANDE BASIN

Much of the Orogrande Basin of Pennsylvanian age is now occupied by the Tularosa Basin, a regional graben which is a fairly recent geological structural province in New Mexico. However, the boundaries of the original basin extends considerably beyond the edges of the present regional feature. Only a few wells have explored the province.

Sediments in the Orogrande Basin are principally of upper Pennsylvanian age. Thousands of feet of Cisco deltaic and basinal strata are present. Upper Pennsylvanian reefs rimmed at least parts of the basin. Cisco reefs which grew on the northwest flank now outcrop in the San Andres Mountains. Sandstone, arkose and limestone on the northern margin of the basin exhibit characteristics of reservoir beds. Dark, petroliferous shales provide favorable source beds.

Oil discoveries from future exploration could come from reefs and from bedded clastic or limestone reservoirs associated with both structural and stratigraphic traps.

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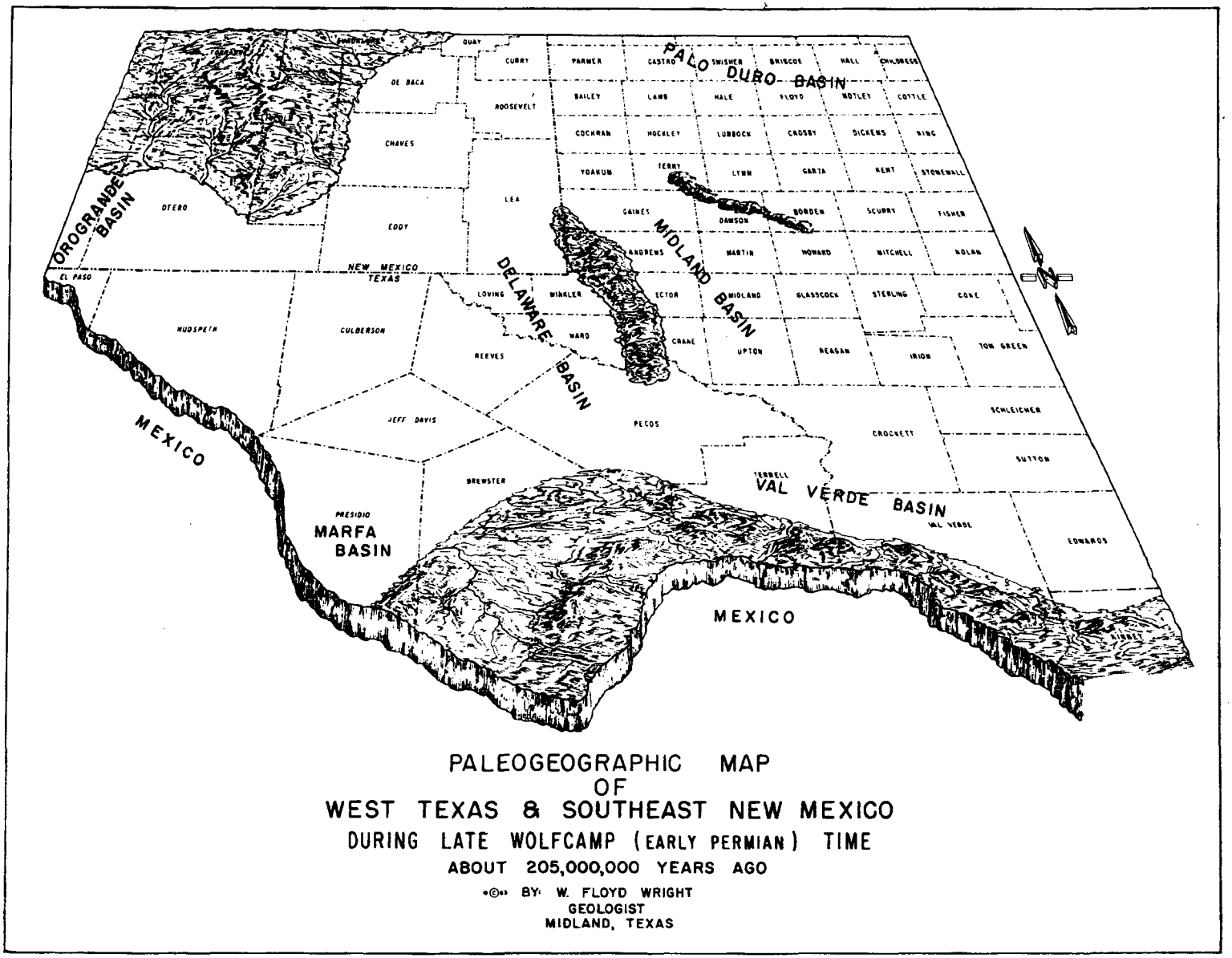

PALEOGEOGRAPHIC MAP
OF
WEST TEXAS & SOUTHEAST NEW MEXICO
DURING LATE WOLFCAMP (EARLY PERMIAN) TIME
ABOUT 205,000,000 YEARS AGO

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Figure 15.