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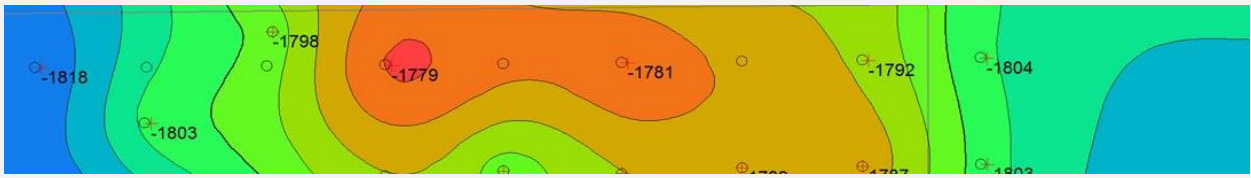

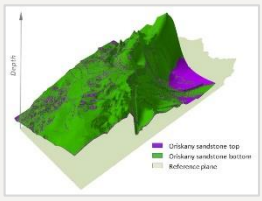

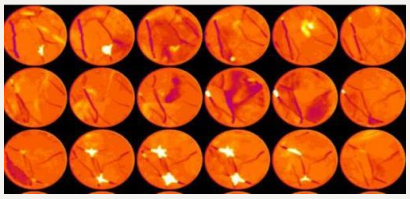

An Eight-County Appraisal of the San Andres Residual Oil Zone (ROZ) "Fairway" of the Permian Basin

September 1, 2020
DOE/NETL-2020/2629

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An Eight-County Appraisal of the San Andres Residual Oil Zone (ROZ) "Fairway" of the Permian Basin

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This report was prepared by Mission Execution and Strategic Analysis (MESA) for the U.S. DOE NETL. This work was completed under DOE NETL Contract Number DE-FE0025912. This work was performed under MESA Activity 205.003.

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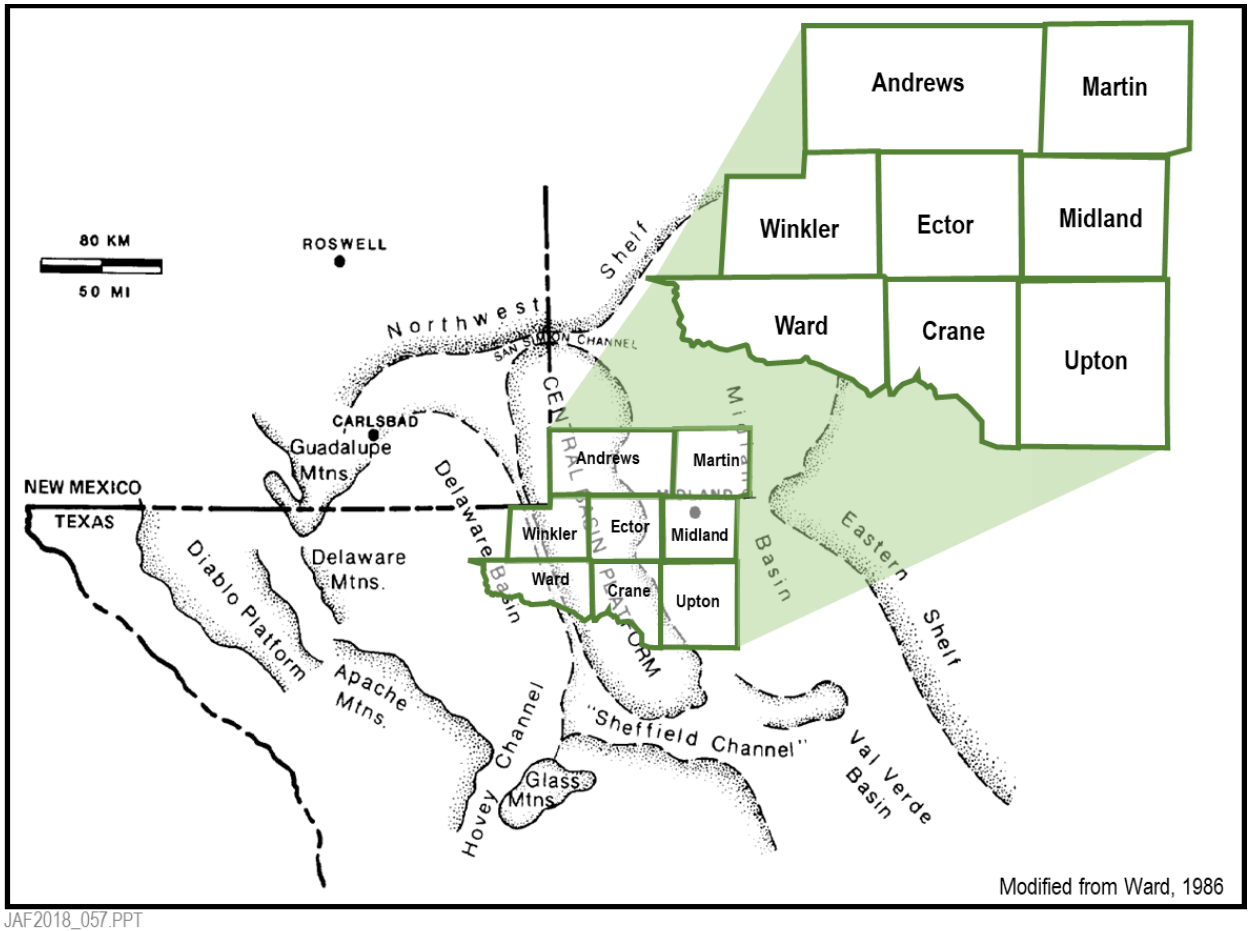
ACRONYMS AND ABBREVIATIONS

ARI	Advanced Resources International, Inc.
bbl	Barrel
B	Billion
Bbls/Acre	Barrels per acre
Bbls/AF	Barrels per acre foot
Bcf	Billion cubic feet
CBP	Central Basin Platform
CO_2	Carbon dioxide
DOE	Department of Energy
EIA	Energy Information Administration
EOR	Enhanced oil recovery
FE	Office of Fossil Energy
ft	Feet
FVF	Formation volume of factor
g/cc	Grams per cubic centimeter
GLSAU	Goldsmith-Landreth San Andres Unit
HCPV	Hydrocarbon pore volume
Mcf	Thousand cubic feet
MESA	Mission Execution and Strategic Analysis
MM	Million
MPZ	Main pay zone
mt	Metric ton
NETL	National Energy Technology Laboratory
O&M	Operation and maintenance
OIP	Oil in-place
PEF	Photoelectric absorption
ROZ	Residual oil zone
RPSEA	Research Partnership to Secure Energy for America
Tcf	Trillion cubic feet
U.S.	United States
UTPB	University of Texas Permian Basin
WACC	After tax weighted average cost of capital
WAG	Water-alternating-gas
WTI	West Texas Intermediate
μ-sec/ft	Microsecond per foot

EXECUTIVE SUMMARY

This report addresses the eight-county San Andres residual oil zone (ROZ) "fairway" resource within the West Texas portion of the Permian Basin—Andrews, Martin, Winkler, Ector, and Midland, and Ward, Crane, and Upton, known collectively as the three Southern Tier counties (Exhibit ES-1). In this report, the term "ROZ fairway" refers to the portion of the ROZ where there is no overlying oil field. The ROZ under a conventional oil field is not included in the assessment.

Exhibit ES-1. San Andres ROZ fairways: eight-county area



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This eight-county San Andres ROZ fairway resource study was undertaken to address five fundamental questions:

1. *What is the size and distribution of the in-place San Andres ROZ fairway oil resource available for CO_2 enhanced oil recovery (EOR) and CO_2 storage?*

The San Andres ROZ fairway resources in the eight counties[a] of the Permian Basin, West Texas hold 71.5 billion barrels of oil in-place (OIP). Much of this resource is higher quality (porosity greater than 8 percent and oil saturation greater than 25 percent), offering promise for commercially viable development (Exhibit ES-2).

Exhibit ES-2. San Andres ROZ fairway in-place resources: eight-county area

County	In-Place Resources		
	Total	Higher Quality	Lower Quality
	B bbl	B bbl	B bbl
Andrews	33.5	28.2	5.3
Martin	6.1	4.3	1.7
Winkler	8.5	7.2	1.3
Ector	6.3	5.0	1.3
Southern Tier	17.1	7.6	9.5
Total San Andres ROZ	71.5	52.3	19.2

Note: Totals may not add due to rounding.

2. *How much of this in-place San Andres ROZ fairway oil resource can be mobilized and technically produced using CO_2 EOR?*

The application of miscible CO_2 EOR enables 22 billion barrels (about 31 percent) of the San Andres ROZ fairway oil in-place (OIP) to become technically recoverable (Exhibit ES-3).

Exhibit ES-3. San Andres ROZ fairway technically recoverable resources: eight-county area

County	Technically Recoverable Resources	
	B bbl	% OIP
Andrews	10.1	30%
Martin	1.8	30%
Winkler	2.7	31%
Ector	1.9	30%
Southern Tier	5.5	32%
Total	**22.0**	**31%**

Note: Totals may not add due to rounding.

[a] The ROZ resource in Midland County is relatively thin and within the Grayburg formation. Therefore, it is not included further in this study and will not appear in the tables.

3. *How much CO_2 can be stored by developing the San Andres ROZ fairway resource in this eight-county area?*

Major volumes, 12.1 billion metric tons (229 Tcf), of primarily anthropogenic CO_2 will be needed to develop the San Andres ROZ fairway resource (Exhibit ES-4). At the completion of the CO_2 flood, essentially all of the purchased CO_2 will be stored in the San Andres ROZ fairway interval. During the operation of the CO_2 flood, the produced CO_2 is re-injected.

Exhibit ES-4. Volume of purchased CO_2 necessary for developing the San Andres ROZ fairway resource: eight-county area

County	Purchased			
	CO_2 Injection		CO_2/Oil Recovery Ratio	
	Tcf	B mt	Mcf/bbl	mt/bbl
Andrews	92	4.9	9.1	0.48
Martin	21	1.1	11.5	0.60
Winkler	28	1.5	10.6	0.56
Ector	21	1.1	11.3	0.60
Southern Tier	67	3.5	12.2	0.64
Total	**229**	**12.1**	**10.4**	**0.55**

Considerably more CO_2 can be stored in the San Andres fairway resource, 0.55 metric tons per barrel of oil produced, than the 0.4 metric tons of CO_2 per barrel in the oil recovered from the San Andres ROZ fairway resource after the oil is combusted.[b]

4. *What portion of the San Andres ROZ fairway resource can be economically developed while providing by-product storage of CO_2?*

A significant portion of the San Andres ROZ fairway resource, equal to 15.5 billion barrels, is commercially viable at an oil price of $75 per barrel, a CO_2 cost of $28.35/metric tons ($1.50/Mcf), and a minimum financial hurdle rate of a 10 percent rate of return after state and federal taxes. Producing this oil with CO_2 EOR will provide geologically secure space for 6.6 billion metric tons (126 Tcf) of by-product storage of CO_2 (Exhibit ES-5). This assumes essentially all the purchased CO_2 is stored.

[b] Note that this is a marginal, rather than a full life-cycle, analysis of CO_2 emissions associated with CO_2 EOR. It is provided to show the magnitude of the difference in carbon-intensity between conventionally produced and CO_2 EOR produced crude oil. Both conventional oil production and CO_2 EOR use additional energy, with their associated CO_2 emissions, for drilling wells, injecting and producing fluids, and conducting other oil field activities.

Exhibit ES-5. Commercially viable oil recovery with by-product CO_2 storage: San Andres ROZ fairway resource, eight-county area

County	Oil Recovery (B bbl)	Purchased CO_2		Purchased CO_2/Oil Recovery Ratio	
		Tcf	B mt	Mcf/bbl	mt/bbl
Andrews	8.8	68	3.6	7.8	0.41
Martin	1.5	12	0.6	7.5	0.40
Winkler	2.3	21	1.1	9.0	0.48
Ector	1.0	7	0.4	7.4	0.39
Southern Tier	1.9	18	0.9	9.2	0.49
Total	**15.5**	**126**	**6.6**	**8.1**	**0.43**

5. *What value could the uneconomic portion of the San Andres ROZ fairway resource provide?*

While the remaining portion of the San Andres ROZ fairway resource in this eight-county area is not commercially viable (at the above oil price and CO_2 costs), this portion of the resource offers geologically viable potential for storing 5.5 billion metric tons (103 Tcf) of CO_2, while providing 6.4 billion barrels of by-product oil recovery (Exhibit ES-6). This assumes essentially all the purchased CO_2 is stored.

Exhibit ES-6. Geologically viable storage of CO_2 with by-product oil recovery: San Andres ROZ fairway resource, eight-county area

County	Purchased CO_2		By-Product Oil Recovery (B bbl)	Purchased CO_2/Oil Recovery Ratio	
	Tcf	B mt		Mcf/bbl	mt/bbl
Andrews	24	1.3	1.3	18.1	0.96
Martin	9	0.5	0.3	32.1	1.70
Winkler	7	0.4	0.4	20.5	1.09
Ector	14	0.7	0.9	15.5	0.82
Southern Tier	49	2.6	3.5	13.8	0.73
Total	**103**	**5.5**	**6.4**	**16.1**	**0.86**

The above assessment of oil recovery and CO_2 storage capacity offered by the San Andres ROZ fairway in the eight-county area has been conducted assuming the use of currently available CO_2 EOR technology. Use of "Next Generation" CO_2 EOR technology would enable significantly more of this resource to become commercially viable and would also enable more CO_2 to be geologically stored.

* * * * *

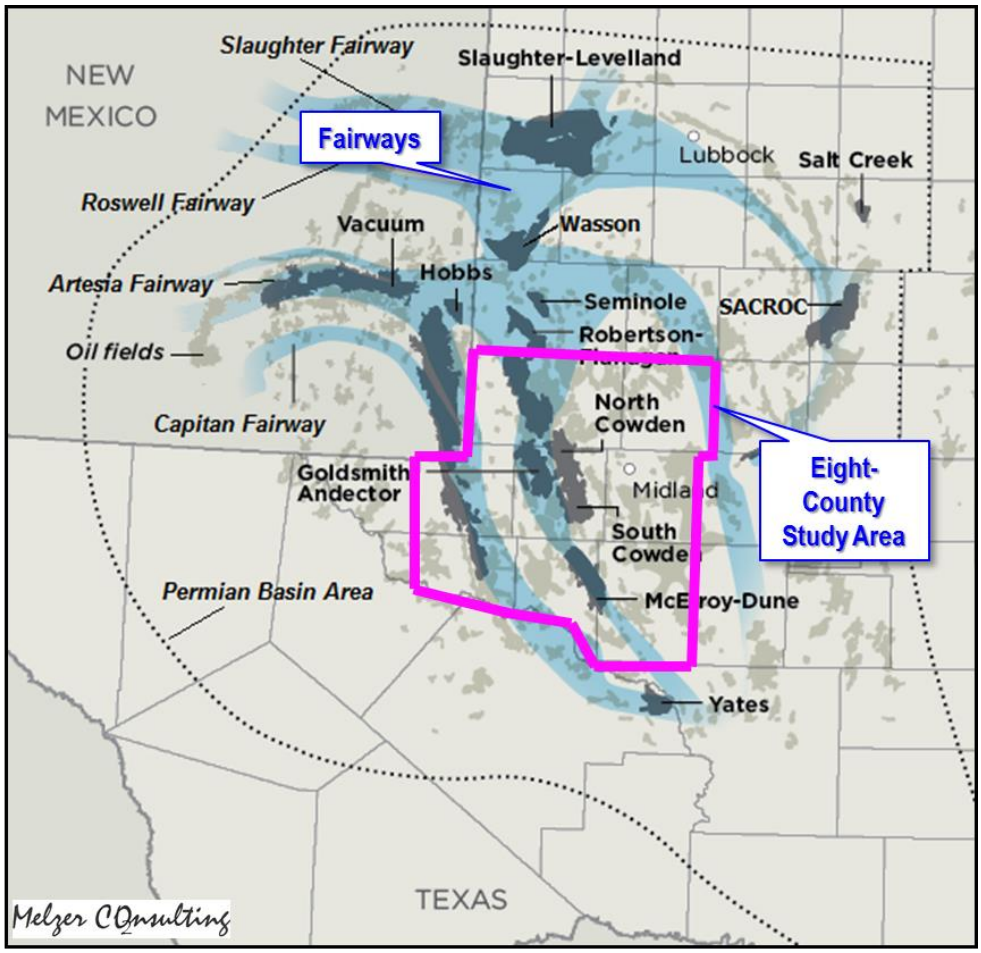
This study draws significantly on prior geological and log analyses performed by Advanced Resources International, Inc. (ARI), in partnership with the University of Texas of the Permian Basin (Dr. Robert Trentham) and Melzer Consulting (Mr. Steve Melzer). This work was sponsored by the Research Partnership to Secure Energy for America (RPSEA) and the United States (U.S.) Department of Energy (DOE) National Energy Technology Laboratory (NETL).

1 THE EIGHT-COUNTY SAN ANDRES RESIDUAL OIL ZONE FAIRWAY STUDY AREA

1.1 INTRODUCTION

This San Andres Residual Oil Zone (ROZ) "fairway" resource study addresses an eight-county area within the West Texas portion of the Permian Basin—Andrews, Martin, Winkler, Ector, and Midland, and Ward, Crane, and Upton, known collectively as the three Southern Tier counties (Exhibit 1-1). This eight-county ROZ study incorporates the Artesia and Capitan ROZ fairways in the southern portion of the Permian Basin.

Exhibit 1-1. San Andres ROZ fairways of the Permian Basin West Texas



The Artesia ROZ Fairway aligns with the Lower and Middle San Andres shelf margins of the Central Basin Platform (CBP). The Capitan ROZ Fairway follows the western margins of the San Andres shelf, where porous dolomite grain-stones and packstones of middle and outer shelf facies are replaced by supratidal evaporites, tidal mud flats, and fine-grained clastic deposits of the interior shelf.

A series of major oil fields, Cowden (North and South), Foster, Fullerton, and Goldsmith, among others, are located within these eight counties. The areas underneath the structural closure of these oil fields have been excluded from the San Andres ROZ fairway resource study. An initial estimate for the volumes of San Andres ROZ resources below existing Permian Basin oil fields is available in a separate report prepared by Advanced Resources International (ARI). [2]

The ROZ resource in the San Andres Formation in the study area represents the bypassed oil in a huge paleo-oil reservoir that was swept by a natural waterflood during the Tertiary period. Establishing the size and economic viability of oil recovery from this ROZ fairway resource with CO_2 enhanced oil recovery (EOR) is a primary purpose of this study. Equally important is establishing the size of the opportunity for geologic storage of CO_2 with CO_2 EOR.

1.2 THE PERMIAN BASIN

1.2.1 Geologic Setting

The Permian Basin, located in West Texas and Southeast New Mexico, contains one of the world's thickest deposits of sediments from the Permian period. It encompasses a massive area, 250 miles east to west and 300 miles north to south.

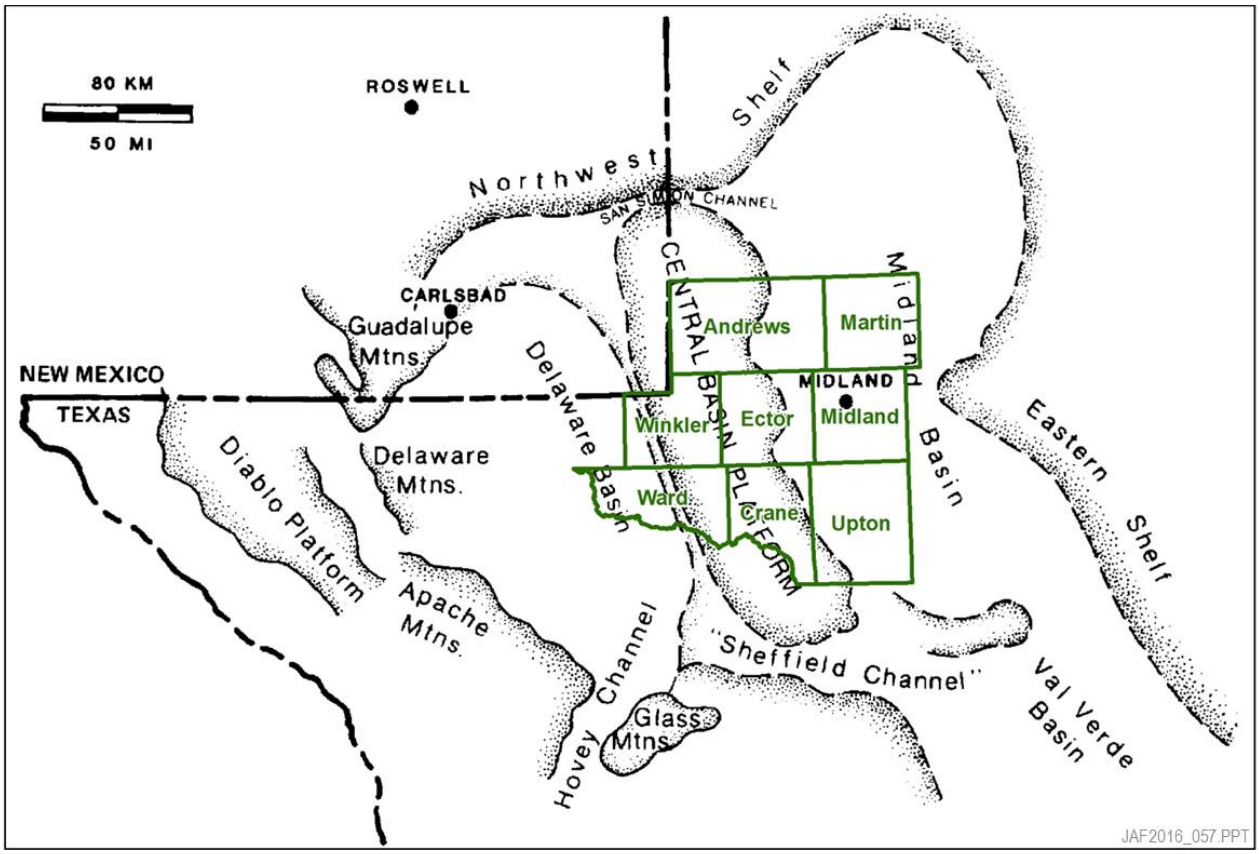
Throughout the Permian period, the CBP was the site of carbonate shelf and shelf/margin deposition on top of a basement uplift that separated the deep Delaware Basin on the west and the shallower Midland Basin on the east. Broad and extensive carbonate shelves developed along the eastern, northern and northwestern margins of the Midland and Delaware Basins.

The eight-county area addressed by this San Andres ROZ fairway resource study includes four distinct paleogeographic features of the Permian Basin that have significantly influenced the distribution and accumulation of the remaining oil in the ROZ, namely

- Sheffield Channel
- CBP
- Delaware Basin on the west
- Midland Basin on the east

These four prominent features are shown in Exhibit 1-2, which superimposes the location of the four-county study area on the configuration of the Permian Basin during the initial deposition of the San Andres Formation. [3]

Exhibit 1-2. Key Permian Basin paleographic features



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The San Andres Formation in the study area is 1,200 feet to 1,600 feet thick. It is underlain by the Glorieta/San Angelo Formation and overlain by the Grayburg and other formations of the Upper Permian Artesia Group (Exhibit 1-3). [4, 5, 6] The San Andres Formation is characterized by an overall shallowing-upward sequence of shelf carbonates. [7]

Exhibit 1-3. Stratigraphic column: Permian interval of the Permian Basin

<table>
<tr><th colspan="2">SYSTEM</th><th>Stage</th><th>High Frequency Stratigraphic Sequence</th><th colspan="2">Delaware Basin</th><th colspan="2">Central Basin Platform</th><th colspan="2">Midland Basin</th></tr>
<tr><td rowspan="14">PERMIAN</td><td rowspan="11">Upper</td><td rowspan="11">Guadalupian</td><td>G 25 - 28</td><td rowspan="11">Delaware Mountain Grp.</td><td rowspan="4">Bell Canyon</td><td rowspan="6">Artesia Grp./ Capitan</td><td>Tansill</td><td rowspan="6">Artesia Grp.</td><td>Tansill</td></tr>
<tr><td>G 21 - 24</td><td>Yates</td><td>Yates</td></tr>
<tr><td>G 17 - 20</td><td>Seven Rivers</td><td>Seven Rivers</td></tr>
<tr><td>G 13 - 16</td><td rowspan="3">Cherry Canyon</td><td>Queen</td><td>Queen</td></tr>
<tr><td>G 10 - 12</td><td>Grayburg</td><td>Grayburg</td></tr>
<tr><td>G 9</td><td colspan="2">Upper San Andres</td><td rowspan="2" colspan="2">San Andres</td></tr>
<tr><td>G 8</td><td rowspan="2">Brushy Canyon</td><td>Upper San Andres</td><td>Judkins</td></tr>
<tr><td>G 5-7</td><td colspan="2"></td><td colspan="2">Brushy Canyon Equiv</td></tr>
<tr><td>G 3-4</td><td colspan="2">Cutoff</td><td>Middle San Andres</td><td>Intermediate</td><td colspan="2" rowspan="2"></td></tr>
<tr><td>G 1-2</td><td colspan="2">Bone Spring/ Cutoff</td><td rowspan="2">Lower San Andres</td><td>McKnight</td></tr>
<tr><td rowspan="3">Lower</td><td rowspan="3">Leonardian</td><td>L 7-8</td><td rowspan="3" colspan="2">Bone Spring</td><td>Holt</td><td>Lower San Andres</td><td>Holt</td></tr>
<tr><td rowspan="2">L 5-6</td><td colspan="2">Glorieta</td><td colspan="2">Glorieta/ San Angelo</td></tr>
<tr><td colspan="2">Clear Fork Group
Abo/Wichita</td><td colspan="2">Clear Fork Group/ Spraberry</td></tr>
</table>

In the eight-county study area, the ROZ interval in the CBP occurs in the Middle to Lower San Andres, in dolostones originating as subtidal and intertidal deposits of the middle and inner shelf. In other portions of the Midland Basin, the ROZ interval occurs in the Upper San Andres. The multiple stratigraphic sequences within the overall shoaling-upward framework of the San Andres have compartmentalized the porous reservoir. Potential barriers to flow are provided by dolomudstones at the base of individual depositional sequences and by interbedded anhydrite, siltstone, and low porosity dolomite at the top of individual sequences. [8]

Permeability development is heterogeneous but often increases upward within individual stratigraphic sequences. Permeability development is influenced by the type of primary pore system and by the post-depositional diagenesis of the San Andres formation, which included multiple episodes of dolomitization, leaching of dolomite, and subsequent alteration of anhydrite. Principal pore types in the Lower San Andres include interparticle and intercrystalline porosity, moldic pores, and vugs of various sizes. [9]

1.2.2 Prograding Shelf Margins During San Andres Deposition

Oil fields producing from the Middle to Upper San Andres in the Midland Basin are located east of the Lower and Middle San Andres oil fields of the CBP. This appears to be in response to contraction of the Midland Basin during the Middle and Upper San Andres and the seaward prograding of the margin of the carbonate shelf, shown in Exhibit 1-4 and Exhibit 1-5.

Exhibit 1-4. Map of prograding shelf margins during San Andres deposition: Lower – Middle San Andres oil fields

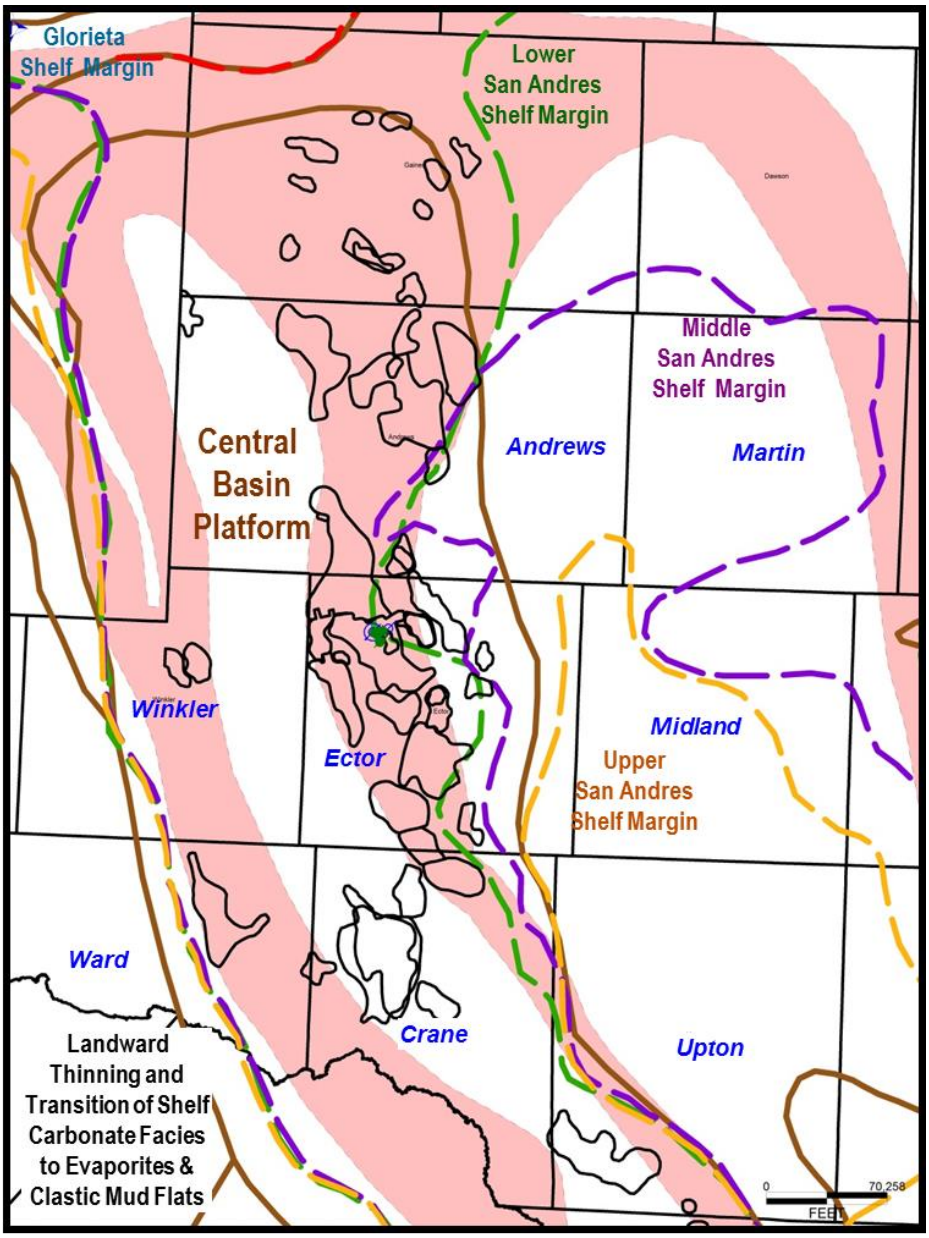

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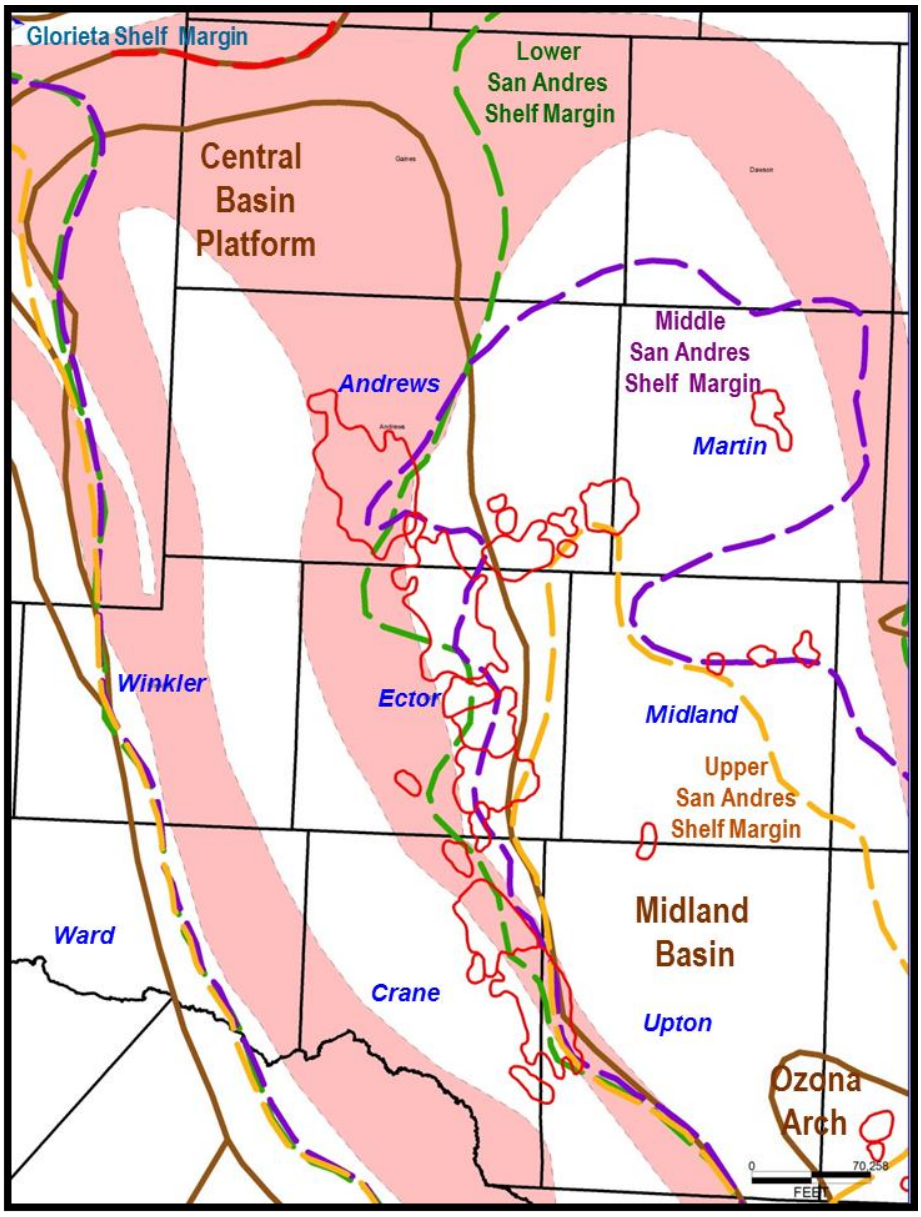
Exhibit 1-5. Map of prograding shelf margins during San Andres deposition: Middle – Upper San Andres/Grayburg oil fields



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1.3 Permian Basin ROZ

1.3.1 The San Andres ROZ Resource

Permian Basin operators have known for some time about the presence of low oil and high water saturation intervals below the main pay zones (MPZs) of their San Andres oil fields. Testing of these low residual oil intervals typically led to the production of large volumes of water with low to non-commercial volumes of oil.

Initially, the reservoir engineering community judged these low oil saturation intervals below the MPZ to be limited in size, "transition" zones created by capillary forces. The pioneering work by Mr. Steve Melzer and Dr. Robert Trentham of the University of Texas Permian Basin (UTPB) helped establish that these low residual oil saturation settings consisted of residual oil left behind by very slow, Tertiary-age hydrodynamic flow through the San Andres interval of the Permian Basin, giving birth to the term ROZ. [10]

Industry's initial efforts targeted the ROZ intervals below existing oil fields such as at Wasson, Seminole and Goldsmith. Early laboratory and field tests showed that the application of high pressure, miscible CO_2 EOR could mobilize this residual oil. Based on this positive information, industry began deepening existing wells and drilling new wells into the ROZ below their San Andres oil fields and started injecting high pressure CO_2 to produce this residual oil. In geologically favorable settings, these initial efforts demonstrated potential for commercial levels of oil production. [2] Subsequently, Trentham and Melzer, assisted by others, established that ROZs in the Permian Basin existed not just under existing oil fields but also in laterally extensive fairways beyond the structural closure of oil fields. [11]

Only recently has industry ventured beyond the structural limits of their existing oil fields to define and develop the oil resources of the San Andres ROZ fairway, the areally extensive settings outside the structural limits of existing oil fields. Uncertainty about the ability of existing logs to establish reliable oil saturation values along with limitations on available CO_2 supplies have constrained more aggressive development.

1.3.2 Characteristics of the San Andres ROZ

The primary oil producing interval of the San Andres Formation in the study area is porous dolomite located approximately 400 to 500 feet below the top of the San Andres Formation. This section, referred to as the MPZ, is defined by the closure of the structural trap above the ROZ and can have a gross thickness of 100 to 200 feet. The MPZ consists of multiple porous dolomite intervals, typically 10 to 30 feet thick on well logs, often interbedded with thin layers of mudstone, siltstone, and anhydrite.

Below the MPZ (where present) and its producing oil/water contact is a thick Lower San Andres section of porous and permeable dolomite often described as "pervasively dolomitized." This interval comprises the ROZ. If no MPZ is present, the entire porous San Andres interval has been swept and is called a "greenfield" ROZ.

In the eight-county study area, the porous dolomite of the ROZ interval ranges from 100 feet to more than 600 feet thick. In the eastern portion of the study area, the pervasive dolomite interval loses its oil saturation in the lower portion of the ROZ. It is postulated that these lower sections may never have been fully oil saturated.

The porous San Andres ROZ is indicated by a drilling break on mud logs and by a distinctive increase in porosity and corresponding decrease in resistivity on open-hole logs. Hydrocarbon shows are common while drilling through the Lower San Andres ROZ including gas shows, oil stain, and a streaming "cut" of oil from drill cuttings and core. Typically, the ROZ interval has bright fluorescence in the upper portion and duller fluorescence in its deeper section,

suggesting the oil properties may be changing in the ROZ interval. Oil saturations in conventional whole core commonly range from below 20 percent to above 30 percent in the ROZ interval.

In the eight-county study area, the lowermost boundary of the ROZ is typically determined by the change in lithology from dolomite to limestone or, if limestone is not present, by the top of the Glorieta Formation. Distinct differences in calculated porosity and oil saturation are often observed between the upper part of the ROZ interval and the lower ROZ dolomite located above the San Andres limestone.

1.4 ESTIMATING ROZ FAIRWAY RESOURCES

1.4.1 Overview of Methodology

This San Andres ROZ fairway resource study assembled logs for 152 wells drilled in the eight-county area, concentrating on logs that fully penetrated the San Andres ROZ interval below the main San Andres pay zone. From this larger data set, digital logs (LAS files) were acquired for 120 wells with higher quality log data. The digital logs were analyzed using IHS Petra workstation software to establish the key volumetric reservoir properties and calculate the San Andres ROZ fairway oil in-place (OIP). A key objective was to apply as consistent a log analysis approach as possible to the ROZ across the entire study area.

A significant number of working cross-sections were constructed using all the study wells to correlate geophysical log characteristics and guide understanding of reservoir thickness, lithology and stratigraphic continuity within the San Andres ROZ. Based on these cross-sections, each county in the study area was divided into geologically similar partitions, corresponding to features in the study wells such as apparent porosity, total dolomite thickness, calculated oil saturation, and log character (particularly the gamma ray and resistivity logs.)

Four of the counties (Andrews, Martin, Winkler, and Ector) were treated as distinct entities and were further divided into nine partitions corresponding to key geologic features of the San Andres ROZ, including lithology, thickness, porosity and resistivity from well logs. The three Southern Tier counties of Crane, Upton, and Ward were treated as a single entity containing four San Andres ROZ partitions. The partitions generally align with the margins of the CBP and the Midland Basin. Each partition is represented by a higher and a lower quality average well comprising the average log-based reservoir properties for the ROZ from the study wells within each partition.

The San Andres ROZ in the eighth county of this study, Midland County, is very thin or missing altogether.

Additional details of the study methodology and data sources are described below:

- Obtained logs that included neutron, density and sonic porosity plus resistivity, gamma ray, photoelectric absorption (PEF), and caliper. A minimum acceptable log suite consisted of sonic porosity, resistivity, and gamma ray.

- Calibrated log analyses of the San Andres ROZ with core data from the Goldsmith-Landreth San Andres Unit (GLSAU) and also to areas of San Andres with productive main pay. Determined the top and base of the ROZ for each study well, using logs calibrated to core and other benchmark data.
- Used the 120 well log suite to identify "net pay" of the San Andres ROZ, including its porosity and oil saturation. Computed OIP in the San Andres ROZ for each study well using these data to create an average well for each partition.
- Aggregated the San Andres ROZ resource calculations for each partition to county and overall totals to provide an estimate for the total San Andres ROZ resource in this eight-county area.

A total of 2,462,400 acres were assessed for San Andres ROZ fairway resources in the eight-county study area.

- The bulk of the assessed area is located on the CBP with the remaining area located in the Midland Basin. The characteristics of the San Andres ROZ vary greatly depending on whether the area is located in the CBP or is located in the Midland Basin.
- Two regional stratigraphic cross-sections (as well as numerous local cross-sections) were constructed to illustrate the variability of the San Andres ROZ fairway resource in the eight-county study area, with cross-section locations shown in Exhibit 1-6.
    - Cross-section A-A' illustrates the San Andres ROZ from north to south in the CBP (Exhibit 1-7).
    - Cross-section B-B' provides a west to east view of the San Andres ROZ from the CBP into the central Midland Basin (Exhibit 1-8).

Exhibit 1-6. Location of two regional cross-sections for the eight-county area study

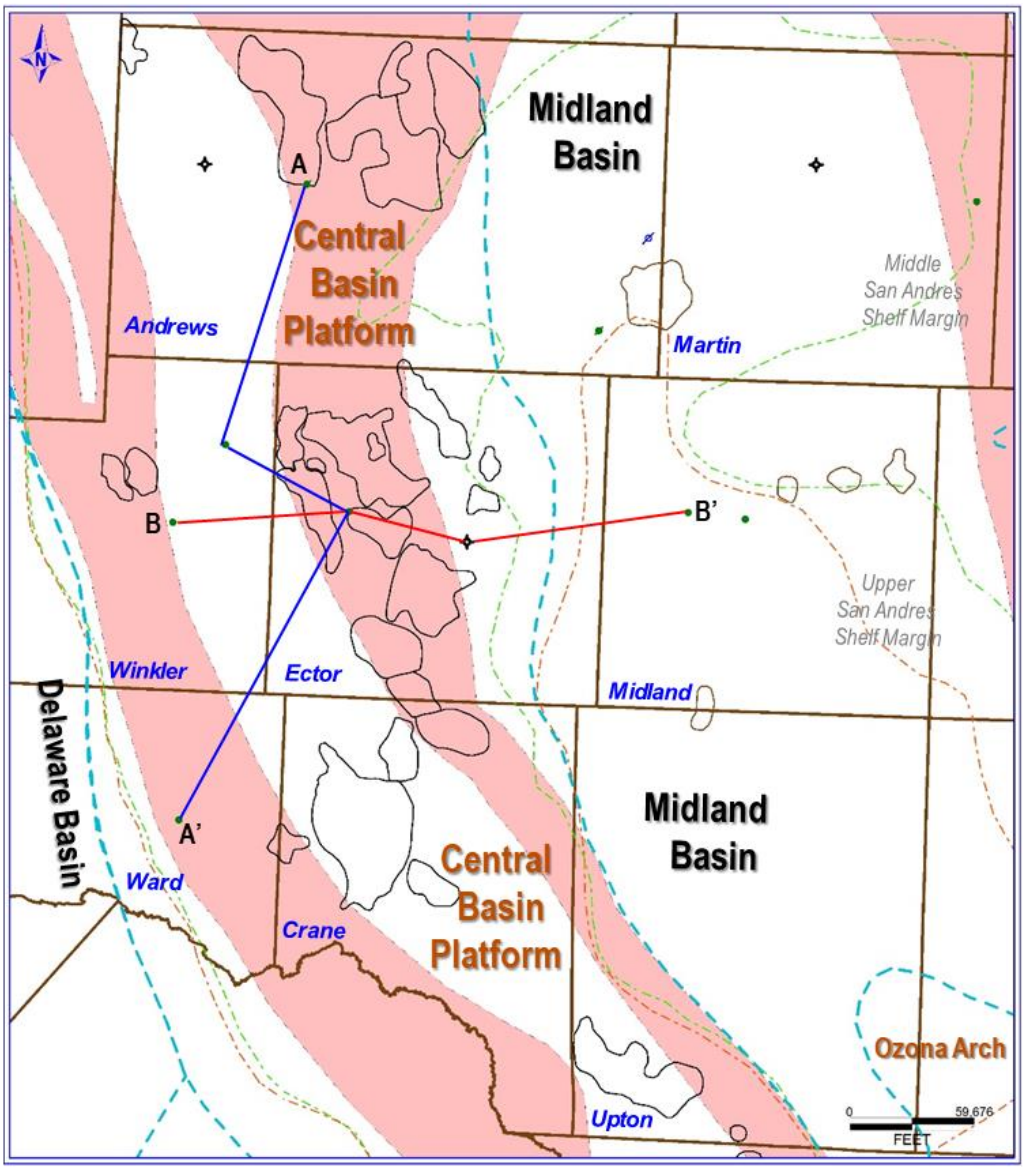
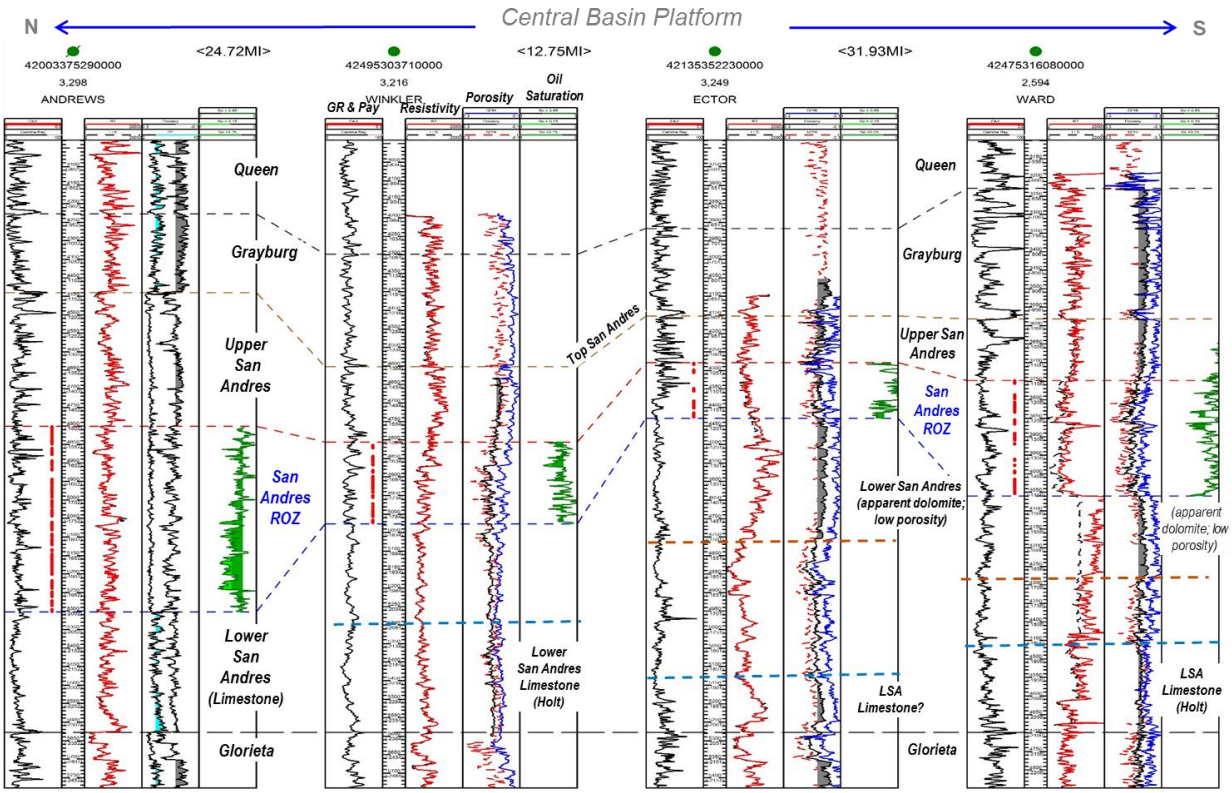
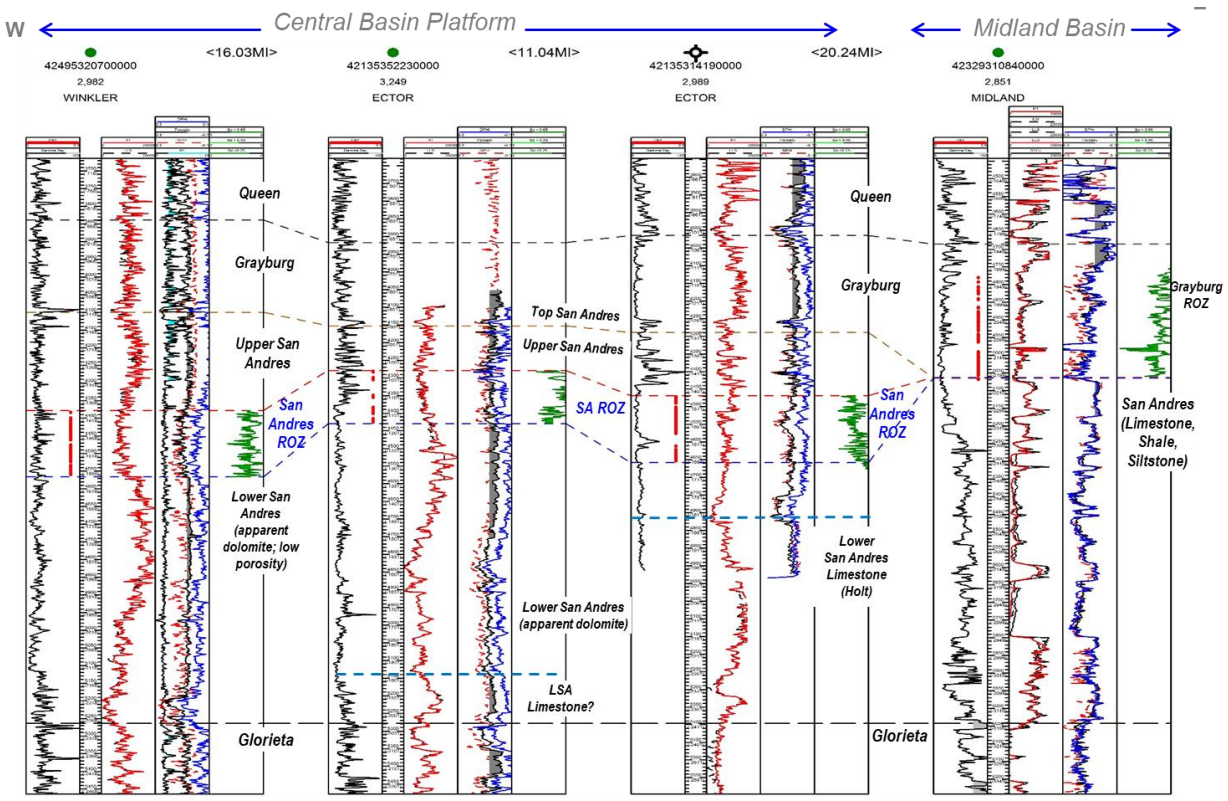


Exhibit 1-7. North-South cross-section A-A' showing San Andres ROZ type wells



Note: Stratigraphic cross-section hung on the Glorieta Formation. Porosity logs for cross-section wells are density-neutron cross-plot porosity or sonic porosity. Gray shading indicates porosity less than 0.06. Green shading in Track 4 indicates calculated So between 0.25 and 0.45. Vertical red bar in Track 1 = net pay indicator where ROZ "pay" has porosity >0.06; no S or pay cutoff applied.

Exhibit 1-8. West-East cross-section B-B' showing San Andres ROZ type wells



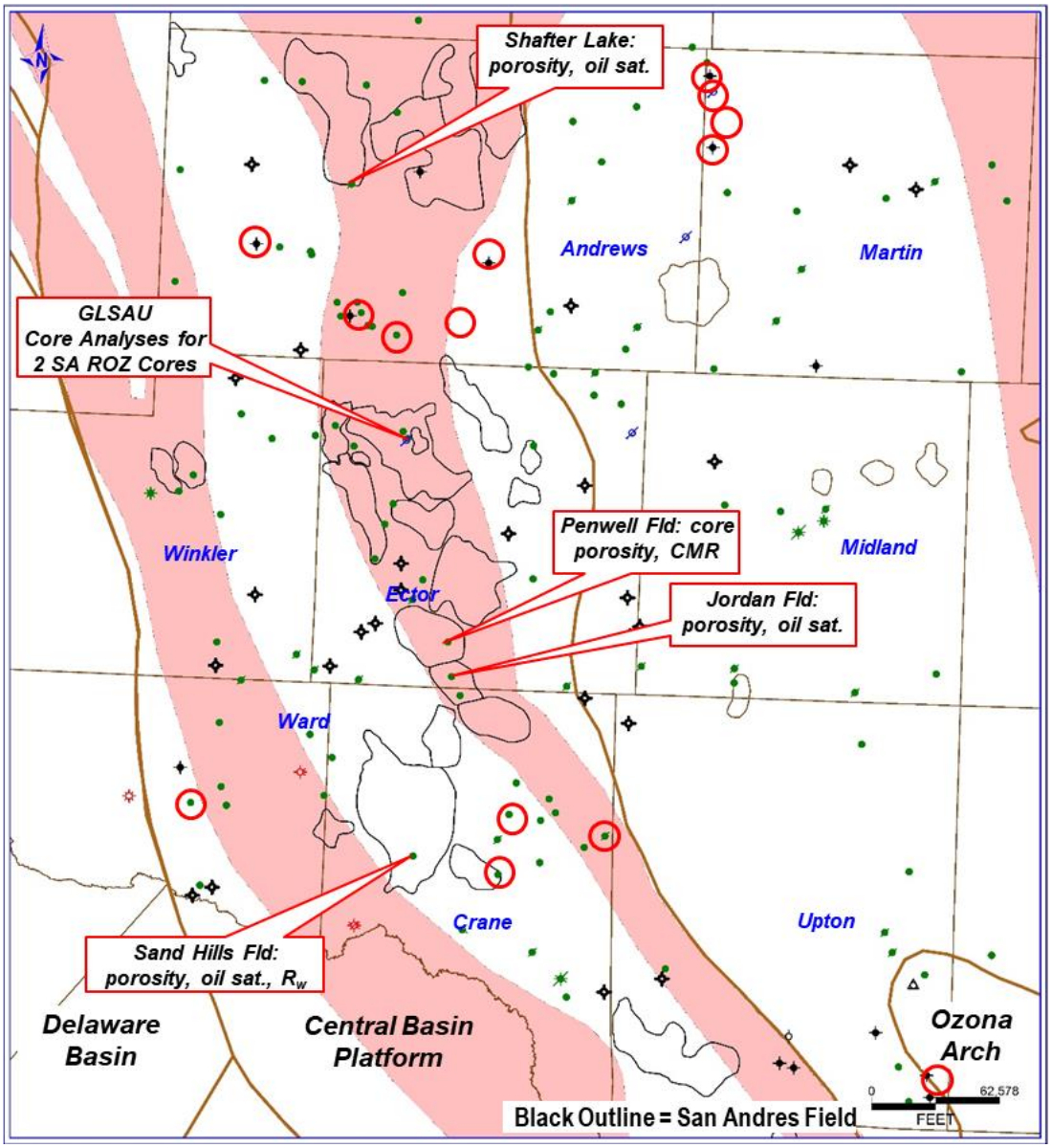
Note: Stratigraphic cross-section hung on the Glorieta Formation. Porosity logs for cross-section wells are density-neutron cross-plot porosity. Gray shading indicates porosity less than 0.06. Green shading in Track 4 indicates calculated So between 0.25 and 0.45. Vertical red bar in Track 1 = net pay indicator where ROZ "pay" has porosity >0.06; no Sor pay cutoff applied.

1.4.2 Data Sources and Published Studies

1.4.2.1 Study Wells and Core Data

Exhibit 1-9 shows the location of the study wells and the core data used for this study. The log data were calibrated to publicly available data from the San Andres ROZ fairway interval in this eight-county area.

Exhibit 1-9. Location of data for eight-county area study



Recent core data for the ROZ interval were available from two wells drilled at GLSAU in north-eastern Ector County (Exhibit 1-9). These cores showed that the log calculations successfully delineated the ROZ interval in this area. Oil shows observed in 14 mud logs provided additional support for the calculated oil saturations.

Log calculations for the San Andres ROZ were also calibrated to other data, highlighted in Exhibit 1-9. In four producing fields, Shafter Lake, Penwell, Jordan, and Sand Hills, published values for porosity, oil saturation, and formation water salinity in the San Andres MPZ were used to calibrate the calculations of porosity and oil saturation for the San Andres ROZ.

1.4.2.2 Published Studies

Numerous published field and petrophysical studies of the San Andres Formation were reviewed that provided useful information for stratigraphic correlations, for calculating porosity in individual study wells, and for understanding porosity variations throughout the study area.

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- Garber, R.A. and P.M. Harris, 1986, Depositional facies of Grayburg/San Andres dolomite reservoirs, Central Basin Platform, Permian Basin, in D.G Bebout and P.M. Harris, eds., Geologic and Engineering Approaches in Evaluation of San Andres/Grayburg Hydrocarbon Reservoirs, Permian Basin SEPM Publication 86-26, p. 61-66. [13]
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1.4.3 Computing Porosity in the ROZ

Porosity was computed using all available logs, including compensated neutron, density, and sonic logs. Lithology corrections and environmental corrections were applied as needed; bad values and obvious shale zones were excluded from the analysis. Compensated neutron and sidewall neutron logs were corrected for dolomite, which reduced the compensated neutron porosity by approximately 6 to 8 porosity units and the sidewall neutron porosity by 1 to 3 porosity units. Standard published dolomite log corrections were used for all logs.

Density porosity was calculated from bulk density using a matrix density of 2.83 to 2.85 grams per cubic centimeter (g/cc) (based on core data) and a fluid density of 1.0 to 1.05 g/cc. Sonic porosity was computed using the Wylie relationship and fluid travel time of 188 microseconds per foot (μ-sec/ft). For most wells throughout the study area, a matrix travel time of 43 μ-sec/ft was used to compute sonic porosity. For wells with multiple porosity logs, the best available

porosity log (usually the density-neutron cross-plot porosity log) was selected for calculating oil saturation.

1.4.4 Computing Oil Saturation in the ROZ

The water saturation (Sw) in the ROZ was computed for the 120 log data set using the classic Archie model:

$$Sw^n = ((a \times Rw)/(Rt \times \phi^m))$$

Oil saturation (So) at reservoir conditions was computed as 1-Sw. The parameters used for the Archie equation are defined and summarized in Exhibit 1-10.

Exhibit 1-10. Input parameters for calculating oil saturation in the ROZ

Porosity Φ	Study wells were selected with available open hole neutron, density, and/or sonic logs Lithology-corrected density-neutron cross-plot porosity log was most commonly used	Density porosity: used matrix grain density of 2.83 g/cc to 2.85 g/cc and fluid density of 1.0 to 1.05 g/cc Sonic porosity: used matrix and fluid travel times of 43 μ–sec/ft and 188 μ–sec/ft; varied matrix travel time in select areas of the Midland Basin
Archie Parameters	'm' = cementation exponent 'n' = saturation exponent 'a' = further correction for tortuosity of electrical pathway	Used 'a' = 1, 'm'=2.3, 'n'= 3.4 for the CBP Used 'a' = 1, 'm'=2.3, 'n'=3 for the Midland Basin
Rw	Regional formation water salinity values for the San Andres were used to compute Rw at formation temperature	Rw values used for log analysis range from 0.07 ohm-m for Andrews County to 0.19 ohm-m for the Southern Tier counties
Rt	Deep resistivity or 'Rt' log	Used deep reading resistivity log, corrected for invasion where needed; used 'Rt' log if available

The calculation of water saturation, Sw, is most sensitive to porosity and the parameter 'm,' cementation exponent. The parameter 'n,' saturation exponent, is also important for pore systems that may not be entirely water-wet. The parameters 'm' and 'n' are commonly assumed to be '2.0' in carbonates. Laboratory derived values of 'm' are frequently higher than 2.0 for carbonate pore systems with vugs and moldic porosity, and laboratory-derived values for 'n' may range from 2 to 4 (or greater) for oil wet reservoirs.

1.4.5 Comparing Log Derived Characterization with Published Data

This study's assessments of the key volumetric San Andres ROZ fairway properties—gross and net pay, porosity, and oil saturation—have been calibrated with publicly available data. For example, the geologic data reported for the ROZ interval below the MPZ of Well #190 in the GLSAU oil field in Ector County are similar to the data derived from this study's log analysis for Partition #2 of Ector County (Exhibit 1-11).

Exhibit 1-11. Comparison of Ector County Partition #2 volumetric reservoir properties with Goldsmith Landreth San Andres Unit oil field ROZ

Volumetric Reservoir Properties	Goldsmith Landreth San Andres Unit	This Study Partition #2
	San Andres ROZ	San Andres ROZ
Depth (to top) (ft)	4,290	4,240
Gross Pay (ft)	125	135
Net Pay (ft)	86	96
Porosity (%)	11.6%	9.5%
Oil Saturation (%)	35%	27%

1.4.6 Computing OIP and High-Grading the ROZ Resource

After porosity and oil saturation were calculated for each well, a porosity cut-off of 6 percent was applied to define net pay. No oil saturation cut-off was applied. Questionable high porosity and oil saturation values were excluded from net pay. A gamma ray index of 0.4 was computed and applied to exclude apparent shale zones from net pay.

After all porosity cut-offs and pay exclusions were applied, the calculated net pay intervals were flagged. Total net pay was summed for the ROZ interval and the average porosity of net pay and the average oil saturation of net pay were computed. The value of total net pay, average porosity of net pay, and average oil saturation of net pay were then used to compute OIP for the ROZ interval. A partition-specific formation volume of factor (FVF), typically ranging from 1.1 to 1.3, was applied to convert reservoir barrels to stock tank barrels.

1.4.7 High-Grading the ROZ Resources

The ROZ fairway resources were further analyzed to establish "higher quality" and "lower quality" resources. A higher quality ROZ resource is established for areas where the average computed net pay log values are greater than 8 percent for porosity and 25 percent for oil saturation. If either the average porosity or the average oil saturation of net pay is below the above cut-off values, then the ROZ resource in the area represented by the study wells is characterized as lower quality. For example, if the ROZ pay in a well has an average porosity value of 12 percent and an average oil saturation of 24 percent, the ROZ resource in the entire area represented by that study well is characterized as lower quality based on oil saturation.

1.5 Size and Quality of the San Andres ROZ Fairway Resource

1.5.1 Areal Coverage of the ROZ Fairway Resource Assessment

The eight-county area ROZ study assessed a significant land area, nearly 4.88 million acres. Approximately half of the area (2.41 million acres), where the San Andres ROZ is absent or where the San Andres ROZ is below the structural closure of existing San Andres oil fields, was excluded, leaving a ROZ fairway assessment area of 2.46 million acres (Exhibit 1-12).

Exhibit 1-12. San Andres ROZ fairway assessment area: eight-county area

County	Total Area	Outside Study Boundaries	Below Existing Oil Fields	Assessment Area	Quality Area	
					Higher	Lower
	Acres	Acres	Acres	Acres	Acres	Acres
Andrews	960,500	(192,500)	(110,400)	657,600	376,900	280,700
Martin	586,100	(232,400)	-	353,700	202,100	151,600
Winkler	342,800	*	-	342,800	245,200	97,600
Ector	577,000	(106,800)	(121,900)	348,300	202,900	145,400
Southern Tier	1,833,000	(910,000)	(163,000)	760,000	227,000	533,000
Midland	577,400	(577,400)	-	-	-	-
Total San Andres	**4,876,800**	**(2,019,100)**	**(395,300)**	**2,462,400**	**1,254,100**	**1,208,300**

*The Delaware Basin portion of Winkler County was not included in the study.

1.5.2 OIP of the ROZ Fairway Resource Assessment

This study of the San Andres ROZ fairway resources in the eight counties of West Texas identified 71.5 billion barrels of OIP. Much of the in-place ROZ fairway resource is higher quality, estimated at 52.3 billion barrels of OIP, offering promise for commercially viable development with by-product storage of CO_2 (Exhibit 1-13). The remainder of the resource, 19.2 billion barrels of OIP is lower quality, offering geologic space for storing CO_2 with by-product production of oil.

Exhibit 1-13. In-place San Andres ROZ fairway resources: eight-county area

County	In-Place Resource		
	Total	Higher Quality	Lower Quality
	B bbl	B bbl	B bbl
Andrews	33.5	28.2	5.3
Martin	6.1	4.3	1.7
Winkler	8.5	7.2	1.3
Ector	6.3	5.0	1.3
Southern Tier	17.1	7.6	9.5
Total San Andres ROZ	**71.5**	**52.3**	**19.2**

Note: Totals may not add due to rounding.

Andrews County. The western and central areas of Andrews County, on the CBP, contain a thick package of ROZ net pay, ranging from 150 to 400 feet, with favorable oil saturations of 34 percent. The eastern portion of Andrews County, in the Midland Basin, has appreciably lower net pay (50 to 100 feet) and lower oil saturation. Andrews County holds 33.5 billion barrels of San Andres ROZ fairway OIP, with nearly 85 percent of the in-place resource judged as "higher quality."

Martin County. The western and central areas of Martin County, in the Midland Basin, hold a moderate package of ROZ net pay, on the order of 100 feet, with oil saturations below 25 percent. The eastern area of the county, particularly within the previously defined ROZ fairway, has thicker net pay, ranging from 120 to 170 feet, with moderate oil saturation of 30 percent. Martin County holds 6.1 billion barrels of San Andres ROZ fairway OIP, with 70 percent of the in-place resource judged as higher quality.

Winkler County. The central and eastern areas of Winkler County, in the CBP, contain an attractive package of ROZ net pay, ranging from 130 to 180 feet, and oil saturations of 35 to 40 percent. Winkler County holds 8.5 billion barrels of San Andres ROZ fairway OIP, with nearly 85 percent of the in-place resource judged as higher quality.

Ector County. The central portion of Ector County, on the CBP, has widely variable ROZ net pay, ranging from 100 feet to pockets in excess of 250 feet. Oil saturations range from 30 to 35 percent, with porosities (for net pay) of about 10 percent. Ector County holds 6.3 billion barrels of San Andres ROZ fairway OIP, with nearly 80 percent of the in-place resource judged as higher quality.

Southern Tier counties. The ROZ fairway resource in Crane, Upton and Ward counties is highly variable, ranging from 200 net feet of moderate porosity on the west to 100 net feet of lower porosity pay on the east. Oil saturation tends to be lower, ranging from 25 to 30 percent. The three Southern Tier counties hold 17.1 billion barrels of San Andres ROZ fairway OIP, with only about 45 percent of this in-place resource judged as higher quality.

Midland County. The ROZ resource in Midland County is within the Grayburg formation and is not included further in this study.

Exhibit 1-14 provides additional county- and partition-level detail on the size and quality of the in-place San Andres ROZ fairway resource. The reservoir data developed for each partition is stored in an open-source database available on the National Energy Technology Laboratory (NETL) website. NETL is part of the Office of Fossil Energy (FE) in the United States (U.S.) Department of Energy (DOE). [19]

Exhibit 1-14. ROZ fairway resources: eight-county area

County	Partition	Higher Quality ROZ Resource (B bbl)	Lower Quality ROZ Resource (B bbl)	TOTAL ROZ Resource (B bbl)
Andrews	#1	17.4	0.5	17.9
	#2	10.8	3.4	14.2
	#3	-	1.4	1.4
	Total	**28.2**	**5.3**	**33.5**
Martin	#1	4.3	1.7	6.1
	Total	**4.3**	**1.7**	**6.1**
Winkler	#1	5.6	-	5.6
	#2	1.6	1.3	2.9
	Total	**7.2**	**1.3**	**8.5**
Ector	#1	0.2	0.5	0.7
	#2	1.6	0.4	2.0
	#3	3.2	0.4	3.6
	Total	**5.0**	**1.3**	**6.3**
Southern Tier	Ward Co. #1	3.7	3.8	7.5
	Crane Co. #2	1.7	2.2	3.9
	Crane Co. #3	2.2	0.6	2.8
	Upton Co. #4	-	3.0	3.0
	Total	**7.6**	**9.5**	**17.1**
San Andres ROZ Fairway Resource Total		**52.3**	**19.2**	**71.5**

1.6 Technically Recoverable ROZ Resources

1.6.1 Applying CO_2 Enhanced Oil Recovery to the ROZ

A miscible CO_2 flood, involving a "tapered" CO_2 water-alternating-gas (WAG) with one hydrocarbon pore volume (HCPV) of CO_2 injection, was used to establish oil recovery from the eight-county area. (A tapered CO_2 WAG involves a large initial volume of CO_2 injection with a modest volume of water, followed by progressively smaller volumes of CO_2 injection and larger volumes of water injection.) Analytical modeling by ARI of alternative miscible CO_2 enhanced oil recovery (EOR) designs showed that a tapered CO_2 WAG provided an optimum CO_2 flooding design.

The above miscible CO_2 EOR design, along with data on volumetric and other reservoir properties specific to each of the 26 analytical ROZ reservoir units, were incorporated into the

FE/NETL CO_2 Prophet Model ("Prophet Model") to calculate oil recovery, water production, CO_2 injection and recycling, and CO_2 storage. The Prophet Model is a simplified streamline and streamtube reservoir simulator program comprising two programs, StrmtbGen and StrmtbFlow. The StrmtbFlow program, which simulates multiphase flow in porous media, was used in this study.[c]

The model input data for each analytic unit consisted of the volumetric data calculated by the study (presented in more detail in the individual chapters for each of the eight counties), and other reservoir-specific data contributed from ARI's proprietary Big Oil Fields Data Base for the Permian Basin.

1.6.2 Technically Recoverable ROZ Resources and Demand for Purchased CO_2

The study established that 22.0 billion barrels (31 percent) of the San Andres ROZ fairway OIP is technically recoverable, primarily from higher quality portions of the eight-county study area, Exhibit 1-15.

Exhibit 1-15. Volumes of technically recoverable resources and demand for purchased CO_2: San Andres ROZ fairway, eight-county area

County	Technically Recoverable Oil		Purchased			
			CO_2 Injection		CO_2/Oil Recovery Ratio	
	B bbl	% OIP	Tcf	B mt	Mcf/B	mt/B
Andrews	10.1	30%	92	4.9	9.1	0.48
Martin	1.8	30%	21	1.1	11.5	0.60
Winkler	2.7	31%	28	1.5	10.6	0.56
Ector	1.9	30%	21	1.1	11.3	0.60
Southern Tier	5.5	32%	67	3.5	12.2	0.64
Total San Andres ROZ	**22.0**	**31%**	**229**	**12.1**	**10.4**	**0.55**

To produce the technically recoverable ROZ oil, a purchased CO_2 volume of 12.1 billion metric tons (229 Tcf) will be required (Exhibit 1-15). Overall, considerably more CO_2 is stored, 0.55 metric tons of CO_2 per barrel of oil produced, than is contained in the oil recovered as part of developing the San Andres ROZ fairway resource.[d] A barrel of oil releases approximately 0.4 metric tons of CO_2 when combusted.

[c] The FE/NETL CO_2 Prophet Model has been posted to the NETL website.

[d] Please note that this is a marginal, rather than a full life-cycle, analysis of CO_2 emissions associated with CO_2 EOR. It is provided to show the magnitude of the difference in carbon-intensity between conventionally produced and CO_2 EOR produced crude oil. Both conventional oil production and CO_2 EOR use additional energy, with their associated CO_2 emissions, for drilling wells, injecting and producing fluids, and conducting other oil field activities.

1.7 ESTIMATING COMMERCIALLY VIABLE OIL RECOVERY

1.7.1 Cost and Economics Models

The FE/NETL Onshore CO_2 EOR Cost Model ("CO_2 EOR Cost Model")[e] was utilized for estimating the commercial (economic) viability[f] of producing oil and storing CO_2 in the San Andres ROZ fairway of the eight-county study area.

Project costs for this study were based on "greenfield" ROZ partitions, with no existing oil field infrastructure in place. CO_2 EOR Cost Model assumptions included up-front costs for legal agreements with surface and mineral rights owners, drilling and construction permits, installing characterization wells, operation design, and building and road construction, as well as installation of new wells, pipelines, and fluid processing facilities. Costs also include construction of a CO_2 pipeline spur from a main CO_2 transportation pipeline, and a new CO_2 recycling plant. The CO_2 EOR Cost Model also accounts for the costs of well operation and maintenance (O&M), for lifting the produced fluids, and for capturing, separating, and reinjecting the produced CO_2. The capital costs for a greenfield ROZ operation are considerably higher than the capitals costs associated with implementing CO_2 EOR at a conventional oil field. The O&M costs for the two project types are comparable. The CO_2 EOR Cost Model accounts for royalties, and severance and ad valorem taxes, as well as any oil gravity and market location discounts (or premiums) from the West Texas Intermediate (WTI) crude oil "marker" oil price. The economic analysis for this study included a traditional cash flow model, consistent with industry standards that provides results on a field-wide basis.

The inputs and assumptions of the CO_2 EOR Cost Model used for this San Andres ROZ fairway resource study include the following key items:

- Oil Price—$75 per barrel (WTI reference price), escalating at 2.3% per year. The oil price selected for the analysis is consistent with a mid-term outlook for oil prices in the Energy Information Administration's (EIA) 2018 Annual Energy Outlook
- CO_2 Sales Price—$1.50/Mcf, equal to $28.35/metric tons (delivered at pressure to the oil field). The CO_2 sales price used by the ROZ study is consistent with historical ratios relating the CO_2 sales price to the oil price
- Project Financing—60% equity and 40% debt, based on EIA's assumptions in their Oil and Gas Supply Module within the National Energy Modeling System
- Financial Hurdle Rate—10% after tax weighted average cost of capital (WACC); (13% for equity and 6.6% for debt, adjusted for tax effects)
- Royalties—17% on gross production

[e] The FE/NETL Onshore CO_2 EOR Cost Model is being posted to the NETL website at the same time as this report.

[f] Commercially viable means the after tax rate of return for a specific ROZ partition would exceed the weighted average cost of capital or WACC. The expression "after tax" includes all state and federal taxes.

- State Severance/Ad Valorem Taxes—The Texas state severance and ad valorem tax rates used by the study did not incorporate special incentives for operating a CO_2 flood or for storing CO_2
- Federal Income Tax—21% on earnings after state and local taxes

More detailed results are presented on a county and partition basis in the subsequent chapters and sections of this report.

1.7.2 Commercially Viable Oil Recovery with By-Product CO_2 Storage

Using the above cost and economic variables, the study estimates that the San Andres ROZ fairway in the eight-county area would provide 15.5 billion barrels of commercially viable oil recovery.

The pursuit of this ROZ oil would also provide 6.6 billion metric tons of by-product CO_2 storage (Exhibit 1-16). This assumes essentially all the purchased CO_2 is stored.

Exhibit 1-16. Commercially viable oil recovery with by-product storage of CO_2: San Andres ROZ fairway resource, eight-county area

County	Oil Recovery (B bbl)	Purchased CO_2		Purchased CO_2/Oil Recovery Ratio	
		Tcf	B mt	Mcf/B	mt/B
Andrews	8.8	68	3.6	7.8	0.41
Martin	1.5	12	0.6	7.5	0.40
Winkler	2.3	21	1.1	9.0	0.48
Ector	1.0	7	0.4	7.4	0.39
Southern Tier	1.9	18	0.9	9.2	0.49
Total San Andres ROZ	**15.5**	**126**	**6.6**	**8.1**	**0.43**

*Totals may not add due to rounding.

The CO_2 EOR project in the commercially viable portion of the San Andres ROZ fairway stores, at the margin, 0.43 metric tons of CO_2 per barrel of oil produced. As such, this produced oil is carbon neutral or "green" given the approximately 0.4 metric ton of CO_2 content (when combusted) in a barrel of oil.[g]

[g] Please note that this is a marginal, rather than a full life-cycle, analysis of CO_2 emissions associated with CO_2 EOR. It is provided to show the magnitude of the difference in carbon-intensity between conventionally produced and CO_2 EOR produced crude oil. Both conventional oil production and CO_2 EOR use additional energy, with their associated CO_2 emissions, for drilling wells, injecting and producing fluids, and conducting other oil field activities.

1.8 Geologically Viable CO_2 Storage with By-Product Oil Recovery

Significant portions of the San Andres ROZ fairway are not commercially viable to develop at the above combination of oil prices and CO_2 costs. However, in nearly all partitions considerable volumes of by-product oil is recovered that would help defray a portion of the costs of capturing and storing CO_2.

Overall, the geologically viable but non-commercial portion of the San Andres ROZ fairway in the eight-county area could provide 5.5 billion metric tons of CO_2 storage capacity along with 6.4 billion barrels of by-product oil recovery, providing revenues that would help lower the net costs of CO_2 capture and storage (Exhibit 1-17). This assumes essentially all the purchased CO_2 is stored.

Exhibit 1-17. Geologically viable CO_2 storage with by-product recovery of oil: San Andres ROZ fairway resource, eight-county area

County	Purchased CO_2		By-Product Oil Recovery (B bbl)	Purchased CO_2/Oil Recovery Ratio	
	Tcf	B mt		Mcf/B	mt/B
Andrews	24	1.3	1.3	18.1	0.96
Martin	9	0.5	0.3	32.1	1.70
Winkler	7	0.4	0.4	20.5	1.09
Ector	14	0.7	0.9	15.5	0.82
Southern Tier	49	2.6	3.5	13.8	0.73
Total San Andres ROZ	**103**	**5.5**	**6.4**	**16.1**	**0.86**

2 ANDREWS COUNTY

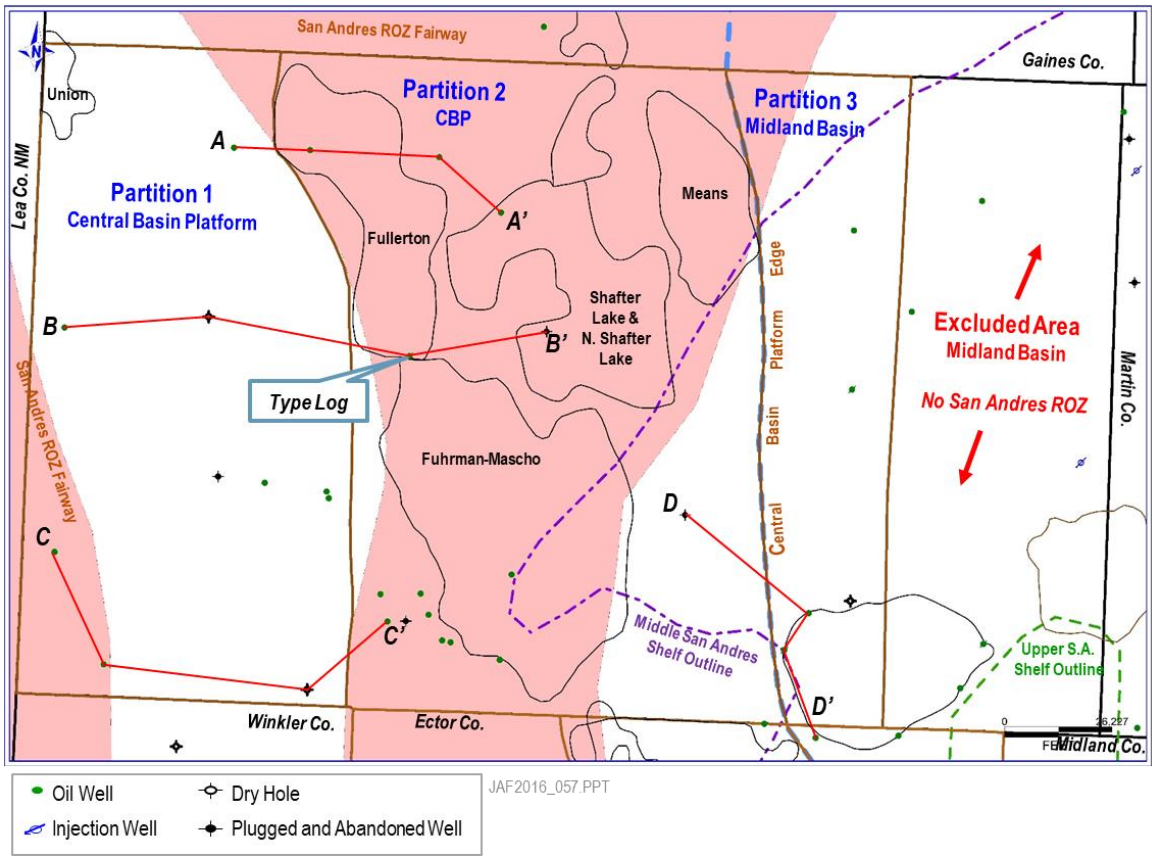
2.1 GEOLOGIC SETTING OF THE ANDREWS COUNTY SAN ANDRES ROZ FAIRWAY

Andrews County, Texas, covers a 960,500-acre area in the West Texas portion of the Permian Basin. Approximately two-thirds of the county is on the CBP. The remainder of the county is east of this prominent Permian Basin feature but within the southward prograding Lower and Middle San Andres shelf margins of the Midland Basin.

Andrews County contains numerous San Andres oil fields, including Emma, Fuhrman-Mascho, Fullerton, Mabee, Means, Midland Farms, and Shafter Lake, among others. The ROZ resource below these and other existing San Andres oil fields has been excluded from the resource assessment of the San Andres ROZ fairway.

The Andrews County map (Exhibit 2-1) shows 1) the location of 35 study wells with 21 wells selected for detailed analysis, 2) the three San Andres ROZ fairway partitions established by the study, 3) the boundaries of the previously established San Andres ROZ fairway, 4) the outline of the CBP, and 5) the location of four regional cross-sections featuring the San Andres ROZ. The map also shows the major San Andres oil fields and highlights the eastern portion of the county that have been excluded from the San Andres ROZ fairway resource assessment.

Exhibit 2-1. Andrews County: geologic partitions, major oil fields, and study well locations



2.1.1 Example Andrews County Cross-Sections

The delineation and characterization of the San Andres ROZ fairway interval in Andrews County utilized a series of working cross-sections. Four of these cross-sections are included in this report.

- Andrews Co. cross-section A-A' (Exhibit 2-2) provides a west to east view of the San Andres ROZ interval on the CBP.
- Andrews Co. cross-section B-B' (Exhibit 2-3) provides an additional west to east view of the San Andres ROZ interval through the center of the county.
- Andrews Co. cross-section C-C' (Exhibit 2-4) provides a west to east view of the variability of the San Andres ROZ interval in the southwestern portion of the county.
- Andrews Co. cross-section D-D' (Exhibit 2-5) illustrates the changes in the San Andres ROZ interval from the eastern edge of the CBP into the Midland Basin.

Exhibit 2-2. Andrews County cross-section A-A'

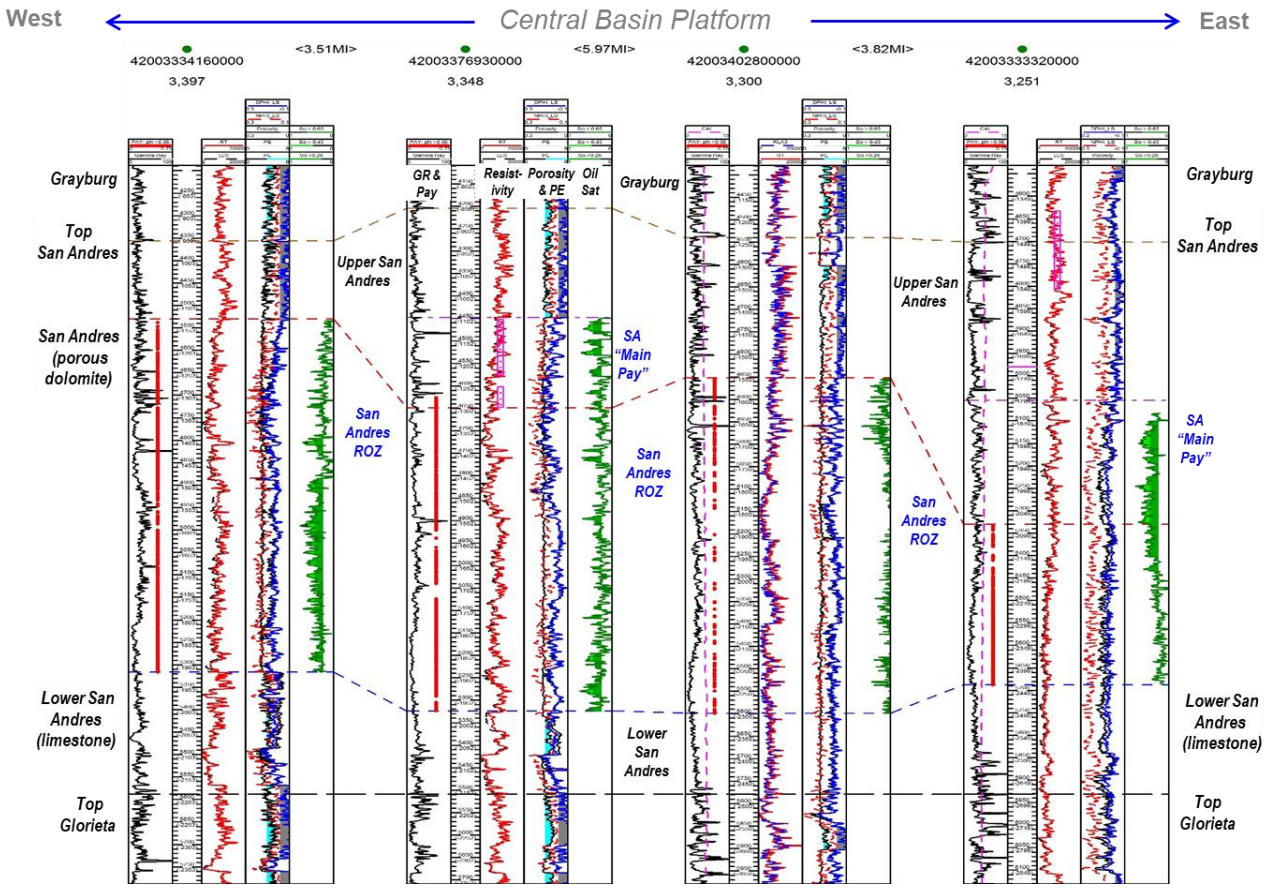


Exhibit 2-3. Andrews County cross-section B-B'

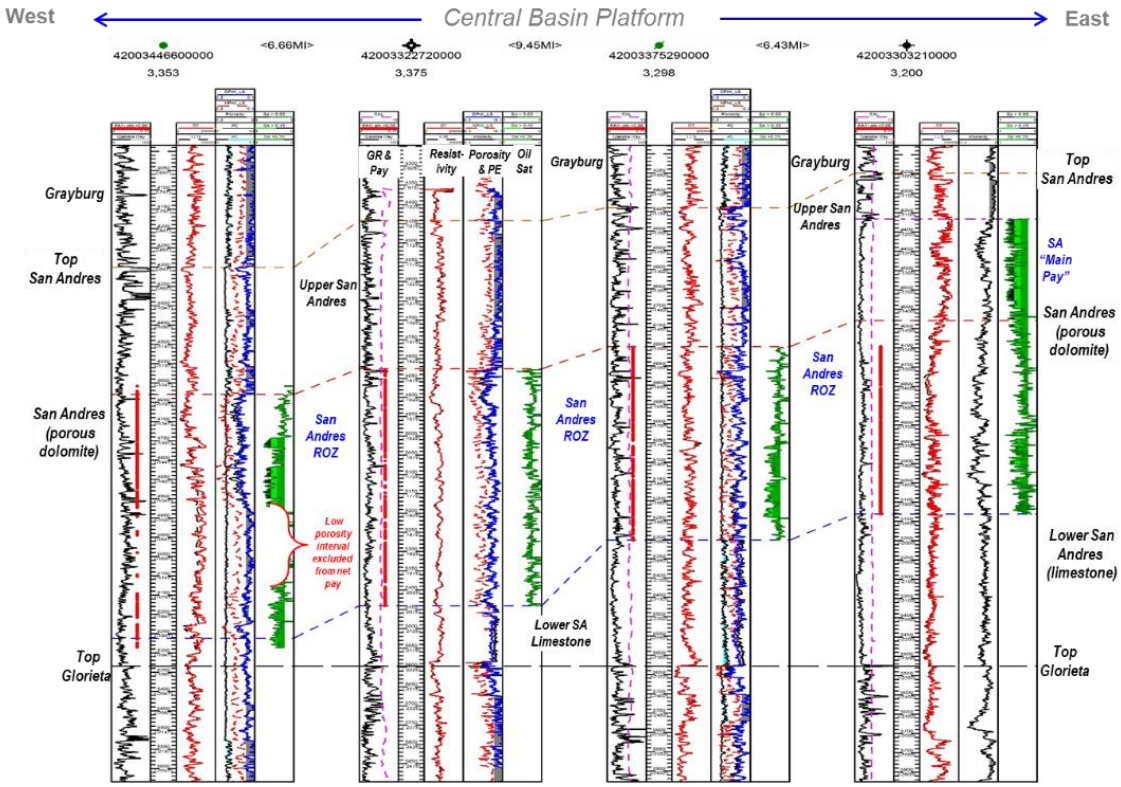


Exhibit 2-4. Andrews County cross-section C-C'

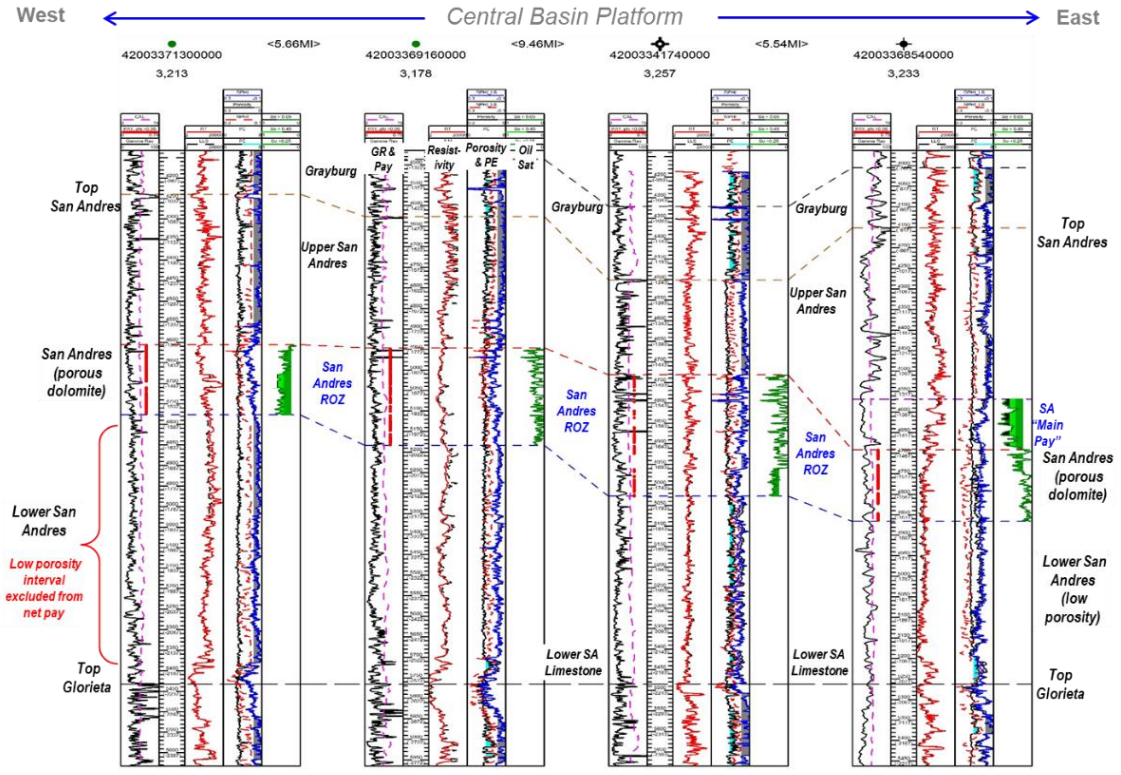
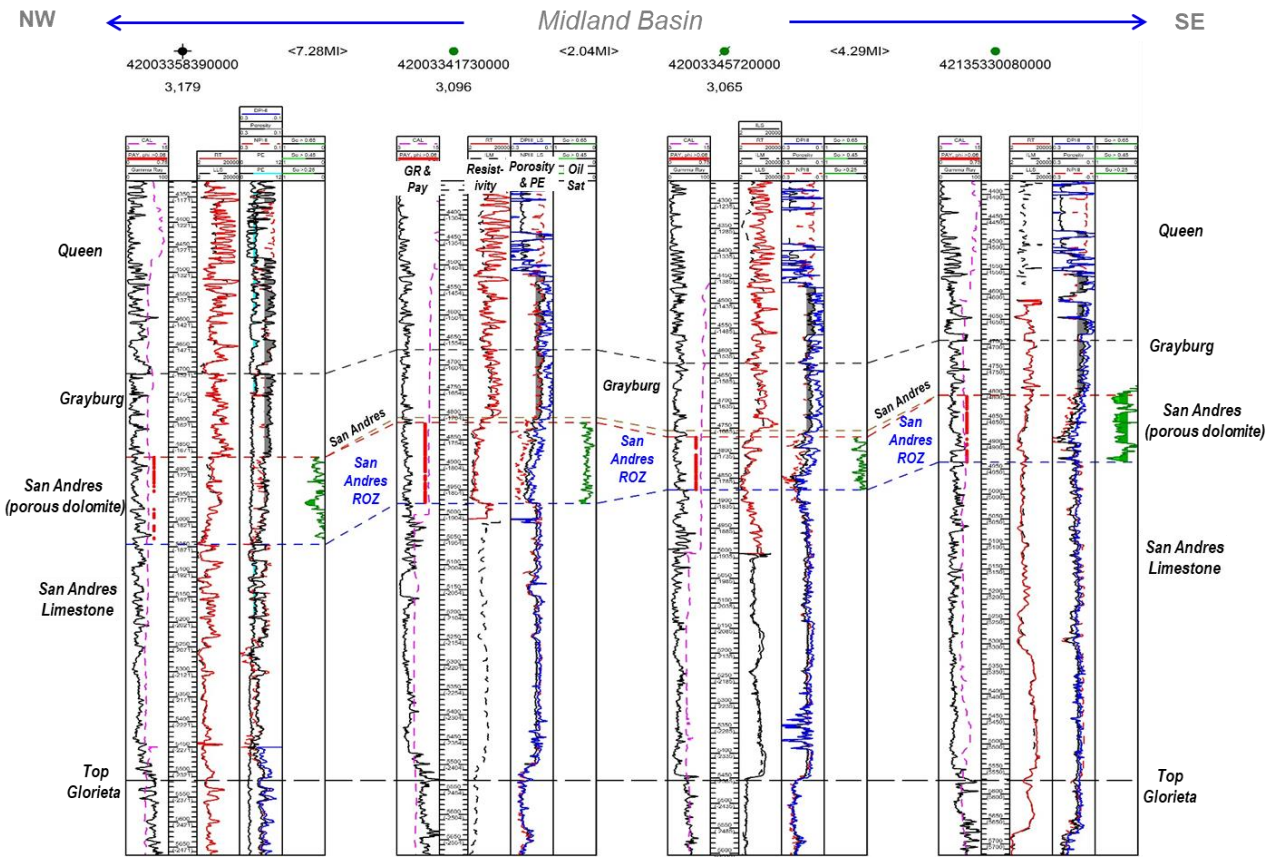


Exhibit 2-5. Andrews County cross-section D-D'



2.1.2 Interpretation of Andrews County Cross-Sections

For logs from the ROZ fairway, the top of the San Andres porous dolomite is picked as the top of the ROZ for this resource assessment.

The cross-sections display gamma-ray and caliper logs in Track 1 on the left. Resistivity logs are shown in Track 2, with the deep resistivity log shown in red. Track 3 shows the porosity logs. Uncorrected neutron porosity (for limestone) is red; uncorrected density porosity (for limestone) is blue. The porosity curve used for the OIP calculation is black. The PEF curve, if available, is also displayed in Track 3. PEF values greater than 4 are shaded in blue. Within and below the ROZ interval, high PEF values generally indicate the presence of limestone, dolomitic limestone, or anhydrite.

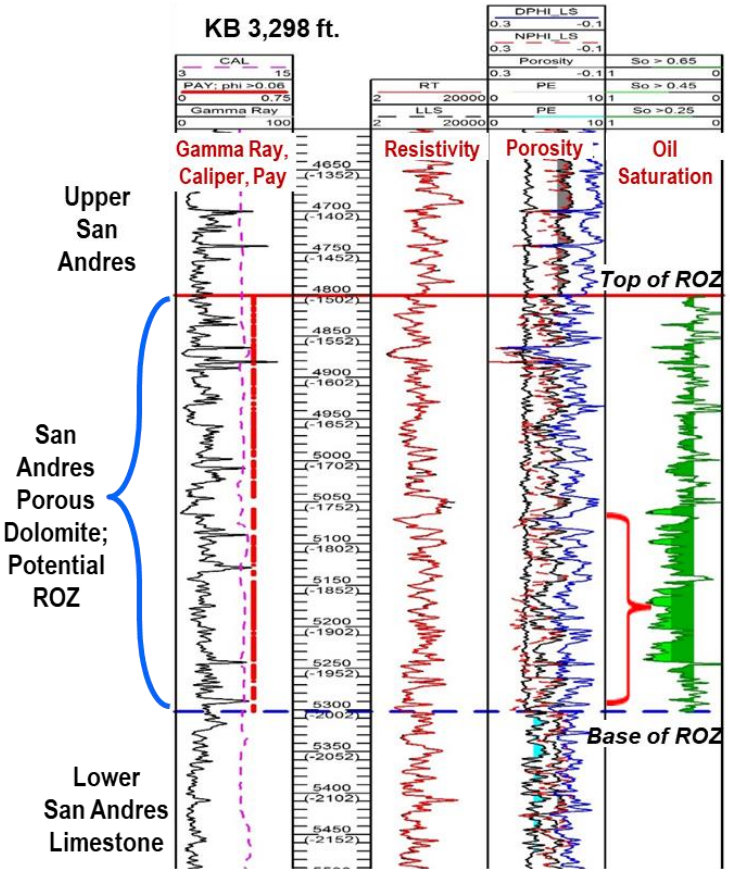
Track 4 on the right shows the calculated oil saturation. Calculated oil saturations between 25 percent and 40 percent are dark green and calculated oil saturations between 45 percent and 60 percent are light green.

The base of the ROZ is where either calculated oil saturation or apparent porosity (or both) diminish in the Lower San Andres. If a Lower San Andres limestone is prominent, the top of the limestone defines the base of the ROZ.

2.1.3 Andrews County Type Log

A "type log" was selected from the Andrews County study wells to illustrate the ROZ resource analysis undertaken for the county (Exhibit 2-6). In this well, porosity diminishes toward the base of the ROZ where the gamma ray log shows increasing shale in the ROZ interval. The base of the ROZ is picked at the top of a thick low porosity interval at about 5,300 feet.

Exhibit 2-6. Andrews County San Andres ROZ type well 42-003-37529



- Density and neutron porosity logs are corrected for dolomite; cross-plot of porosity is used to compute oil saturation.
- Cross-plot porosity is shown in black. Uncorrected neutron porosity (limestone) shown in red. Uncorrected density porosity (limestone) shown in blue.
- Calculated porosity less than 0.06 is shaded dark gray. Calculated oil saturation greater then 0.25 is shaded in green
- Type well is a Clear Fork test located in the San Andres "Fairway", at the boundary of a large San Andres Field.
- Potential ROZ is approx. 500' thick with net pay of 358'.
- Base of ROZ is low porosity limestone of the Lower San Andres.
- Archie parameters used to compute oil saturation from well logs: Rw=0.07 ohm-m, m=2.3, n=3.4, a=1.
- Average oil saturation = 37%; Average porosity = 10.5%.

The oil saturation for the type log ROZ was calculated using the following Archie parameters—'m' of 2.3, 'n' of 3.4, 'a' of 1, and formation water resistivity (Rw) of 0.07 ohm-m. A porosity cut-off of 6 percent was applied to define net pay in the ROZ. Intervals identified as ROZ pay are shown by the red "pay" flag in Track 1 in Exhibit 2-6.

2.2 Partitioning the Andrews County San Andres ROZ Fairway Resource

The ROZ fairway in Andrews County has been divided into three partitions, as illustrated in Exhibit 2-1. Individual San Andres ROZ fairway resource assessments were undertaken for each of the three partitioned areas. The eastern portion of Andrews County encompassing 192,500 acres where the San Andres ROZ is absent and the 110,400 acres below existing oil fields have

been excluded, leaving a remaining San Andres ROZ fairway assessment area of 657,600 acres (Exhibit 2-7).

Exhibit 2-7. Andrews County San Andres ROZ fairway partitions

Partition	Total Area	Excluded Area Below Oil Fields	Assessment Area
	Acres	Acres	Acres
#1	268,800	2,700	266,100
#2	380,000	99,300	280,700
#3	119,200	8,400	110,800
Total	**768,000**	**110,400**	**657,600**

Partition #1. Covers a 268,800-acre area of western Andrews County on the CBP. The Union oil field, covering 2,700 acres, has been excluded from Partition #1, leaving a ROZ fairway area of 266,100 acres.

Partition #2. Covers a 380,000-acre area of central Andrews County on the CBP. Five large San Andres oil fields—Emma (5,400 acres), Fuhrman-Mascho (49,600 acres), Fullerton (13,600 acres), Means (14,900 acres), and Shafter Lake (15,800 acres)—have been excluded from Partition #2, leaving an area of 280,700 acres.

Partition #3. Covers an 119,200-acre area of eastern Andrews County in the Midland Basin. An 8,400-acre area, encompassing the western portion of the Midland Farms San Andres oil field, has been excluded from Partition #3, leaving a fairway area of 110,800 acres.

2.3 Size and Quality of the Andrews County San Andres ROZ Fairway Resource

Andrews County, Texas holds 33,480 million barrels of OIP in the San Andres ROZ fairway outside the structural closure of the existing oil fields. The OIP and resource quality values for each of the three partitions of Andrews County are shown in Exhibit 2-8.

- Higher Quality ROZ Fairway Resources. A significant portion, 28,150 million barrels, of the San Andres ROZ fairway OIP in Andrews County has higher quality reservoir properties (porosity greater than 8 percent and oil saturation equal to or greater than 25%).
- Lower Quality ROZ Fairway Resources. The remainder, 5,330 million barrels, of the San Andres ROZ fairway OIP in Andrews County has lower quality reservoir properties (porosity equal to or less than 8 percent and/or oil saturation of less than 25%).

Exhibit 2-8. Andrews County San Andres ROZ fairway resource in-place (MM bbl)

Partitions	Higher Quality	Lower Quality	Total
#1	17,330	530	17,860
#2	10,820	3,420	14,240
#3	-	1,380	1,380
Total	**28,150**	**5,330**	**33,480**

2.4 Technically Recoverable Andrews County ROZ Fairway Resource

2.4.1 Methodology for Estimating Technically Recoverable Resources

The average volumetric reservoir properties for each partition of Andrews County, along with proprietary reservoir properties from ARI's Big Oil Fields Data Base, were used as input into the Prophet Model. Additionally, it was assumed that 80 percent of each partition area was suitable for development, while 20 percent of the partition had a combination of net pay, porosity, or oil saturation that was not suitable for development. It was also assumed that 90 percent of the OIP in each partition resides in the area suitable for development. The net pay for the developed portion of the partition was increased so that the OIP in the developed portion equaled 90 percent of the OIP calculated for the entire partition. The Prophet Model was then used to calculate the volumes of recoverable oil and water as well as the volumes of injected and stored CO_2. The Prophet Model was run assuming five-spot patterns were implemented for each partition. ROZ fairway well pattern spacings of 40 acres per CO_2 injection well were selected to achieve a target of approximately 30 years of operation for the miscible CO_2 flood.

2.4.2 Summary of Technically Recoverable Resources

A significant portion of the San Andres ROZ fairway OIP in Andrews County is technically recoverable using miscible CO_2 EOR, while also providing major volumes of pore space for storing CO_2 (Exhibit 2-9).

- Total technically viable oil recovery is estimated at 10,080 million barrels, produced primarily from the higher quality portions of the ROZ resource.
- While the oil recovery efficiencies vary by partition, overall recovery efficiency is 30 percent of OIP in response to one HCPV injection of CO_2 using a tapered WAG miscible CO_2 flood.
- The San Andres ROZ fairway interval in Andrews County offers the potential for significant storage of CO_2, equal to 4,863 million metric tons (91,910 Bcf).

Exhibit 2-9. Andrews County technically recoverable San Andres ROZ fairway resource

Partitions	Oil Recovery		Purchased CO_2	
	MM bbl	%OIP	Bcf	MM mt
#1	5,460	31%	41,270	2,184
#2	4,250	30%	44,860	2,374
#3	370	27%	5,780	306
Total	**10,080**	**30%**	**91,910**	**4,864**

2.5 Viability of Oil Recovery and CO_2 Storage in the Andrews County ROZ Fairway Resource

The CO_2 EOR Cost Model used by the study assumes a first-year oil price (WTI) of $75 per barrel linked to an initial CO_2 purchase cost of $1.50 per Mcf ($28.35 per metric ton of CO_2).

2.5.1 Commercially Viable Oil Recovery with By-Product CO_2 Storage

The three San Andres ROZ fairway partitions of Andrews County offer the potential for 8,770 million barrels of commercially viable oil recovery with 3,605 million metric tons (68,130 Bcf) of by-product storage of CO_2, Exhibit 2-10.

Exhibit 2-10. Andrews County commercially viable oil recovery with by-product CO_2 storage

Partition	Oil Recovery (MM bbl)	Purchased CO_2		Purchased CO_2/Oil Recovery (Ratio)	
		Bcf	MM mt	Mcf/B	mt/B
#1	5,320	39,210	2,075	7.4	0.39
#2	3,450	28,920	1,530	8.4	0.44
#3	-	-	-	-	-
Total	**8,770**	**68,130**	**3,605**	**7.8**	**0.41**

The commercially viable portion of the ROZ resource has a purchased CO_2 to produced oil ratio of 0.41 metric tons of CO_2 per barrel of recovered oil (7.8 Mcf per barrel), ranging from 0.39 metric ton per barrel in Partition #1 to 0.44 metric ton per barrel in Partition #2.

2.5.2 Geologically Viable CO_2 Storage with By-Product Oil Recovery

The three San Andres ROZ fairway partitions of Andrews County also offer potential for 1,258 million metric tons (23,780 Bcf) of geologically viable CO_2 storage with 1,310 million barrels of by-product oil recovery, as shown in Exhibit 2-11.

Exhibit 2-11. Andrews County geologically viable CO_2 storage with by-product oil recovery

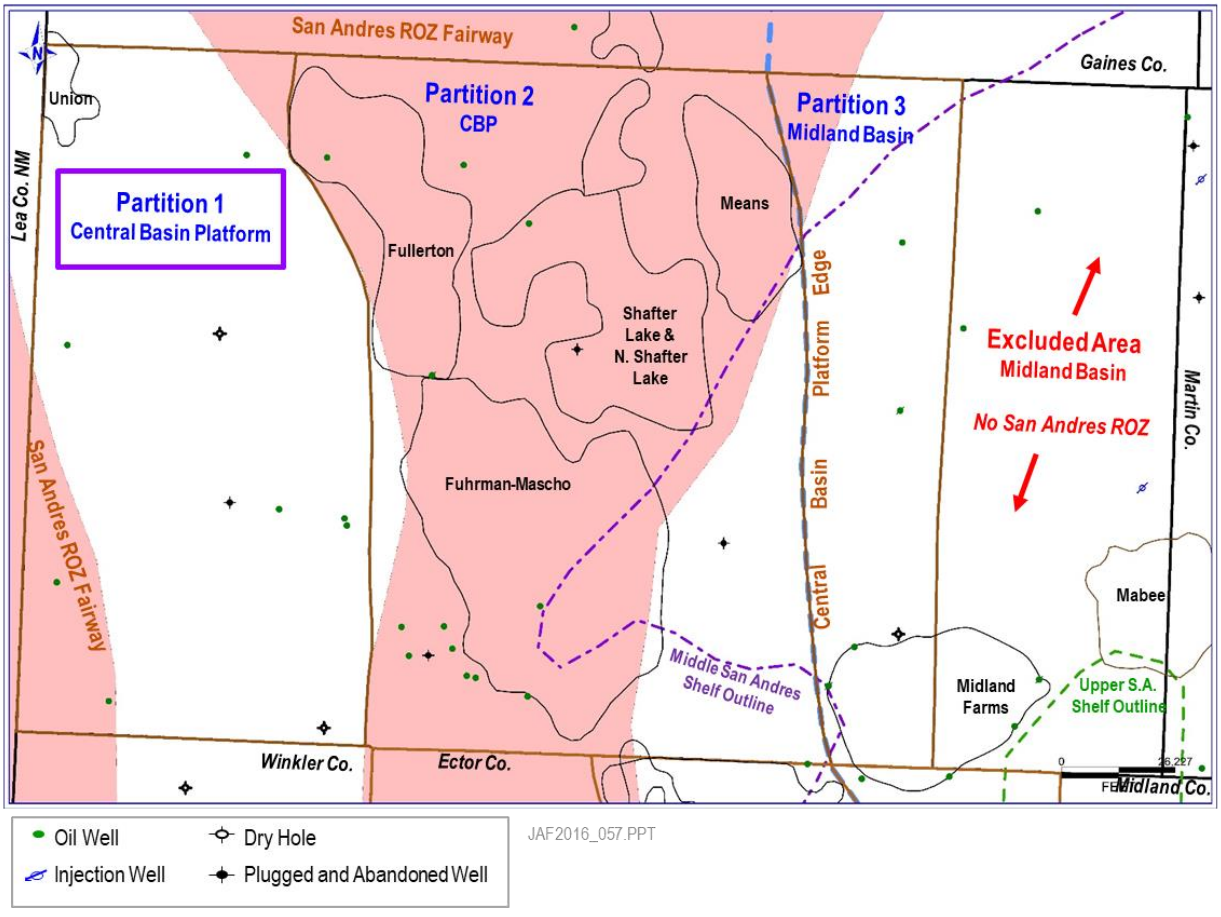
Partition	Purchased CO_2		By-Product Oil Recovery (MM bbl)	Purchased CO_2/ Oil Recovery (Ratio)	
	Bcf	MM mt		Mcf/B	mt/B
#1	2,060	109	140	14.7	0.78
#2	15,940	843	800	19.9	1.05
#3	5,780	306	370	15.6	0.83
Total	**23,780**	**1,258**	**1,310**	**18.1**	**0.96**

2.6 Partition #1. Western Andrews County

2.6.1 Geologic Setting

Partition #1, located in western Andrews County, covers a San Andres ROZ fairway area of 266,100 acres (Exhibit 2-12). The partition excludes areas underlain by San Andres oil fields (2,700 acres). Partition #1 is located west of the previously established San Andres ROZ fairway boundaries, in the CBP.

Exhibit 2-12. San Andres ROZ fairway Partition #1, Andrews County



2.6.2 Analytic ROZ Reservoir Properties

Nine well log-based reservoir data sets plus a series of working level cross-sections were used to allocate the San Andres ROZ fairway resource in Partition #1 of Andrews County into two analytical ROZ fairway reservoir units:

- A higher quality ROZ resource
- A lower quality ROZ resource

The average volumetric reservoir properties for the two analytical San Andres ROZ fairway reservoir units of Partition #1 of Andrews County are provided in Exhibit 2-13.

Exhibit 2-13. Average San Andres ROZ fairway reservoir properties: Partition #1, Andrews County

Property	Higher Quality	Lower Quality
Depth (to top) (ft)	4,640	4,950
Gross Thickness (ft)	526	246
Net Pay (ft)	368	172
Avg. Porosity (fraction)	0.110	0.095
Avg. Oil Saturation (fraction)	0.35	0.21
Avg. Formation Volume Factor (res B/bbl)	1.20	1.20
OIP (BBLS/AF, for net pay)	249	129

2.6.3 ROZ OIP

The San Andres ROZ fairway in Partition #1 of Andrews County contains 17,860 million barrels of OIP, Exhibit 2-14. The bulk of the ROZ OIP (17,330 million barrels) meets the higher ROZ resource quality criteria. The remainder of the ROZ OIP of 530 million barrels meets the lower resource quality criteria.

Exhibit 2-14. San Andres ROZ fairway OIP: Partition #1, Andrews County

Property	Higher Quality	Lower Quality
OIP (Bbls/Acre)	91,610	22,200
Area Extent (Acres)	189,200	23,680
OIP (MM bbl)	17,330	530

2.6.4 Technically Recoverable Resources

Of the 17,860 million barrels of San Andres ROZ OIP in Partition #1 of Andrews County, approximately 5,460 million barrels is technically recoverable from the application of miscible CO_2 EOR, giving a recovery efficiency of 31 percent of OIP.

In addition, significant volumes of CO_2 are injected and stored as part of applying miscible CO_2 EOR for recovering a portion of the ROZ OIP. Approximately 2,180 million metric tons (41,270

Bcf) of CO_2 are purchased for the San Andres ROZ fairway EOR project in Partition #1 of Andrews County, with essentially all of the purchased CO_2 securely stored at the end of the CO_2 flood.

2.6.5 Commercially Viable Oil Recovery with By-Product CO_2 Storage

Of the 5,460 million barrels of technically recoverable San Andres ROZ fairway oil resource available from Partition #1 of Andrews County, 5,320 million barrels are commercially viable to develop under the economic assumptions used in this study.

The application of CO_2 EOR to the commercially viable portion of the San Andres ROZ fairway resource in Partition #1 of Andrews County also provides 2,075 million metric tons (39,210 Bcf) of by-product storage of CO_2 (Exhibit 2-15).

Exhibit 2-15. Commercially viable oil recovery with by-product CO_2 storage: Partition #1, Andrews County

Oil Recovery (MM bbl)	Purchased CO_2		Purchased CO_2/Oil Recovery (Ratio)	
	Bcf	MM mt	Mcf/B	mt/B
5,320	39,210	2,075	7.4	0.39

The production of one barrel of San Andres ROZ fairway oil in Partition #1 of Andrews County brings with it, at the margin, the storage of 0.39 metric tons of CO_2 when using high pressure CO_2 injection as the oil recovery method.

2.6.6 Geologically Viable CO_2 Storage with By-Product Oil Recovery

Pursuing the geologically viable, but economically non-viable, portion of the San Andres ROZ fairway resource in Partition #1 of Andrews County with miscible CO_2 flooding provides 109 million metric tons (2,060 Bcf) of CO_2 storage capacity with 140 million barrels of by-product oil recovery (Exhibit 2-16).

Exhibit 2-16. Geologically viable storage of CO_2 with by-product oil recovery: Partition #1, Andrews County

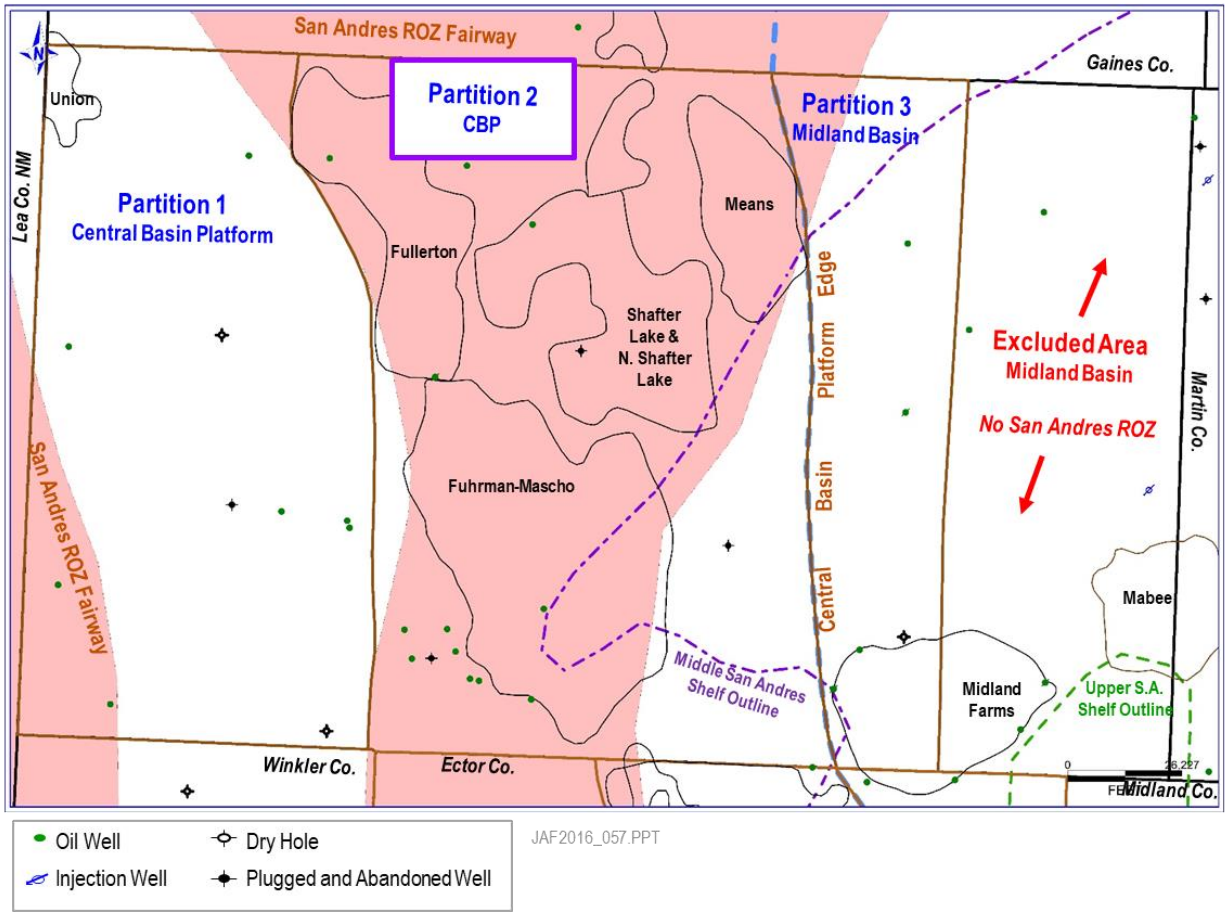
Purchased CO_2		By-Product Oil Recovery (MM bbl)	Purchased CO_2/ Produced Oil (Ratio)	
Bcf	MM mt		Mcf/B	mt/B
2,060	109	140	14.7	0.78

2.7 Partition #2. Central Andrews County

2.7.1 Geologic Setting

Partition #2, located in central Andrews County, covers a San Andres ROZ fairway area of 280,700 acres (Exhibit 2-17). The partition excludes areas underlain by San Andres oil fields (99,300 acres). Much of Partition #2 is located inside the previously established San Andres ROZ fairway boundaries, in the CBP.

Exhibit 2-17. San Andres ROZ fairway Partition #2, Andrews County



2.7.2 Analytic ROZ Reservoir Properties

Eight well log-based reservoir data sets plus a series of working level cross-sections were used to allocate the San Andres ROZ fairway resource in Partition #2 of Andrews County into two analytical ROZ fairway reservoir units:

- A higher quality ROZ resource
- A lower quality ROZ resource

The average volumetric reservoir properties for the two analytical San Andres ROZ fairway reservoir units of Partition #2 of Andrews County are provided in Exhibit 2-18.

Exhibit 2-18. Average San Andres ROZ fairway reservoir properties: Partition #2, Andrews County

Property	Higher Quality	Lower Quality
Depth (to top) (ft)	4,690	4,940
Gross Thickness (ft)	516	412
Net Pay (ft)	424	243
Avg. Porosity (fraction)	0.114	0.106
Avg. Oil Saturation (fraction)	0.32	0.19
Avg. Formation Volume Factor (res B/bbl)	1.25	1.25
OIP (BBLS/AF, for net pay)	227	125

2.7.3 ROZ OIP

The San Andres ROZ fairway in Partition #2 of Andrews County contains 14,240 million barrels of OIP (Exhibit 2-19). The bulk of the ROZ OIP (10,820 million barrels) meets the higher ROZ resource quality criteria. The remainder of the ROZ OIP of 3,420 million barrels meets the lower resource quality criteria.

Exhibit 2-19. San Andres ROZ fairway OIP: Partition #2, Andrews County

Property	Higher Quality	Lower Quality
OIP (Bbls/Acre)	96,270	30,380
Area Extent (Acres)	112,280	112,280
OIP (MM bbl)	10,820	3,420

2.7.4 Technically Recoverable Resources

Of the 14,240 million barrels of San Andres ROZ OIP in Partition #2 of Andrews County, approximately 4,250 million barrels are technically recoverable from the application of miscible CO_2 EOR, giving a recovery efficiency of 30 percent of OIP.

In addition, significant volumes of CO_2 are injected and stored as part of applying miscible CO_2 EOR for recovering a portion of the ROZ OIP. Approximately 44,860 million metric tons (2,370 Bcf) of CO_2 are purchased for the San Andres ROZ fairway EOR project in Partition #2 of Andrews County, with essentially all of the purchased CO_2 securely stored at the end of the CO_2 flood.

2.7.5 Commercially Viable Oil Recovery with By-Product CO_2 Storage

Of the 4,250 million barrels of technically recoverable San Andres ROZ fairway oil resource available from Partition #2 of Andrews County, 3,450 million barrels are commercially viable to develop under the economic assumptions used in this study.

The application of CO_2 EOR to the commercially viable portion of the San Andres ROZ fairway resource in Partition #2 of Andrews County also provides 1,531 million metric tons (28,920 Bcf) of by-product storage of CO_2 (Exhibit 2-20).

Exhibit 2-20. Commercially viable oil recovery with by-product CO_2 storage: Partition #2, Andrews County

Oil Recovery (MM bbl)	Purchased CO_2		Purchased CO_2/Oil Recovery (Ratio)	
	Bcf	MM mt	Mcf/B	mt/B
3,450	28,920	1,531	8.4	0.44

The production of one barrel of San Andres ROZ fairway oil in Partition #2 of Andrews County brings with it, at the margin, the storage of 0.44 metric tons of CO_2 when using high pressure CO_2 injection as the oil recovery method.

2.7.6 Geologically Viable CO_2 Storage with By-Product Oil Recovery

Pursuing the geologically viable, but economically non-viable, portion of the San Andres ROZ fairway resource in Partition #2 of Andrews County, with 800 million barrels of miscible CO_2 flooding provides 843 million metric tons (15,940 Bcf) of CO_2 storage capacity and 800 million barrels of by-product oil recovery (Exhibit 2-21).

Exhibit 2-21. Geologically viable storage of CO_2 with by-product oil recovery: Partition #2, Andrews County

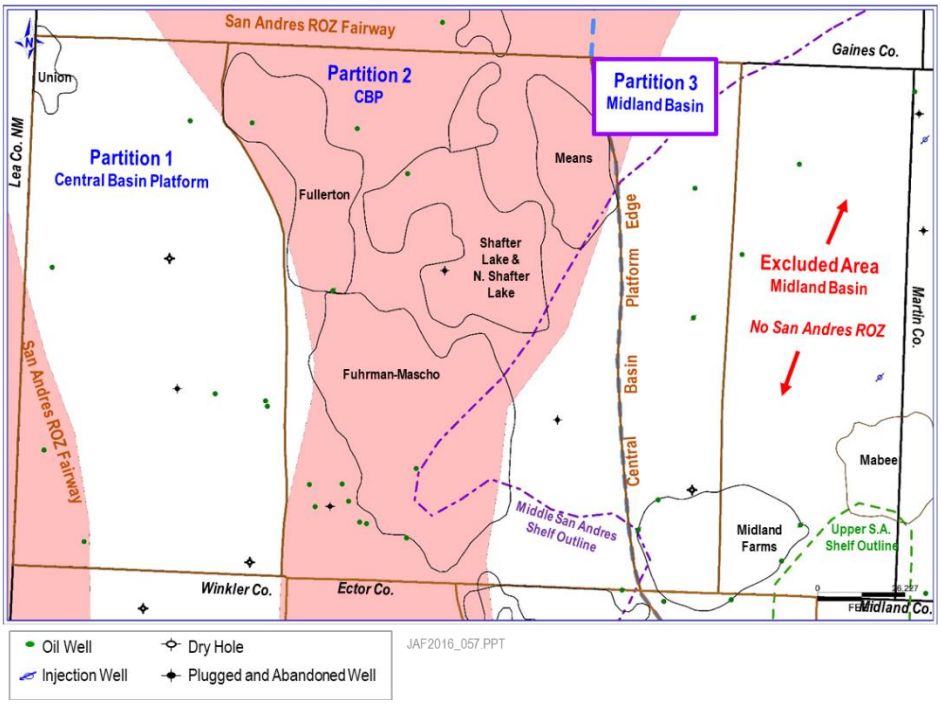
Purchased CO_2		By-Product Oil Recovery (MM bbl)	Purchased CO_2/Produced Oil (Ratio)	
Bcf	MM mt		Mcf/B	mt/B
15,940	843	800	19.9	1.05

2.8 Partition #3. Eastern Andrews County

2.8.1 Geologic Setting

Partition #3, located in eastern Andrews County, covers a San Andres ROZ fairway area of 110,800 acres (Exhibit 2-22). The partition excludes areas underlain by San Andres oil fields (8,400 acres). Partition #3 is located outside the previously established San Andres ROZ fairway boundaries, in the Midland Basin of the Permian Basin.

Exhibit 2-22. San Andres ROZ fairway Partition #3, Andrews County



2.8.2 Analytic ROZ Reservoir Properties

Four well log-based reservoir data sets plus a series of working level cross-sections were used to allocate the San Andres ROZ fairway resource in Partition #3 of Andrews County into one analytical ROZ fairway reservoir unit:

- A lower quality ROZ resource

The average volumetric reservoir properties for the one analytical San Andres ROZ fairway reservoir unit of Partition #3 of Andrews County are provided in Exhibit 2-23.

Exhibit 2-23. Average San Andres ROZ fairway reservoir properties: Partition #3, Andrews County

Property	Higher Quality	Lower Quality
Depth (to top) (ft)	-	4,950
Gross Thickness (ft)	-	133
Net Pay (ft)	-	87
Avg. Porosity (fraction)	-	0.121
Avg. Oil Saturation (fraction)	-	0.21
Avg. Formation Volume Factor (res B/bbl)	-	1.10
OIP (BBLS/AF, for net pay)	-	179

2.8.3 ROZ OIP

The San Andres ROZ fairway in Partition #3 of Andrews County contains 1,380 million barrels of OIP (Exhibit 2-24). The ROZ OIP in Partition #3 meets the lower resource quality criteria.

Exhibit 2-24. San Andres ROZ fairway OIP: Partition #3, Andrews County

Property	Higher Quality	Lower Quality
OIP (Bbls/Acre)	-	15,500
Area Extent (Acres)	-	88,640
OIP (MM bbl)	-	1,380

2.8.4 Technically Recoverable Resources

Of the 1,380 million barrels of San Andres ROZ OIP in Partition #3 of Andrews County, 370 million barrels is technically recoverable from the application of miscible CO_2 EOR, giving a recovery efficiency of 27 percent of OIP.

In addition, significant volumes of CO_2 are injected and stored as part of applying miscible CO_2 EOR for recovering a portion of the ROZ OIP. Approximately 306 million metric tons (5,780 Bcf) of CO_2 are purchased for the San Andres ROZ fairway EOR project in Partition #3 of Andrews County, with essentially all of the purchased CO_2 securely stored at the end of the CO_2 flood.

2.8.5 Commercially Viable Oil Recovery with By-Product CO_2 Storage

Of the 370 million barrels of technically recoverable San Andres ROZ fairway oil resource in Partition #3 of Andrews County, no portion of this resource is economically viable to develop under the economic assumptions used in this study (Exhibit 2-25).

Exhibit 2-25. Commercially viable oil recovery with by-product CO_2 storage: Partition #3, Andrews County

Oil Recovery (MM bbl)	Purchased CO_2		Purchased CO_2/Oil Recovery (Ratio)	
	Bcf	MM mt	Mcf/B	mt/B
-	-	-	-	-

2.8.6 Geologically Viable CO_2 Storage with By-Product Oil Recovery

Pursuing the geologically viable, but economically non-viable, portion of the San Andres ROZ fairway resource in Partition #3 of Andrews County with miscible CO_2 flooding provides 306 million metric tons (5,780 Bcf) of CO_2 storage capacity with 370 million barrels of by-product oil recovery (Exhibit 2-26).

Exhibit 2-26. Geologically viable storage of CO_2 with by-product oil recovery: Partition #3, Andrews County

Purchased CO_2		By-Product Oil Recovery (MM bbl)	Purchased CO_2/Produced Oil (Ratio)	
Bcf	MM mt		Mcf/B	mt/B
5,780	306	370	15.6	0.83

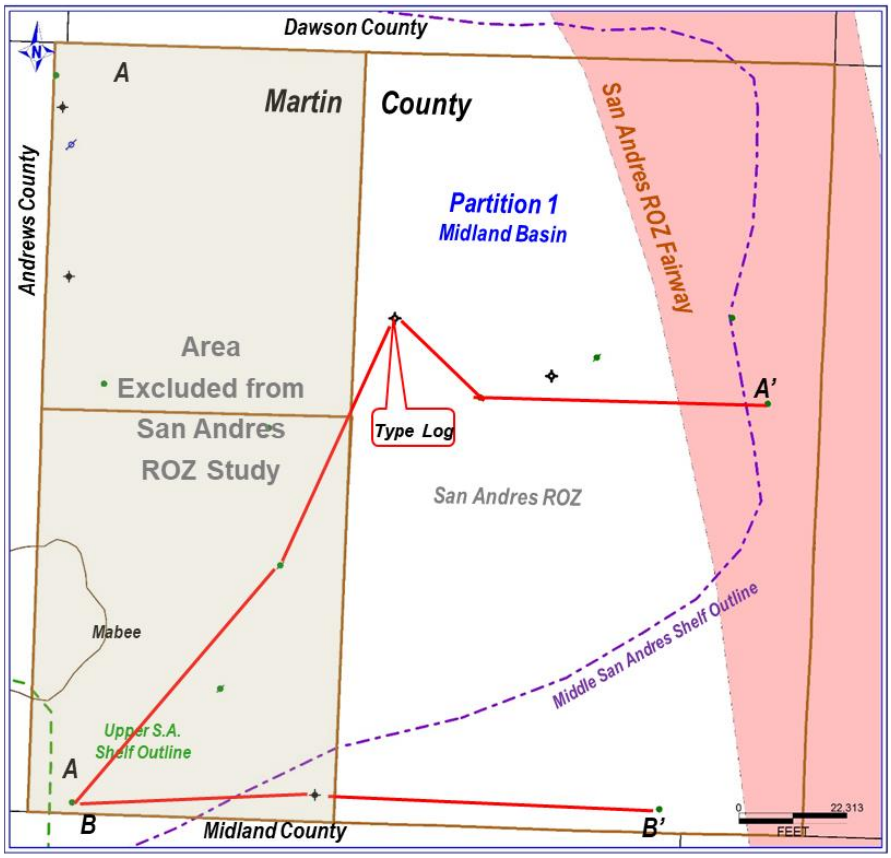
3 MARTIN COUNTY

3.1 GEOLOGIC SETTING OF THE MARTIN COUNTY SAN ANDRES ROZ FAIRWAY

Martin County, Texas, covers a 586,100-acre area in the West Texas portion of the Permian Basin. The county is east of the CBP and within the eastward prograding Lower and Middle San Andres shelf margins of the Midland Basin. The western portion of Martin County, covering 232,400 acres where the San Andres ROZ is absent along with any ROZ below existing oil fields, has been excluded from the San Andres ROZ fairway resource assessment.

The Martin County map (Exhibit 3-1) shows 1) the location of seven study wells, 2) the one San Andres ROZ fairway partition established by the study, 3) the boundaries of the previously established San Andres ROZ fairway, 4) the outline of the Middle San Andres shelf, and 5) the location of two regional cross-sections featuring the San Andres ROZ. The map also shows the major San Andres oil fields excluded from the San Andres ROZ fairway resource assessment in Martin County.

Exhibit 3-1. Martin County: geologic partitions, major oil fields, and study well locations



* Ward, R.F., Kendall, C., Harris, P.M., 1986, Upper Permian (Guadalupian) Facies and Their Association with Hydrocarbons – Permian Basin, West Texas and New Mexico, AAPG Bulletin, V. 70, No.3, p. 239-262.

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3.1.1 Example Martin County Cross-Sections

The delineation and characterization of the San Andres ROZ fairway interval in Martin County utilized a series of working cross-sections. Two of these cross-sections are included in this report.

- Martin Co. cross-section A-A' (Exhibit 3-2) provides a southwest to northeast view of the San Andres ROZ interval in the Midland Basin.
- Martin Co. cross-section B-B' (Exhibit 3-3) provides an additional west to east view of the San Andres ROZ interval through the southern portion of the county.

Exhibit 3-2. Martin County cross-section A-A'

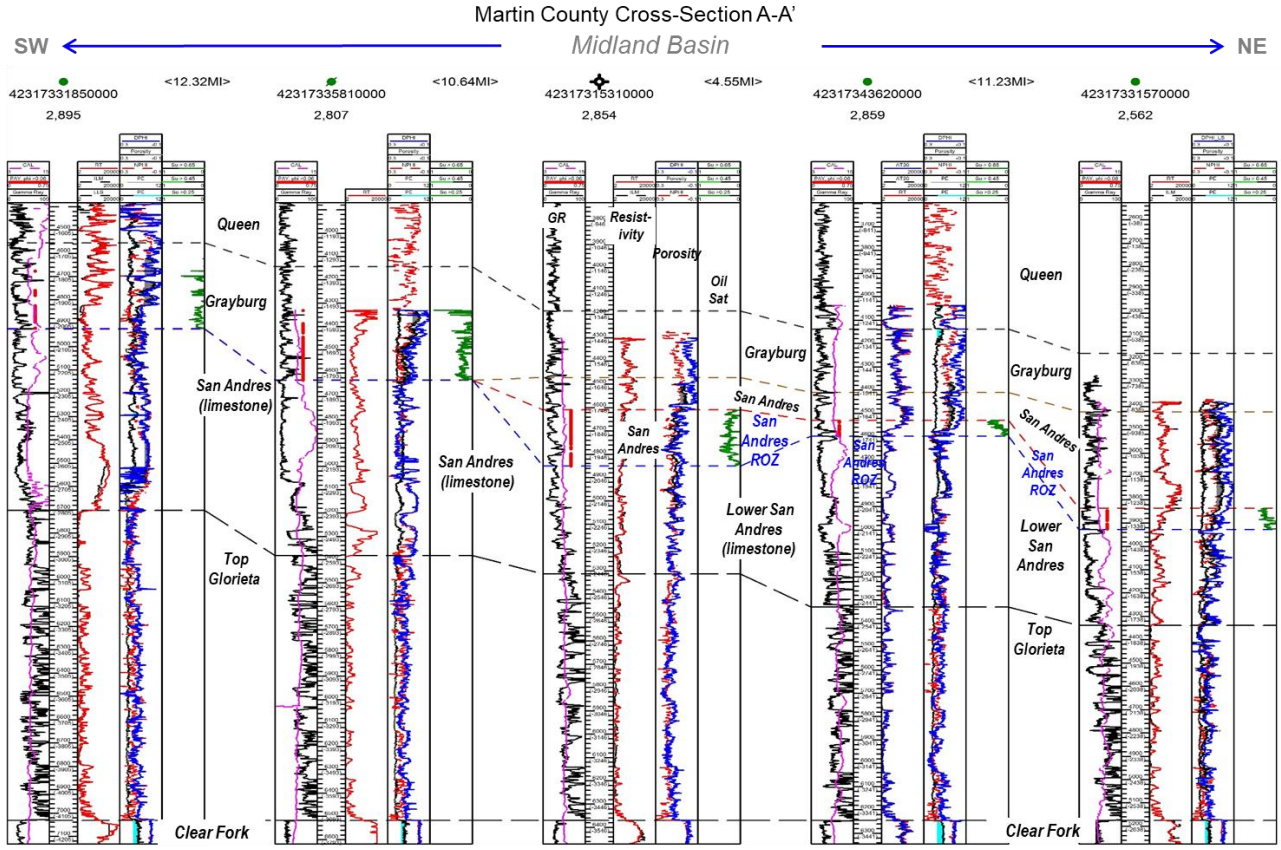
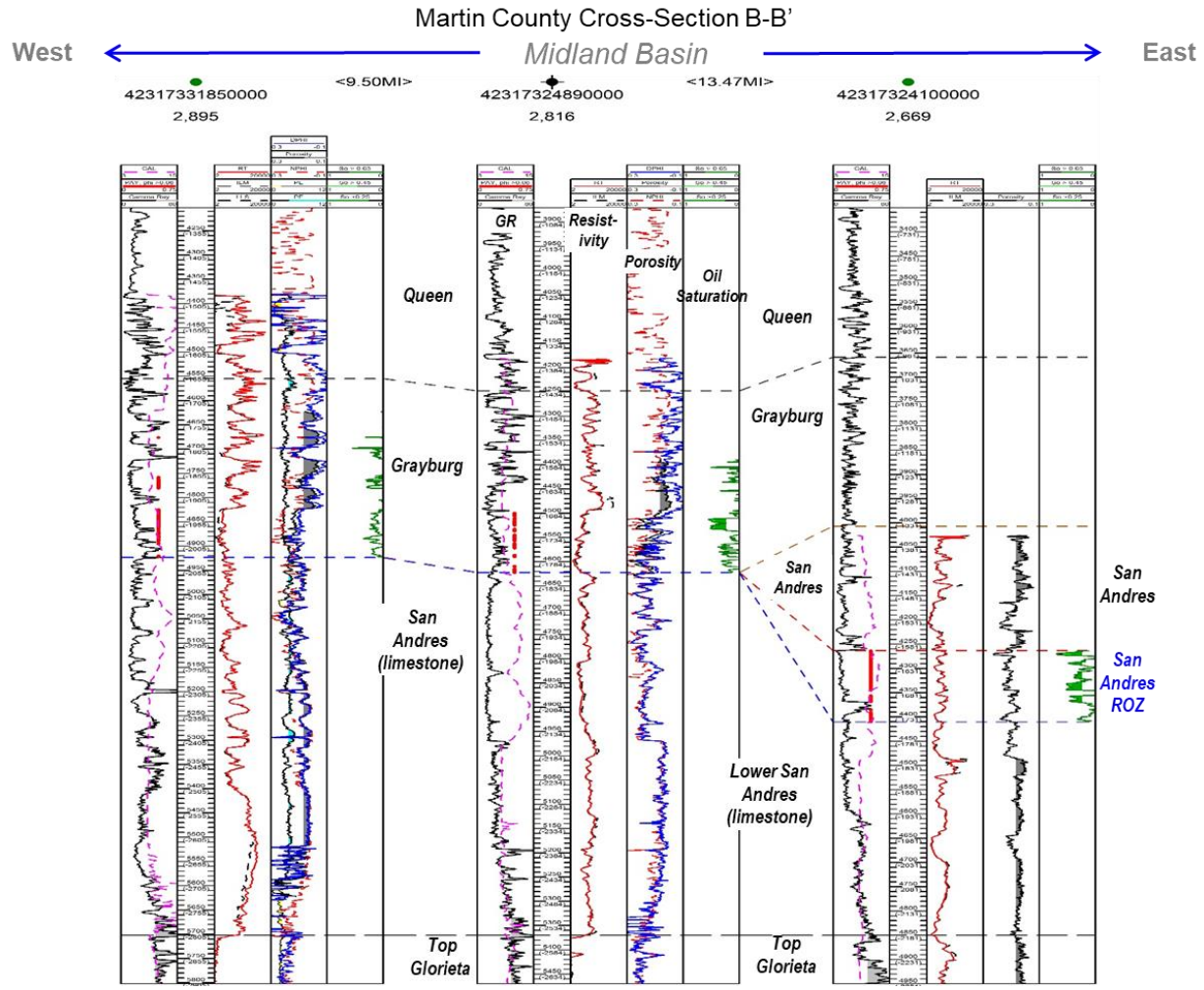


Exhibit 3-3. Martin County cross-section B-B'



3.1.2 Interpretation of Martin County Cross-Sections

For logs from the ROZ fairway, the top of the San Andres porous dolomite is picked as the top of the ROZ for this resource assessment.

The cross-sections display gamma-ray and caliper logs in Track 1 on the left. Resistivity logs are shown in Track 2, with the deep resistivity log shown in red. Track 3 shows the porosity logs. Uncorrected neutron porosity (for limestone) is red; uncorrected density porosity (for limestone) is blue. The porosity curve used for the OIP calculation is black.

The PEF curve, if available, is also displayed in Track 3. PEF values greater than 4 are shaded in blue. Within and below the ROZ interval, high PEF values generally indicate the presence of limestone, dolomitic limestone, or anhydrite.

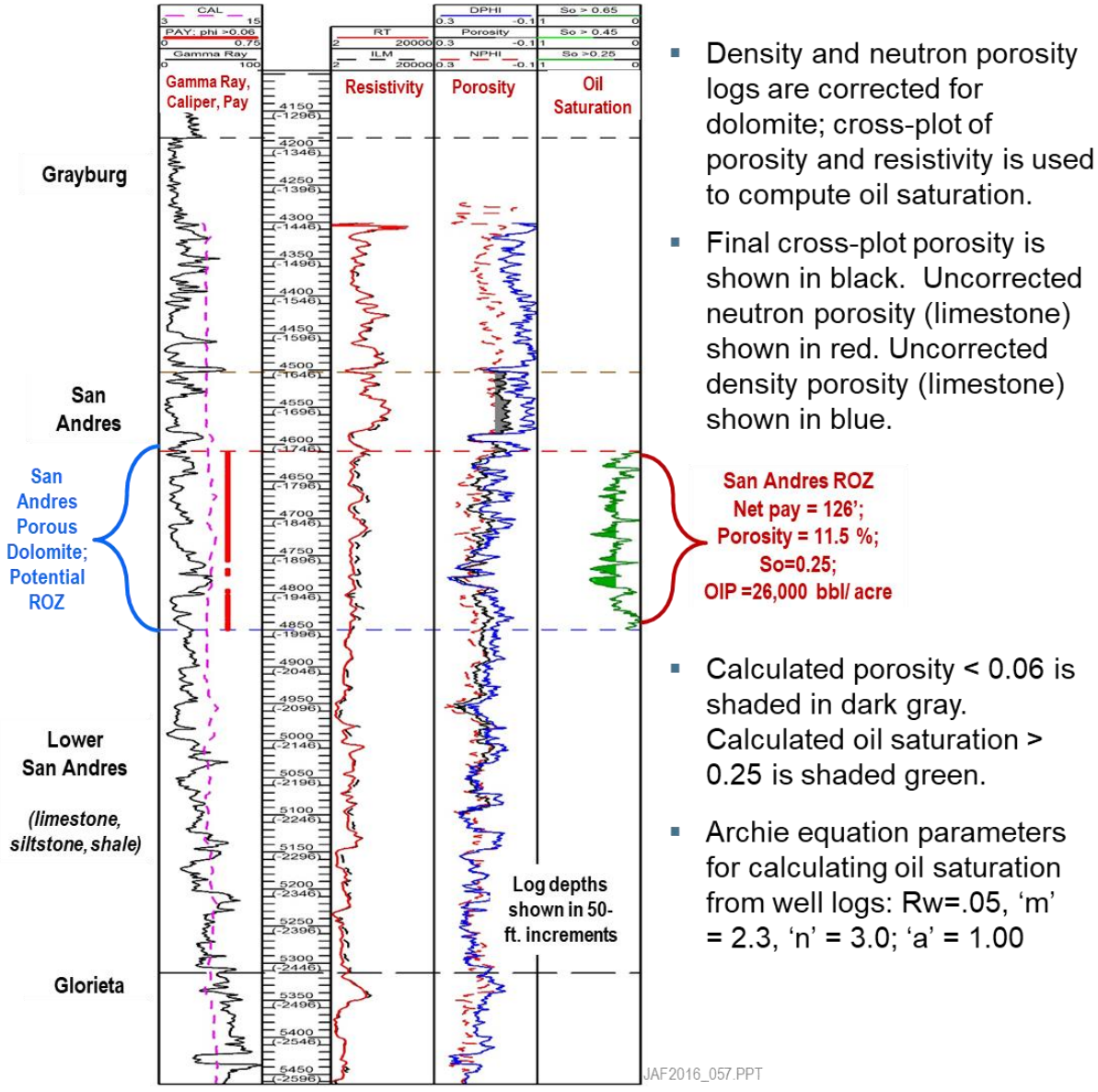
Track 4 on the right shows the calculated oil saturation. Calculated oil saturations between 25 percent and 40 percent are dark green; calculated oil saturations between 45 percent and 60 percent are light green; and oil saturation greater than 65 percent, typically present in only the MPZ, are black.

The base of the ROZ is where either calculated oil saturation or apparent porosity (or both) diminish in the Lower San Andres. If a Lower San Andres limestone is prominent, the top of the limestone defines the base of the ROZ.

3.1.3 Martin County Type Log

A type log was selected from the Martin County study wells to illustrate the ROZ resource analysis undertaken for the county (Exhibit 3-4). The base of the ROZ is picked at the top of a thick low porosity interval.

Exhibit 3-4. Martin County San Andres ROZ type well 42-003-37529



- Density and neutron porosity logs are corrected for dolomite; cross-plot of porosity and resistivity is used to compute oil saturation.
- Final cross-plot porosity is shown in black. Uncorrected neutron porosity (limestone) shown in red. Uncorrected density porosity (limestone) shown in blue.
- Calculated porosity < 0.06 is shaded in dark gray. Calculated oil saturation > 0.25 is shaded green.
- Archie equation parameters for calculating oil saturation from well logs: Rw=.05, 'm' = 2.3, 'n' = 3.0; 'a' = 1.00

The oil saturation for the type log ROZ was calculated using the following Archie parameters — 'm' of 2.3, 'n' of 3.0, 'a' of 1, and formation water resistivity (Rw) of 0.05 ohm-m. A porosity cut-off of 6 percent was applied to define net pay in the ROZ. Intervals identified as ROZ pay are shown by the red pay flag in Track 1 in (Exhibit 3-4).

3.2 Partitioning the Martin County San Andres ROZ Fairway

The ROZ fairway in Martin County contains one partition, as illustrated in Exhibit 3-1. Partition #1 of Martin County does not contain any significant San Andres oil fields. The western portion of Martin County, encompassing 232,400 acres where the San Andres ROZ is absent, has been excluded, leaving a remaining San Andres ROZ fairway assessment area of 353,700 acres, Exhibit 3-5.

- *Partition #1.* Covers a 353,700-acre area of Martin County on the Middle San Andres shelf. There are no San Andres oil fields within this partition, so the full partition area was included in the resource assessment.

Exhibit 3-5. Martin County San Andres ROZ fairway partition

Partition	Total Area	Excluded Area Below Oil Fields	Assessment Area
	Acres	Acres	Acres
Total	353,700	-	353,700

3.3 Size and Quality of the Martin County San Andres ROZ Fairway Resource

Martin County, Texas holds 6,060 million barrels of OIP in the San Andres ROZ fairway outside the structural closure of the existing oil fields. The OIP and resource quality values for the Martin County partition are shown in Exhibit 3-6.

- Higher Quality ROZ Fairway Resources. A significant portion, 4,320 million barrels, of the San Andres ROZ fairway OIP in Martin County has higher quality reservoir properties (porosity greater than 8 percent and oil saturation equal to or greater than 25%).
- Lower Quality ROZ Fairway Resources. The remainder, 1,740 million barrels, of the San Andres ROZ fairway OIP in Martin County has lower quality reservoir properties (porosity equal to or less than 8 percent and/or oil saturation of less than 25%).

Exhibit 3-6. Martin County San Andres ROZ fairway resource in-place (MM bbl)

Partitions	Higher Quality	Lower Quality	Total
Total	4,320	1,740	6,060

3.4 Technically Recoverable Martin County ROZ Fairway Resource

3.4.1 Methodology for Estimating Technically Recoverable Resources

The average volumetric reservoir properties for the Martin County Partition, along with proprietary reservoir properties from ARI's Big Oil Fields Data Base, were used as input into the Prophet Model. Additionally, it was assumed that 80 percent of each partition area was suitable for development, while 20 percent of the partition had a combination of net pay, porosity, or oil saturation that was not suitable for development. It was also assumed that 90 percent of the OIP in each partition resides in the area suitable for development. The net pay for the developed portion of the partition was increased so that the OIP in the developed portion equaled 90 percent of the OIP calculated for the entire partition. The Prophet Model was then used to calculate the volumes of recoverable oil and water as well as the volumes of injected and stored CO_2. The Prophet Model was run assuming five-spot patterns were implemented for each partition. ROZ fairway well pattern spacings of 40 acres per CO_2 injection well were selected to achieve a target of approximately 30 years of operation for the miscible CO_2 flood.

3.4.2 Summary of Technically Recoverable Resources

A significant portion of the San Andres ROZ fairway OIP in Martin County is technically recoverable using miscible CO_2 EOR, while also providing major volumes of pore space for storing CO_2 (Exhibit 3-7).

- Total technically viable oil recovery is estimated at 1,820 million barrels, produced primarily from the higher quality portions of the ROZ resource.
- While the oil recovery efficiencies vary by partition, overall recovery efficiency is 30% of OIP in response to one HCPV injection of CO_2 using a tapered WAG miscible CO_2 flood.
- The San Andres ROZ fairway interval in Martin County offers the potential for significant storage of CO_2, equal to 1,100 million metric tons (20,850 Bcf).

Exhibit 3-7. Martin County technically recoverable San Andres ROZ fairway resource

Partitions	Oil Recovery		Purchased CO_2	
	MM bbl	%OIP	Bcf	MM mt
Total	1,820	30%	20,850	1,100

3.5 Viability of Oil Recovery and CO_2 Storage in the Martin County ROZ Fairway

The CO_2 EOR Cost Model used by the study assumes a first-year oil price (WTI) of $75 per barrel linked to an initial CO_2 purchase cost of $1.50 per Mcf ($28.35 per metric ton of CO_2).

3.5.1 Commercially Viable Oil Recovery with By-Product CO_2 Storage

The Martin County San Andres ROZ fairway partition offers the promise for 1,540 million barrels of commercially viable oil recovery with 610 million metric tons (11,550 Bcf) of by-product storage of CO_2 (Exhibit 3-8).

Exhibit 3-8. Martin County commercially viable oil recovery with by-product CO_2 storage

Partition	Oil Recovery (MM bbl)	Purchased CO_2		Purchased CO_2/Oil Recovery (Ratio)	
		Bcf	MM mt	Mcf/B	mt/B
Total	1,540	11,550	610	7.5	0.40

The commercially viable portion of the ROZ resource has purchased CO_2 to produced oil ratio of 0.40 metric ton of CO_2 per barrel of recovered oil (7.5 Mcf per barrel).

3.5.2 Geologically Viable CO_2 Storage with By-Product Oil Recovery

The Martin County San Andres ROZ fairway partition also offers the potential for 490 million metric tons (9,300 Bcf) of geologically viable CO_2 storage with 290 million barrels of by-product oil recovery, as shown in Exhibit 3-9.

Exhibit 3-9. Martin County geologically viable CO_2 storage with by-product oil recovery

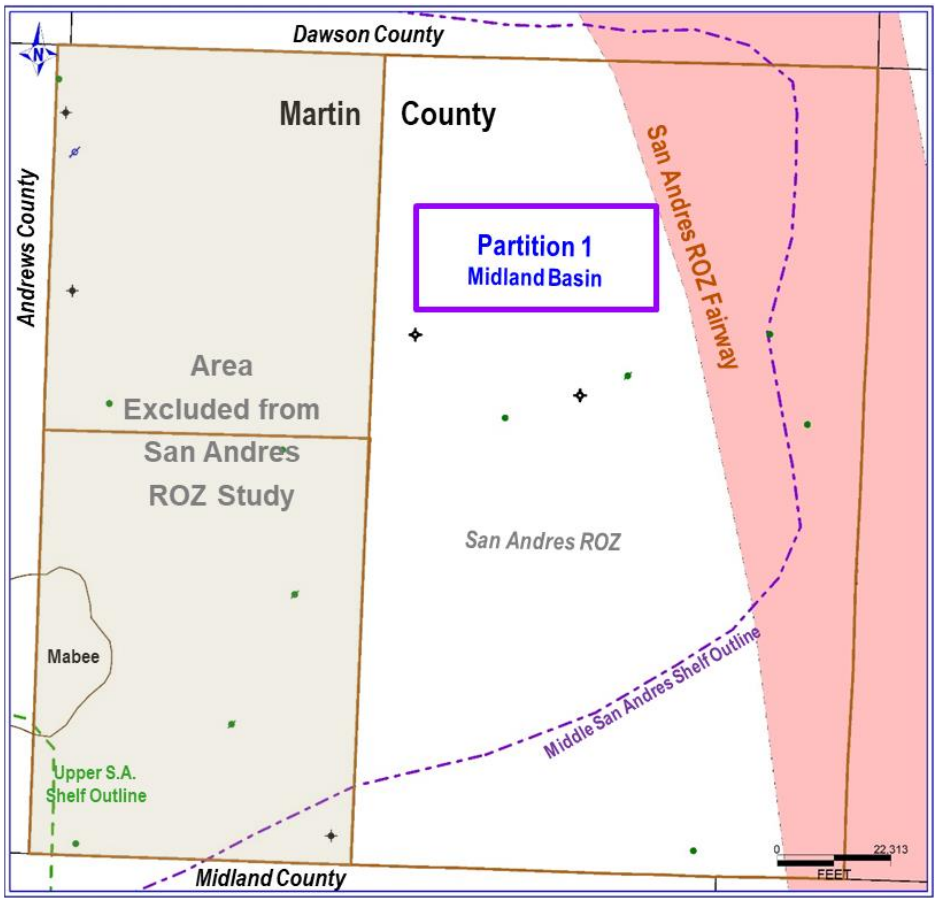
Partition	Purchased CO_2		By-Product Oil Recovery (MM bbl)	Purchased CO_2/Oil Recovery (Ratio)	
	Bcf	MM mt		Mcf/B	mt/B
Total	9,300	490	290	32.1	1.70

3.6 Partition #1. Eastern Martin County

3.6.1 Geologic Setting

Partition #1, located in eastern Martin County, covers a San Andres ROZ fairway area of 353,700 acres (Exhibit 3-10). Partition #1 contains a portion of the previously established San Andres fairway boundaries in the Midland Basin of the Permian Basin.

Exhibit 3-10. San Andres ROZ fairway Partition #1, eastern Martin County



3.6.2 Analytic ROZ Reservoir Properties

Seven well log-based reservoir data sets plus a series of working level cross-sections were used to allocate the San Andres ROZ fairway resource in Partition #1 of Martin County into two analytical ROZ fairway reservoir units:

- A higher quality ROZ resource
- A lower quality ROZ resource

The average volumetric reservoir properties for the two analytical San Andres ROZ fairway reservoir units of Partition #1 of Martin County are provided in Exhibit 3-11.

Exhibit 3-11. Average San Andres ROZ fairway reservoir properties: Partition #1, Martin County

Property	Higher Quality	Lower Quality
Depth (to top) (ft)	4,150	4,350
Gross Thickness (ft)	120	140
Net Pay (ft)	115	110
Avg. Porosity (fraction)	0.108	0.121
Avg. Oil Saturation (fraction)	0.30	0.15
Avg. Formation Volume Factor (res B/bbl)	1.08	1.08
OIP (BBLS/AF, for net pay)	233	130

3.6.3 ROZ OIP

The San Andres ROZ fairway in Partition #1 of Martin County contains 6,060 million barrels of OIP (Exhibit 3-12). The bulk of the ROZ OIP (4,320 million barrels) meets the higher ROZ resource quality criteria. The remainder of the ROZ OIP of 1,740 million barrels meets the lower resource quality criteria.

Exhibit 3-12. San Andres ROZ fairway OIP: Partition #1, Martin County

Property	Higher Quality	Lower Quality
OIP (Bbls/Acre)	26,750	14,340
Area Extent (Acres)	161,680	121,280
OIP (MM bbl)	4,320	1,740

3.6.4 Technically Recoverable Resources

Of the 6,060 million barrels of San Andres ROZ OIP in Partition #1 of Martin County, approximately 1,820 million barrels are technically recoverable from the application of miscible CO_2 EOR, giving a recovery efficiency of 30 percent of OIP.

In addition, significant volumes of CO_2 are injected and stored as part of applying miscible CO_2 EOR for recovering a portion of the ROZ OIP. Approximately 1,100 million metric tons (20,850 Bcf) of CO_2 are purchased for the San Andres ROZ fairway EOR project in Partition #1 of Martin County, with essentially all of the purchased CO_2 securely stored at the end of the CO_2 flood.

3.6.5 Commercially Viable Oil Recovery with By-Product CO_2 Storage

Of the 1,820 million barrels of technically recoverable San Andres ROZ fairway oil resource available from Partition #1 of Martin County, 1,540 million barrels are commercially viable to develop under the economic assumptions used in this study.

The application of CO_2 EOR to the commercially viable portion of the San Andres ROZ fairway resource in Partition #1 of Martin County also provides 610 million metric tons (11,550 Bcf) of by-product storage of CO_2 (Exhibit 3-13).

Exhibit 3-13. Commercially viable oil recovery with by-product CO_2 storage: Partition #1, Martin County

Oil Recovery (MM bbl)	Purchased CO_2		Purchased CO_2/Oil Recovery (Ratio)	
	Bcf	MM mt	Mcf/B	mt/B
1,540	11,550	610	7.5	0.40

The production of one barrel of San Andres ROZ fairway oil in Partition #1 of Martin County brings with it, at the margin, the storage of 0.40 metric tons of CO_2 when using high pressure CO_2 injection as the oil recovery method.

3.6.6 Geologically Viable CO_2 Storage with By-Product Oil Recovery

Pursuing the geologically viable, but economically non-viable, portion of the San Andres ROZ fairway resource in Partition #1 of Martin County with miscible CO_2 flooding provides 490 million metric tons (9,300 Bcf) of CO_2 storage capacity and 290 million barrels of by-product oil recovery (Exhibit 3-14).

Exhibit 3-14. Geologically viable storage of CO_2 with by-product oil recovery: Partition #1, Martin County

Purchased CO_2		By-Product Oil Recovery (MM bbl)	Purchased CO_2/Produced Oil (Ratio)	
Bcf	MM mt		Mcf/B	mt/B
9,300	490	290	32.1	1.70

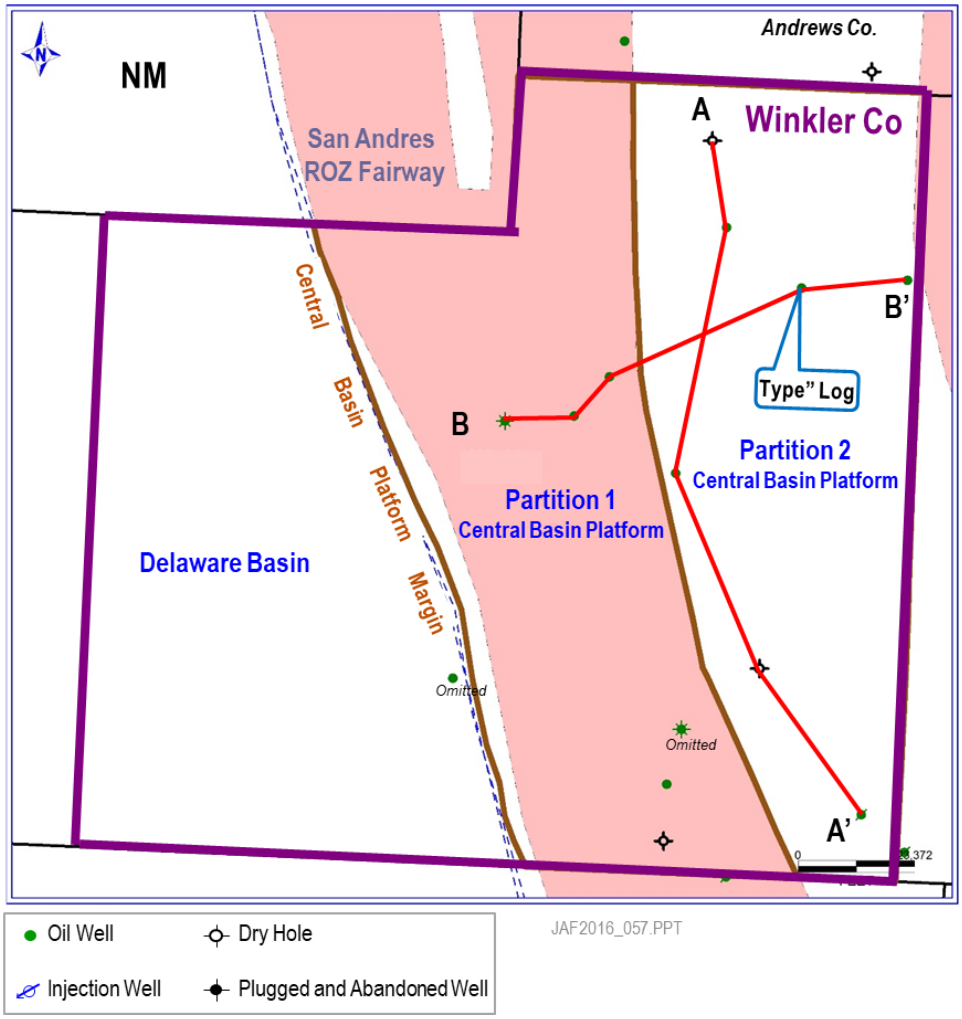
4 WINKLER COUNTY

4.1 GEOLOGIC SETTING OF THE WINKLER COUNTY SAN ANDRES ROZ "FAIRWAY"

Winkler County, Texas, covers a 342,800-acre area in the West Texas portion of the Permian Basin. Approximately two-thirds of the county is located on the CBP. The remainder of the county is west of this prominent Permian Basin feature and is located in the Delaware Basin where the San Andres Formation is absent. The county does not contain any large San Andres oil fields.

The Winkler County map (Exhibit 4-1) shows 1) the location of 12 study wells, 2) the two San Andres ROZ fairway partitions established by the study, 3) the boundaries of the previously established San Andres ROZ fairway, 4) the outline of the CBP, and 5) the location of two regional cross-sections featuring the San Andres ROZ. The map also shows the western portion of the county that has been excluded from the San Andres ROZ fairway resource assessment.

Exhibit 4-1. Winkler County: geologic partitions, major oil fields, and study well locations



4.1.1 Example Winkler County Cross-Sections

The delineation and characterization of the San Andres ROZ fairway interval in Winkler County utilized a series of working cross-sections. Two of these cross-sections are included in this report.

- Winkler County cross-section A-A' (Exhibit 4-2) provides a north to south view of the San Andres ROZ interval on the CBP.
- Winkler County cross-section B-B' (Exhibit 4-3) provides an additional west to east view of the San Andres ROZ interval through the center of the county.

Exhibit 4-2. Winkler County cross-section A-A'

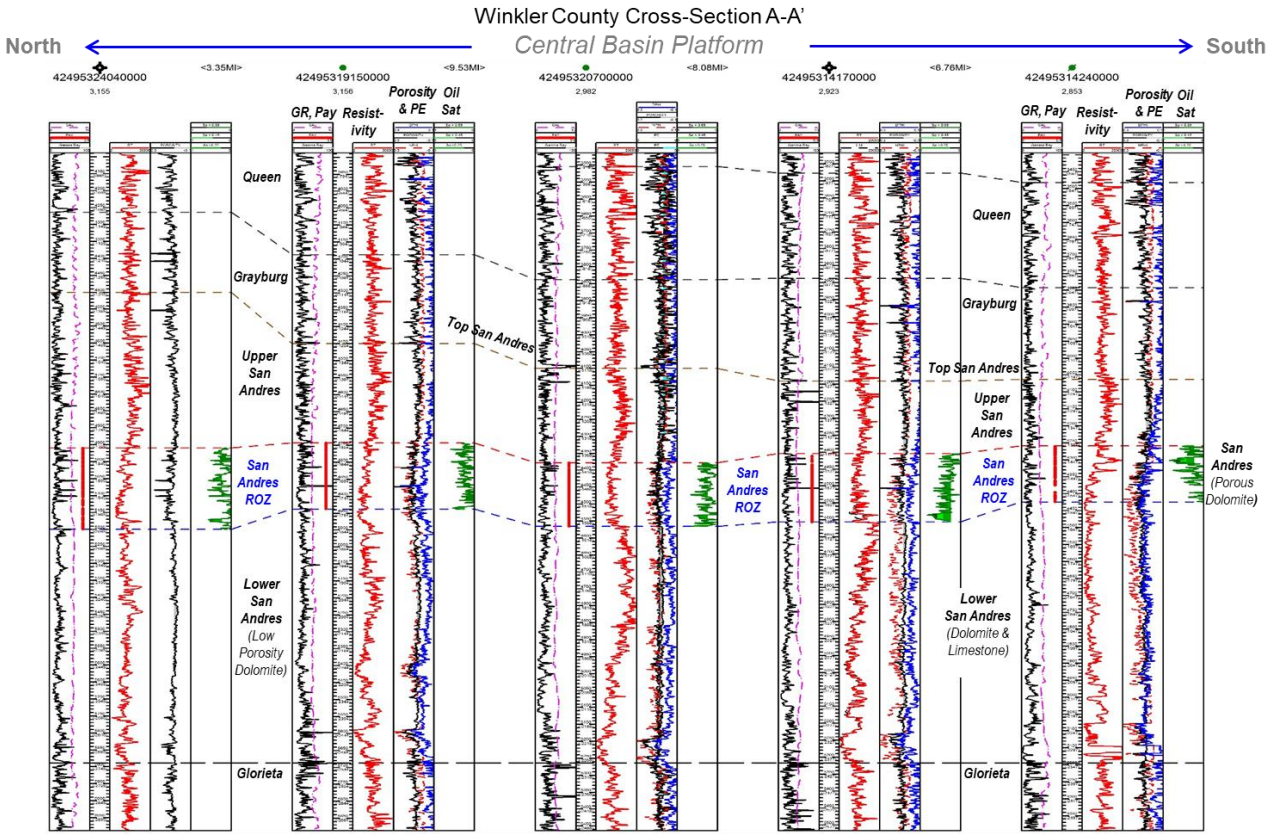
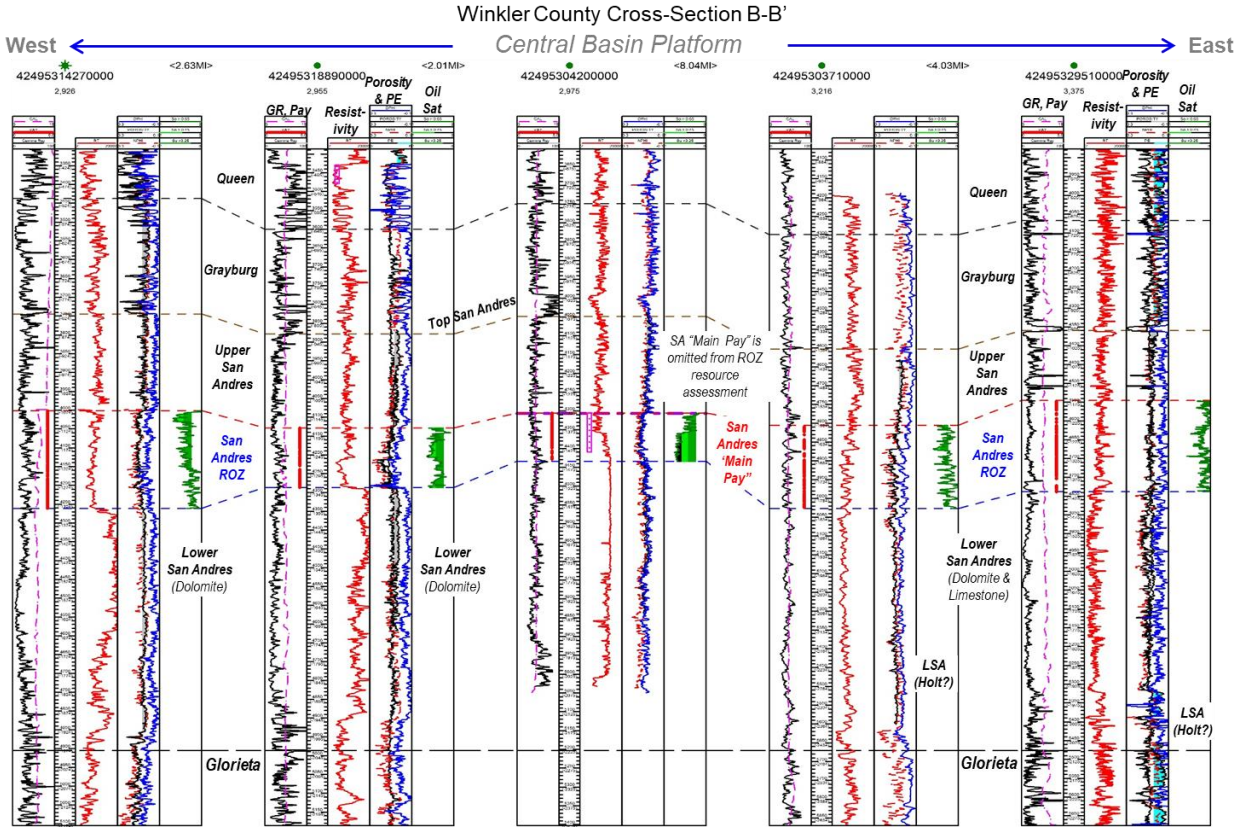


Exhibit 4-3. Winkler County cross-section B-B'



4.1.2 Interpretation of Winkler County Cross-Sections

For logs from the ROZ fairway, the top of the San Andres porous dolomite is picked as the top of the ROZ for this resource assessment.

The cross-sections display gamma-ray and caliper logs in Track 1 on the left. Resistivity logs are shown in Track 2, with the deep resistivity log shown in red. Track 3 shows the porosity logs. Uncorrected neutron porosity (for limestone) is red; uncorrected density porosity (for limestone) is blue. The porosity curve used for the OIP calculation is black. The PEF curve, if available, is also displayed in Track 3. PEF values greater than 4 are shaded in blue. Within and below the ROZ interval, high PEF values generally indicate the presence of limestone, dolomitic limestone or anhydrite.

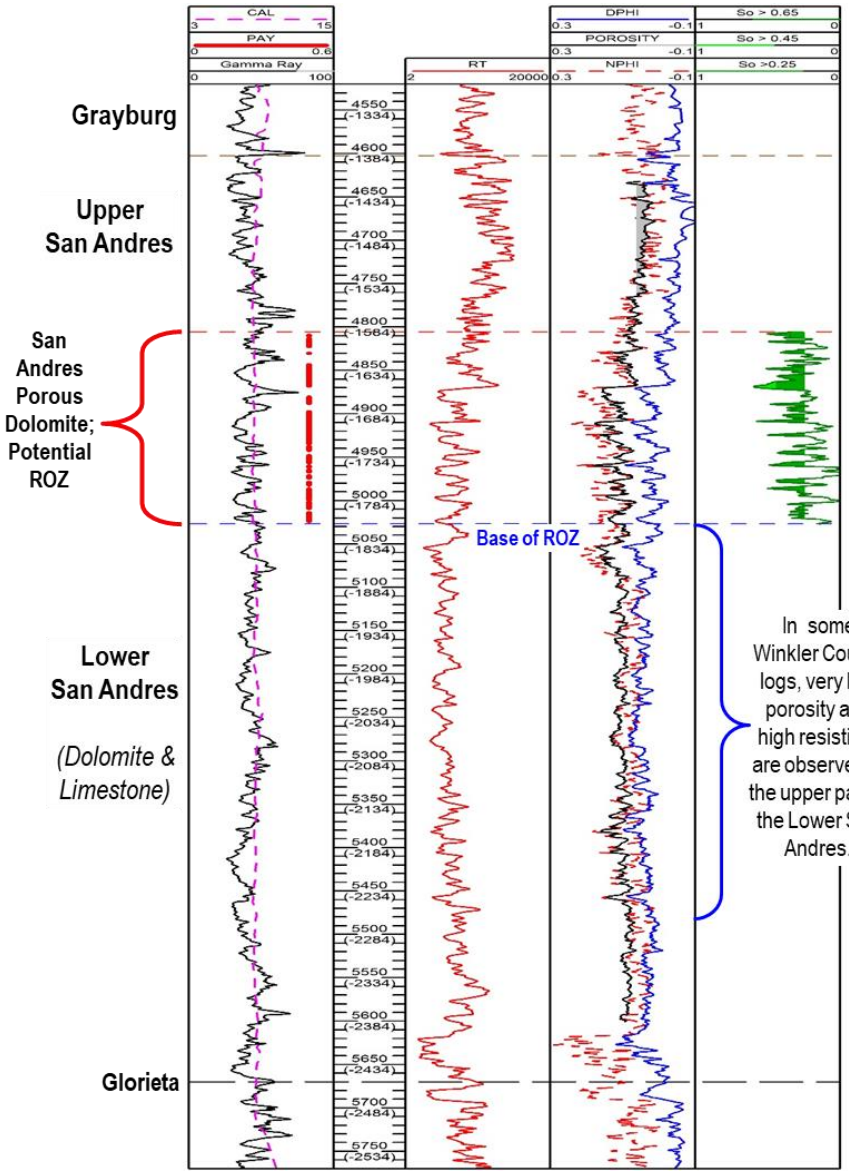
Track 4 on the right shows the calculated oil saturation. Calculated oil saturations between 25 percent and 40 percent are dark green; calculated oil saturations between 45 percent and 60 percent are light green; and oil saturation greater than 65 percent, typically present in only the MPZ, are black.

The base of the ROZ is where either calculated oil saturation or apparent porosity (or both) diminish in the Lower San Andres. If a Lower San Andres limestone is prominent, the top of the limestone defines the base of the ROZ.

4.1.3 Winkler County Type Log

A type log was selected from the Winkler County study wells to illustrate the ROZ resource analysis undertaken for the county (Exhibit 4-4). In this well the base of the ROZ is picked where the lithology changes from dolomite to limestone.

Exhibit 4-4. Winkler County San Andres ROZ type well 42-003-37529



- Density and neutron porosity logs are corrected for dolomite.
- Cross-plot porosity is used to compute oil saturation.
- In Winkler Co., an additional correction was applied to reduce the neutron porosity response to the presence of gypsum.
- Cross-plot porosity is shown in black. Neutron porosity (limestone) shown in red. Density porosity (limestone) shown in blue.
- Archie equation parameters for calculating oil saturation: Rw = 0.10 ohm-n. 'm' = 2.3, 'n' = 3.4, 'a' = 1.

The oil saturation for the type log ROZ was calculated using the following Archie parameters—'m' of 2.3, 'n' of 3.4, 'a' of 1, and formation water resistivity (Rw) of 0.10 ohm-m. A porosity cut-off of 6 percent was applied to define net pay in the ROZ. Intervals identified as ROZ pay are shown by the red pay flag in Track 1 in Exhibit 4-4.

4.2 Partitioning the Winkler County San Andres ROZ Fairway

The ROZ fairway in Winkler County has been divided into two partitions, as illustrated in Exhibit 4-1. Individual San Andres ROZ fairway resource assessments were undertaken for each of the two partitioned areas. The western portion of Winkler County where the San Andres ROZ is absent has been excluded, leaving a remaining San Andres ROZ fairway assessment area of 342,800 acres (Exhibit 4-5).

- *Partition #1.* Covers a 172,000-acre area of western Winkler County on the CBP. No area has been excluded from Partition #1.
- *Partition #2.* Covers a 170,800-acre area of central Winkler County on the CBP. No area has been excluded from Partition #2.

Exhibit 4-5. Winkler County San Andres ROZ fairway partitions

Partition	Total Area	Excluded Area Below Oil Fields	Assessment Area
	Acres	Acres	Acres
#1	172,000	-	172,000
#2	170,800	-	170,800
Total	**342,800**	-	**342,800**

4.3 Size and Quality of the Winkler County San Andres ROZ Fairway Resource

Winkler County holds 8,520 million barrels of OIP in the San Andres ROZ fairway outside the structural closure of the existing oil fields. The OIP and resource quality values for each of the two partitions of Winkler County are shown in Exhibit 4-6.

- Higher Quality ROZ Fairway Resources. A significant portion, 7,180 million barrels, of the San Andres ROZ fairway OIP in Winkler County has higher quality reservoir properties (porosity greater than 8 percent and oil saturation equal to or greater than 25%).
- Lower Quality ROZ Fairway Resources. The remainder, 1,340 million barrels, of the San Andres ROZ fairway OIP in Winkler County has lower quality reservoir properties (porosity equal to or less than 8 percent and/or oil saturation of less than 25%).

Exhibit 4-6. Winkler County San Andres ROZ fairway resource in-place (MM bbl)

Partitions	Higher Quality	Lower Quality	Total
#1	5,560	-	5,560
#2	1,620	1,340	2,960
Total	**7,180**	**1,340**	**8,520**

4.4 Technically Recoverable Winkler County ROZ Fairway Resource

4.4.1 Methodology for Estimating Technically Recoverable Resources

The average volumetric reservoir properties for each partition of Winkler County, along with proprietary reservoir properties from ARI's Big Oil Fields Data Base, were used as input into the Prophet Model. Additionally, it was assumed that 80 percent of each partition area was suitable for development, while 20 percent of the partition had a combination of net pay, porosity, or oil saturation that was not suitable for development. It was also assumed that 90 percent of the OIP in each partition resides in the area suitable for development. The net pay for the developed portion of the partition was increased so that the OIP in the developed portion equaled 90 percent of the OIP calculated for the entire partition. The Prophet Model was then used to calculate the volumes of recoverable oil and water as well as the volumes of injected and stored CO_2. The Prophet Model was run assuming five-spot patterns were implemented for each partition. ROZ fairway well pattern spacings of 40 acres per CO_2 injection well were selected to achieve a target of approximately 30 years of operation for the miscible CO_2 flood.

4.4.2 Summary of Technically Recoverable Resources

A significant portion of the San Andres ROZ fairway OIP in Winkler County is technically recoverable using miscible CO_2 EOR, while also providing major volumes of pore space for storing CO_2 (Exhibit 4-7).

- Total technically viable oil recovery is estimated at 2,660 million barrels, produced primarily from the higher quality portions of the ROZ resource.
- While the oil recovery efficiencies vary by partition, overall recovery efficiency is 31% of OIP in response to one HCPV injection of CO_2 using a tapered WAG miscible CO_2 flood.
- The San Andres ROZ fairway interval in Winkler County offers the potential for significant storage of CO_2, equal to 1,490 million metric tons (28,090 Bcf).

Exhibit 4-7. Winkler County technically recoverable San Andres ROZ fairway resource

Partitions	Oil Recovery		Purchased CO_2	
	MM bbl	%OIP	Bcf	MM mt
#1	1,760	32%	15,780	840
#2	900	30%	12,310	650
Total	**2,660**	**31%**	**28,090**	**1,490**

4.5 Viability of Oil Recovery and CO_2 Storage in the Winkler County ROZ Fairway

The CO_2 EOR Model used by this study assumes a first-year oil price (WTI) of $75 per barrel linked to an initial CO_2 purchase cost of $1.50 per Mcf ($28.35 per metric ton of CO_2).

4.5.1 Commercially Viable Oil Recovery with By-Product CO_2 Storage

The two San Andres ROZ fairway partitions of Winkler County offer the potential for 2,310 million barrels of commercially viable oil recovery with 1,110 million metric tons (20,900 Bcf) of by-product storage of CO_2 (Exhibit 4-8).

The commercially viable portion of the ROZ resource has purchased CO_2 to produced oil ratio of 0.48 metric tons of CO_2 per barrel of recovered oil (9.0 Mcf per barrel), ranging from 0.47 metric tons per barrel in Partition #1 to 0.49 metric tons per barrel in Partition #2.

Exhibit 4-8. Winkler County commercially viable oil recovery with by-product CO_2 storage

Partition	Oil Recovery (MM bbl)	Purchased CO_2		Purchased CO_2/Oil Recovery (Ratio)	
		Bcf	MM mt	Mcf/B	mt/B
#1	1,760	15,780	840	9.0	0.47
#2	550	5,120	270	9.3	0.49
Total	**2,310**	**20,900**	**1,110**	**9.0**	**0.48**

4.5.2 Geologically Viable CO_2 Storage with By-Product Oil Recovery

The two San Andres ROZ fairway partitions of Winkler County also offer the potential for 380 million metric tons (7,190 Bcf) of geologically viable CO_2 storage with 350 million barrels of by-product oil recovery, as shown in Exhibit 4-9.

Exhibit 4-9. Winkler County geologically viable CO_2 storage with by-product oil recovery

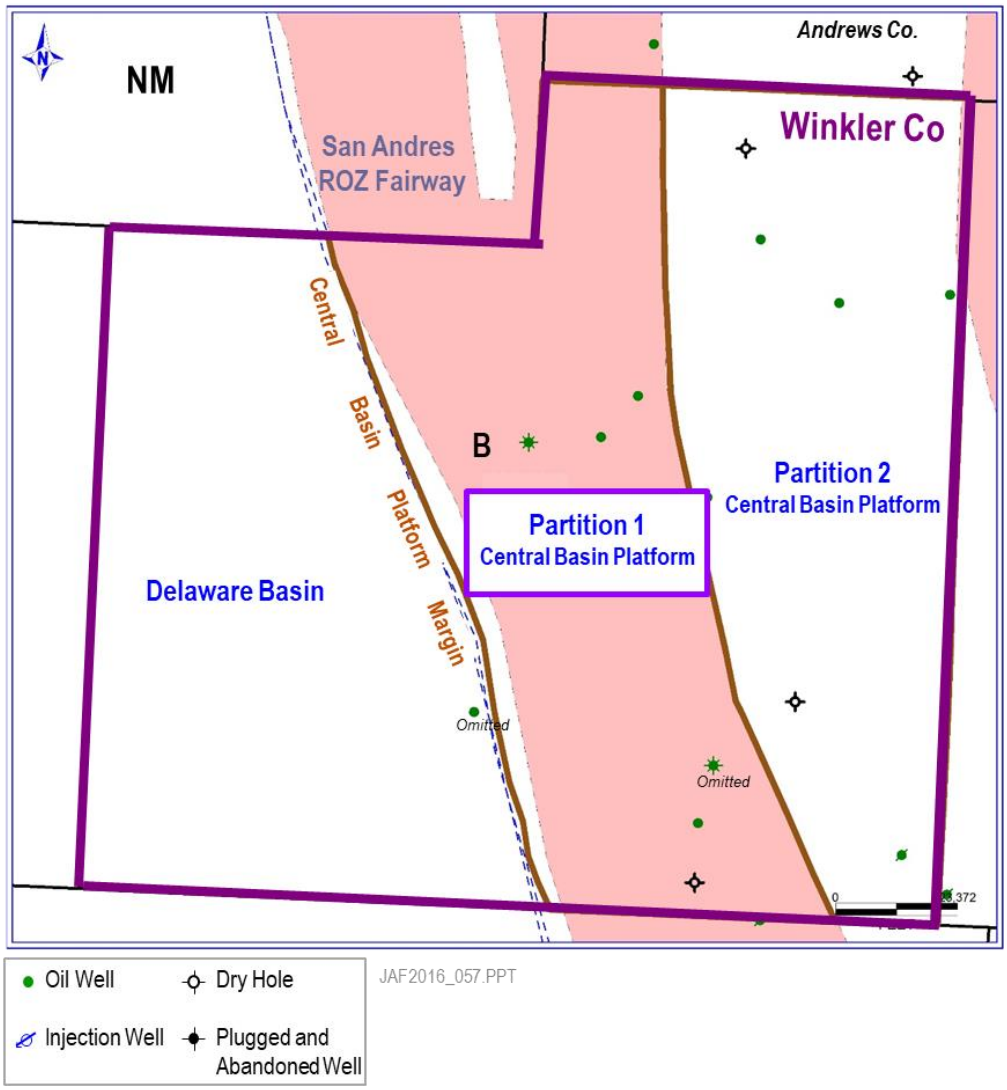
Partition	Purchased CO_2		By-Product Oil Recovery (MM bbl)	Purchased CO_2/Oil Recovery (Ratio)	
	Bcf	MM mt		Mcf/B	mt/B
#1	-	-	-	-	-
#2	7,190	380	350	20.5	1.09
Total	**7,190**	**380**	**350**	**20.5**	**1.09**

4.6 Partition #1. Winkler County

4.6.1 Geologic Setting

Partition #1, located in Winkler County, covers a San Andres ROZ fairway area of 172,000 acres (Exhibit 4-10). Partition #1 contains the previously established San Andres ROZ fairway boundaries, on the western edge of the CBP.

Exhibit 4-10. San Andres ROZ fairway Partition #1, Winkler County



4.6.2 Analytic ROZ Reservoir Properties

Five well log-based reservoir data sets plus a series of working level cross-sections were used to allocate the San Andres ROZ fairway resource in Partition #1 of Winkler County into one analytical ROZ fairway reservoir unit:

- A higher quality ROZ resource

The average volumetric reservoir properties for the one analytical San Andres ROZ fairway reservoir unit of Partition #1 of Winkler County are provided in Exhibit 4-11.

Exhibit 4-11. Average San Andres ROZ fairway reservoir properties: Partition #1, Winkler County

Property	Higher Quality	Lower Quality
Depth (to top) (ft)	4,060	-
Gross Thickness (ft)	225	-
Net Pay (ft)	199	-
Avg. Porosity (fraction)	0.099	-
Avg. Oil Saturation (fraction)	0.37	-
Avg. Formation Volume Factor (res B/Bbl)	1.40	-
OIP (BBLS/AF, for net pay)	203	-

4.6.3 ROZ OIP

The San Andres ROZ fairway in Partition #1 of Winkler County contains 5,560 million barrels of OIP (Exhibit 4-12). All the ROZ OIP meets the higher ROZ resource quality criteria.

Exhibit 4-12. San Andres ROZ fairway OIP: Partition #1, Winkler County

Property	Higher Quality	Lower Quality
OIP (Bbls/Acre)	40,400	-
Area Extent (Acres)	137,600	-
OIP (MM bbl)	5,560	-

4.6.4 Technically Recoverable Resources

Of the 5,560 million barrels of San Andres ROZ OIP in Partition #1 of Winkler County, approximately 1,760 million barrels is technically recoverable from the application of miscible CO_2 EOR, giving a recovery efficiency of 32 percent of OIP.

In addition, significant volumes of CO_2 are injected and stored as part of applying miscible CO_2 EOR for recovering a portion of the ROZ OIP. Approximately 840 million metric tons (15,780 Bcf) of CO_2 are purchased for the San Andres ROZ fairway EOR project in Partition #1 of Winkler County, with essentially all of the purchased CO_2 securely stored at the end of the CO_2 flood.

4.6.5 Commercially Viable Oil Recovery with By-Product CO_2 Storage

All of the 1,760 million barrels of technically recoverable San Andres ROZ fairway oil resource available from Partition #1 of Winkler County is commercially viable to develop under the economic assumptions used in this study.

The application of CO_2 EOR to the commercially viable portion of the San Andres ROZ fairway resource in Partition #1 of Winkler County also provides 840 million metric tons (15,780 Bcf) of by-product storage of CO_2 (Exhibit 4-13).

Exhibit 4-13. Commercially viable oil recovery with by-product CO_2 storage: Partition #1, Winkler County

Oil Recovery (MM bbl)	Purchased CO_2		Purchased CO_2/Oil Recovery (Ratio)	
	Bcf	MM mt	Mcf/B	mt/B
1,760	15,780	840	9.0	0.47

The production of one barrel of San Andres ROZ fairway oil in Partition #1 of Winkler County brings with it, at the margin, the storage of 0.47 metric tons of CO_2 when using high pressure CO_2 injection as the oil recovery method.

4.6.6 Geologically Viable CO_2 Storage with By-Product Oil Recovery

All of the 1,760 million barrels of technically recoverable San Andres ROZ fairway oil resource available from Partition #1 of Winkler County is commercially viable to develop under the economic assumptions used in this study. Therefore, there are no geologically viable portions of the resource remaining (Exhibit 4-14).

Exhibit 4-14. Geologically viable storage of CO_2 with by-product oil recovery: Partition #1 Winkler County

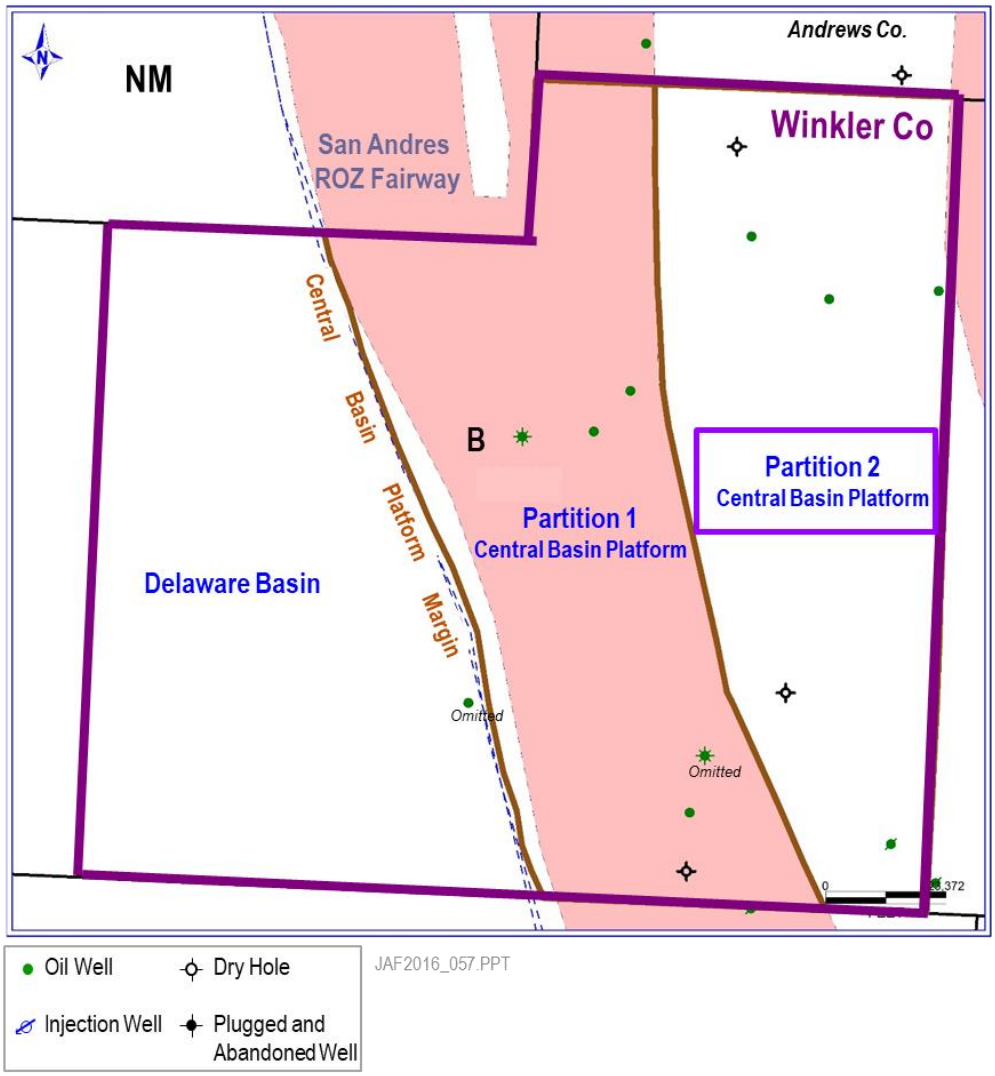
Purchased CO_2		By-Product Oil Recovery (MM bbl)	Purchased CO_2/Produced Oil (Ratio)	
Bcf	MM mt		Mcf/B	mt/B
-	-	-	-	-

4.7 Partition #2. Winkler County

4.7.1 Geologic Setting

Partition #2, located in Winkler County, covers a San Andres ROZ fairway area of 170,800 acres (Exhibit 4-15). Partition #2 is located east of the previously established San Andres ROZ fairway boundaries, in the CBP.

Exhibit 4-15. San Andres ROZ fairway Partition #2, Winkler County



4.7.2 Analytic ROZ Reservoir Properties

Seven well log-based reservoir data sets plus a series of working level cross-sections were used to allocate the San Andres ROZ fairway resource in Partition #2 of Winkler County into two analytical ROZ fairway reservoir units:

- A higher quality ROZ resource
- A lower quality ROZ resource

The average volumetric reservoir properties for the two analytical San Andres ROZ fairway reservoir units of Partition #2 of Winkler County are provided in Exhibit 4-16.

Exhibit 4-16. Average San Andres ROZ fairway reservoir properties: Partition #2, Winkler County

Property	Higher Quality	Lower Quality
Depth (to top) (ft)	4,350	4,770
Gross Thickness (ft)	185	244
Net Pay (ft)	153	153
Avg. Porosity (fraction)	0.099	0.101
Avg. Oil Saturation (fraction)	0.33	0.20
Avg. Formation Volume Factor (res B/bbl)	1.40	1.40
OIP (BBLS/AF, for net pay)	181	112

4.7.3 ROZ OIP

The San Andres ROZ fairway in Partition #2 of Winkler County contains 2,960 million barrels of OIP, Exhibit 4-17. The bulk of the ROZ OIP (1,620 million barrels) meets the higher ROZ resource quality criteria. The remainder of the ROZ OIP of 1,340 million barrels meets the lower resource quality criteria.

Exhibit 4-17. San Andres ROZ fairway OIP: Partition #2, Winkler County

Property	Higher Quality	Lower Quality
OIP (Bbls/Acre)	27,690	17,140
Area Extent (Acres)	58,560	78,080
OIP (MM bbl)	1,620	1,340

4.7.4 Technically Recoverable Resources

Of the 2,960 million barrels of San Andres ROZ OIP in Partition #2 of Winkler County, approximately 900 million barrels is technically recoverable from the application of miscible CO_2 EOR, giving a recovery efficiency of 30 percent of OIP.

In addition, significant volumes of CO_2 are injected and stored as part of applying miscible CO_2 EOR for recovering a portion of the ROZ OIP. Approximately 650 million metric tons (12,310 Bcf) of CO_2 are purchased for the San Andres ROZ fairway EOR project in Partition #2 of Winkler County, with essentially all of the purchased CO_2 securely stored at the end of the CO_2 flood.

4.7.5 Commercially Viable Oil Recovery with By-Product CO_2 Storage

Of the 900 million barrels of technically recoverable San Andres ROZ fairway oil resource available from Partition #2 of Winkler County, 550 million barrels are commercially viable to develop under the economic assumptions used in this study.

The application of CO_2 EOR to the commercially viable portion of the San Andres ROZ fairway resource in Partition #2 of Winkler County also provides 270 million metric tons (5,120 Bcf) of by-product storage of CO_2 (Exhibit 4-18).

Exhibit 4-18. Commercially viable oil recovery with by-product CO_2 storage: Partition #2, Winkler County

Oil Recovery (MM bbl)	Purchased CO_2		Purchased CO_2/Oil Recovery (Ratio)	
	Bcf	MM mt	Mcf/B	mt/B
550	5,120	270	9.3	0.49

The production of one barrel of San Andres ROZ fairway oil in Partition #2 of Winkler County brings with it, at the margin, the storage of 0.49 metric tons of CO_2 when using high pressure CO_2 injection as the oil recovery method.

4.7.6 Geologically Viable CO_2 Storage with By-Product Oil Recovery

Pursuing the geologically viable, but economically non-viable, portion of the San Andres ROZ fairway resource in Partition #2 of Winkler County with miscible CO_2 flooding provides 380 million metric tons (7,190 Bcf) of CO_2 storage capacity and 350 million barrels of by-product oil recovery (Exhibit 4-19).

Exhibit 4-19. Geologically viable storage of CO_2 with by-product oil recovery: Partition #2, Winkler County

Purchased CO_2		By-Product Oil Recovery (MM bbl)	Purchased CO_2/Produced Oil (Ratio)	
Bcf	MM mt		Mcf/B	mt/B
7,190	380	350	20.5	1.09

5 ECTOR COUNTY

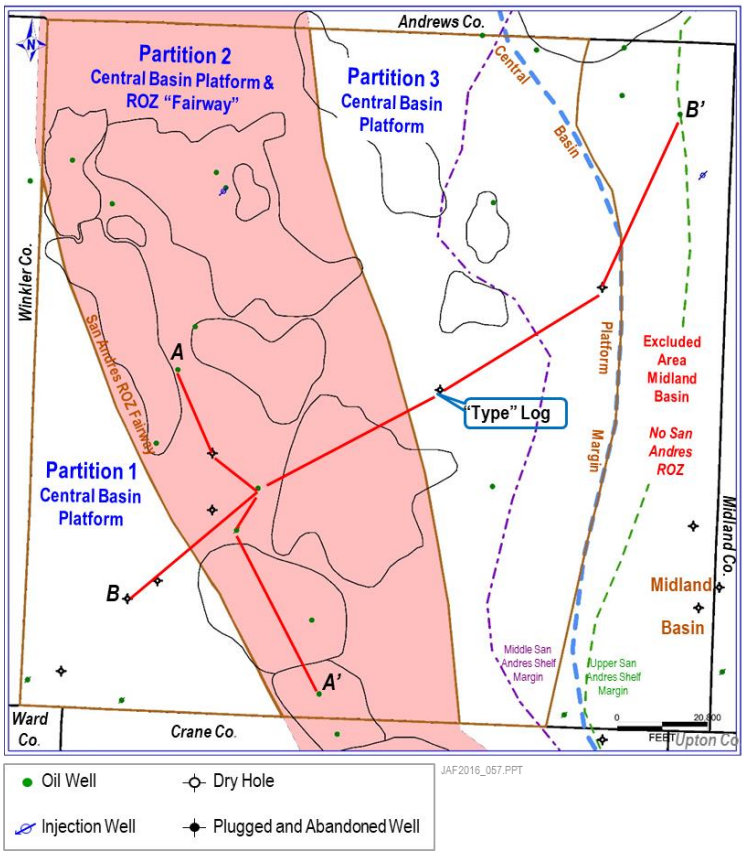
5.1 GEOLOGIC SETTING OF THE ECTOR COUNTY SAN ANDRES ROZ FAIRWAY

Ector County covers a 577,000-acre area in the West Texas portion of the Permian Basin. Approximately eighty percent of the county is on the CBP. The remainder of the county is east of this prominent Permian Basin feature but within the southward prograding Upper and Middle San Andres shelf margins of the Midland Basin.

Ector County contains numerous San Andres oil fields, including Cowden North and South, Foster, Goldsmith, Harper, Penwell, and TXL, among others. The ROZ resource below these and other existing San Andres oil fields has been excluded from the San Andres ROZ fairway resource assessment.

The Ector County map (Exhibit 5-1) shows 1) the location of 31 study wells, 2) the three San Andres ROZ fairway partitions established by the study, 3) the boundaries of the previously established San Andres ROZ fairway, 4) the outline of the CBP, and 5) the location of two regional cross-sections featuring the San Andres ROZ. The map also shows the major San Andres oil fields excluded from the San Andres ROZ fairway resource assessment in Ector County.

Exhibit 5-1. Ector County: geologic partitions, major oil fields, and study well locations



5.1.1 Example Ector County Cross-Sections

The delineation and characterization of the San Andres ROZ fairway interval in Ector County utilized a series of working cross-sections. Two of these cross-sections are included in this report.

- Ector Co. cross-section A-A' (Exhibit 5-2) provides a north to south view of the San Andres ROZ interval on the CBP.
- Ector Co. cross-section B-B' (Exhibit 5-3) provides a southwest to northeast view of the San Andres ROZ interval through the center of the county.

Exhibit 5-2. Ector County cross-section A-A'

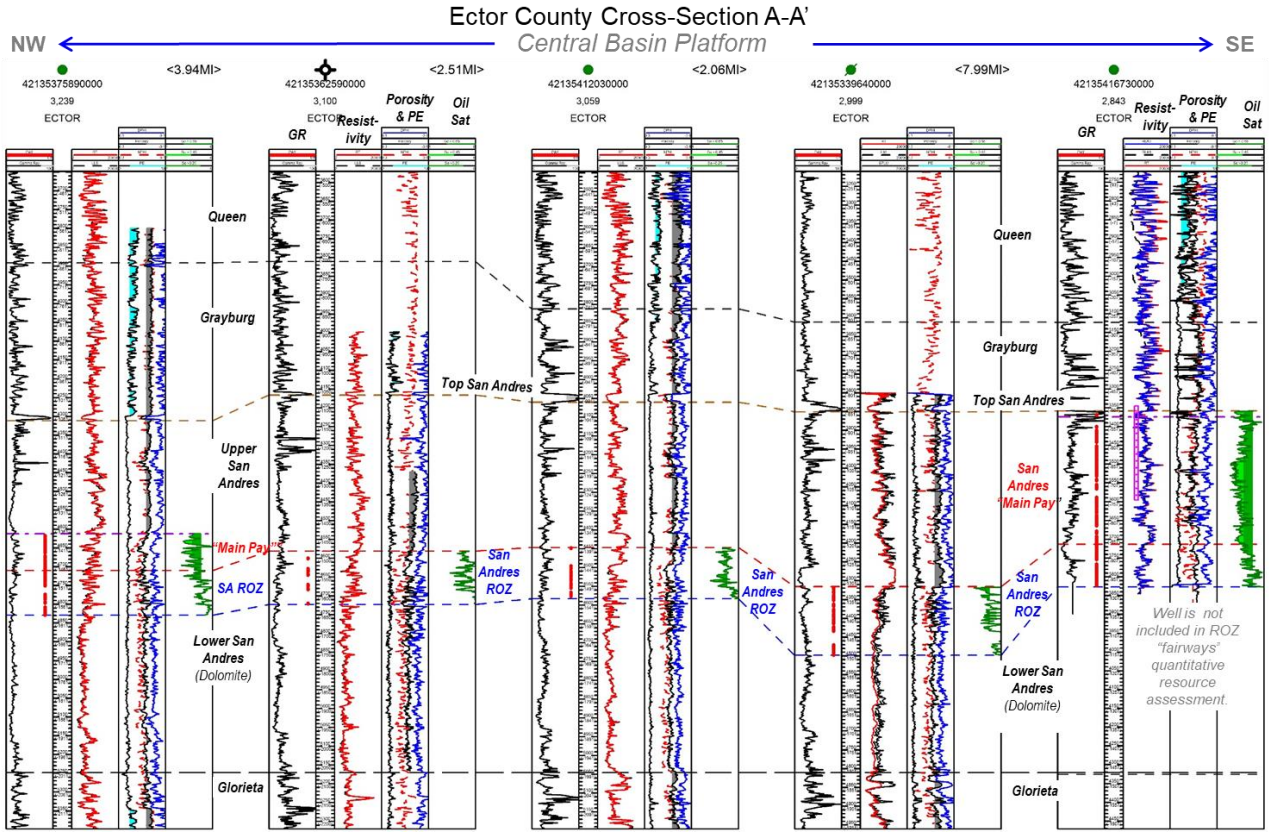
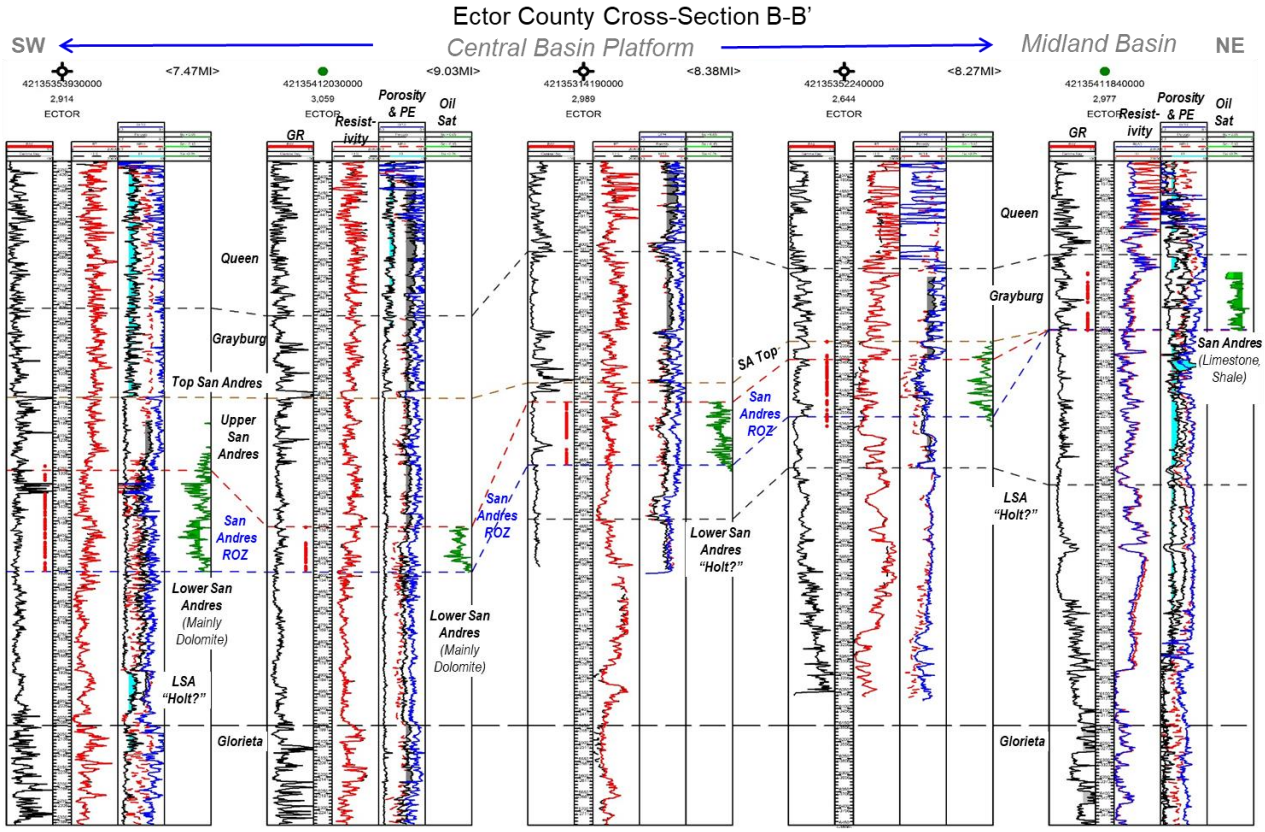


Exhibit 5-3. Ector County cross-section B-B'



5.1.2 Interpretation of Ector County Cross-Sections

For logs from the ROZ fairway, the top of the San Andres porous dolomite is picked as the top of the ROZ for this resource assessment.

The cross-sections display gamma-ray and caliper logs in Track 1 on the left. Resistivity logs are shown in Track 2, with the deep resistivity log shown in red. Track 3 shows the porosity logs. Uncorrected neutron porosity (for limestone) is red; uncorrected density porosity (for limestone) is blue. The porosity curve used for the OIP calculation is black.

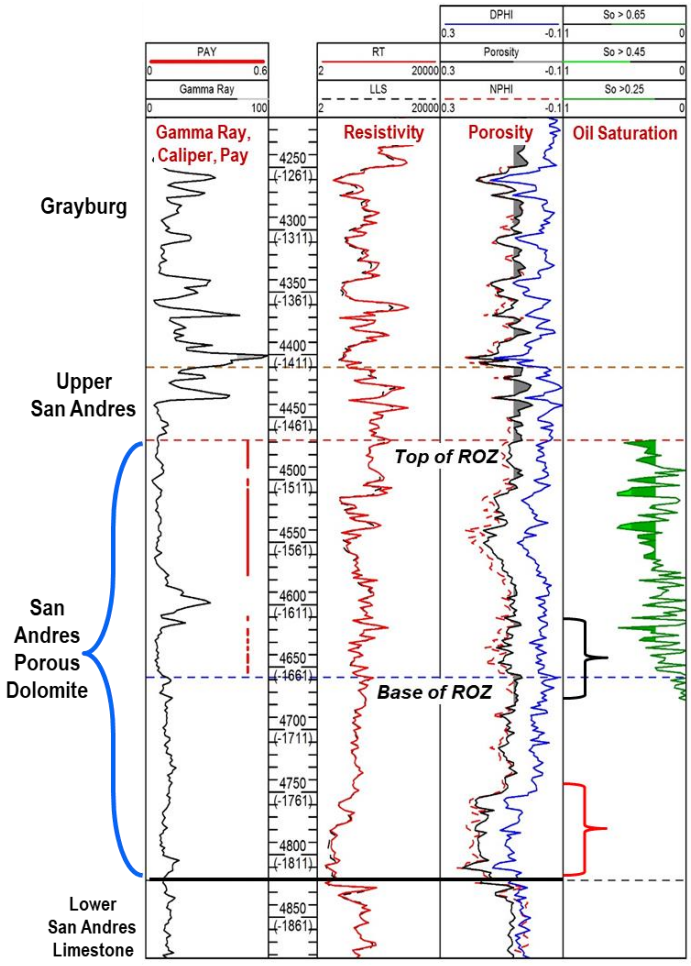
The PEF curve, if available, is also displayed in Track 3. PEF values greater than 4 are shaded in blue. Within and below the ROZ interval, high PEF values generally indicate the presence of limestone, dolomitic limestone or anhydrite. Track 4 on the right shows the calculated oil saturation. Calculated oil saturations between 25 percent and 40 percent are dark green; calculated oil saturations between 45 percent and 60 percent are light green; and oil saturation greater than 65 percent, typically present in only the MPZ, are black.

The base of the ROZ is where either calculated oil saturation or apparent porosity (or both) diminish in the Lower San Andres. If a Lower San Andres limestone is prominent, the top of the limestone defines the base of the ROZ.

5.1.3 Ector County Type Log

A type log was selected from the Ector County study wells to illustrate the ROZ resource analysis undertaken for the county (Exhibit 5-4). This exhibit provides a close-up display of calculated porosity and oil saturation for the ROZ in the type log. The calculated oil saturation diminishes significantly at the base of ROZ. The base of the ROZ is picked at the top of a thick low porosity interval.

Exhibit 5-4. Ector County San Andres ROZ type well 42-003-37529



- Density and neutron porosity logs are corrected for dolomite & a cross-plot porosity is used to compute oil saturation.
- Final cross-plot porosity is shown in black. Uncorrected neutron porosity (limestone) is shown in red. Uncorrected density porosity (limestone) is shown in blue.
- Calculated porosity less than 6 percent is shaded in gray.
- Archie parameters for calculating water saturation: Rw = .07 ohm-m; 'm' = 2.3, 'a' = 1; 'n' = 3.4
  - Total 'net pay' of ROZ = 146' (porosity > 0.06)
  - Average porosity of net pay = 0.095
  - Average oil saturation of net pay = 0.30
  - ROZ in this well is characterized as "high quality."

The oil saturation for the type log ROZ was calculated using the following Archie parameters—'m' of 2.3, 'n' of 3.4, 'a' of 1, and formation water resistivity (Rw) of 0.07 ohm-m. A porosity cut-off of 6 percent was applied to define net pay in the ROZ. Intervals identified as ROZ pay are shown by the red pay flag in Track 1 in Exhibit 5-4.

5.2 Partitioning the Ector County San Andres ROZ Fairway

The ROZ fairway in Ector County has been divided into three partitions, as illustrated in Exhibit 5-1. Individual San Andres ROZ fairway resource assessments were undertaken for each of the

three partitioned areas. Individual ROZ fairway resource assessments were undertaken for each of the three partitioned areas. The eastern portion of Ector County encompassing 106,800 acres where the San Andres ROZ is absent and 121,900 acres below existing oil fields have been excluded, leaving a remaining San Andres ROZ fairway assessment area of 348,300 acres (Exhibit 5-5).

- *Partition #1.* Covers a 73,800-acre area of Ector County on the CBP.
- *Partition #2.* Covers a 224,600-acre area of Ector County on the CBP. A series of large oil fields, covering 71,800 acres, have been excluded from Partition #1, leaving a ROZ fairway area of 152,800 acres.
- *Partition #3.* Covers a 171,800-acre area of Ector County on the CBP. Four large oil fields, covering 50,100 acres, have been excluded from Partition #1, leaving a ROZ fairway area of 121,700 acres.

Exhibit 5-5. Ector County San Andres ROZ fairway partitions

Partition	Total Area	Excluded Area Below Oil Fields	Assessment Area
	Acres	Acres	Acres
#1	73,800	-	73,800
#2	224,600	71,800	152,800
#3	171,800	50,100	121,700
Total	**470,200**	**121,900**	**348,300**

5.3 Size and Quality of the Ector County San Andres ROZ Fairway Resource

Ector County holds 6,270 million barrels of OIP in the San Andres ROZ fairway outside the structural closure of the existing oil fields. The OIP and resource quality values for each of the three partitions of Ector County are shown in Exhibit 5-6.

- Higher Quality ROZ Fairway Resources. A significant portion, 4,990 million barrels, of the San Andres ROZ fairway OIP in Ector County has higher quality reservoir properties (porosity greater than 8 percent and oil saturation equal to or greater than 25%).
- Lower Quality ROZ Fairway Resources. The remainder, 1,280 million barrels, of the San Andres ROZ fairway OIP in Ector County has lower quality reservoir properties (porosity equal to or less than 8 percent and/or oil saturation of less than 25%).

Exhibit 5-6. Ector County San Andres ROZ fairway resource in-place (MM bbl)

Partitions	Higher Quality	Lower Quality	Total
#1	200	490	690
#2	1,630	390	2,020
#3	3,160	400	3,560
Total	**4,990**	**1,280**	**6,270**

5.4 Technically Recoverable Ector County ROZ Fairway Resource

5.4.1 Methodology for Estimating Technically Recoverable Resources

The average volumetric reservoir properties for each partition of Ector County, along with proprietary reservoir properties from ARI's Big Oil Fields Data Base, were used as input into the Prophet Model. Additionally, it was assumed that 80 percent of each partition area was suitable for development, while 20 percent of the partition had a combination of net pay, porosity, or oil saturation that was not suitable for development. It was also assumed that 90 percent of the OIP in each partition resides in the area suitable for development. The net pay for the developed portion of the partition was increased so that the OIP in the developed portion equaled 90 percent of the OIP calculated for the entire partition. The Prophet Model was then used to calculate the volumes of recoverable oil and water as well as the volumes of injected and stored CO_2. The Prophet Model was run assuming five-spot patterns were implemented for each partition. ROZ fairway well pattern spacings of 40 to 80 acres per CO_2 injection well were selected to achieve a target of approximately 30 years of operation for the miscible CO_2 flood.

5.4.2 Summary of Technically Recoverable Resources

A significant portion of the San Andres ROZ fairway OIP in Ector County is technically recoverable using miscible CO_2 EOR, while also providing major volumes of pore space for storing CO_2 (Exhibit 5-7).

- Total technically viable oil recovery is estimated at 1,850 million barrels, produced primarily from the higher quality portions of the ROZ resource.
- While the oil recovery efficiencies vary by partition, overall recovery efficiency is 30% of OIP in response to one HCPV injection of CO_2 using a tapered WAG miscible CO_2 flood.
- The San Andres ROZ fairway interval in Ector County offers the potential for significant storage of CO_2, equal to 1,110 million metric tons (20,990 Bcf).

Exhibit 5-7. Ector County technically recoverable San Andres ROZ fairway resource

Partitions	Oil Recovery		Purchased CO_2	
	MM bbl	%OIP	Bcf	MM mt
#1	160	23%	4,020	210
#2	660	33%	7,300	390
#3	1,030	29%	9,670	510
Total	**1,850**	**30%**	**20,990**	**1,110**

5.5 Viability of Oil Recovery and CO_2 Storage in the Ector County ROZ Fairway

The CO_2 EOR Cost Model used by the study assumes a first-year oil price (WTI) of $75 per barrel linked to an initial CO_2 purchase cost of $1.50 per Mcf ($28.35 per metric ton of CO_2).

5.5.1 Commercially Viable Oil Recovery with By-Product CO_2 Storage

The three San Andres ROZ fairway partitions of Ector County offer the potential for 970 million barrels of commercially viable oil recovery with 380 million metric tons (7,210 Bcf) of by-product storage of CO_2 (Exhibit 5-8).

Exhibit 5-8. Ector County commercially viable oil recovery with by-product CO_2 storage

Partition	Oil Recovery (MM bbl)	Purchased CO_2		Purchased CO_2/Oil Recovery (Ratio)	
		Bcf	MM mt	Mcf/B	mt/B
#1	-	-	-	-	-
#2	-	-	-	-	-
#3	970	7,210	380	7.4	0.39
Total	**970**	**7,210**	**380**	**7.4**	**0.39**

The commercially viable portion of the ROZ resource has purchased CO_2 to produced oil ratio of 0.39 metric tons of CO_2 per barrel of recovered oil (7.4 Mcf per barrel), all of which is produced from Partition #3.

5.5.2 Geologically Viable CO_2 Storage with By-Product Oil Recovery

The three San Andres ROZ fairway partitions of Ector County also offer the potential for 730 million metric tons (13,780 Bcf) of geologically viable CO_2 storage with 890 million barrels of by-product oil recovery, as shown in Exhibit 5-9.

Exhibit 5-9. Ector County geologically viable CO_2 storage with by-product oil recovery

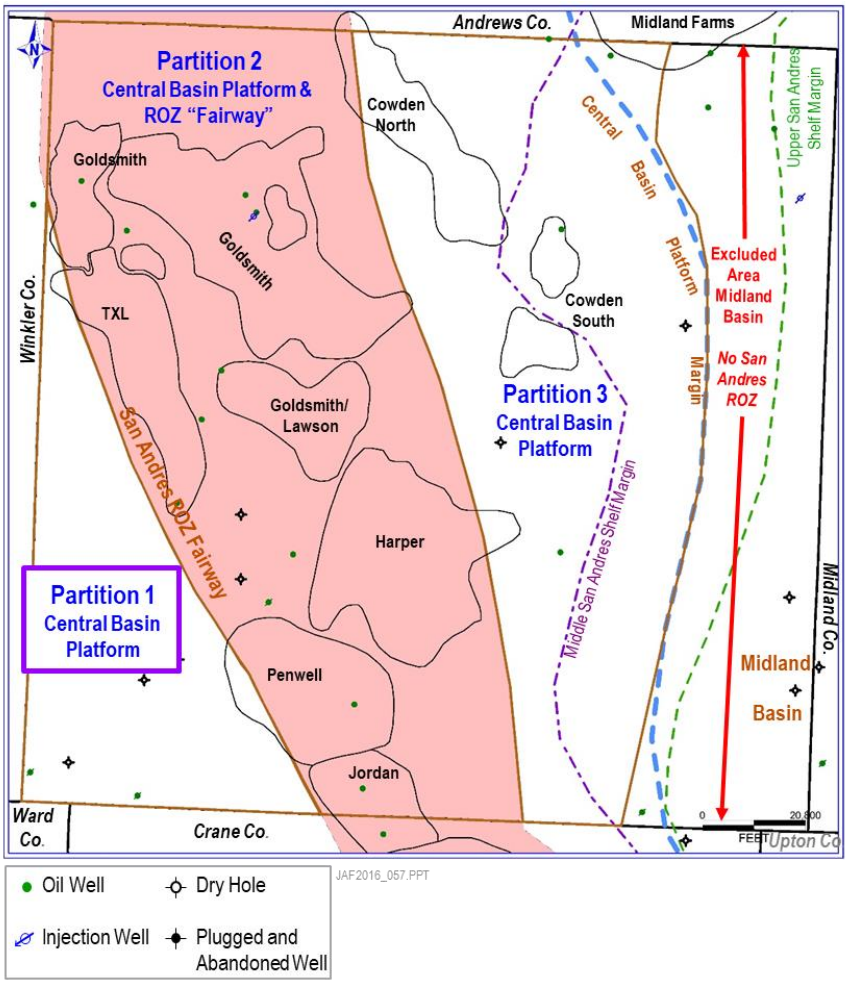
Partition	Purchased CO_2		By-Product Oil Recovery (MM bbl)	Purchased CO_2/Oil Recovery (Ratio)	
	Bcf	MM mt		Mcf/B	mt/B
#1	4,020	210	160	25.1	1.33
#2	7,300	390	660	11.1	0.59
#3	2,460	130	70	35.1	1.86
Total	**13,780**	**730**	**890**	**15.5**	**0.82**

5.6 Partition #1. Ector County

5.6.1 Geologic Setting

Partition #1, located in Ector County, covers a San Andres ROZ fairway area of 73,800 acres (Exhibit 5-10). The partition does not contain any major San Andres oil fields. Partition #1 is located west of the previously established San Andres ROZ fairway boundaries, in the CBP.

Exhibit 5-10. San Andres ROZ fairway Partition #1, Ector County



5.6.2 Analytic ROZ Reservoir Properties

Five well log-based reservoir data sets plus a series of working level cross-sections were used to allocate the San Andres ROZ fairway resource in Partition #1 of Ector County into two analytical ROZ fairway reservoir units:

- A higher quality ROZ resource
- A lower quality ROZ resource

The average volumetric reservoir properties for the two analytical San Andres ROZ fairway reservoir units of Partition #1 of Ector County are provided in Exhibit 5-11.

Exhibit 5-11. Average San Andres ROZ fairway reservoir properties: Partition #1, Ector County

Property	Higher Quality	Lower Quality
Depth (to top) (ft)	4,320	4,150
Gross Thickness (ft)	213	170
Net Pay (ft)	96	83
Avg. Porosity (fraction)	0.093	0.109
Avg. Oil Saturation (fraction)	0.27	0.16
Avg. Formation Volume Factor (res B/bbl)	1.22	1.22
OIP (BBLS/AF, for net pay)	160	111

5.6.3 ROZ OIP

The San Andres ROZ fairway in Partition #1 of Ector County contains 690 million barrels of OIP, Exhibit 5-12. Only a modest portion of the ROZ OIP (200 million barrels) meets the higher ROZ resource quality criteria. The majority of the ROZ OIP of 490 million barrels meets the lower resource quality criteria.

Exhibit 5-12. San Andres ROZ fairway OIP: Partition #1, Ector County

Property	Higher Quality	Lower Quality
OIP (Bbls/Acre)	17,280	10,37
Area Extent (Acres)	11,840	47,200
OIP (MM bbl)	200	490

5.6.4 Technically Recoverable Resources

Of the 690 million barrels of San Andres ROZ OIP in Partition #1 of Ector County, approximately 160 million barrels is technically recoverable from the application of miscible CO_2 EOR, giving a recovery efficiency of 23 percent of OIP.

In addition, significant volumes of CO_2 are injected and stored as part of applying miscible CO_2 EOR for recovering a portion of the ROZ OIP. Approximately 210 million metric tons (4,020 Bcf)

of CO_2 are purchased for the San Andres ROZ fairway EOR project in Partition #1 of Ector County, with essentially all of the purchased CO_2 securely stored at the end of the CO_2 flood.

5.6.5 Commercially Viable Oil Recovery with By-Product CO_2 Storage

No portion of the 160 million barrels of technically recoverable San Andres ROZ fairway oil resource available from Partition #1 of Ector County is commercially viable to develop under the economic assumptions used in this study (Exhibit 5-13).

Exhibit 5-13. Commercially viable oil recovery with by-product CO_2 storage: Partition #1, Ector County

Oil Recovery (MM bbl)	Purchased CO_2		Purchased CO_2/Oil Recovery (Ratio)	
	Bcf	MM mt	Mcf/B	mt/B
-	-	-	-	-

5.6.6 Geologically Viable CO_2 Storage with By-Product Oil Recovery

Pursuing the geologically viable, but economically non-viable, portion of the San Andres ROZ fairway resource in Partition #1 of Ector County with miscible CO_2 flooding provides 210 million metric tons (4,020 Bcf) of CO_2 storage capacity and 160 million barrels of by-product oil recovery (Exhibit 5-14).

Exhibit 5-14. Geologically viable storage of CO_2 with by-product oil recovery: Partition #1 Ector County

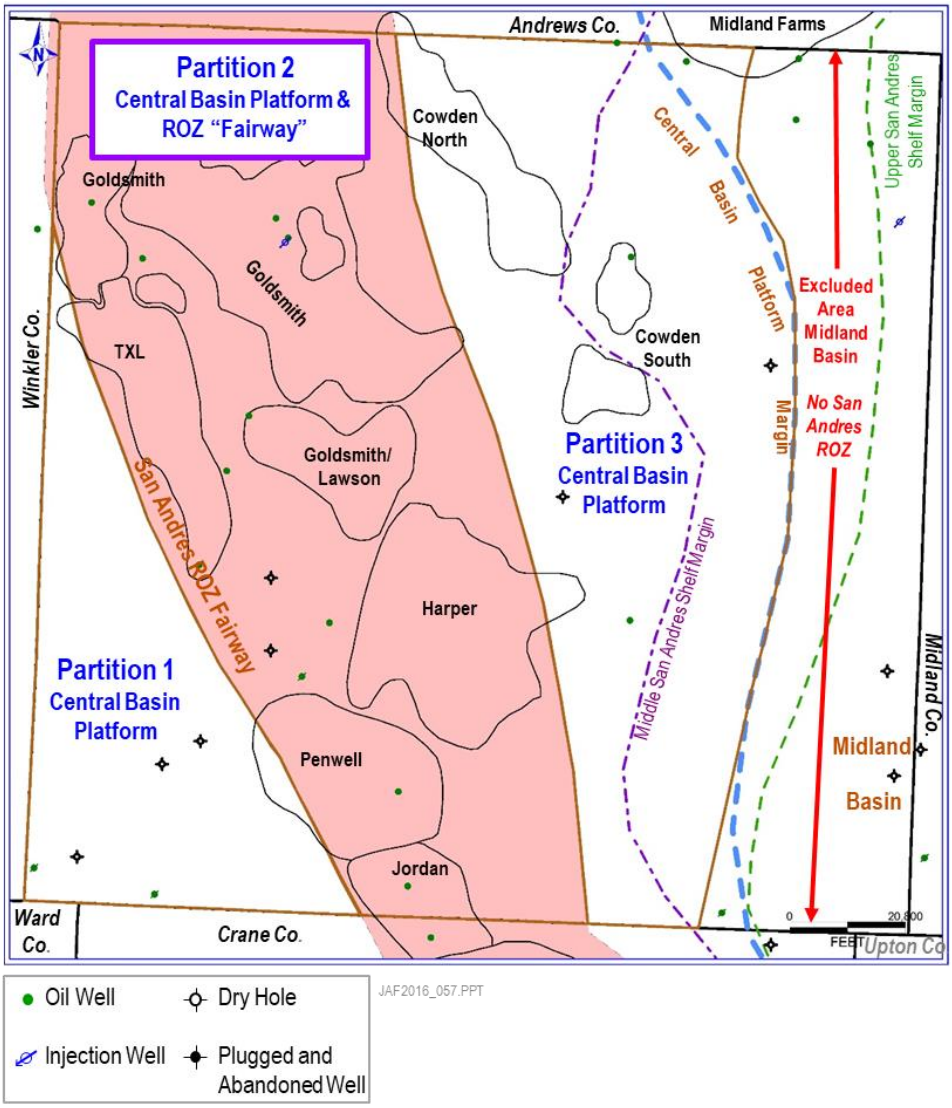
Purchased CO_2		By-Product Oil Recovery (MM bbl)	Purchased CO_2/Produced Oil (Ratio)	
Bcf	MM mt		Mcf/B	mt/B
4,020	210	160	25.1	1.33

5.7 Partition #2. Ector County

5.7.1 Geologic Setting

Partition #2, located in Ector County, covers a San Andres ROZ fairway area of 152,800 acres, Exhibit 5-15. The partition excludes areas underlain by San Andres oil fields (71,800 acres). Partition #1 is located inside the previously established San Andres ROZ fairway boundaries, in the CBP.

Exhibit 5-15. San Andres ROZ fairway Partition #2, Ector County



5.7.2 Analytic ROZ Reservoir Properties

Ten well log-based reservoir data sets plus a series of working level cross-sections were used to allocate the San Andres ROZ fairway resource in Partition #2 of Ector County into two analytical ROZ fairway reservoir units:

- A higher quality ROZ resource
- A lower quality ROZ resource

The average volumetric reservoir properties for the two analytical San Andres ROZ fairway reservoir units of Partition #2 of Ector County are provided in Exhibit 5-16.

Exhibit 5-16. Average San Andres ROZ fairway reservoir properties: Partition #2, Ector County

Property	Higher Quality	Lower Quality
Depth (to top) (ft)	4,250	4,590
Gross Thickness (ft)	135	141
Net Pay (ft)	101	84
Avg. Porosity (fraction)	0.094	0.096
Avg. Oil Saturation (fraction)	0.35	0.23
Avg. Formation Volume Factor (res B/bbl)	1.36	1.36
OIP (BBLS/AF, for net pay)	188	126

5.7.3 ROZ OIP

The San Andres ROZ fairway in Partition #2 of Ector County contains 2,020 million barrels of OIP (Exhibit 5-17). The bulk of the ROZ OIP (1,630 million barrels) meets the higher ROZ resource quality criteria. The remainder of the ROZ OIP of 390 million barrels meets the lower resource quality criteria.

Exhibit 5-17. San Andres ROZ fairway OIP: Partition #2, Ector County

Property	Higher Quality	Lower Quality
OIP (Bbls/Acre)	19,040	10,630
Area Extent (Acres)	85,600	36,640
OIP (MM bbl)	1,630	390

5.7.4 Technically Recoverable Resources

Of the 2,020 million barrels of San Andres ROZ OIP in Partition #2 of Ector County, approximately 660 million barrels is technically recoverable from the application of miscible CO_2 EOR, giving a recovery efficiency of 33 percent of OIP.

In addition, significant volumes of CO_2 are injected and stored as part of applying miscible CO_2 EOR for recovering a portion of the ROZ OIP. Approximately 390 million metric tons (7,300 Bcf) of CO_2 are purchased for the San Andres ROZ fairway EOR project in Partition #2 of Ector County, with essentially all of the purchased CO_2 securely stored at the end of the CO_2 flood.

5.7.5 Commercially Viable Oil Recovery with By-Product CO_2 Storage

No portion of the 660 million barrels of technically recoverable San Andres ROZ fairway oil resource available from Partition #1 of Ector County is commercially viable to develop under the economic assumptions used in this study (Exhibit 5-18).

Exhibit 5-18. Commercially viable oil recovery with by-product CO_2 storage: Partition #2, Ector County

Oil Recovery (MM bbl)	Purchased CO_2		Purchased CO_2/Oil Recovery (Ratio)	
	Bcf	MM mt	Mcf/B	mt/B
-	-	-	-	-

5.7.6 Geologically Viable CO_2 Storage with By-Product Oil Recovery

Pursuing the geologically viable, but economically non-viable, portion of the San Andres ROZ fairway resource in Partition #2 of Ector County with miscible CO_2 flooding provides 390 million metric tons (7,300 Bcf) of CO_2 storage capacity and 660 million barrels of by-product oil recovery (Exhibit 5-19).

Exhibit 5-19. Geologically viable storage of CO_2 with by-product oil recovery: Partition #2, Ector County

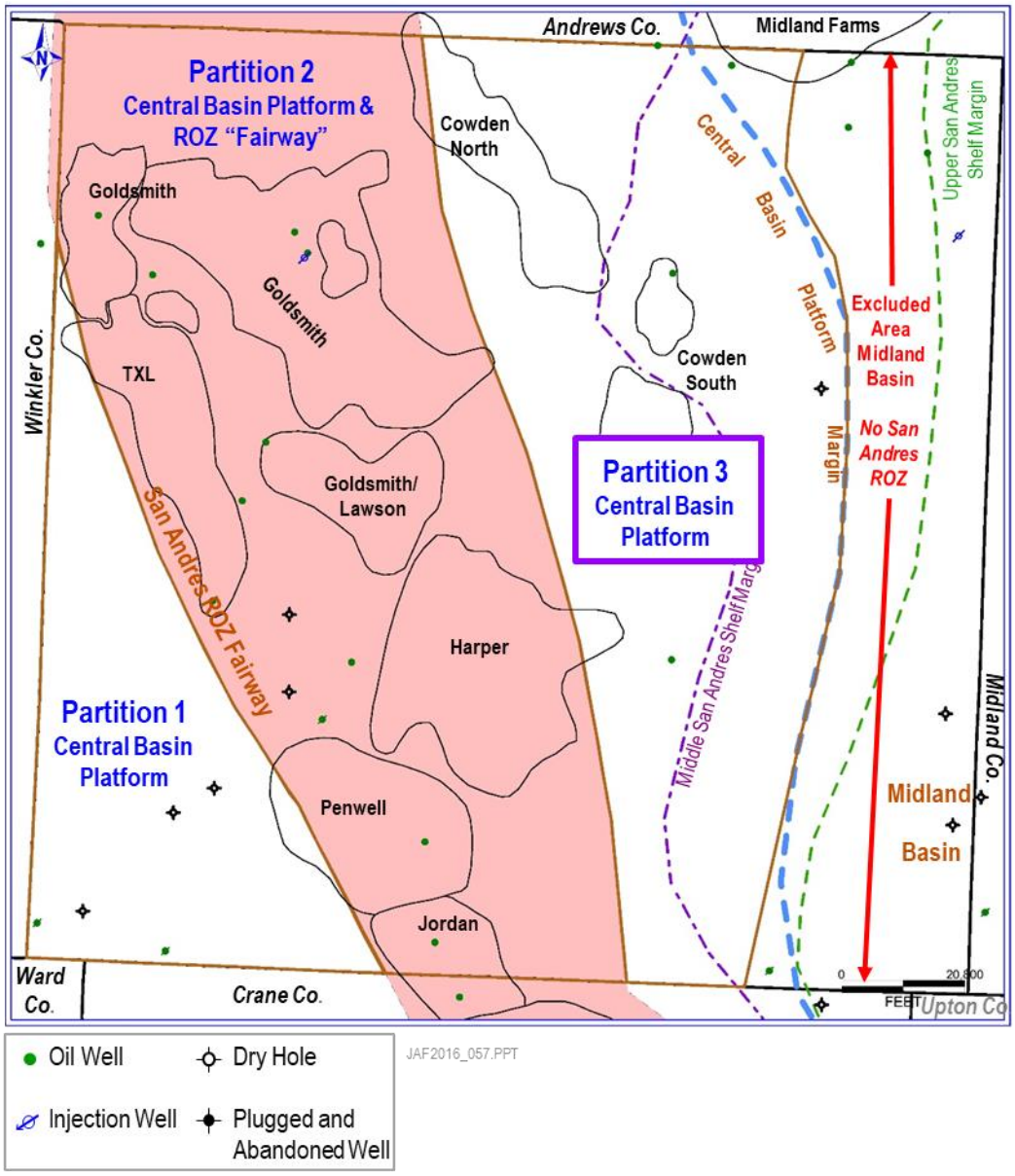
Purchased CO_2		By-Product Oil Recovery (MM bbl)	Purchased CO_2/Produced Oil (Ratio)	
Bcf	MM mt		Mcf/B	mt/B
7,300	390	660	11.1	0.59

5.8 Partition #3. Ector County

5.8.1 Geologic Setting

Partition #3, located in Ector County, covers a San Andres ROZ fairway area of 121,700 acres (Exhibit 5-20). The partition excludes areas underlain by San Andres oil fields (50,100 acres). Partition #3 is located outside of the previously established San Andres ROZ fairway boundaries, in the CBP.

Exhibit 5-20. San Andres ROZ fairway Partition #3, Ector County



5.8.2 Analytic ROZ Reservoir Properties

Six well log-based reservoir data sets plus a series of working level cross-sections were used to allocate the San Andres ROZ fairway resource in Partition #3 of Ector County into two analytical ROZ fairway reservoir units:

- A higher quality ROZ resource
- A lower quality ROZ resource

The average volumetric reservoir properties for the two analytical San Andres ROZ fairway reservoir units of Partition #3 of Ector County are provided in Exhibit 5-21.

Exhibit 5-21. Average San Andres ROZ fairway reservoir properties: Partition #3, Ector County

Property	Higher Quality	Lower Quality
Depth (to top) (ft)	4,470	4,490
Gross Thickness (ft)	278	240
Net Pay (ft)	219	123
Avg. Porosity (fraction)	0.10	0.110
Avg. Oil Saturation (fraction)	0.36	0.15
Avg. Formation Volume Factor (res B/bbl)	1.26	1.26
OIP (BBLS/AF, for net pay)	222	102

5.8.3 ROZ OIP

The San Andres ROZ fairway in Partition #3 of Ector County contains 3,560 million barrels of OIP (Exhibit 5-22). The bulk of the ROZ OIP (3,160 million barrels) meets the higher ROZ resource quality criteria. The remainder of the ROZ OIP of 400 million barrels meets the lower resource quality criteria.

Exhibit 5-22. San Andres ROZ fairway OIP: Partition #3, Ector County

Property	Higher Quality	Lower Quality
OIP (Bbls/Acre)	48,710	12,510
Area Extent (Acres)	64,880	32,480
OIP (MM bbl)	3,160	400

5.8.4 Technically Recoverable Resources

Of the 3,560 million barrels of San Andres ROZ OIP in Partition #3 of Ector County, approximately 1,030 million barrels is technically recoverable from the application of miscible CO_2 EOR, giving a recovery efficiency of 29 percent of OIP.

In addition, significant volumes of CO_2 are injected and stored as part of applying miscible CO_2 EOR for recovering a portion of the ROZ OIP. Approximately 510 million metric tons (9,670 Bcf) of CO_2 are purchased for the San Andres ROZ fairway EOR project in Partition #3 of Ector County, with essentially all of the purchased CO_2 securely stored at the end of the CO_2 flood.

5.8.5 Commercially Viable Oil Recovery with By-Product CO_2 Storage

Of the 1,030 million barrels of technically recoverable San Andres ROZ fairway oil resource available from Partition #3 of Ector County, 970 million barrels are commercially viable to develop under the economic assumptions used in this study.

The application of CO_2 EOR to the commercially viable portion of the San Andres ROZ fairway resource in Partition #3 of Ector County also provides 380 million metric tons (7,210 Bcf) of by-product storage of CO_2 (Exhibit 5-23).

Exhibit 5-23. Commercially viable oil recovery with by-product CO_2 storage: Partition #3, Ector County

Oil Recovery (MM bbl)	Purchased CO_2		Purchased CO_2/Oil Recovery (Ratio)	
	Bcf	MM mt	Mcf/B	mt/B
970	7,210	380	7.4	0.39

The production of one barrel of San Andres ROZ fairway oil in Partition #3 of Ector County brings with it, at the margin, the storage of 0.39 metric tons of CO_2 when using high pressure CO_2 injection as the oil recovery method.

5.8.6 Geologically Viable CO_2 Storage with By-Product Oil Recovery

Pursuing the geologically viable, but economically non-viable, portion of the San Andres ROZ fairway resource in Partition #3 of Ector County with miscible CO_2 flooding provides 130 million metric tons (2,460 Bcf) of CO_2 storage capacity and 70 million barrels of by-product oil recovery (Exhibit 5-24).

Exhibit 5-24. Geologically viable storage of CO_2 with by-product oil recovery: Partition #3, Ector County

Purchased CO_2		By-Product Oil Recovery (MM bbl)	Purchased CO_2/Produced Oil (Ratio)	
Bcf	MM mt		Mcf/B	mt/B
2,460	130	70	35.1	1.86

6 SOUTHERN TIER COUNTIES

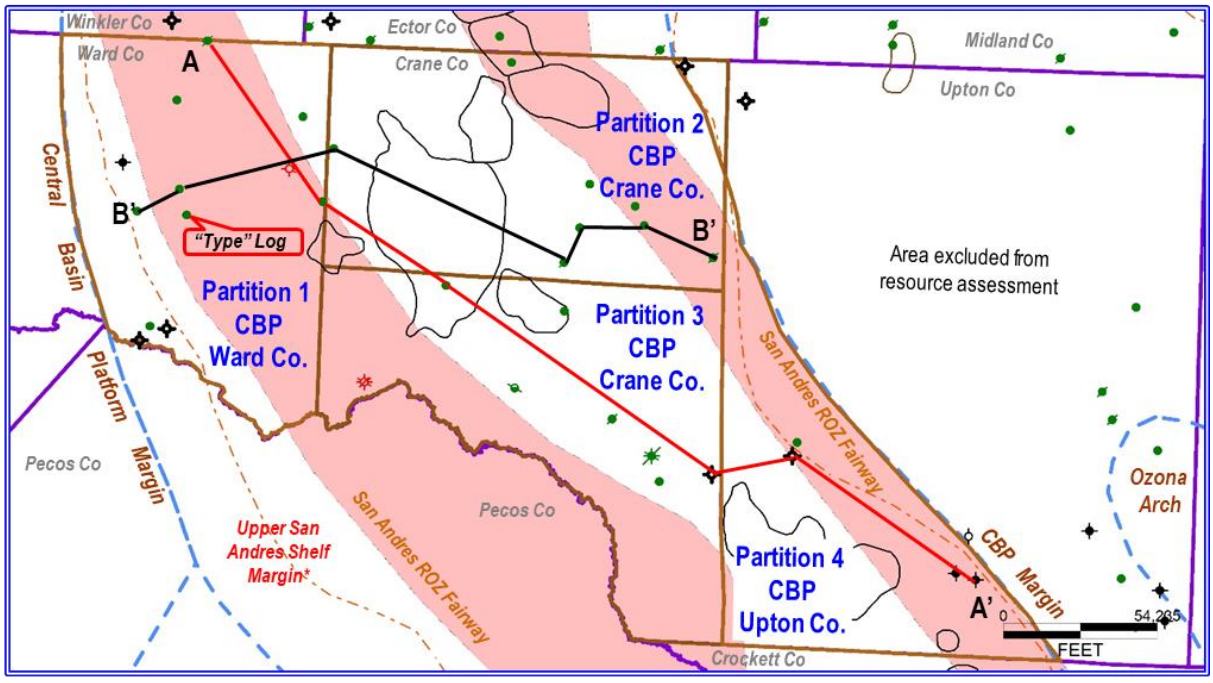
6.1 GEOLOGIC SETTING OF THE SOUTHERN TIER COUNTIES SAN ANDRES ROZ FAIRWAY

The Southern Tier counties—Ward, Crane, and Upton—cover a 1,833,000-acre area in the West Texas portion of the Permian Basin. Approximately two-thirds of the three-county area is on the CBP. The remainder of the area is east and west of this prominent Permian Basin feature.

The Southern Tier counties map contains numerous San Andres oil fields, including Lea, C. Bar, McCamey, Sand Hills, and Waddell, among others. The ROZ resource below these and other existing San Andres oil fields has been excluded from the resource assessment of the San Andres ROZ fairway.

The Southern Tier counties map (Exhibit 6-1) shows 1) the location of 45 study wells, 2) the four San Andres ROZ fairway partitions established by the study, 3) the boundaries of the previously established San Andres ROZ fairway, 4) the outline of the CBP, and 5) the location of two regional cross-sections featuring the San Andres ROZ. The map also shows the major San Andres oil fields excluded from the San Andres ROZ fairway resource assessment in the Southern Tier counties.

Exhibit 6-1. Southern Tier counties: geologic partitions, major oil fields, and study well locations



6.1.1 Example Southern Tier Counties Cross-Sections

The delineation and characterization of the San Andres ROZ fairway interval in the Southern Tier counties utilized a series of working cross-sections. Two of these cross-sections are included in this study.

- Southern Tier counties cross-section A-A' (Exhibit 6-2) provides a northwest to southeast view of the San Andres ROZ interval on the CBP.
- Southern Tier counties cross-section B-B' (Exhibit 6-3) provides a west to east view of the San Andres ROZ interval through the center of these counties.

Exhibit 6-2. Southern Tier counties cross-section A-A'

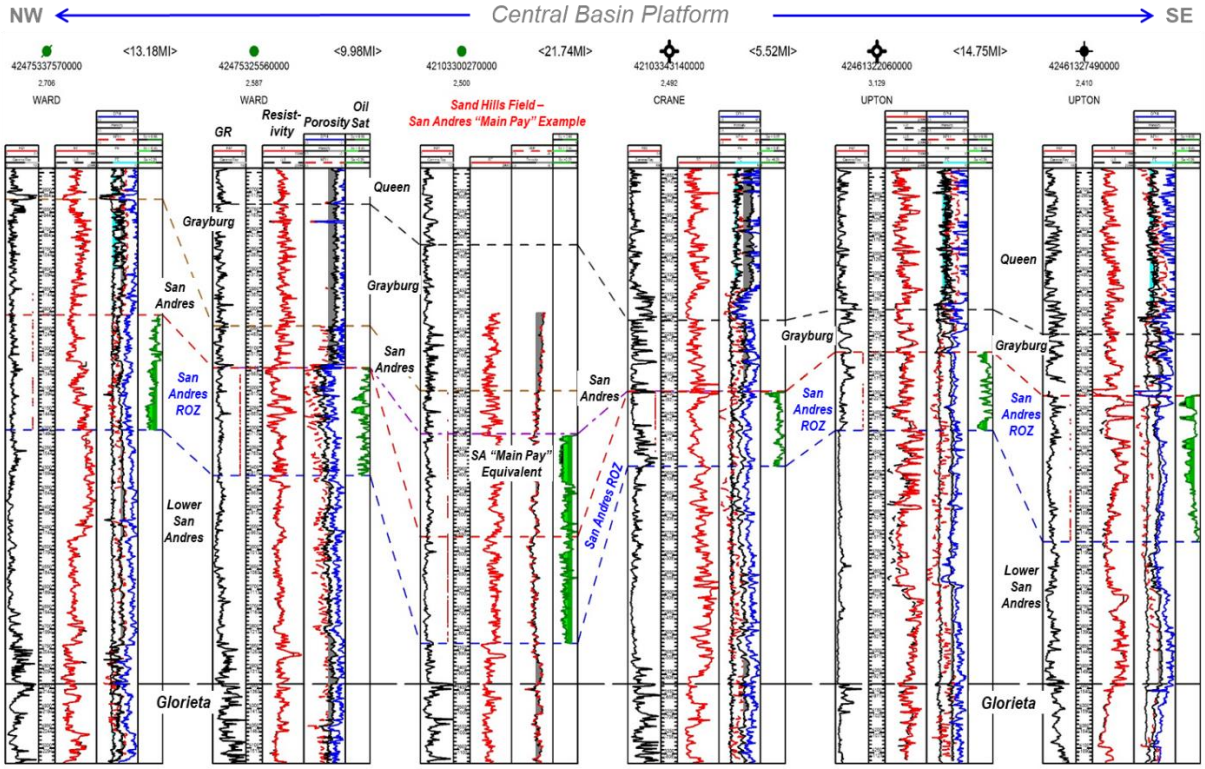
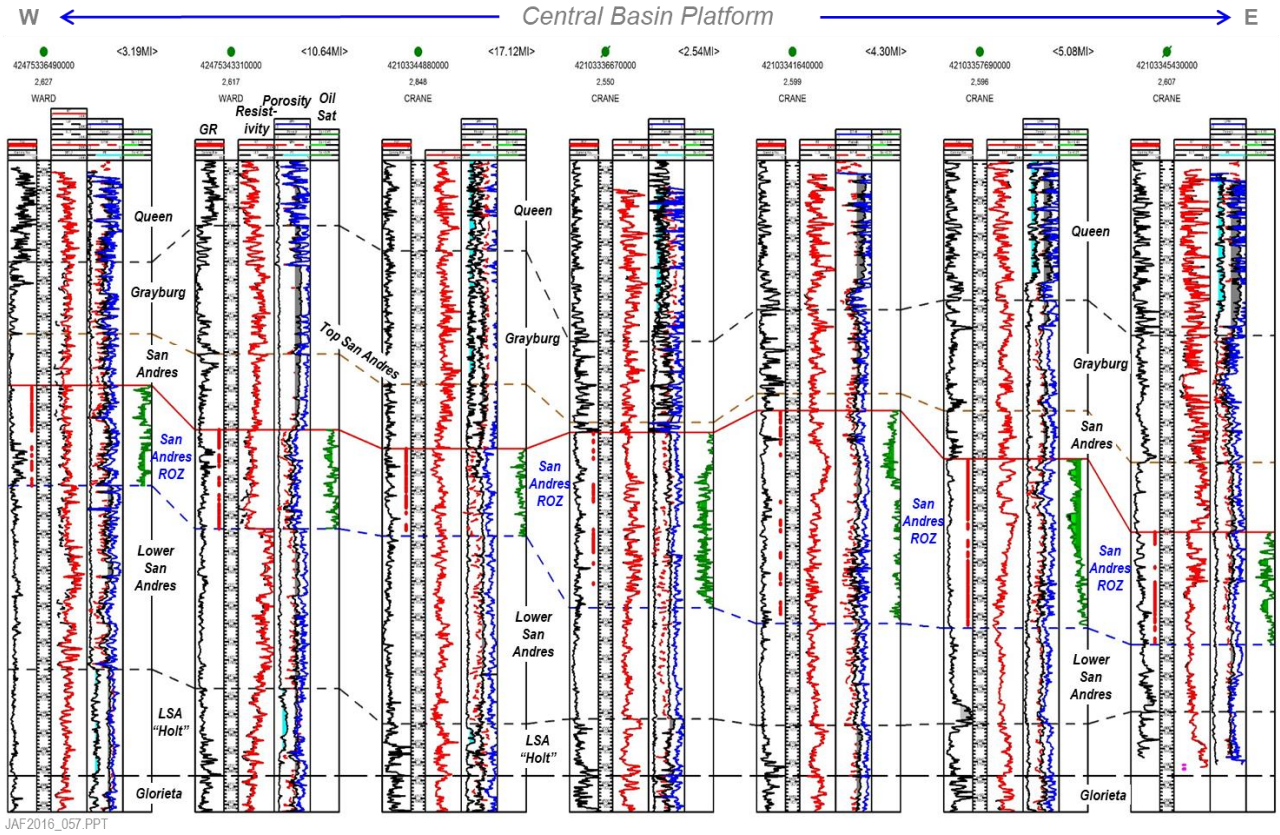


Exhibit 6-3. Southern Tier counties cross-section B-B'



6.1.2 Interpretation of Southern Tier Counties Cross-Sections

For logs from the ROZ fairway, the top of the San Andres porous dolomite is picked as the top of the ROZ for this resource assessment.

The cross-sections display gamma-ray and caliper logs in Track 1 on the left. Resistivity logs are shown in Track 2, with the deep resistivity log shown in red. Track 3 shows the porosity logs. Uncorrected neutron porosity (for limestone) is red; uncorrected density porosity (for limestone) is blue. The porosity curve used for the OIP calculation is black. The PEF curve, if available, is also displayed in Track 3. PEF values greater than 4 are shaded in blue. Within and below the ROZ interval, high PEF values generally indicate the presence of limestone, dolomitic limestone, or anhydrite.

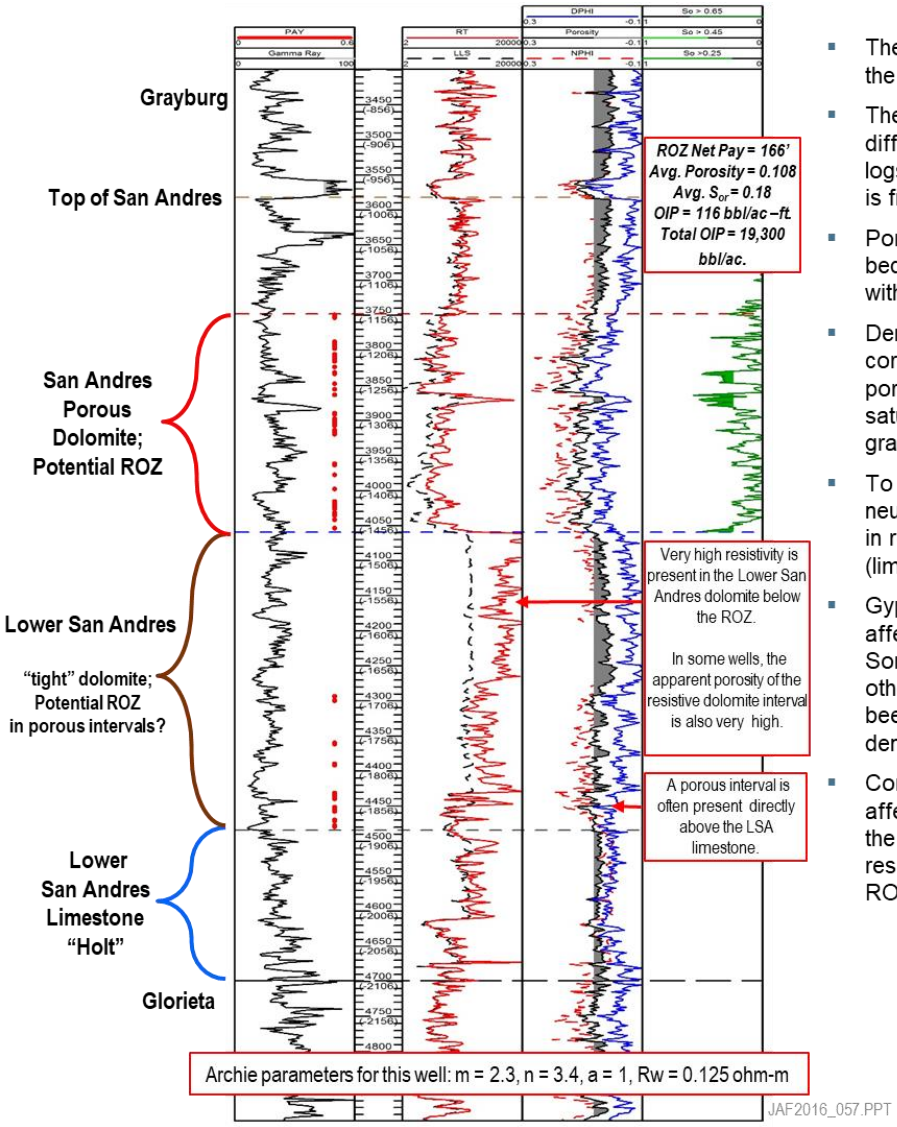
Track 4 on the right shows the calculated oil saturation. Calculated oil saturations between 25 percent and 40 percent are dark green and calculated oil saturations between 45 percent and 60 percent are light green.

The base of the ROZ is where either calculated oil saturation or apparent porosity (or both) diminish in the Lower San Andres. If a Lower San Andres limestone is prominent, the top of the limestone defines the base of the ROZ.

6.1.3 Southern Tier Counties Type Log

A type log was selected from the Southern Tier counties study wells to illustrate the ROZ resource analysis undertaken for this area (Exhibit 6-4).

Exhibit 6-4. Southern Tier counties San Andres ROZ type well 42-003-37529



- The ROZ exists at or near the top of the San Andres.
- The Grayburg and San Andres are difficult to discriminate based on well logs. The San Andres top shown here is from the well record.
- Porosity is developed in fairly thin beds that appear to be interbedded with shale or siltstone.
- Density and neutron porosity logs are corrected for dolomite. Cross-plot porosity (black) is used to compute oil saturation. Porosity < 0.06 is shaded gray.
- To illustrate lithology, uncorrected neutron porosity (limestone) is shown in red; uncorrected density porosity (limestone) is shown in blue.
- Gypsum and elemental sulfur may affect neutron and density porosity. Sonic porosity is used if available; otherwise additional corrections have been applied to the neutron and density logs.
- Complex lithology may also be affecting the resistivity log response in the Lower San Andres. Unusually high resistivity zones are omitted from the ROZ analysis.

The oil saturation for the type log ROZ was calculated using the following Archie parameters—'m' of 2.3, 'n' of 3.4, 'a' of 1, and formation water resistivity (Rw) of 0.125 ohm-m. A porosity cut-off of 6 percent was applied to define net pay in the ROZ. Intervals identified as ROZ pay are shown by the red pay flag in Track 1 in Exhibit 6-4.

6.2 Partitioning the Southern Tier Counties San Andres ROZ Fairway

The ROZ fairway in the Southern Tier counties has been divided into four partitions, as illustrated in Exhibit 6-1. Individual San Andres ROZ fairway resource assessments were undertaken for each of the four partitioned areas. The eastern portion of Upton County and the western portion of Ward County (plus a small area of Crane County) together encompassing 910,000 acres where the San Andres ROZ is thin or absent and 163,000 acres below a series of existing oil fields have been excluded, leaving a remaining San Andres ROZ fairway assessment area of 760,000 acres (Exhibit 6-5).

Exhibit 6-5. Southern Tier counties San Andres ROZ fairway partitions

Partition	Total Area	Excluded Area Below Oil Fields	Assessment Area
	Acres	Acres	Acres
#1 (Ward Co.)	240,000	1,000	239,000
#2 (N. Crane Co.)	248,000	113,000	135,000
#3 (S. Crane Co.)	246,000	35,000	211,000
#4 (Upton Co.)	189,000	14,000	175,000
Total	**923,000**	**163,000**	**760,000**

- ***Partition #1 (Ward Co.).*** Covers a 240,000-acre area of eastern Ward County on the CBP. The Sand Hills oil field, covering 1,000 acres, has been excluded from Partition #1, leaving a ROZ fairway area of 239,000 acres. An area of 304,000 acres in Ward County in the Delaware Basin is outside Partition #1.
- ***Partition #2 (N. Crane Co.).*** Covers a 248,000-acre area of northern Crane County on the CBP. A total of 113,000 acres under existing oil fields has been excluded, and an area of 8,000 acres in northeast Crane County where San Andres dolomite is absent is outside of Partition #2, leaving a ROZ fairway area of 135,000 acres.
- ***Partition #3 (S. Crane Co.).*** Covers a 246,000-acre area of southern Crane County on the CBP. A total of 35,000 acres under existing oil fields has been excluded from Partition #3, leaving a ROZ fairway area of 211,000 acres.
- ***Partition #4 (Upton Co.).*** Covers a 189,000-acre area of Upton County on the CBP. A total of 14,000 acres under existing oil fields is excluded, and an area of 606,000 acres of northwest Upton County where porous San Andres dolomite is thin or absent is outside of Partition #4, leaving a ROZ fairway area of 175,000 acres.

6.3 Size and Quality of the Southern Tier Counties San Andres ROZ Fairway Resource

The Southern Tier counties hold 17,130 million barrels of OIP in the San Andres ROZ fairway outside the structural closure of the existing oil fields. The OIP and resource quality values for each of the four partitions of the Southern Tier counties are shown in Exhibit 6-6.

- Higher Quality ROZ Fairway Resources. A total of 7,590 million barrels of the San Andres ROZ fairway OIP in the Southern Tier counties has higher quality reservoir properties (porosity greater than 8 percent and oil saturation equal to or greater than 25%).
- Lower Quality ROZ Fairway Resources. The remainder, 9,540 million barrels, of the San Andres ROZ fairway OIP in the Southern Tier counties has lower quality reservoir properties (porosity equal to or less than 8 percent and/or oil saturation of less than 25%).

Exhibit 6-6. Southern Tier counties San Andres ROZ fairway resource in-place (MM bbl)

Partitions	Higher Quality	Lower Quality	Total
#1 (Ward Co.)	3,730	3,760	7,490
#2 (N. Crane Co.)	1,670	2,190	3,870
#3 (S. Crane Co.)	2,190	600	2,780
#4 (Upton Co.)	-	2,990	2,990
Total	**7,590**	**9,540**	**17,130**

6.4 Technically Recoverable Southern Tier Counties ROZ Fairway Resource

6.4.1 Methodology for Estimating Technically Recoverable Resources

The average volumetric reservoir properties for each partition of the Southern Tier counties, along with proprietary reservoir properties from ARI's Big Oil Fields Data Base, were used as input into the Prophet Model. Additionally, it was assumed that 80 percent of each partition area was suitable for development, while 20 percent of the partition had a combination of net pay, porosity, or oil saturation that was not suitable for development. It was also assumed that 90 percent of the OIP in each partition resides in the area suitable for development. The net pay for the developed portion of the partition was increased so that the OIP in the developed portion equaled 90 percent of the OIP calculated for the entire partition. The Prophet Model was then used to calculate the volumes of recoverable oil and water as well as the volumes of injected and stored CO_2. The Prophet Model was run assuming five-spot patterns were implemented for each partition. ROZ fairway well pattern spacings of 40 to 80 acres per CO_2 injection well were selected to achieve a target of approximately 30 years of operation for the miscible CO_2 flood.

6.4.2 Summary of Technically Recoverable Resources

A significant portion of the San Andres ROZ fairway OIP in the Southern Tier counties is technically recoverable using miscible CO_2 EOR, while also providing major volumes of pore space for storing CO_2 (Exhibit 6-7).

- Total technically viable oil recovery is estimated at 5,480 million barrels, produced primarily from the lower quality portions of the ROZ resource.
- While the oil recovery efficiencies vary by partition, overall recovery efficiency is 32 percent of OIP in response to one HCPV injection of CO_2 using a tapered WAG miscible CO_2 flood.
- The San Andres ROZ fairway interval in the Southern Tier counties offers the potential for significant storage of CO_2, equal to 3,530 million metric tons (66,710 Bcf).

Exhibit 6-7. Southern Tier counties technically recoverable San Andres ROZ fairway resource

Partitions	Oil Recovery		Purchased CO_2	
	MM bbl	%OIP	Bcf	MM mt
#1 (Ward Co.)	2,400	32%	30,350	1,606
#2 (N. Crane Co.)	1,140	29%	16,880	893
#3 (S. Crane Co.)	880	32%	9,340	494
#4 (Upton Co.)	1,060	35%	10,140	537
Total	**5,480**	**32%**	**66,710**	**3,530**

6.5 Viability of Oil Recovery and CO_2 Storage in the Southern Tier Counties ROZ Fairway

The CO_2 EOR Cost Model used by the study assumes a first-year oil price (WTI) of $75 per barrel linked to an initial CO_2 purchase cost of $1.50 per Mcf ($28.35 per metric ton of CO_2).

6.5.1 Commercially Viable Oil Recovery with By-Product CO_2 Storage

The four San Andres ROZ fairway partitions of the Southern Tier counties offer potential for 1,940 million barrels of commercially viable oil recovery with 949 million metric tons (17,930 Bcf) of by-product storage of CO_2 (Exhibit 6-8).

Exhibit 6-8. Southern Tier counties commercially viable oil recovery with by-product CO_2 storage

Partition	Oil Recovery (MM bbl)	Purchased CO_2		Purchased CO_2/ Oil Recovery (Ratio)	
		Bcf	MM mt	Mcf/B	mt/B
#1	1,350	12,040	637	8.9	0.47
#2	590	5,890	312	10.0	0.53
#3	-	-	-	-	-
#4	-	-	-	-	-
Total	**1,940**	**17,930**	**949**	**9.2**	**0.49**

The commercially viable portion of the ROZ resource has purchased CO_2 to produced oil ratio of 0.49 metric ton of CO_2 per barrel of recovered oil (9.2 Mcf per barrel), ranging from 0.47 metric ton per barrel in Partition #1 to 0.53 metric ton per barrel in Partition #2.

6.5.2 Geologically Viable CO_2 Storage with By-Product Oil Recovery

The four San Andres ROZ fairway partitions of the Southern Tier counties also offer potential for 2,581 million metric tons (48,790 Bcf) of geologically viable CO_2 storage with 3,540 million barrels of by-product oil recovery, as shown in Exhibit 6-9.

Exhibit 6-9. Southern Tier counties geologically viable CO_2 storage with by-product oil recovery

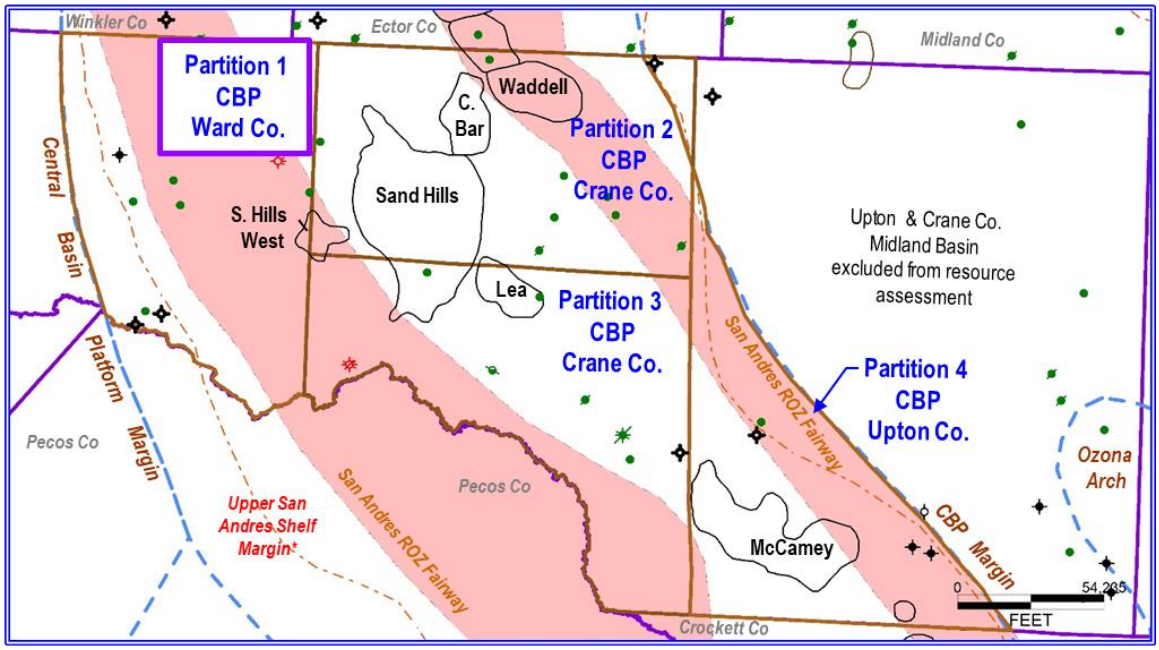
Partition	Purchased CO_2		By-Product Oil Recovery (MM bbl)	Purchased CO_2/Oil Recovery (Ratio)	
	Bcf	MMmt		Mcf/B	mt/B
#1	18,320	969	1,050	17.4	0.92
#2	10,990	581	550	20.0	1.06
#3	9,340	494	880	10.6	0.56
#4	10,140	537	1,060	9.6	0.51
Total	**48,790**	**2,581**	**3,540**	**13.8**	**0.73**

6.6 Partition #1. Eastern Ward County, Southern Tier

6.6.1 Geologic Setting

Partition #1, located in eastern Ward County, covers a San Andres ROZ fairway area of 239,000 acres (Exhibit 6-10). The partition excludes areas underlain by the Sand Hills West oil field (1,000 acres). Partition #1 includes much of the previously established San Andres ROZ fairway boundaries in the CBP.

Exhibit 6-10. San Andres ROZ fairway Partition #1, Southern Tier counties



6.6.2 Analytic ROZ Reservoir Properties

Eleven well log-based reservoir data sets plus a series of working level cross-sections were used to allocate the San Andres ROZ fairway resource in Partition #1 of the Southern Tier counties into two analytical ROZ fairway reservoir units:

- A higher quality ROZ resource
- A lower quality ROZ resource

The average volumetric reservoir properties for the two analytical San Andres ROZ fairway reservoir units of Partition #1 of the Southern Tier counties are provided in Exhibit 6-11.

Exhibit 6-11. Average San Andres ROZ fairway reservoir properties: Partition #1, Southern Tier counties

Property	Higher Quality	Lower Quality
Depth (to top) (ft)	3,490	3,560
Gross Thickness (ft)	321	435
Net Pay (ft)	242	235
Avg. Porosity (fraction)	0.116	0.105
Avg. Oil Saturation (fraction)	0.32	0.21
Avg. Formation Volume Factor (res B/bbl)	1.30	1.30
OIP (BBLS/AF, for net pay)	222	132

6.6.3 ROZ OIP

The San Andres ROZ fairway in Partition #1 of the Southern Tier counties contains 7,490 million barrels of OIP (Exhibit 6-12). Approximately half of the ROZ OIP (3,730 million barrels) meets the higher ROZ resource quality criteria. The remainder of the ROZ OIP of 3,760 million barrels meets the lower resource quality criteria.

Exhibit 6-12. San Andres ROZ fairway OIP: Partition #1, Southern Tier counties

Property	Higher Quality	Lower Quality
OIP (Bbls/Acre)	53,700	31,030
Area Extent (Acres)	69,600	121,600
OIP (MM bbl)	3,730	3,760

6.6.4 Technically Recoverable Resources

Of the 7,490 million barrels of San Andres ROZ OIP in Partition #1 of the Southern Tier counties, approximately 2,400 million barrels is technically recoverable from the application of miscible CO_2 EOR, giving a recovery efficiency of 32 percent of OIP.

In addition, significant volumes of CO_2 are injected and stored as part of applying miscible CO_2 EOR for recovering a portion of the ROZ OIP. Approximately 1,606 million metric tons (30,350 Bcf) of CO_2 are purchased for the San Andres ROZ fairway EOR project in Partition #1 of the Southern Tier counties, with essentially all of the purchased CO_2 securely stored at the end of the CO_2 flood.

6.6.5 Commercially Viable Oil Recovery with By-Product CO_2 Storage

Of the 2,400 million barrels of technically recoverable San Andres ROZ fairway oil resource available from Partition #1 of the Southern Tier counties, 1,350 million barrels are commercially viable to develop under the economic assumptions used in this study.

The application of CO_2 EOR to the commercially viable portion of the San Andres ROZ fairway resource in Partition #1 of the Southern Tier counties also provides 637 million metric tons (12,040 Bcf) of by-product storage of CO_2 (Exhibit 6-13).

Exhibit 6-13. Commercially viable oil recovery with by-product CO_2 storage: Partition #1, Southern Tier counties

Oil Recovery (MM bbl)	Purchased CO_2		Purchased CO_2/Oil Recovery (Ratio)	
	Bcf	MM mt	Mcf/B	mt/B
1,350	12,040	637	8.9	0.47

The production of one barrel of San Andres ROZ fairway oil in Partition #1 of the Southern Tier counties brings with it, at the margin, the storage of 0.47 metric tons of CO_2 when using high pressure CO_2 injection as the oil recovery method.

6.6.6 Geologically Viable CO_2 Storage with By-Product Oil Recovery

Pursuing the geologically viable, but economically non-viable, portion of the San Andres ROZ fairway resource in Partition #1 of the Southern Tier counties with miscible CO_2 flooding provides 969 million metric tons (18,320 Bcf) of CO_2 storage capacity and 1,050 million barrels of by-product oil recovery (Exhibit 6-14).

Exhibit 6-14. Geologically viable storage of CO_2 with by-product oil recovery: Partition #1, Southern Tier counties

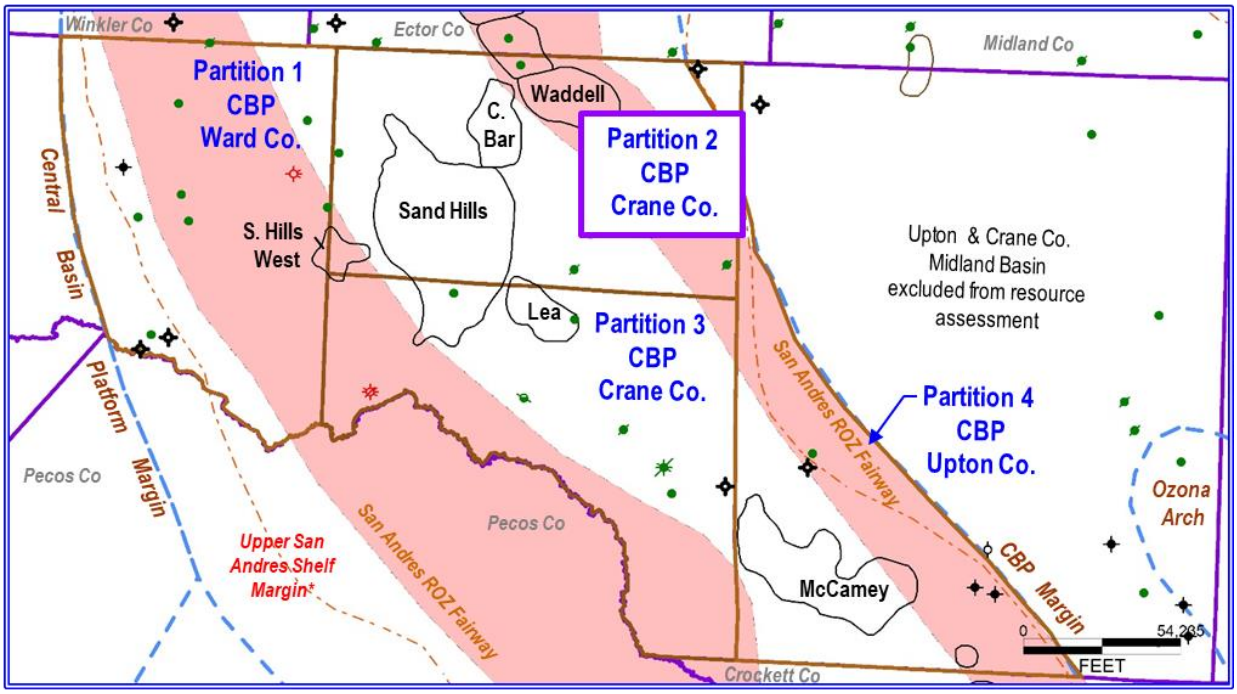
Purchased CO_2		By-Product Oil Recovery (MM bbl)	Purchased CO_2/Produced Oil (Ratio)	
Bcf	MM mt		Mcf/B	mt/B
18,320	969	1,050	17.4	0.92

6.7 Partition #2. Northern Crane County, Southern Tier

6.7.1 Geologic Setting

Partition #2, located in northern Crane County, covers a San Andres ROZ fairway area of 135,000 acres, Exhibit 6-15. The partition excludes areas underlain by San Andres oil fields (113,000 acres) and a small area (8,000 acres) where the San Andres ROZ interval is thin or missing. Partition #2 includes a small portion of the previously established San Andres ROZ fairway in the CBP.

Exhibit 6-15. San Andres ROZ fairway Partition #2, Southern Tier counties



6.7.2 Analytic ROZ Reservoir Properties

Seven well log-based reservoir data sets plus a series of working level cross-sections were used to allocate the San Andres ROZ fairway resource in Partition #2 of the Southern Tier counties into two analytical ROZ fairway reservoir units:

- A higher quality ROZ resource
- A lower quality ROZ resource

The average volumetric reservoir properties for the two analytical San Andres ROZ fairway reservoir units of Partition #2 of the Southern Tier counties are provided in Exhibit 6-16.

Exhibit 6-16. Average San Andres ROZ fairway reservoir properties: Partition #2, Southern Tier Counties

Property	Higher Quality	Lower Quality
Depth (to top) (ft)	3,570	3,480
Gross Thickness (ft)	621	611
Net Pay (ft)	354	255
Avg. Porosity (fraction)	0.098	0.087
Avg. Oil Saturation (fraction)	0.29	0.20
Avg. Formation Volume Factor (res B/bbl)	1.27	1.27
OIP (BBLS/AF, for net pay)	174	106

6.7.3 ROZ OIP

The San Andres ROZ fairway in Partition #2 of the Southern Tier counties contains 3,870 million barrels of OIP (Exhibit 6-17). Less than half of the ROZ OIP (1,670 million barrels) meets the higher ROZ resource quality criteria. The remainder of the ROZ OIP of 2,190 million barrels meets the lower resource quality criteria.[h]

Exhibit 6-17. San Andres ROZ fairway OIP: Partition #2, Southern Tier counties

Property	Higher Quality	Lower Quality
OIP (Bbls/Acre)	61,670	27,070
Area Extent (Acres)	27,200	80,800
OIP (MM bbl)	1,670	2,190

6.7.4 Technically Recoverable Resources

Of the 3,870 million barrels of San Andres ROZ OIP in Partition #2 of the Southern Tier counties, approximately 1,140 million barrels is technically recoverable from the application of miscible CO_2 EOR, giving a recovery efficiency of 29 percent of OIP.

[h] The higher and lower quality resource in-place values do not sum to 3,870 million barrels due to rounding.

In addition, significant volumes of CO_2 are injected and stored as part of applying miscible CO_2 EOR for recovering a portion of the ROZ OIP. Approximately 893 million metric tons (16,880 Bcf) of CO_2 are purchased for the San Andres ROZ fairway EOR project in Partition #2 of the Southern Tier counties, with essentially all of the purchased CO_2 securely stored at the end of the CO_2 flood.

6.7.5 Commercially Viable Oil Recovery with By-Product CO_2 Storage

Of the 1,140 million barrels of technically recoverable San Andres ROZ fairway oil resource available from Partition #2 of the Southern Tier counties, 590 million barrels are commercially viable to develop under the economic assumptions used in this study.

The application of CO_2 EOR to the commercially viable portion of the San Andres ROZ fairway resource in Partition #2 of the Southern Tier counties also provides 312 million metric tons (5,890 Bcf) of by-product storage of CO_2 (Exhibit 6-18).

Exhibit 6-18. Commercially viable oil recovery with by-product CO_2 storage: Partition #2, Southern Tier counties

Oil Recovery (MM bbl)	Purchased CO_2		Purchased CO_2/Oil Recovery (Ratio)	
	Bcf	MM mt	Mcf/B	mt/B
590	5,890	312	10.0	0.53

The production of one barrel of San Andres ROZ fairway oil in Partition #1 of the Southern Tier counties brings with it, at the margin, the storage of 0.53 metric tons of CO_2 when using high pressure CO_2 injection as the oil recovery method.

6.7.6 Geologically Viable CO_2 Storage with By-Product Oil Recovery

Pursuing the geologically viable, but economically non-viable, portion of the San Andres ROZ fairway resource in Partition #2 of the Southern Tier counties with miscible CO_2 flooding provides 581 million metric tons (10,990 Bcf) of CO_2 storage capacity and 550 million barrels of by-product oil recovery (Exhibit 6-19).

Exhibit 6-19. Geologically viable storage of CO_2 with by-product oil recovery: Partition #2, Southern Tier counties

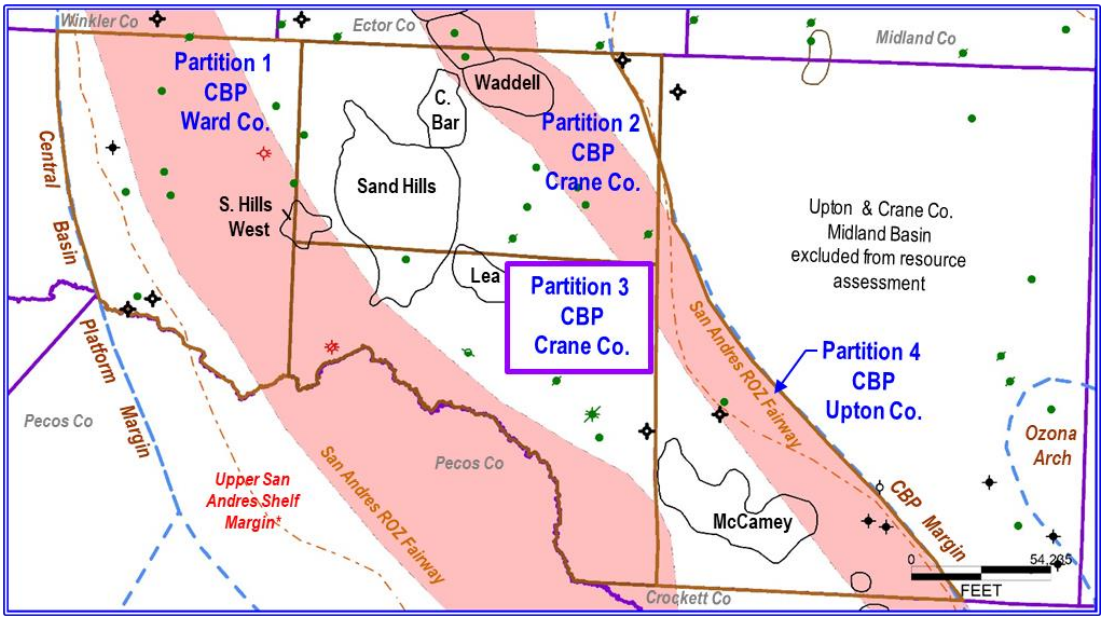
Purchased CO_2		By-Product Oil Recovery (MM bbl)	Purchased CO_2/Produced Oil (Ratio)	
Bcf	MM mt		Mcf/B	mt/B
10,990	581	550	20.0	1.06

6.8 Partition #3. Southern Crane County, Southern Tier

6.8.1 Geologic Setting

Partition #3, located in southern Crane County, covers a San Andres ROZ fairway area of 211,000 acres (Exhibit 6-20). The partition excludes areas underlain by San Andres oil fields (35,000 acres). Partition #3 includes a small portion of the previously established San Andres ROZ fairway in the CBP.

Exhibit 6-20. San Andres ROZ fairway Partition #3, Southern Tier counties



6.8.2 Analytic ROZ Reservoir Properties

Six well log-based reservoir data sets plus a series of working level cross-sections were used to allocate the San Andres ROZ fairway resource in Partition #3 of the Southern Tier counties into two analytical ROZ fairway reservoir units:

- A higher quality ROZ resource
- A lower quality ROZ resource

The average volumetric reservoir properties for the two analytical San Andres ROZ fairway reservoir units of Partition #3 of the Southern Tier counties are provided in Exhibit 6-21.

Exhibit 6-21. Average San Andres ROZ fairway reservoir properties: Partition #3, Southern Tier counties

Property	Higher Quality	Lower Quality
Depth (to top) (ft)	2,580	2,380
Gross Thickness (ft)	178	153
Net Pay (ft)	108	53
Avg. Porosity (fraction)	0.107	0.105
Avg. Oil Saturation (fraction)	0.33	0.19
Avg. Formation Volume Factor (res B/bbl)	1.15	1.15
OIP (BBLS/AF, for net pay)	239	135

6.8.3 ROZ OIP

The San Andres ROZ fairway in Partition #3 of the Southern Tier counties contains 2,780 million barrels of OIP (Exhibit 6-22). The majority of the ROZ OIP (2,190 million barrels) meets the higher ROZ resource quality criteria. The remainder of the ROZ OIP of 600 million barrels meets the lower resource quality criteria.[i]

Exhibit 6-22. San Andres ROZ fairway OIP: Partition #3, Southern Tier counties

Property	Higher Quality	Lower Quality
OIP (Bbls/Acre)	25,810	7,140
Area Extent (Acres)	84,800	84,000
OIP (MM bbl)	2,190	600

6.8.4 Technically Recoverable Resources

Of the 2,780 million barrels of San Andres ROZ OIP in Partition #3 of the Southern Tier counties, approximately 880 million barrels is technically recoverable from the application of miscible CO_2 EOR, giving a recovery efficiency of 32 percent of OIP.

In addition, significant volumes of CO_2 are injected and stored as part of applying miscible CO_2 EOR for recovering a portion of the ROZ OIP. Approximately 494 million metric tons (9,340 Bcf) of CO_2 are purchased for the San Andres ROZ fairway EOR project in Partition #3 of the Southern Tier counties, with essentially all of the purchased CO_2 securely stored at the end of the CO_2 flood.

6.8.5 Commercially Viable Oil Recovery with By-Product CO_2 Storage

Of the 880 million barrels of technically recoverable San Andres ROZ fairway oil resource available from Partition #3 of the Southern Tier counties, none of the resource is commercially viable to develop under the economic assumptions used in this study (Exhibit 6-23).

Exhibit 6-23. Commercially viable oil recovery with by-product CO_2 storage: Partition #3, Southern Tier counties

Oil Recovery (MM bbl)	Purchased CO_2		Purchased CO_2/Oil Recovery (Ratio)	
	Bcf	MM mt	Mcf/B	mt/B
-	-	-	-	-

6.8.6 Geologically Viable CO_2 Storage with By-Product Oil Recovery

Pursuing the geologically viable, but economically non-viable, portion of the San Andres ROZ fairway resource in Partition #3 of the Southern Tier counties with miscible CO_2 flooding provides 494 million metric tons (9,340 Bcf) of CO_2 storage capacity and 880 million barrels of by-product oil recovery (Exhibit 6-24).

[i] The higher and lower quality resource in-place values do not sum to 2,780 million barrels due to rounding.

Exhibit 6-24. Geologically viable storage of CO_2 with by-product oil recovery: Partition #3, Southern Tier counties

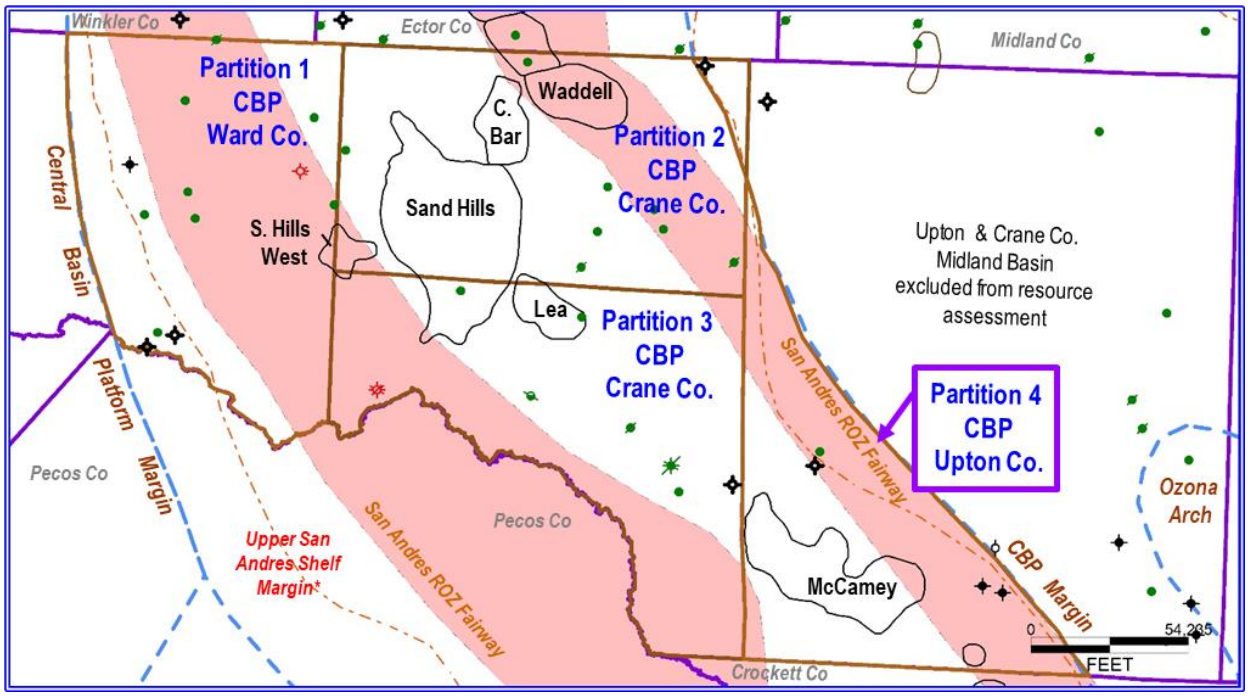
Purchased CO_2		By-Product Oil Recovery (MM bbl)	Purchased CO_2/Produced Oil (Ratio)	
Bcf	MM mt		Mcf/B	mt/B
9,340	494	880	10.6	0.56

6.9 Partition #4. Western Upton County, Southern Tier

6.9.1 Geologic Setting

Partition #4, located in western Upton County, covers a San Andres ROZ fairway area of 175,000 acres (Exhibit 6-25). The partition excludes areas underlain by the McCamey oil field (14,000 acres). Partition #4 includes a small portion of the previously established San Andres ROZ fairway along the eastern margin of the CBP.

Exhibit 6-25. San Andres ROZ fairway Partition #4, Southern Tier counties



6.9.2 Analytic ROZ Reservoir Properties

Three well log-based reservoir data sets plus a series of working level cross-sections were used to allocate the San Andres ROZ fairway resource in Partition #4 of the Southern Tier counties into one analytical ROZ fairway reservoir unit:

- A lower quality (LQ) ROZ resource

The average volumetric reservoir properties for the one analytical San Andres ROZ fairway reservoir unit of Partition #4 of the Southern Tier counties are provided in Exhibit 6-26.

Exhibit 6-26. Average San Andres ROZ fairway reservoir properties: Partition #4, Southern Tier counties

Property	Higher Quality	Lower Quality
Depth (to top) (ft)	-	3,450
Gross Thickness (ft)	-	506
Net Pay (ft)	-	150
Avg. Porosity (fraction)	-	0.075
Avg. Oil Saturation (fraction)	-	0.27
Avg. Formation Volume Factor (res B/bbl)	-	1.10
OIP (BBLS/AF, for net pay)	-	143

6.9.3 ROZ OIP

The San Andres ROZ fairway in Partition #4 of the Southern Tier counties contains 2,990 million barrels of OIP (Exhibit 6-27). All of this resource meets the lower resource quality criteria.

Exhibit 6-27. San Andres ROZ fairway OIP: Partition #4, Southern Tier counties

Property	Higher Quality	Lower Quality
OIP (Bbls/Acre)	-	21,390
Area Extent (Acres)	-	140,000
OIP (MM bbl)	-	2,990

6.9.4 Technically Recoverable Resources

Of the 2,990 million barrels of San Andres ROZ OIP in Partition #4 of the Southern Tier counties, approximately 1,060 million barrels is technically recoverable from the application of miscible CO_2 EOR, giving a recovery efficiency of 35 percent of OIP.

In addition, significant volumes of CO_2 are injected and stored as part of applying miscible CO_2 EOR for recovering a portion of the ROZ OIP. Approximately 537 million metric tons (10,140 Bcf) of CO_2 are purchased for the San Andres ROZ fairway EOR project in Partition #4 of the Southern Tier counties, with essentially all of the purchased CO_2 securely stored at the end of the CO_2 flood.

6.9.5 Commercially Viable Oil Recovery with By-Product CO_2 Storage

Of the 1,060 million barrels of technically recoverable San Andres ROZ fairway oil resource available from Partition #4 of the Southern Tier counties, none of this resource is commercially viable to develop under the economic assumptions used in this study Exhibit 6-28).

Exhibit 6-28. Commercially viable oil recovery with by-product CO_2 storage: Partition #4, Southern Tier counties

Oil Recovery (MM bbl)	Purchased CO_2		Purchased CO_2/Oil Recovery (Ratio)	
	Bcf	MM mt	Mcf/B	mt/B
-	-	-	-	-

6.9.6 Geologically Viable CO_2 Storage with By-Product Oil Recovery

Pursuing the geologically viable, but economically non-viable, portion of the San Andres ROZ fairway resource in Partition #4 of the Southern Tier counties with miscible CO_2 flooding provides 537 million metric tons (10,140 Bcf) of CO_2 storage capacity and 1,060 million barrels of by-product oil recovery (Exhibit 6-29).

Exhibit 6-29. Geologically viable storage of CO_2 with by-product oil recovery: Partition #4, Southern Tier counties

Purchased CO_2		By-Product Oil Recovery (MM bbl)	Purchased CO_2/Produced Oil (Ratio)	
Bcf	MM mt		Mcf/B	mt/B
10,140	537	1,060	9.6	0.51

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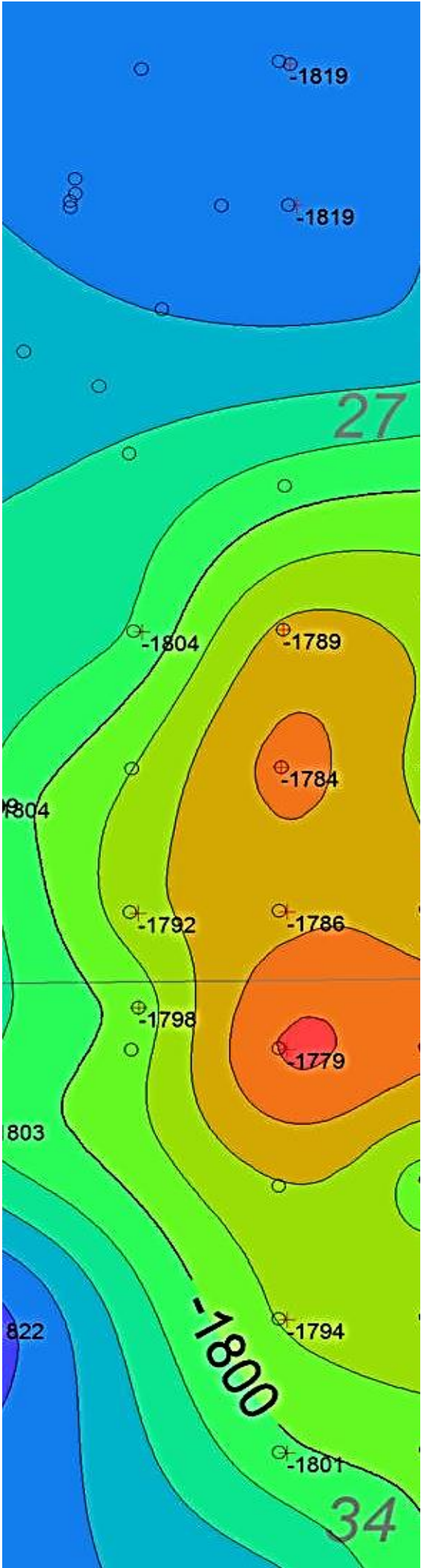

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