

# THE OIL RECOVERY GROWTH POTENTIAL OF THE PERMIAN BASIN, USA

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### INTRODUCTION AND BACKGROUND

The Permian Basin is located in the southwestern United States in west Texas and southeast New Mexico. As defined by the American Association of Petroleum Geologists Committee on Statistics of Drilling in their 1991 Geologic Provinces Code Map, the Permian Basin (AAPG-CSD Province Code #430) covers 67 countries in these two states: four in southeast New Mexico, two in Texas RRC District 1, six in Texas RRC District 7B, fourteen in Texas RRC District 7C, nineteen in Texas RRC District 8, twenty-one in Texas RRC District 8A, and one in Texas RRC District 9.

The Permian Basin is usually divided into seven major sub-provinces (regional structural elements) as shown in Figure 1. These include the Central Basin Platform, Midland Basin, and Ozona Platform in the center, the Eastern Shelf on the east, the Val Verde Basin to the southeast, the Delaware Basin to the southwest, and Northwest Shelf to the northwest. These regional elements, formed during the late Paleozoic, overlie the ancestral early Paleozoic Tobosa Basin. The eastern portion of the Northwest Shelf has often been characterized as the North Basin Platform. The central portion of the Northwest Shelf is commonly referred to as the Tatum Basin.

The Permian Basin is one of the eight largest oil provinces in the world. As of December 31, 2004, known recoverable resources (EUR) of petroleum liquids in the basin were 45.3 billion barrels (7.2 bcm). This consisted of 37.3 billion barrels (5.9 bcm) of crude oil and 8.0 billion barrels (1.3 bcm) of natural gas liquids (NGL). Of the known resources, 87% have already been produced through 2004 - 32.7 billion barrels (5.2 bcm) of crude oil and 6.7 billion barrels (1.1 bcm) of NGL. Remaining proved developed producing reserves total 4.6 billion barrels (0.7 bcm) of crude oil and 1.3 billion barrels (0.2 bcm) of NGL.

**TABLE 1. THE DISTRIBUTION OF PETROLEUM LIQUIDS BY FIELD SIZE CLASS IN THE PERMIAN BASIN, 1979-2004 (millions of barrels)**

Field Size Class (# fields)	Crude Oil EUR		NGL EUR	
	1979	2004	1979	2004
<b>World Class Giant (20)</b> (≥ 500 MM BBL)	14,657	20,245	2,326	3,733
<b>Large National Class Giant (15)</b> (200-500 MM BBL)	3,334	4,280	654	941
<b>Small National Class Giant (25)</b> (100-200 MM BBL)	1,997	2,662	450	886
<b>Large (40)</b> (50-100 MM BBL)	1,902	2,362	273	426
<b>Other (3000+)</b>	5,477	6,896	759	1,903*
<b>1980 - 2004 Discoveries (600+)</b>	0	838	0	150
<b>Permian Basin Total</b>	<b>27,367</b>	<b>37,283</b>	<b>4,462</b>	<b>8,039</b>

Sources: API; EIA; NRG Associates, The Significant Oil and Gas Fields of the United States Database

\*Notes: Includes c. 400 million barrels that should properly be allocated to the larger fields.

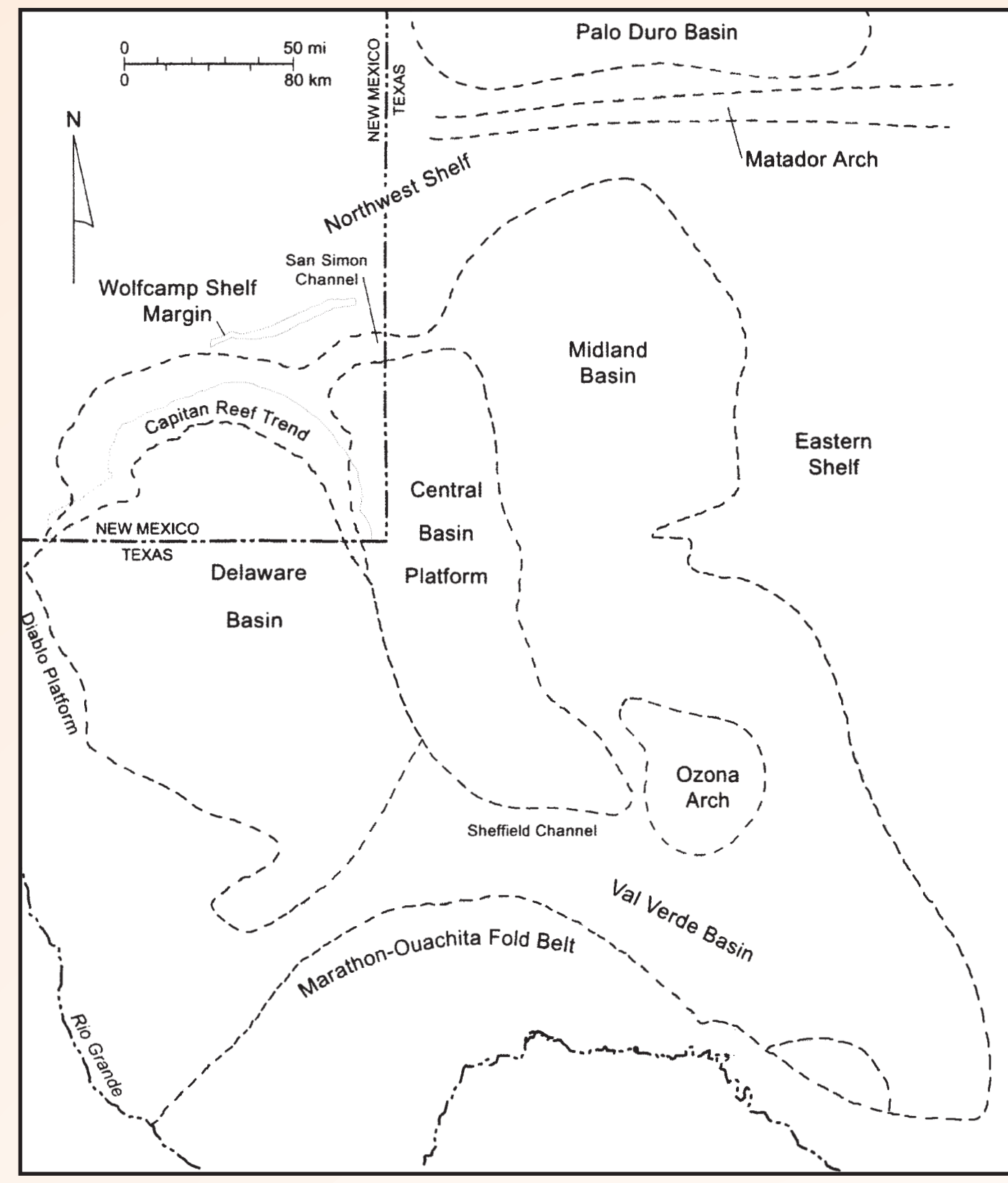


Figure 1. Major Subdivisions of the Permian Basin in West Texas and Southeast New Mexico. Source: Dutton and others (2005). Used by permission.

Like nearly all major oil provinces, the oil resources of the Permian Basin are concentrated in a small number of giant fields (Table 1). The twenty world class giant oil fields in the basin (those with an ultimate recovery exceeding 500 million barrels) have at least 24.0 billion barrels (3.8 bcm), providing more than half (52.9%) of the basin's known resources of petroleum liquids. Another 11.5% -- 5.2 billion barrels (0.83 bcm) -- of these known resources are in 15 large national class giant fields (200-500 million barrels each). The 25 small national class giant fields (100-200 million barrels each) contained 3.55 billion barrels (0.56 bcm), 7.8% of the basin total. The 100 largest fields in the Permian Basin (all those with an ultimate recovery of 50 million barrels or more petroleum liquids) together had a known recovery of 35.9 billion barrels (5.7 bcm), 79.2% of the basin total. By comparison, the remaining 9.4 billion barrels (1.5 bcm) was spread over more than 3600 fields.

Oil in the Permian Basin has been discovered throughout the Paleozoic section - Cambrian through Permian (Figure 2). The productivity of the basin varies substantially by system and series (Table 2). The oil resources of the Permian Basin are highly concentrated in late Paleozoic (Pennsylvanian and Permian) reservoirs - these two systems containing 39.5 billion barrels (6.3 bcm), 87.2% of the basin total.

The Permian system clearly dominates, having more than twice as much oil as all the other systems together. Petroleum liquids in the four Permian series total 31.4 billion barrels (5.0 bcm), 69.3% of the basin total. This concentration explains why the Permian Basin received its name.

**TABLE 2. THE DISTRIBUTION OF PETROLEUM LIQUIDS BY SYSTEM AND SERIES IN THE PERMIAN BASIN, 1979 AND 2004 (millions of barrels)**

System/Series	Crude Oil EUR		NGL EUR	
	1979	2004	1979	2004
<b>Permian (Total)</b>	<b>18,920</b>	<b>26,854</b>	<b>2,474</b>	<b>4,559</b>
Ochoan	(43)	(46)	(0)	(0)
Guadalupian	(14,886)	(19,916)	(1,489)	(2,608)
Leonardian	(3,502)	(6,071)	(835)	(1,704)
Wolfcampian	(489)	(821)	(150)	(247)
<b>Pennsylvanian*</b>	<b>4,768</b>	<b>5,981</b>	<b>1,072</b>	<b>2,106</b>
Mississippian	15	26	12	15
Devonian	864	1,124	589	892
Silurian	1,028	1,293	63	96
Ordovician	1,730	1,958	246	364
Cambrian	42	47	6	7
<b>Total</b>	<b>27,367</b>	<b>37,283</b>	<b>4,462</b>	<b>8,039</b>

Source: NRG Associates, The Significant Oil and Gas Fields of the United States Database

\* Note: Includes all Permo-Pennsylvanian reservoirs straddling the system boundary

**TABLE 3. GIANT AND LARGE OIL FIELD DISCOVERIES IN THE PERMIAN BASIN BY DECADE, 1920-1999 (Number of fields/EUR of petroleum liquids in million barrels)**

Decade of Discovery	World Class Giants	Large National Giants	Small National Giants	Large	Total
1920-1929	8 (7,750)	2 (928)	8 (1,269)	2 (103)	20 (10,050)
1930-1939	9 (11,334)	1 (412)	4 (557)	2 (132)	16 (12,435)
1940-1949	3 (4,894)	9 (2,717)	6 (775)	16 (1,130)	34 (9,516)
1950-1959	0	3 (1,164)	3 (436)	16 (1,159)	22 (2,759)
1960-1969	0	0	3 (404)	2 (126)	5 (530)
1970-1979	0	0	1 (107)	2 (138)	3 (245)
1980-1989	0	0	0	0	0
1990-1999	0	0	0	0	0
<b>Totals</b>	<b>20</b> (23,978)	<b>15</b> (5,221)	<b>25</b> (3,548)	<b>40</b> (2,788)	<b>100</b> (35,535)

Source: NRG Associates, The Significant Oil and Gas Fields of the United States Database.

in play definition. Typically, differences in geologic characteristics correlate closely with differences in the time of discovery among different groups of reservoirs.

Because the reservoirs within a play have similar geologic characteristics, they are also likely to have similar producing characteristics. These similarities create a basis for relevant and reliable intra-play comparisons among reservoirs. Higher recovery efficiencies that have been achieved in more intensively developed reservoirs are probable in less intensively developed reservoirs within the same play. Inter-play comparisons between plays with similar geologic characteristics in different geographic locations provide another basis for evaluation and extrapolation.

This evaluation of the recovery growth potential of the Permian Basin is organized basically by system and series. Six major stratigraphic intervals are evaluated: the Guadalupian, Leonardian, and Wolfcampian series within the Permian system, and the Pennsylvanian, Siluro-Devonian, and Cambro-Ordovician systems. The latter two units are each a combination of two systems because each system by itself is relatively small. The Ochoan series within the Permian system and the Mississippian system are not evaluated because their known oil resources and thus their growth potential are insignificant.

Not all plays within these six stratigraphic intervals are evaluated. The plays that are discussed and formally evaluated are limited to those with a potential (combining both current known recovery and future growth) of at least 500 million barrels (80 x 10<sup>6</sup> m<sup>3</sup>) of petroleum liquids. Twenty-one plays meet this criteria. Together these twenty-one plays account for 90% of the known recovery of petroleum liquids in the Permian Basin. In the concluding summary for each of the six major stratigraphic intervals, a brief discussion of the known liquids resources and growth potential for other plays is included to complete the evaluation.

Accompanying the focus on major plays is a focus on the large and giant reservoirs -- all those with a known recovery exceeding 50 million barrels (8 x 10<sup>6</sup> m<sup>3</sup>) of petroleum liquids -- in each play. These large reservoirs are emphasized because they contain the great majority of the original oil-in-place and known recoverable liquids resources within the Permian Basin. Within the six largest plays -- those with a known recovery in excess of 2.5 billion barrels (0.4 bcm), 85 to 95% (a mean of 92.3%) of each play's known liquid resources are in these large and giant reservoirs. (These six plays contain 60% of the known petroleum liquid resources of the Permian Basin.) In the next four largest plays -- those with a known recovery between 1.0 and 2.5 billion barrels (0.16-0.4 bcm), 50 to 85% (a mean of 65.4%) of each play's known resources are in these large and giant reservoirs. Large and giant reservoirs thus provide much more than just an illustrative sample.

Each major play is summarized by a table indicating its resource size, its discovery and development history, and its key geologic characteristics. This information is provided for all large and giant reservoirs individually. Size, recent growth, and recent discoveries are provided in sum for all other significant reservoirs in each play. (A significant reservoir is defined as one with an ultimate recovery of at least 0.5 million BOE.)

Estimates of original oil-in-place (OOIP) are provided to show both the potential of and the limits to future growth. Because the Permian Basin is a mature province in which most sizeable reservoirs have undergone water flooding, published estimates of original oil-in-place are generally available. Wherever the 2004 crude oil EUR exceeded 10 million barrels, oil-in-place was estimated by the volumetric method. Where oil-in-place estimates were not available or were not calculated by the volumetric method -- mostly for small reservoirs, oil-in-place was extrapolated, assuming the same current recovery efficiency in those reservoirs as in the other (smaller) reservoirs for which oil-in-place estimates existed. Because oil-in-place estimates were usually available for reservoirs with 75 to 90% of the 2004 crude oil EUR in the other reservoir category, we concluded that this procedure provided reasonably reliable estimates. All estimates of original oil-in-place that depend on our own calculations or extrapolations are indicated by a "c."

Play and reservoir size is also indicated by the estimates of 2004 EUR for crude oil and NGL. The sum of these two numbers provides the total current estimate of petroleum liquids recovery. The current estimate of crude oil EUR divided by the estimate of original oil-in-place provides the current estimate of oil recovery efficiency. The estimates of 1979 EUR for crude oil and NGL are provided to show (by comparison with the 2004 EUR estimates) recent recovery growth by reservoir, groups of reservoirs, and the play as a whole. Recent growth provides an excellent indicator of how active development has been in each reservoir or group of reservoirs over the past quarter century. To distinguish true reserve growth from reserve additions as a whole, separate estimates of 2004 EUR are provided for all reservoirs (as a group) discovered from 1980 to 2004. This row, when compared to the play totals, indicates the importance (or lack thereof) of recent discoveries to play known recovery.

Several rock and fluid characteristics are relevant to recovery growth potential in general. The following play tables show only four for all large and giant reservoirs: lithology, depth to top, average net thickness, and permeability. These four variables were considered most relevant to the evaluation of oil recovery growth potential in the Permian Basin. (Additional descriptions of the geologic characteristics of the oil plays of the Permian Basin, particularly their depositional environments and factors affecting reservoir heterogeneity, can be found in Dutton and others, *Play Analysis and Digital Portfolio of Major Oil Reservoirs in the Permian Basin*, Bureau of Economic Geology Report of Investigations No. 271, Austin, 2005.)

Lithology is shown because most of the major oil plays in the Permian Basin are carbonate, not clastic plays. In general, carbonate reservoirs are more heterogeneous and have more compartmentalization than clastic plays. Depth to top is included because depth is a major determinant of well costs. This is relevant for the evaluation of recovery growth potential in the Permian Basin because infill drilling (reservoir downspacing) has been and remains a major means of achieving recovery growth. Average net thickness, when combined with porosity and initial oil saturation, provides a useful indicator of the resources in place per spacing unit. Permeability is included because it is a major constraint on oil recovery in the Permian Basin, being typically either low (1-10md) or mediocre (10-50md). It also provides an indicator of the likely drainage area of individual wells.

Reservoir development history and intensity are summarized in three different ways. The reservoir discovery year provided for all large and giant reservoirs indicates how long the reservoir has been producing and under development. For the large and giant reservoirs in the Permian Basin, this is generally a period of 50 to 80 years. Well spacing provides an indicator of both how intensively the reservoir has been developed and, when combined with permeability, how well the reservoir is likely being drained. Where two spacings are indicated, the current predominant spacing is listed first. Post-primary recovery methods indicate which methods beyond primary recovery have already been employed in each large and giant reservoir. This provides a second measure of the intensity of reservoir development. Where multiple methods have been employed, they are listed in order of implementation. The abbreviations used are as follows: CO<sub>2</sub>-CO<sub>2</sub> injection, GC-gas cycling, GI-gel injection, NI-nitrogen injection, PF-polymer flood, and WF-waterflood. Most of these are reservoir wide projects. The primary exception to this are the polymer floods which were initiated in the early 1980's as pilot projects and terminated a few years later when their prices crashed.

This information is used as the basis for the assessment. In each play, we first review the reservoirs with the best recovery efficiencies, considering both the reservoir conditions and the development efforts that produced these results. These reservoirs are assessed for their future growth potential. The potential in these reservoirs is typically restricted by a maximum achievable recovery efficiency. Reservoirs with lower efficiencies are then examined to determine whether and to what degree more intensive development efforts could be employed in them to improve recovery efficiencies. These estimates are added to obtain the estimates of play growth potential. Because of the substantial uncertainties inherent in this estimation procedure, the potential is expressed as a rough approximation of a 90% - 10% range.

This method has a modest conservative bias. It assumes a crude oil price range of \$50-75/barrel and does not consider the impact of significantly higher prices (which are clearly a possibility between 2015 and 2050). It assumes the employment of drilling, completion, and production technologies that have been developed over the past twenty years. It does not incorporate the effects of future major technological changes, whatever those may prove to be. Nonetheless, the estimates shown require a substantial development effort if they are to be achieved by 2050.

Recent recovery growth was concentrated in the hundred largest fields. Growth in these fields from 1979 to 2004 totaled 10.34 billion barrels (1.64 bcm), 82.7% of the recovery growth in the Permian Basin (Table 1). This growth was pervasive. All but one of the sixty largest fields - all the world-class and national-class giant fields - grew during this period (Table 4). In 75% of these fields, ultimate recovery increased by at least 20%. In 23% of these fields, growth in ultimate recovery exceeded 60%.

Recent growth was particularly concentrated in the world-class giant fields. Growth in these 20 fields totaled at least 7.0 billion barrels, 55.9% of the basin total. Seven of these twenty fields achieved world-class giant status because of this growth. Although all of these fields were discovered at least thirty years before 1980 - and thus well beyond the initial years of rapid field development, two -- the Spraberry Trend and Robertson-Flanagan -- more than doubled in size. Another six, including the two largest, grew by more than 50%. Estimated recovery efficiency in these 20 fields increased from 26.1% in 1979 to 36.1% of original oil-in-place in 2004. The recovery efficiency of all sixty giant fields, both world-class and national-class, increased from 26.6% in 1979 to 36.1% in 2004. Enhanced oil recovery efforts, principally miscible CO<sub>2</sub> injection, and intensive infill drilling efforts were concentrated during this period in the world-class giant and the large national class giant fields.

### METHODOLOGY

This poster present an evaluation of the recovery growth potential for petroleum liquids in the Permian Basin. Typically, evaluations of recovery growth potential have used historical growth factors as their method of assessment. This approach was first developed in the United States during the 1950's when oil field development was constrained by oil demand and accompanying production regulation, when oil prices were low, and when oil drilling and production technology was at best improving incrementally. The method was useful in predicting how oil fields grew and would grow under these conditions in the first 30 years of their productive lives.

Such a method seems wholly inappropriate for projecting how oil fields might grow 40 to 120 years after they began production, under conditions of high oil prices, low to non-existent surplus production capacity, and substantial improvements in oil drilling, completion, and production technology. Thus, the method employed here adapts the play and prospect approach for assessing future discovery potential to the task of assessing recovery growth potential. Instead of play and prospects, the basic units for the assessment are plays and reservoirs.

Plays provide ideal units for evaluating recovery growth potential in mature basins because by definition they are sets of geologically similar reservoirs within a geographically contiguous area. Geologic similarity in play definition is primarily defined by stratigraphy (the reservoir formation) and trapping mechanism. Reservoir depositional environment and lithology, fluid type (oil or gas), and petroleum source are other geologic characteristics frequently used in play definition.

**TABLE 4. THE GIANT OIL FIELDS OF THE PERMIAN BASIN**

Field-Discovery Year	Est. OOIP	Crude Oil EUR		NGL EUR		
		1979	2004	1979	2004	
<b>WORLD CLASS GIANTS</b>						
Wasson Area	-1936	5,485	1,900	2,940	243	368
Slaughter-Levelland	-1936	5,550	1,520	2,380	166	296
Scurry	-1948	2,780	1,331	1,735	337	425
Spraberry Trend	-1949	9,675	569	1,410	280	672
Yates	-1926	4,290	2,000	1,775	14	27
Eunice Area	-1929	4,350	825	1,005	302	386
Goldsmith-Andector	-1934	2,710	818	1,005	196	256
South Sand Belt	-1926	3,670	885	990	87	137
McElroy-Dune	-1926	3,375	676	876	56	65
Vacuum	-1929	1,725	460	745	46	169
Seminole	-1936	1,405	536	784	29	94
Cowden, North	-1930	2,080	451	758	73	96
Cowden, South	-1932	2,120	518	656	40	63
Fullerton Area	-1941	1,510	380	526	115	126
Robertson-Flanagan	-1936	1,575	242	560	17	29
Blinebry-Drinkard	-1936	900	269	347	115	192
Hobbs	-1928	855	309	473	48	65
Artesia-Maljammar	-1923	790	340	466	28	52
Sand Hills	-1930	1,445	239	295	134	215
Howard-Glasscock	-1925	1,421	389	509	*	*
<b>World Class Giant Total</b>		<b>57,391</b>	<b>14,657</b>	<b>20,245</b>	<b>2,326</b>	<b>3,733</b>
<b>LARGE NATIONAL GIANTS</b>						
Salt Creek	-1950	650	248	416	18	57
Penwell-Waddell	-1926	1,355	352	419	40	47
Keystone	-1929	1,060	327	358	73	104
Dora Roberts-Virey						
Headlee	-1953	500	142	151	240	275
Means-McFarland	-1934	780	269	396	9	16
TXL Area	-1944	1,135	262	306	46	67
Dollarhide	-1945	635	224	317	16	33
Cogdell	-1949	562	265	300	40	44
Black 31 & East	-1945	361	225	243	49	98
Midland Farms	-1944	720	233	283	30	41
Pegasus	-1949	477	138	154	73	114
Empire:Abo	-1957	383	163	237	8	28
Anton-Irish	-1944	628	178	256	0	0
Prentice Area	-1945	630	163	240	8	10
Welch	-1942	637	145	204	4	7
<b>Large National Giants Total</b>		<b>9,838</b>	<b>3,334</b>	<b>4,280</b>	<b>654</b>	<b>941</b>
<b>Small National Giants</b>						
<b>Total</b>		<b>7,710</b>	<b>1,997</b>	<b>2,662</b>	<b>450</b>	<b>886</b>
<b>ALL GIANTS TOTAL</b>		<b>75,003</b>	<b>19,988</b>	<b>27,187</b>	<b>3,430</b>	<b>5,560</b>

Source: NRG Associates, The Significant Oil and Gas Fields of the United States Database

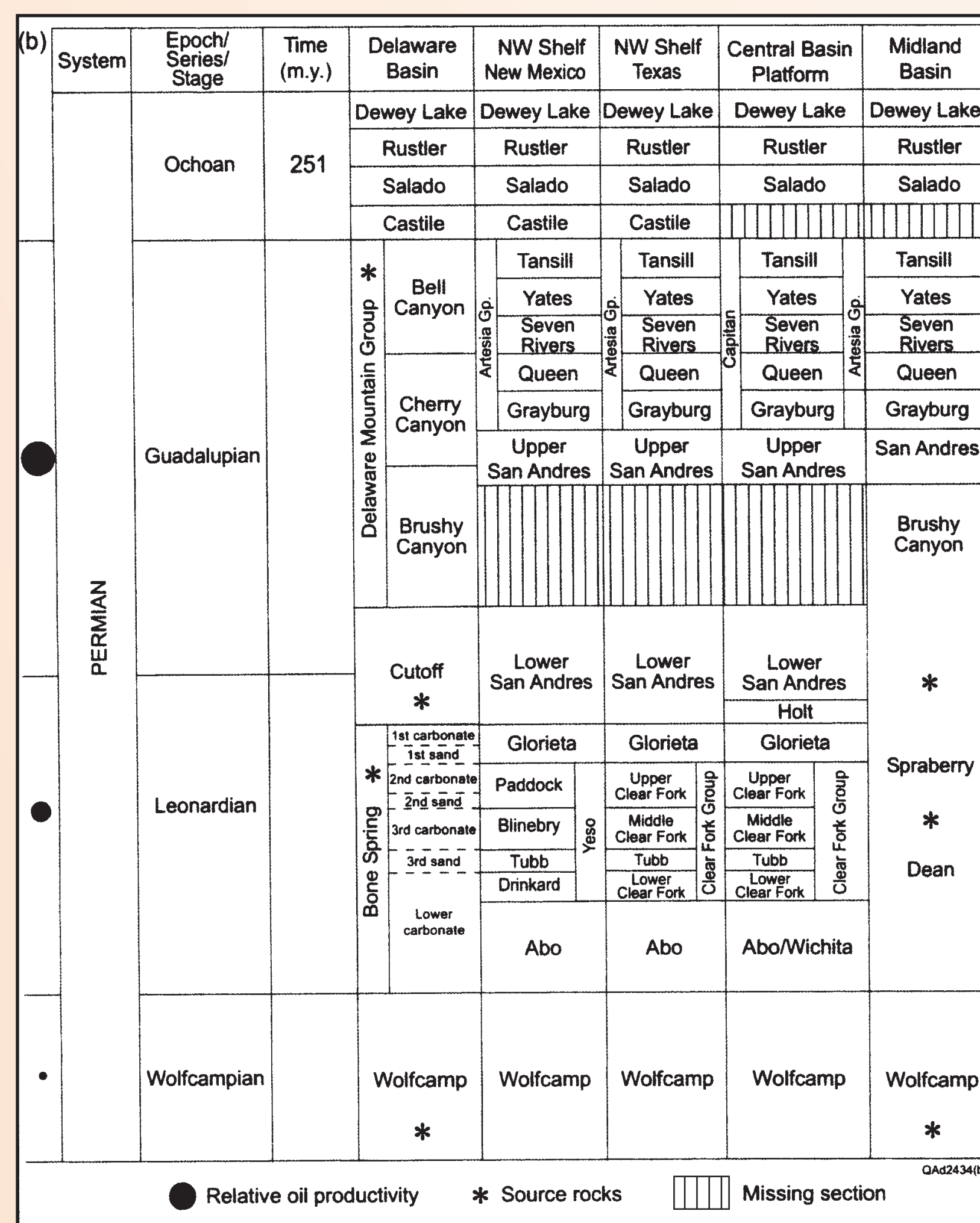


Figure 2A. Stratigraphic Nomenclature for the Permian Section in the Permian Basin.

Source: Dutton and others (2005). Used by permission.

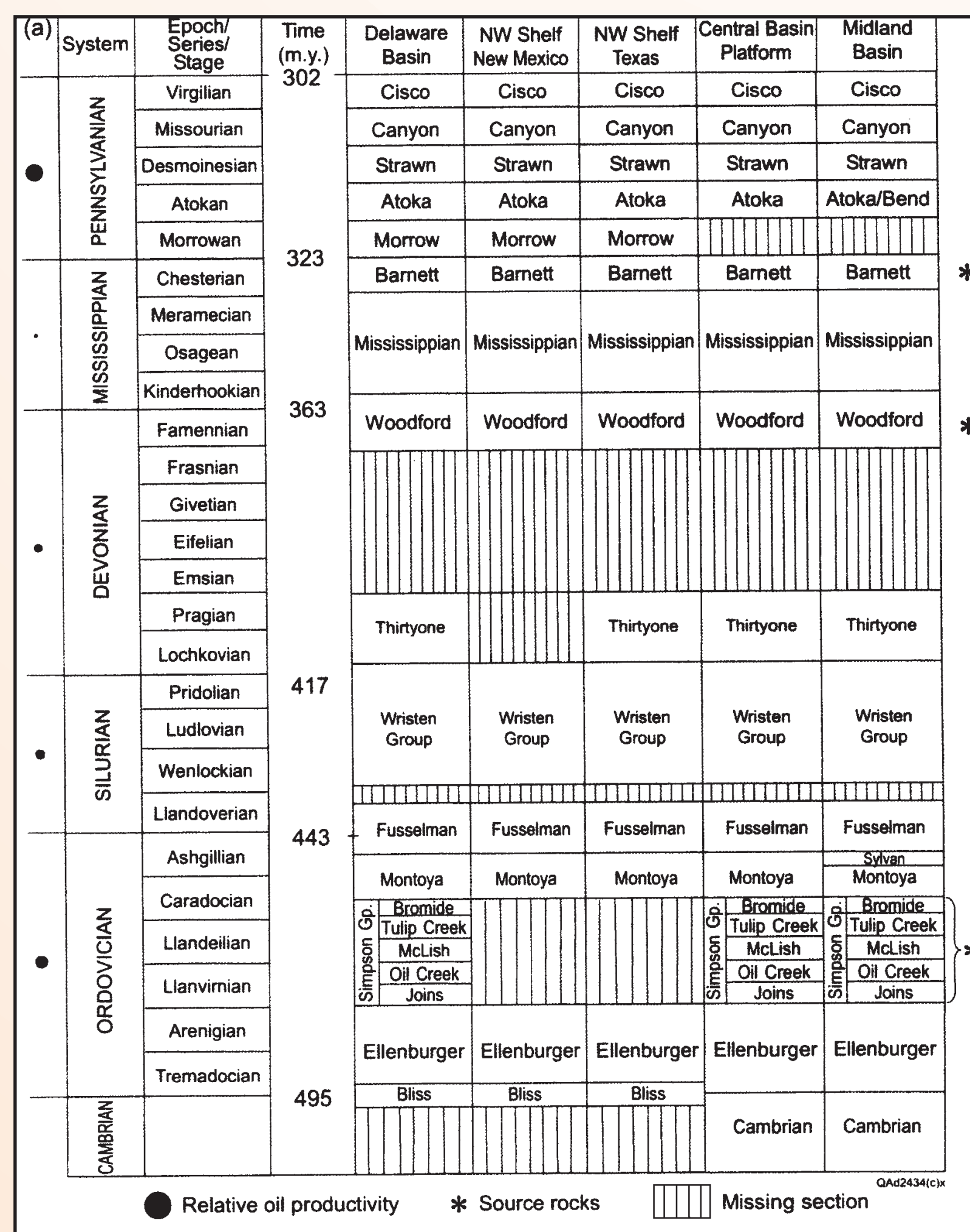


Figure 2B. Stratigraphic Nomenclature for the Cambrian through Pennsylvanian Section of the Permian Basin.

Source: Dutton and others (2005). Used by permission.





## Leonardian Summary

The other four Leonardian plays account for little more than 3% of Leonardian potential. But two – the Central Basin Platform Wichita-Albany and the Northwest Shelf Bone Spring - have grown rapidly in the past 25 years because of extensions and new discoveries. They are thus assigned some modest future growth potential.

To 2050, total recovery growth potential for the Leonardian plays is estimated at 1,550 to 5,000 million barrels (246-795 x 10<sup>6</sup> m<sup>3</sup>) of petroleum liquids. If realized, this would increase known recovery in the Leonardian 20.7 to 66.8%. As the range indicates, Leonardian growth potential has the greatest uncertainty of any of the six major stratigraphic units assessed. (Table 6)

## WOLFCAMPIAN

The Wolfcampian series of the Permian system is the smallest of the six major stratigraphic units in the Permian Basin, having a known recovery of only 1027 million barrels (163 x 10<sup>6</sup> m<sup>3</sup>) of petroleum liquids. There are seven Wolfcampian plays. Only one – the Platform/Basin Wolfcamp – even approaches major status.

**Table 6. Summary of Recovery Growth in the Leonardian Plays, 1979-2004**

Play	OOIP (MM bbls)	Oil EUR		2004 Rec.Eff. (%)	NGL EUR		Growth Potential (Crude & NGL) (MM bbls)
		1979	2004		1979	2004	
Midland Basin	c. 12,800	866	1,906	14.9	335	740	750 - 2,875
Spraberry							
Central Basin Platform	c. 6,365	1,287	1,960	30.8	411	609	405 - 1,050
Clearfork							
Eastern Shelf Margin	c.3,175	448	696	21.9	1	3	175 - 425
Leonardian							
Northern Shelf Margin	c.2,275	339	632	27.8	30	43	105 - 310
Clearfork							
Northwest Shelf	c. 1,685	597	36.0	49	565	245	
Margin Abo							
Other Plays (4)	c. 950	65	196	20.6	9	50	30 - 95
Totals	c.27,225	3,490	5,987	22.0	835	1,501	1,550 - 5,000

Source: NRG Associates, The Significant Oil and Gas Fields of the United States Database

### Platform/Basin Wolfcamp

This play consists of Wolfcampian carbonate reservoirs on both the eastern margin of the Central Basin Platform and the western half of the Midland Basin. There are 76 significant reservoirs in the play. This one play could easily be divided into two plays based on depositional environment: platform carbonates on the Central Basin Platform and erosional slope and basin carbonates in the Midland Basin. They are combined here primarily to create at least one play in the Wolfcampian worthy of assessment.

Reservoirs in this play are 7,500-9,500 feet (2,280-2,890 m) deep on the Central Basin Platform and 9,000-10,000 feet (2,735-3,040 m) deep in the Midland Basin. Trapping is both structural and stratigraphic. Reservoir net thickness is 30-120 feet (9-36 m). Reservoir porosity is mediocre to moderate (8-12%). Reservoir permeability is also mediocre to moderate (10-150 md). The crude oil in these reservoirs is medium to light (36-42° API).

This play is the smallest of all the twenty-one evaluated. Known recovery as of 2004 was only 378 million barrels (60 x 10<sup>6</sup> m<sup>3</sup>) of crude oil and 53 million barrels (8.4 x 10<sup>6</sup> m<sup>3</sup>) of NGL.

**Table 7A. Recovery Growth in the Platform/Basin Wolfcamp Play, 1979-2004**

Field	Res Disc. Year	OOIP (MM bbls)	Oil EUR		NGL EUR		Lithology
			1979	2004	1979	2004	
Others (61)	N.A.	c.1,005	257	360	31	50	Carbonate
1980-2004 Disc. (15)	N.A.	c. 115	0	18	0	3	
Totals		c.1,120	257	378	31	53	

Source: NRG Associates, The Significant Oil and Gas Fields of the United States Database

totalling 431 million barrels (68.5 x 10<sup>6</sup> m<sup>3</sup>) of petroleum liquids (Table 7A). There are no large fields in the play. Nearly half of the known resources is concentrated in six fields with 30 to 42 million barrels (4.8 - 6.7 x 10<sup>6</sup> m<sup>3</sup>) each. Most reservoirs in the Central Basin Platform portion were discovered in the 1950's; most reservoirs in the Midland Basin portion were discovered in the past thirty years.

Recent recovery growth has been good; known recovery in pre-1980 discoveries increased 42% from 1979 to 2004. This was the result of extensions to the largest reservoir, better reservoir characterization, and some infill drilling and secondary recovery. Current crude oil recovery efficiency is moderate at 33.8% of the estimated original oil-in-place.

During the next forty years, this growth is likely to continue, albeit at a diminished pace. The recovery growth potential of the play is estimated to be 50-130 million barrels (8-21 x 10<sup>6</sup> m<sup>3</sup>).

### Wolfcampian Summary

Given the small reservoir sizes typical of the Wolfcampian plays, the recovery growth potential is limited (Table 7). Most recent reserve additions in the other Wolfcampian plays came from new reservoir discoveries or extensions to reservoirs discovered in the late 1970's. Growth potential in the other plays as a group is thus likely to be only slightly higher than that in the Platform/Basin Wolfcamp play. Total reserve growth potential of the Wolfcampian is estimated to be only 110-270 million barrels (17.5-43 x 10<sup>6</sup> m<sup>3</sup>).

## PENNSYLVANIAN

The Pennsylvanian system is the second largest oil-producing stratigraphic unit of the Permian Basin, having a known recovery of 7,747 million barrels (1,232 x 10<sup>6</sup> m<sup>3</sup>) of petroleum liquids. There are 25 Pennsylvanian plays in the Permian Basin (including the five Permo-Penn plays). Five of these plays are major - the Horseshoe Atoll Permo-Penn (the third largest oil play in the Permian Basin), the Eastern Shelf Pennsylvanian Reef/Bank, the Tatum Basin Permo-Penn, the Midland Basin Pennsylvanian Slope, and the Ozona-Val Verde Pennsylvanian.

### Horseshoe Atoll Permo-Pennsylvanian

This play consists of Strawn (Middle Pennsylvanian) through Wolfcampian (Lower Permian) carbonate buildups on the Horseshoe Atoll in the northern Midland Basin. There are 81 significant reservoirs in the play.

Reservoirs in this play range from 6,000 to 10,000 feet (1,825 - 3,040 m). Trapping is stratigraphic, consisting of isolated carbonate knolls and pinnacles on an underlying Strawn platform. Reservoir thickness varies substantially from less than 10 feet (3 m) in some of the smaller reservoirs to more than 250 feet (76 m) in the largest ones. Reservoir porosity ranges from mediocre to medium (5-20%). Permeability is also mediocre to average (5-200 md). The crude oil is light (38-45° API).

The Horseshoe Atoll Permo-Pennsylvanian play dominates the Pennsylvanian plays, containing nearly half the known recovery of petroleum liquids in this system. As of 2004, known recovery was 2,975 million barrels (473 x 10<sup>6</sup> m<sup>3</sup>) of crude oil and 622 million barrels (99 x 10<sup>6</sup> m<sup>3</sup>) of NGL, totalling 3,597 million barrels (572 x 10<sup>6</sup> m<sup>3</sup>) of petroleum liquids (Table 8A), 46.4% of Pennsylvanian known recovery. There are eight large and giant fields in the play, including the world-class giant Scurry field (Kelly-Snyder-Diamond M). These eight fields contain 92.8% of the known recovery of petroleum liquids in the play.

All of the large and giant reservoirs were discovered immediately afterwards the initial discoveries in the play in 1948. Nearly all reservoirs in the play with a known recovery exceeding 2 million barrels (0.3 x 10<sup>6</sup> m<sup>3</sup>) were discovered in the following decade. Although a substantial proportion (18.5%) of the significant reservoirs in the play have been discovered since 1979, these very small reservoirs have added less than 0.5% of the play's known recovery.

Recent recovery growth in the Horseshoe Atoll Permo-Pennsylvanian play has been moderate. From 1979 - 2004, 737 million barrels (117 x 10<sup>6</sup> m<sup>3</sup>) of petroleum liquids were added to the reservoirs discovered prior to 1980, an increase of 26.1%. High crude oil recovery efficiencies have already been achieved in all the large and giant reservoirs. Because these eight reservoirs contain nearly all of the known recovery, the overall recovery efficiency of the play is an impressive 53.4% of the estimated original oil-in-place.

This current high recovery efficiency is the major constraint on the recovery growth potential of the play. Future growth is likely to come from extending CO<sub>2</sub> flooding to the medium size reservoirs in the play, optimizing existing CO<sub>2</sub> floods (some of which have only begun in the past decade), and some reservoir downspacing to 40 acres. Recovery growth potential over the next 40 years is estimated to be from 245 to 775 million barrels (39-123 x 10<sup>6</sup> m<sup>3</sup>) of petroleum liquids.

**Table 8A. Recovery Growth in the Horseshoe Atoll Permo-Pennsylvanian Play, 1979-2004**

Field	Res Disc. Year	OOIP (MM bbls)	Oil EUR		NGL EUR		Lithology	Depth Top (feet)	Avg. Net			Post Primary
			1979	2004	1979	2004			Thick	Perm.	Spacing	
Scurry	1948	2,965	1,300	1,697	336	424	Limestone	6,750	220	19.4	40	WF,CO2
Salt Creek	1950	650	248	416	18	57	Limestone	6,200	102	10.5	40, 20	GI,WF,CO2
Cogdell	1949	550	262	297	40	44	Limestone	6,800	108	17.6	40, 80	GI,WF,CO2
Reinecke	1950	168	81	90	23	25	Limestone	6,800	65	200	40	WF,CO2
Wellman	1950	156	87	75	12	13	Carbonate	9,700	260	100	40	WF,CO2
Vealmoor, East	1950	139	62	64	16	19	Limestone	7,400	76	150	80, 40	WF
Adair	1950	110	53	53	4	4	Carbonate	8,500	60	28	80, 40	WF
Good	1949	120	51	50	11	11	Limestone	7,900	123	50	160, 80	WF
Others (58)	N.A.	c.667	215	219	22	24						
1980-2004 Disc. (15)	N.A.	c. 50	0	14	0	1						
Totals		c.5,575	2,359	2,975	482	622						

Source: NRG Associates, The Significant Oil and Gas Fields of the United States Database

### Eastern Shelf Pennsylvanian Reef/Bank Play

This play consists of scattered Pennsylvanian Strawn and Canyon reefs and mounds on the Eastern Shelf. There are 125 significant reservoirs in this play.

Reservoir depths in this play are mostly between 4,500 and 7,000 feet (1,368-2,128 m). Trapping is stratigraphic, consisting of several varieties of limestone buildups. The thickness of these buildups varies substantially, ranging from 10 to more than 150 feet (3-45 m). Porosity is mediocre to average (5-20%). Permeability also varies widely, ranging from low to average (2-150 md). Crude oil produced from this play is light (38 - 48° API).

Although the Eastern Shelf Pennsylvanian Reef/Bank play is the second largest play in the Pennsylvanian system, it is a modest sized major play. Known recovery as of 2004 was 635 million barrels (101 x 10<sup>6</sup> m<sup>3</sup>) of crude oil and 122 million barrels (19 x 10<sup>6</sup> m<sup>3</sup>) of NGL, totalling 757 million barrels (120 x 10<sup>6</sup> m<sup>3</sup>) petroleum liquids (Table 8B). There are only four large reservoirs in the play, a play that is dominated by medium size reservoirs. These four reservoirs provide only 32.9% of the known recovery of the play.

Compared with most major plays in the Permian Basin, this play has a relatively long peak discovery period. Nearly all of the large and medium reservoirs were discovered over a span of three decades from 1940 to 1970. Sixteen significant discoveries (12.8% of the play total) have been made since 1979. These minimally significant discoveries contain only 1.4% of play known recovery.

Recent recovery growth has been comparatively small; known recovery from pre-1980 discoveries only increased by 64 million barrels (10 x 10<sup>6</sup> m<sup>3</sup>) from 1979 to 2004. Neither the large or the smaller reservoirs grew significantly; overall play growth was only 9.4%.

Rather than a lack of future opportunities, this pattern suggests a underdeveloped play. Current recovery efficiencies are moderately low, only 32.8%. Substantial opportunities still exist for waterflooding, CO<sub>2</sub> flooding, and infill drilling. Thus the recovery growth potential for the Eastern Shelf Pennsylvanian Reef/Bank play is estimated to be 125 to 280 million barrels (20-45 x 10<sup>6</sup> m<sup>3</sup>) of petroleum liquids.

**Table 8B. Recovery Growth in the Eastern Shelf Pennsylvanian Reef/Bank Play, 1979-2004**

Field	Res Disc. Year	OOIP (MM bbls)	Oil EUR		NGL EUR		Lithology	Depth Top (feet)	Avg. Net			Post Primary
			1979	2004	1979	2004			Thick	Perm.	Spacing	
Claytonville	1952	135	63	66	12	13	Limestone	5,700	155	10	80	WF,GI
Jameson Area	1946	114	47	49	26	27	Limestone	5,800	71	2.0	80	WF
Round Top	1946	122	50	55	16	17	Limestone	4,750	47	7.1	40	WF
Nena Lucia Area	1955	168	36	40	18	20	Limestone	6,900	55	5.5	80	WF
Others (105)	N.A.	c.1,371	377	416	38	44						
1980-2004 Disc. (16)	N.A.	c. 25	0	9	0	1						
Totals		c.1,935	573	635	110	122						

Source: NRG Associates, The Significant Oil and Gas Fields of the United States Database

### Tatum Basin Permo-Penn

This play consists of Virgilian (Pennsylvanian) and Wolfcampian (Permian) limestone reservoirs in the Tatum Basin (roughly the central part of the Northwest Shelf. The play is designated as a Permo-Pennsylvanian play because the boundary in this area between the two systems is still debatable. There are 94 significant reservoirs in the play.

Reservoirs in this play are between 8,500 to 11,500 feet (2,585 -3,495m) deep. Trapping is predominantly stratigraphic. Reservoir thicknesses range from 10 to 100 feet (3-30 m). Porosity is generally mediocre (5-10%). Permeability varies widely from low to average (1-200 md). The oil is light (38-46° API).

The Tatum Basin Permo-Penn play is one of several marginally major Pennsylvanian plays. Known recovery as of 2004 was 473 million barrels (75 x 10<sup>6</sup> m<sup>3</sup>) of crude oil and 70 million barrels (11 x 10<sup>6</sup> m<sup>3</sup>) of NGL, totalling 543 million barrels (86 x 10<sup>6</sup> m<sup>3</sup>) of petroleum liquids (Table 8C). The small play size reflects a lack of large reservoirs. There are only two major reservoirs in the play; together they have only 30% of play known recovery.

**Table 8C. Recovery Growth in the Tatum Basin Permo-Penn Play, 1979-2004**

Field	Res Disc. Year	OOIP (MM bbls)	Oil EUR		NGL EUR		Lithology	Depth Top (feet)	Avg. Net			Post Primary
			1979	2004	1979	2004			Thick	Perm.	Spacing	
Vada-Inbe	1956	263	68	70	15	15	Limestone	9,650	60	104	160, 80	-----
Bagley & North	1949	c. 210	55	59	16	19	Limestone	8,600	50	N.A.	80, 160	-----
Others (73)	N.A.	c.1,145	276	330	28	36						
1980-2004 Disc. (19)	N.A.	c. 52	0	14	0	*						
Totals		c.1,670	399	473	59	70						

Source: NRG Associates, The Significant Oil and Gas Fields of the United States Database

Discovery of the larger reservoirs in the play occurred primarily from 1950 to 1965. Since 1979, nineteen reservoirs (20% of the play's significant reservoirs) have been discovered. Together, these recent discoveries contributed only 2.6% of the total recovery in the play.

Recent recovery growth has been modest. From 1979 to 2004, known recovery in the pre-1980 discoveries only increased by 71 million barrels (11 x 10<sup>6</sup> m<sup>3</sup>), an increase of only 15.5%. The evidence suggests another relatively underdeveloped play. Well spacing is still relatively high; even waterflooding is rare; the recovery efficiency for crude oil is relatively low at 28.3%.

This low level of development, compared to other Permian Basin plays, suggests substantial opportunities for recovery growth. Downspacing to at least 80 acres and more widespread use of waterflooding should lead to a realization of an estimated recovery growth potential of 140-240 million barrels (22-38 x 10<sup>6</sup> m<sup>3</sup>) of petroleum liquids.

### Midland Basin Pennsylvanian Slope

This play consists of Upper Pennsylvanian (Strawn, Canyon, and Cisco) sandstone reservoirs formed at the base of the Eastern Shelf margin as it prograded into the Midland Basin. Because the present western margin of the Eastern Shelf is of late Permian age, many of these reservoirs underlie the current Eastern Shelf. There are 110 significant reservoirs in this play.

Reservoir depths in the play vary between 4,000 and 8,000 feet (1,215-2,430 m). Trapping is predominantly stratigraphic, encompassing a broad range of depositional facies changes. Net thickness ranges from 5 to 150 feet (2-45 m). Porosity is predominantly of medium quality (10-20%). Reported permeabilities vary from low to good (1-500 md). Like the other Pennsylvanian plays, crude oil in this play is also light (40-48° API).

The Midland Basin Pennsylvanian Slope play is a major play only because of its potential growth. As of 2004, known recovery was only 259 million barrels (41 x 10<sup>6</sup> m<sup>3</sup>) of crude oil and 206 million barrels (33 x 10<sup>6</sup> m<sup>3</sup>) of NGL, a total of 465 million barrels (74 x 10<sup>6</sup> m<sup>3</sup>) of petroleum liquids (Table 8D). There is only one large reservoir in the play, providing 22.4% of play known recovery. Known recovery in the play is concentrated in small reservoirs with 1 to 10 million barrels each.

**Table 8D. Recovery Growth in the Midland Basin Pennsylvanian Slope Play, 1979-2004**

Field	Res Disc. Year	OOIP (MM bbls)	Oil EUR		NGL EUR		Lithology	Depth Top (feet)	Avg. Net			Post Primary
			1979	2004	1979	2004			Thick	Perm.	Spacing	
Conger-Big Salute	1973	c.125	14	22	27	82	Sandstone	7,700	61	1.0	160, 80	WF
Others (91)	N.A.	c.885	177	209	68	100						
1980-2004 Disc. (18)	N.A.	c.130	0	28	0	24						
Totals		c.1,140	191	259	95	206						

Source: NRG Associates, The Significant Oil and Gas Fields of the United States Database

Because of the elusive nature of the traps in this play, its peak discovery period spans the three decades from 1950 through 1979. Not only have 18 significant reservoirs been discovered since 1979; they also provide 11.2% of the current known recovery.

Proportionately, the play has seen decent recovery growth since 1979. Reservoirs discovered prior to 1979 grew 43.7% – by 126 million barrels (20 x 10<sup>6</sup> m<sup>3</sup>) of petroleum liquids. This growth was primarily the result of extensions to reservoirs that were discovered in the 1970's such as Conger-Big Salute, and was concentrated in the deeper, NGL-rich reservoirs. Because of the chaotic nature of reservoir deposition, reservoir compartmentalization is high and crude oil recovery efficiency is low (only an estimated 22.7%).

This pervasive compartmentalization limits recovery growth potential. Some infill drilling appears possible in the thicker reservoirs; waterflooding may be possible in a few more of the larger reservoirs. Recovery growth potential is estimated to be only 30-80 million barrels (5-13 x 10<sup>6</sup> m<sup>3</sup>) of petroleum liquids.

### Ozona - Val Verde Pennsylvanian

This play consists of Upper Pennsylvanian Strawn, Canyon, and Cisco sandstone (with some limestone) reservoirs covering the eastern Ozona Platform and eastern Val Verde Basin. It should be considered as a southern extension of the Midland Basin Pennsylvanian Slope play. There are 80 reservoirs in the play.

Reservoirs in this play are 4,000 to 8,000 feet (1,215-2,430 m) deep. Trapping is both stratigraphic and structural; depositional facies changes and anticlines predominate. Reservoirs are 10 to 200 feet (3-60 m) thick. Porosity is mediocre to moderate (5-15%). This play is regarded as a "tight" sandstone gas play with permeabilities in the microdarcy range. The play is a major gas play with substantial NGLs. The API gravities of reservoir liquids are thus in the condensate range (55-65°).

**Table 8E. Recovery Growth in the Ozona-Val Verde Pennsylvanian Play, 1979-2004**

Field	Res Disc. 
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The Ozona-Val Verde Pennsylvanian play is the only major liquids play in the Permian Basin in which natural gas liquids predominate. Known recovery as of 2004 was only 9 million barrels (1.4 x 10<sup>6</sup> m<sup>3</sup>) of crude oil, but was 403 million barrels (64 x 10<sup>6</sup> m<sup>3</sup>) of NGL (Table 8E). There are only three large reservoirs in the play. Combined, they contained 77.9% of the known recovery in the play.

These three large reservoirs were discovered in the early 1960s. Smaller discoveries have continued steadily since then. From 1980 to 2004, there were 25 significant discoveries in the play, nearly a third of all play discoveries. These small discoveries however provided only 5.1% of current play liquids recovery.

Recent recovery growth in the Ozona-Val Verde Pennsylvanian play has been spectacular. Known recovery of petroleum liquids in pre-1980 discoveries nearly quadrupled from 1979 to 2004, growing from only 103 million barrels (16.4 x 10<sup>6</sup> m<sup>3</sup>) to 391 million barrels (62 x 10<sup>6</sup> m<sup>3</sup>). This growth was essentially the result of extensive infill drilling and better completion and stimulation techniques. Infill drilling should continue, being bolstered both by higher natural gas prices and reduced drilling costs resulting from optimized drilling programs. Completion and stimulation technologies are likely to see incremental improvements also. The recovery growth potential of the Ozona-Val Verde Pennsylvanian Play is thus estimated to be 100 to 300 million barrels (30-90 x 10<sup>6</sup> m<sup>3</sup>) of natural gas liquids.

#### Pennsylvanian Summary

In addition to these five major plays, there are 20 other Pennsylvanian and Permo-Pennsylvanian plays in the Permian Basin. Most are very small with zero to miniscule growth potential. Four, however, show some promise: the Northwest Shelf Middle Pennsylvania Carbonate, the Central Basin Platform Upper/Middle Pennsylvania Limestone, the Western Midland Basin Pennsylvanian, and the Eastern Shelf Strawn. Together these four plays had 1,145 million barrels (182 x 10<sup>6</sup> m<sup>3</sup>) known recovery of petroleum liquids as of 2004. Crude oil recovery efficiencies are low in these four plays, allowing considerable opportunities for improvement. They are thus estimated to have a recovery potential of 130 to 315 million barrels (21-50 x 10<sup>6</sup> m<sup>3</sup>).

Overall, recovery growth potential in the Pennsylvanian plays is substantial. Total potential is estimated to be 770-1,970 million barrels (122-316 x 10<sup>6</sup> m<sup>3</sup>) of petroleum liquids by 2050 (Table 8).

#### SILURO - DEVONIAN

The Siluro-Devonian systems are the third smallest of the six major oil-producing stratigraphic units of the Permian Basin, having a known recovery of 3,295 million barrels (524 x 10<sup>6</sup> m<sup>3</sup>) of petroleum liquids. There are nine Siluro-Devonian plays, two of which are major oil plays. The one major Devonian play is the Central Tobosa Basin Thirty-One play. The one major Silurian play is the Northern Tobosa Basin Wristen Platform play.

#### Central Tobosa Basin Thirty-One (Devonian)

This play consists of Lower Devonian Thirty-One formation carbonates in the central part of the ancestral Tobosa Basin (underlying the Central Basin Platform and southwestern Midland Basin). There are 115 significant reservoirs in this play.

Reservoirs in this play are between 8,000 and 12,500 feet (1,270 to 1,985 m) deep. Trapping is both structural (anticlines) and stratigraphic (erosional truncation). Reservoirs are moderately thick - between 50 and 150 feet (8-24 m). Porosity in these laminated chert and carbonate reservoirs is mediocre to medium (5-20%). Permeability varies from low to medium (1-150 md). Thirty-One formation crude oil is generally light (38-45 ° API).

The Central Tobosa Basin Thirty-One play is the second largest oil play in the Lower Paleozoic, being just behind the Central Basin Platform Ellenburger play. Known recovery as of 2004 was 1,104 million barrels (175 x 10<sup>6</sup> m<sup>3</sup>) of crude oil and 779 million barrels (124 x 10<sup>6</sup> m<sup>3</sup>) of NGL, totalling 1,883 million barrels (299 x 10<sup>6</sup> m<sup>3</sup>) of petroleum liquids (Table 9A). This play is the only major crude oil play in the Permian Basin that also has a substantial proportion (greater than 40%) of its liquid resources as NGL's. There are nine major reservoirs in the play, containing 62.1% of the known recovery of the play.

**Table 9A. Recovery Growth in the Central Tobosa Basin Thirty-One (Devonian) Play, 1979-2004**

Field	Res Disc.		Oil EUR		NGL EUR		Lithology	Avg. Net			Spacing	Post Primary
	Year	OOIP	1979	2004	1979	2004		Top	Thick	Perm.		
	(MM bbls)	(MM bbls)	(MM bbls)	(MM bbls)	(MM bbls)	(MM bbls)	(feet)	(feet)	(md.)	(acres)		
Block 31 & East	1945	340	220	228	48	97	Chert, LS	8,800	100	1.2	40, 80	GI,WF
Dora Roberts-Virey-Headlee	1953	c.50	16	18	224	256	LS,Chert	12,000	145	1.0	40, 160	GI
Dollarhide	1945	216	90	141	6	16	DOL,Chert	8,000	69	38	40	GI,WF,CO2
University Waddell	1949	376	63	76	12	14	Carbonate	9,000	140	8.1	40	GI,WF,CO2
TXL Area	1944	225	60	63	16	19	LS,Chert	8,050	150	50	80	GI,WF
South Sand Belt	1955	*	*	*	50	69	LS,DOL,CH	9,000	60	70	320	-----
Fullerton Area	1944	139	50	59	7	9	DOL,Chert	8,300	75	60	40	WF
Pegasus	1952	c.5	1	2	35	63	Carbonate	12,350	84	0.6	160, 80	GC
Three Bar	1945	94	39	43	11	12	Chert,LS	8,400	95	54	20	GI,WF
Others (96)	N.A.	c.1,690	325	474	147	224						
1980-2004 Disc. (10)	N.A.	c. 55	0	13	0	2						
Totals		c.3,135	864	1,104	556	779						

Source: NRG Associates, The Significant Oil and Gas Fields of the United States Database

The larger reservoirs in the play were all discovered between 1944 and 1956, the peak period of exploration drilling in the Permian Basin. Nearly 9% of all reservoirs in the play have been discovered since 1979. However, these discoveries have added less than 1% to the play's known recovery.

The Central Tobosa Basin Thirty-One play has enjoyed moderate recent growth. Known recovery in the reservoirs discovered prior to 1980 increased by 31.5% from 1979 to 2004, adding 448 million barrels (71 x 10<sup>6</sup> m<sup>3</sup>). Several factors contributed to this increase - infill drilling and both secondary and enhanced recovery projects. By 2004 crude oil recovery efficiency had reached 35.2% (though it is substantially higher in the large giant reservoirs than it is in the smaller reservoirs).

Moderate recovery growth is likely to continue over the next forty years. Because recovery efficiencies in a few of the large reservoirs are quite high (exceeding 60%), future growth will be disproportionately concentrated in smaller reservoirs. Factors contributing to future growth include broader use of CO<sub>2</sub> injection, continued infill drilling, and some horizontal drilling. Recovery growth potential is estimated to be 220-575 million barrels (35-91 x 10<sup>6</sup> m<sup>3</sup>).

#### Northern Tobosa Basin Wristen Platform

This play consists of Upper and Middle Silurian Wristen carbonate reservoirs in the northern half of the ancestral Tobosa Basin (now underlying the northern third of the Central Basin Platform, the northwest Midland Basin, and the eastern half of the Northwest Shelf). There are 116 significant reservoirs in this play.

Reservoirs in this play are between 9,000 and 13,000 feet (2,735 - 3,950 m) deep. Trapping is predominantly structural. Reservoir thickness varies between 10 and 250 feet (3-76 m). Porosity is generally mediocre (4-12%). Permeability is mostly low to average (5-150 md). Crude oil in Wristen reservoirs is light (38-48 ° API).

The Northern Tobosa Basin Wristen Platform play falls just short of the billion barrel mark. Known recovery as of 2004 was 916 million barrels (146 x 10<sup>6</sup> m<sup>3</sup>) of crude oil and 21 million barrels (3 x 10<sup>6</sup> m<sup>3</sup>) of NGL, totalling 937 million barrels (149 x 10<sup>6</sup> m<sup>3</sup>) of petroleum liquids (Table 9B). Although there are five large reservoirs in the play, most only minimally meet that category. Thus the large reservoirs account for only 39.2% of the play's known recovery.

**Table 9B. Recovery Growth in the Northern Tobosa Basin Wristen (Silurian) Platform Play, 1979-2004**

Field	Res Disc.		Oil EUR		NGL EUR		Lithology	Avg. Net			Spacing	Post Primary
	Year	OOIP	1979	2004	1979	2004		Top	Thick	Perm.		
	(MM bbls)	(MM bbls)	(MM bbls)	(MM bbls)	(MM bbls)	(MM bbls)	(feet)	(feet)	(md.)	(acres)		
Denton	1949	371	96	105	10	11	Dolomite	11,250	295	9.6	40	-----
Russell, North	1948	174	79	85	*	*	Carbonate	11,100	75	64.4	80, 160	-----
Gladiola	1950	c. 115	52	53	*	*	Dolomite	11,600	150	N.A.	40	-----
Magutex	1952	95	44	52	1	1	Carbonate	12,500	84	83	160, 320	WF
Hutex	1953	100	44	51	0	0	Carbonate	12,500	152	56	160	-----
Others (91)	N.A.	c.1,195	447	537	7	9						
1980-2004 Disc. (20)	N.A.	c. 110	0	33	0	*						
Totals		c.2,160	762	916	18	21						

Source: NRG Associates, The Significant Oil and Gas Fields of the United States Database

Most of the larger reservoirs in the play were discovered from 1948 to 1958, the period when the number of significant discoveries in the Permian Basin reached their peak. More than 17% of the reservoirs of the play have been discovered since 1979. Yet these small discoveries provide only 3.5% of the play's known recovery.

Recent recovery growth in the Northern Tobosa Basin Wristen Platform play has been relatively low. Known recovery in reservoirs discovered prior to 1980 increased by only 16% from 1979 to 2004 - 124 million barrels (20 x 10<sup>6</sup> m<sup>3</sup>). This is partially attributable to the fact that Wristen reservoirs typically have strong water drives and thus achieve high primary recovery rates. Despite a relative lack of post-primary recovery methods, current indicated recovery efficiencies are quite high at 42.4% of the estimated original oil-in-place.

The high current recovery efficiency suggests only modest potential for future recovery growth. The natural water drive may be augmented in some cases by waterflooding. Some infill and horizontal drilling also appears feasible. Recovery growth potential is thus only 90-270 million barrels (27-82 x 10<sup>6</sup> m<sup>3</sup>).

#### Siluro-Devonian Summary

Recovery growth potential in the Siluro-Devonian is not limited to the two major plays. Three Fusselman (Lower Silurian) plays offer some modest opportunities from infill drilling and more widespread waterflooding (Table 9). Total reserve growth potential in the Siluro-Devonian plays is estimated to be 335-905 million barrels (53-144 x 10<sup>6</sup> m<sup>3</sup>) of petroleum liquids.

**Table 8. Summary of Recovery Growth in the Pennsylvanian Plays, 1979-2004**

Play	OOIP	Oil EUR		2004 Rec.Eff (%)	NGL EUR		Growth Potential (Crude & NGL) (MM bbls)
		1979	2004		1979	2004	
Horseshoe Atoll Permo-Penn	c. 5,575	2,359	2,975	53.4	482	622	245-775
Eastern Shelf Penn Reef/Bank	c. 1,935	573	635	32.8	110	122	125-280
Tatum Basin Permo-Penn	c. 1,670	399	473	28.3	59	70	140-240
Midland Basin Penn Slope	c. 1,140	191	259	22.7	95	206	30-80
Ozona-Val Verde Pennsylvanian	c. 35	5	9	25.7	97	403	100-300
Other Permo-Penn (3)	c. 500	14	104	20.8	36	152	30-90
Other Pennsylvanian (17)	c. 4,730	1,084	1,444	30.5	159	273	100-225
Totals	c.15,585	4,625	5,899	37.9	1,038	1,848	770-1,990

Source: NRG Associates, The Significant Oil and Gas Fields of the United States Database

#### CAMBRO-ORDOVICIAN

The Cambro-Ordovician systems are the second smallest of the six major stratigraphic units of the Permian Basin, having a known recovery of 2,295 million barrels (365 x 10<sup>6</sup> m<sup>3</sup>) of petroleum liquids. There are eleven Cambro-Ordovician plays, only two of which have more than 100 million barrels (16 x 10<sup>6</sup> m<sup>3</sup>) known recovery of petroleum liquids. (Two are major gas plays.) One of these - the Central Basin Platform Ellenburger - is the seventh largest oil play in the Permian Basin and the only major oil play in the Cambro-Ordovician.

#### Central Basin Platform Ellenburger

This play consists of Lower Ordovician Ellenburger group carbonate reservoirs underlying most of the Central Basin Platform and the western flank of the Midland Basin. There are 142 significant reservoirs in this play.

Reservoirs in this play are 8,500 to 13,000 feet (1,350-2,065) deep. The shallower reservoirs underlie the Central Basin Platform; the deeper reservoirs are in the Midland Basin. Trapping is predominantly structural - anticlines and faulted anticlines. Reservoirs are moderately thick; most of the larger reservoirs are 100-300 feet (30-80 m) thick. Net thickness are however uncertain; because the Ellenburger is predominantly a low energy, mud-rich facies, matrix porosities are low (mostly 2-5%), a level below what is typically considered the minimum porosity cut off in most reservoirs. Secondary porosity, both from fractures and vugs, dominates porosity in this play. Consequently, permeability ranges from low to excellent (1-1000 md). Ellenburger crude oil is light (40-50 ° API).

**Table 10A. Recovery Growth in the Central Basin Platform Ellenburger (Ordovician) Play, 1979-2004**

Field	Res Disc.		Oil EUR		NGL EUR		Lithology	Depth	Avg. Net			Spacing	Post Primary
	Year	OOIP	1979	2004	1979	2004			Top	Thick	Perm.		
	(MM bbls)	(MM bbls)	(MM bbls)	(MM bbls)	(MM bbls)	(MM bbls)	(feet)	(feet)	(md.)	(acres)			
Goldsmith-Andector	1946	395	175	183	10	10	Dolomite	9,500	188	2000	160, 80	WF,NI	
Keystone	1943	280	145	150	21	37	Dolomite/SS	9,500	325	100	160,80	GI, WF	
TXL Area	1945	262	129	130	9	10	Carbonate	9,600	120	39	40	-----	
Dora Roberts-Virey Headlee	1953	238	115	121	13	15	Carbonate	9,600	175	211	320	GI,WF	
Pegasus	1949	216	94	98	31	36	Dolomite	12,500	250	8.7	320, 160	WF, GI	
Midland Farms Area	1952	126	69	69	8	9	Dolomite	12,600	135	9	320	WF	
Emma-Triple N.	1952	200	54	55	3	3	Carbonate	13,000	91	83	160	-----	
Penwell-Waddell	1946	98	45	47	3	3	Dolomite	8,800	170	300	80, 160	-----	
Others	N.A.	c.1,945	711	823	77	87							
1980-2004 Disc.	N.A.	c. 90	0	20	0	2							
Totals		c.3,850	1,537	1,696	175	212							

Source: NRG Associates, The Significant Oil and Gas Fields of the United States Database

This play is the largest play in the Lower Paleozoic. Known recovery as of 2004 was 1,696 million barrels (270 x 10<sup>6</sup> m<sup>3</sup>) of crude oil and 212 million barrels (34 x 10<sup>6</sup> m<sup>3</sup>) of NGL, totalling 1,908 million barrels (303 x 10<sup>6</sup> m<sup>3</sup>) of petroleum liquids (Table 10A). There are eight large reservoirs in the play, containing just over half (51.2%) of the petroleum liquids in the play.

The larger reservoirs in the play (those with a known recovery of 10 million barrels -1.6 x 10<sup>6</sup> m<sup>3</sup>) were predominantly discovered from the early 1940's to the mid-1950's. Nearly 10% of the reservoirs in the play have been discovered since 1979; however their contribution to known recovery in the play barely exceeds 1%.

Recent recovery growth has been modest; known recovery in pre-1980 discoveries increased only 10% from 1979-2004. None of the large reservoirs grew significantly, primarily because recovery efficiencies in those reservoirs were already high at 45.7% in 1979.

Given the substantial thickness of Ellenburger reservoirs, the extensive fracturing and karstification within them, and the wide current well spacing, the best opportunities for recovery growth will likely come from drilling multi-lateral wells. Recovery growth potential is estimated to be 145 to 430 million barrels (23-68 x 10<sup>6</sup> m<sup>3</sup>).

#### Cambro - Ordovician Summary

Outside of the predominant Central Basin Platform Ellenburger play, recovery growth potential in the Cambro-Ordovician is limited by small play sizes (Table 10). Only the one Simpson play and the other Ellenburger plays have any potential of note. Total reserve growth potential of the Cambro-Ordovician is estimated to be only 185 to 540 million barrels (29-86 x 10<sup>6</sup> m<sup>3</sup>) of petroleum liquids.

#### SUMMARY

The Permian Basin provides a textbook example of a highly mature basin undergoing major life extension. The continuing contribution of this major basin to national and world oil production is not the result of new discoveries. Only 2.2% of the known recovery of petroleum liquids in the Permian Basin are in fields discovered since 1979. The continuing importance of the Permian Basin is the result of continuing recovery growth in older fields, mostly in giant and large fields discovered more than 50 years ago.

This recovery growth should continue through 2050. The play-by-play assessments summarized in this poster add up to a potential between 6,450 and 17,230 million barrels (1,025 - 2,740 x 10<sup>6</sup> m<sup>3</sup>) of petroleum liquids (Table 11). Such an increase would raise ultimate recovery in the Permian Basin to 51 - 63 billion barrels (c.8-10 bcm).

Given an average rate of 500 million barrels (c.80 x 10<sup>6</sup> m<sup>3</sup>) of reserve additions over the past twenty-five years, this potential appears to be highly achievable. At the high confidence level, it implies average annual reserve additions of 140 million barrels (22 x 10<sup>6</sup> m<sup>3</sup>). At the low confidence level, it implies average annual additions of 375 million barrels (60 x 10<sup>6</sup> m<sup>3</sup>); only 75% of the recent average. By comparison, the amount of petroleum liquids added to reserves in 2005 was 915 million barrels (145 x 10<sup>6</sup> m<sup>3</sup>), 14.2% of the high confidence estimate and 5.3% of the low confidence estimate. This immediate response to higher prices suggests that the potential of the Permian Basin could be even greater than that shown here.

The original oil-in-place as of 2004 in significant reservoirs in the six major stratigraphic intervals in the Permian Basin was c.114.96 billion barrels (18.28 x 10<sup>6</sup> m<sup>3</sup>). The basin total - which adds the oil-in-place associated with the 641 million barrels (102 x 10<sup>6</sup> m<sup>3</sup>) in Ochoan and Mississippian reservoirs and very small fields and reservoirs to this amount - is approximately 118 billion barrels (18.76 x 10<sup>6</sup> m<sup>3</sup>) - of original oil-in-place.

At this level of oil-in-place, current recovery efficiency in the Permian Basin is only 31.6%. Future crude oil growth only (excluding NGL growth) would increase ultimate crude oil recovery to 42.3 - 50.7 billion barrels (6.73 - 8.06 x 10<sup>6</sup> m<sup>3</sup>). This growth would increase crude oil recovery efficiency in the Permian Basin to 35.9 - 43.0%. Despite the intensive effort required to achieve these levels of recovery efficiency, they remain comparatively low because of the pervasive low permeability in nearly all of the basin's major plays.

The current estimate of original oil-in-place of 118 billion barrels (18.76 x 10<sup>6</sup> m<sup>3</sup>) could be significantly higher. As indicated in the preceding discussion of the Midland Basin Spraberry play, reported estimates of original oil-in-place for the play were inconsistent with reported net thickness for reservoirs in the play. This poster used the reported oil-in-place numbers and adjusted the net thicknesses listed in Table 6A to be consistent with them. If we had used reported net thicknesses and revised the oil-in-place numbers to be consistent with these thicknesses, the revisions to oil-in-place in just this one play would increase total Permian Basin oil-in-place to 135-155 billion barrels. (21.46 - 24.64 x 10<sup>6</sup> m<sup>3</sup>). This revision would reduce current recovery efficiency to only 24.1 - 27.6% and reduce estimated ultimate recovery efficiency to 31.3 - 37.6% (at the lower estimate of potential) and 27.3 - 32.7% (at the higher estimate of potential). Resolving this uncertainty and increasing oil recovery in the Midland Basin Spraberry play are thus the primary keys to attaining higher oil recovery in the Permian Basin.

**Table 11. The Recovery Growth Potential of the Permian Basin to 2050**

	2004 Known Recovery			Growth Potential Crude and NGL (MM bbls)	
	OOIP (MM bbls)	Oil (MM bbls)	NGL Total (MM bbls)		
Guadalupian	c. 57,400	19,595	2,302	21,897	3,500 - 8,525
Leonardian	c. 27,225	5,987	1,501	7,488	1,550 - 5,000
Wolfcampian	c. 2,845	809	218	1,027	110 - 270