A "Cookbook" Approach to Evaluating Residual Oil Zones Completed as Horizontal Depressurizing (DUROZ) Wells in the San Andres Formation*

Bob Trentham¹ and L. Stephen Melzer²

Abstract

In 2011 the authors presented a “Cookbook” for outlining the steps utilized to evaluate the potential for successfully CO₂ flooding Residual Oil Zone (ROZ’s) in the San Andres with vertical wells. Since that time, a new unconventional San Andres Play has been developed utilizing horizontals wells and depressuring the upper ROZ (DUROZ). Although many of the concepts developed for evaluating CO₂ EOR in vertical wells apply in the DUROZ play, there are some critical differences to approaching the two distinctly different plays.

Both Brownfields and Greenfields ROZ’s are now being successfully exploited via CO₂ EOR. The Tall Cotton Field in Gaines County has proven the concept of using vertical wells to flood a 300’ San Andres section of a Greenfield ROZ. Parallel with this vertical ROZ CO₂ EOR development has been the development of the DUROZ play. This play, centered in Yoakum County, but with >350 wells spread across six counties in Texas and New Mexico is producing >35,000 BOPD, and has produced >25 million BO since 2011. The wells are typically frac’ed in mile to 1.5-mile-long laterals. The major differences from the vertical wells is in the landing depth, producing interval, frac designs, and production methods.

Not all wells have been equally successful. The geometry of completions and drilling methods vary more significantly than in the vertical ROZ wells, however rock and fluid factors play a significant role in the success or relative failure of individual wells. Having reviewed the importance of the DUROZ components to the vertical CO₂ EOR cookbook, it became apparent that there are critical differences in the evolving practices in the DUROZ: in drilling, mud logging, pilot hole requirements, core analysis, and completion. The same critical factors in controlling how/where to best complete a vertical CO₂ well: depositional environments, diagenesis, sweep and saturations also apply to DUROZ horizontals, however, the weight of each varies.
Technology and innovation has, once again, redefined the world of prospect opportunities. A comparison of the “classic” interpretation of “Goat Pasture” with the new understanding of Greenfield ROZ CO2 EOR, and DUROZ Horizontal development, and the science behind these new resources is presented.

References Cited


Kinder Morgan 2018, Tall Cotton (San Andres) Field: Field Introduction for the 24th Annual CO2-ROZ Conference Field Trip, Seminole, TX, Dec 2018.


A “Cookbook” Approach to Evaluating Residual Oil Zones Completed by Horizontal Depressuring of the Upper San Andres (DUROZ)

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Depressuring the Upper ROZ {DUROZ}

• Where are we?
• Key ROZ Reports and Presentations
• Evolution of a “Play”
• Depressuring of the Upper Residual Oil Zone [DUROZ]
• Engineering and Geology - critical components
• Revised Cookbook - GOR & Fractures
• Summary
Where are we?

- Company interest in ROZs for 30 years
- First Vertical CO₂ EOR ROZ flood pilots in “Brownfields” 20 years ago
- Research and Documentation of ROZs ongoing for >15 years
- First Full Scale Vertical CO₂ EOR ROZ flood in a “Brownfield” ~15 years ago
- First Vertical CO₂ EOR ROZ flood in a “Greenfield” >4 years ago
- Now - The DUROZ play, centered in Yoakum County, with >350 wells across 6 counties in TX & NM, is producing >35,000 BOPD, & having produced >25 million BO.

Presenter’s notes: There has been interest in CO₂ EOR in carbonate reservoirs in the Permian Basin since the early 1970’s. Interest in ROZs ramped up in the 1980’s as companies began to understand the ROZ potential beneath older San Andres fields. After 2 pilot floods, the first Full Scale Vertical CO₂ EOR ROZ flood in a “Brownfield” began at Seminole Field ~15 years ago. The first Vertical CO₂ EOR ROZ flood pilot in a “Brownfield” was in Seminole Field in 1999. Research and Documentation of ROZs became quantified in the early 2000’s and has been ongoing for >15 years. First Vertical CO₂ EOR ROZ flood in a “Greenfield” began >4 years ago with the development of the Tall Cotton Field in Gaines County. The DUROZ play, centered in Yoakum County, with >350 wells across 6 counties in TX & NM, has now produced >25 million BO since 2012, and is presently producing >35,000 BOPD.
Depressuring the Upper ROZ {DUROZ} Definition

- The horizontal wells begin with pressures of 1800 to >2000 #.
- Initial water production until the pressure is dropped below the bubble point.
- Solution Gas Drive causes the oil to be produced {oil wet reservoir}.
- All the wells produce from the upper ROZ with higher oil saturation and a non-economic {vertical} main pay.
- Hence DUROZ

Presenter’s notes: The DUROZ is possible because of the So in the upper ROZ that is similar to the Sorw in older Permian Basin waterfloods. The horizontal wells, landed at +/- 5500’, begin with pressures of 1800 to >2000 #. Initial water production can range upward of 10’s of thousands of barrels until the pressure is dropped below the bubble point and Solution Gas Drive causes the oil to be produced from the primarily oil wet reservoir. All the wells produce from a mix of the upper ROZ, with higher oil saturation, and a non-economic {vertical} main pay. Wells with larger concentrations of fracs in the Main Pay will produce oil sooner, but may eventually have a lower cumulative production. Hence the term DUROZ.
Residual Oil Zones (ROZ's) have been exploited in the Permian Basin since the late 1990's. However, it was only in the last decade that the science of ROZ's has been understood and documented. Beginning in 2006, a series of DOE- and RPSEA-sponsored projects has resulted in a basic understanding, modeling, case histories, a cookbook for identification, and regional evaluation of ROZ potential in the San Andres. These projects, and others, have generated a more complete understanding, which in turn, has led to advancing production from the ROZ's.

Overview


Modeling “Mother Natures Waterflood”


“Brownfield” Goldsmith Case Study


“Greenfield” Regional Reserves and Cookbook Approach to ROZ’s


Presenter’s notes: Although these can be found on the NETL or DOE website, the easiest access is thru the residualoilzones.com website.
Looking for more geologic background? AAPG Search and Discovery:

• R. C. Trentham, 2011, Residual Oil Zones: The Long Term Future of Enhanced Oil Recovery in the Permian Basin and Elsewhere. #40787

• R. C. Trentham, 2014, Goldsmith Landreth San Andres Unit (GLSAU) # 203R – A CO2 Oil Bank Caught in the Act. #10648


• R. C. Trentham, 2018, ROZs: Science and Fairways - An Update. #70353.

• Other relevant presentations have been made at the annual WTGS Fall Symposium in Midland over the past decade.

• Also look for extended versions and other technical presentations presented to engineering audiences at the various annual CO2 Flooding Conferences & the 2018 CO2/ROZ Seminar in Midland. http://www.co2conference.net

Presenter’s notes: The Southwest AAPG presentations provide a timeline of the ongoing research into Residual Oil Zones in the Permian Basin.
Presenter’s notes: The first major deepening to the ROZ and CO₂ EOR development with vertical wells in a “Brownfield” was in the Seminole Field, beginning with a pilot in 1999. The evolution of ROZ continues with the DOE sponsored study of the CO₂ EOR development of the ROZ in the Goldsmith Landreth Unit of the Goldsmith (San Andres) Field. There, vertical wells were deepened thru the ROZ and CO₂ injected into the ROZ in a classic “brownfield”.

The next major development is the Tall Cotton Field in Gaines County where no economic production from a Main Pay San Andres had been developed prior to the initiation of a Greenfield CO₂ flood. The George Allen Field, in northern Gaines County, is a Peripheral CO₂ Greenfield development with patterned injection below the O/W contact around the periphery of the Main Pay.

The Wellman Field is an example of a vertical Sweep of a Pinnacle Reef where CO₂ was injected in the crest of the reef and “pushed” the oil down to be produced between the gas column and the O/W contact. The DUROZ play, centered in Yoakum County, utilizes the depressuring of the reservoir with horizontal wells to produce oil from the ROZ. There is no CO₂ EOR involved in this development. In the future, however, CO₂ may be used.
Presenter’s notes: The most important takeaway from the GLSAU project is the saturation profile. In this 80+ year old field with a long history of primary production and waterflooding, the “Residual to Waterflood” (Sorw) oil saturation averaging in the 30-40% range is typical of a classic San Andres waterflood. When the project was initiated, the operator, Legado, recovered a number of cores thru the main pay and ROZ. As shown, the saturation range is the same for the main pay and ROZ. The Roz was swept by “Mother Nature’s Waterflood” over a 15 Million year time frame resulting in a similar saturation profile. The base of the original oil column is seen at the top of limestone/base of ROZ in this field.
Tall Cotton
A “Greenfield” Vertical CO₂ EOR project without an associated Main Pay.

2 wells, the #1 Keating and the #1-427 Charlene, provided the information necessary to establish the presence of a significant Greenfield ROZ potential in the area.

Presenter’s notes: The Tall Cotton project, initiated by Kinder Morgan in 2014, is the first Greenfield-only CO₂ EOR ROZ development project to date. The project keyed off the cores taken in the ROZ in the Anschutz #1 Keating (dry hole) and the attempted completion of the Read & Stevens #1-427 Charlene well which produced less than 200 BO from the main pay. Kinder Morgan took a number of cores in the field area to prove there was sufficient saturation in the ROZ to begin development. The field was developed on inverted 5 spot patterns.
The Anschutz #1 Keating is a true ROZ. Drilled on a Clearfork seismic anomaly. Core recovered from 2 intervals in the SADR based on mud log shows. Based on core & log analysis Anschutz attempted completion. 1195 BW were recovered before first oil. 

**Over 45 days, the well recovered 2606 BW and 8 BO. P&A.**

Presenter's notes: The Anschutz #1 Keating is a true ROZ. Drilled on a Clearfork seismic anomaly. Whole and sidewall cores were recovered from the SADR (green bars for whole core and points for sidewall cores) based on mud log shows. Based on core and log analysis Anschutz attempted completion (perfs indicated by red pins). Attempts to complete the well continued over a 3 month period. 1195 BW were recovered before first oil.

Once first oil was recovered, over 45 days, the well recovered 8 BO and 2606 BW before being P&A.
The cores indicated that there were open marine to shoal to restricted marine facies in the lower cored interval, and open marine to restricted marine to tidal flat in the upper cored interval. The upper cored interval begins in “main pay” where there is predominantly tidal flat to shallow subtidal faces.
Greenfields ROZ’s are now being successfully exploited via vertical CO₂ EOR. The Tall Cotton Field in Gaines County has proven the concept using vertical wells to CO₂ flood a +/-300’ San Andres section with variable oil saturations.

KM has been injecting CO₂ at Tall Cotton since Nov 2014. In May 2015, they made as much as 40 BOPD. At the end of 2016, daily production was >1200 BOPD, today it is producing >3000 BOPD and work was underway to double the size of the flood.

Presenter’s notes: KM has been injecting CO₂ at Tall Cotton since Nov 2014. In May 2015, for the first time, the field produced as much as 40 BOPD. At the end of 2016, daily production was >1200 BOPD, as of December 2018, the field is producing >3000 BOPD and work was underway to double the size of the flood. With the 5 year history of Tall Cotton production, it has now been proven that Greenfield ROZ’s can be successfully exploited via vertical CO₂ EOR. The Tall Cotton Field CO₂ flood is producing from a +/- 300’ San Andres thick ROZ with variable oil saturations.
**Cookbook for a vertical Greenfield or Brownfield ROZs required we “Shift the Paradigm” of Interpreting the Classic Observations.**

<table>
<thead>
<tr>
<th>ACTIVITY</th>
<th>EVIDENCE</th>
<th>CLASSIC INTERPRETATION</th>
<th>ROZ INTERPRETATION</th>
<th>ROZ EXPLANATION</th>
</tr>
</thead>
<tbody>
<tr>
<td>Drilling</td>
<td>Oil on pits</td>
<td>Transition zone/MP remnant oil</td>
<td>Presence of ROZ highly likely</td>
<td>Oil wet reservoir. Oil is released during drilling. Often seen in ROZ's</td>
</tr>
<tr>
<td>Drilling Break</td>
<td>Aquifer / No Significance</td>
<td>Good Reservoir</td>
<td></td>
<td>Open marine environment. Good cycles and flow units.</td>
</tr>
<tr>
<td>Mud Logging</td>
<td>Cut in samples</td>
<td>Transition Zone/MP Remnant</td>
<td>Oil saturation present</td>
<td>Residual Oil Saturation is present</td>
</tr>
<tr>
<td></td>
<td>Dull gold Fluorescence in samples</td>
<td>Transition Zone/MP Remnant</td>
<td>&quot;Water washed&quot; oil</td>
<td>Indicative of Mother Nature's Waterflood. Reduced Saturation of Oil</td>
</tr>
<tr>
<td></td>
<td>Odor in samples</td>
<td>Transition Zone/MP Remnant</td>
<td>Oil saturation present</td>
<td>Indicative of Mother Nature's Waterflood. Reduced Saturation of Oil</td>
</tr>
<tr>
<td></td>
<td>Gas show</td>
<td>Not expected. From Oil Zone above if present.</td>
<td>Oil saturation present</td>
<td>Indicative of Mother Nature's Waterflood. Reduced Saturation of Oil</td>
</tr>
<tr>
<td></td>
<td>&quot;Free&quot; Sulfur crystals</td>
<td>Suggest at or below O/W contact</td>
<td>Mother Natures Waterflood</td>
<td>Result of activity of Sulfate Reducing Bacteria. Indicates Meteoric Derived Flushing.</td>
</tr>
<tr>
<td></td>
<td>Sulfur and Anhydrite</td>
<td>No significance</td>
<td>Mother Natures Waterflood</td>
<td>Result of activity of Sulfate Reducing Bacteria. Indicates Meteoric Derived Flushing.</td>
</tr>
<tr>
<td></td>
<td>Sulfur and Calcite</td>
<td>No significance</td>
<td>Mother Natures Waterflood</td>
<td>Result of activity of Sulfate Reducing Bacteria. Indicates Meteoric Derived Flushing.</td>
</tr>
<tr>
<td>DST</td>
<td>Sulfur or Black Sulfur water</td>
<td>Not unusual / No significance</td>
<td>To be Expected.</td>
<td>Result of activity of Sulfate Reducing Bacteria. Indicates Meteoric Derived Flushing.</td>
</tr>
<tr>
<td></td>
<td>Salty Sulfur water</td>
<td>Not unusual / No significance</td>
<td>To be Expected.</td>
<td>Result of activity of Sulfate Reducing Bacteria. Indicates Meteoric Derived Flushing.</td>
</tr>
<tr>
<td></td>
<td>Lower Salinity than expected</td>
<td>Not unusual / No significance</td>
<td>Meteoric Derived Flushing</td>
<td>Indicative of Mother Nature's Waterflood. Meteoric Derived Flushing.</td>
</tr>
<tr>
<td></td>
<td>&quot;Skim of Oil&quot;</td>
<td>Not unusual / No significance</td>
<td>To be Expected. Never significant oil</td>
<td>Oil Wet reservoir. Small amounts of Oil is released during pressure drop.</td>
</tr>
<tr>
<td>Good to Excellent Pressure</td>
<td>Not unusual / No significance</td>
<td>To be Expected.</td>
<td>ROZ is not in pressure communication with a Main Pay</td>
<td></td>
</tr>
<tr>
<td>Logging</td>
<td>Rw different than MP</td>
<td>Not unusual / No significance</td>
<td>ROZ water chemistry different than MP</td>
<td>Rw is different because the meteoric derived sweep is composed of lower salty water</td>
</tr>
<tr>
<td></td>
<td>So &gt; 30% in calculations</td>
<td>Might be productive</td>
<td>ROZ, Residual to waterflood and MNW</td>
<td>Rw is different because the meteoric derived sweep is composed of lower salty water</td>
</tr>
<tr>
<td></td>
<td>Different M and N than MP needed</td>
<td>Not unusual / No significance</td>
<td>fabric destructive dolomitization in ROZ only</td>
<td>Rocks have undergone a second diagenetic event</td>
</tr>
<tr>
<td></td>
<td>Excellent Porosity in dolomite</td>
<td>Not unusual / No significance</td>
<td>Open Marine + Sweep associated dolomitization</td>
<td>Thicker open marine cycles and Secondary dolomitization in ROZ during sweep</td>
</tr>
<tr>
<td></td>
<td>&quot;Looks like a Winner&quot;</td>
<td>set casing</td>
<td>ROZ can have appearance of producable on completion</td>
<td>ROZ thicker cycles, secondary dolomitization, salinity differences make calculations difficult</td>
</tr>
</tbody>
</table>

**Presenter’s notes:** At approximately the same time as the Tall Cotton Field was being developed, another RPSEA sponsored project “Identifying and Developing Technology for Enabling Small Producers to Pursue the Residual Oil Zone (ROZ) Fairways” {see slide 5 above for details} was being completed. As part of the project, a review of the method to evaluate and identify those areas where vertical Greenfield or Brownfield ROZs existed. This was done thru the “Cookbook” approach. The development of ROZs required we “Shift the Paradigm” when interpreting the classic observations of wells that were not capable of being completed as producers, but where data was available for the ROZ interval. Now a new Paradigm Shift is needed to evaluate the potential for successful DUROZ wells as many of the parameters are similar to those in vertical CO₂ EOR projects, but many require a completely new interpretation.
The Second “Horizontal Revolution”, centered on Yoakum County, including Yoakum, Cochran, Gaines, Andrews, Ector, and Lea Counties.

Presenter’s notes: The Horizontal DUROZ surface well locations {small black dots} the horizontal leg {black line} and the horizontal segment TD {lite blue dots} are shown. The concentration of DUROZ wells west of Brahaney Field are now referred to as the Platang Field. This Second “Horizontal Revolution”, is centered on Yoakum County, but includes wells in Yoakum, Cochran, Gaines, Andrews, Ector, and Lea Counties.
The Permian Basin’s Horizontal DUROZ San Andres Play: Cum Oil Production Growth - 2012-2018

Six-County Horizontal San Andres Wells

Presenter’s notes: The graph of the Permian Basin’s Horizontal DUROZ San Andres Play Cum Oil Production Growth from 2012-2018 shows the remarkable increase in production over a short time. The 124% growth in production was mostly in Yoakum County. The most recent estimates are that the average well will produce between 250,000 to 350,000 BO over its lifetime.
Depressuring Enhanced Oil Recovery with Horizontal Wells

A tale of 2 wells

Presenter’s notes: The rational for the potential for Depressuring Enhanced Oil Recovery with Horizontal Wells can be seen when comparing the first year’s production from a DUROZ horizontal well (#1H Winbert) to an uneconomic to marginally successful vertical well (#1 Pharr) completed in the Main Pay only.
The Horizontal well, #1 Winbert, producing from the MP & ROZ has made more than 15 times the production of the vertical Pharr well over the first year.

Presenter’s notes: The Horizontal well, #1 Winbert, producing from the combined MP and ROZ, made more than 15 times the production of the vertical Pharr well over the first year. The core from the Main Pay in the Pharr well was described and the production was from shallow subtidal/restricted marine facies. Each cycle shallowed up to a sabkha with “chicken-wire” anhydrite (pink intervals in core description). Only the shallow subtidal rocks had porosity and oil stain. The is typical of the thin, un-economic main pay above a thick ROZ. The presence of increasingly thick evaporates is proposed to result in most of the frac height being downward into the ROZ.
Engineering: Landing Depth and Completion….How much of the Evolving Targets is based on GEOLOGY?

- Lateral Length – increased by moving surface locations off-lease
- Stage Count – gradually increased – room for more
- 100 Mesh – reduced to minimum needed to reduce near wellbore tortuosity
- Proppant Size can easily pump either 30/50 or 20/40 but 20/40 is more readily available
- Fluids – gradually shifted to fully cross-linked proppant laden fluid
- Gel – a more robust gel system creates more frac width, reducing need for sweeps
- Scale Treatment – fairly consistent throughout program
  - Water cleansed with chlorine dioxide
  - Liquid Scale Inhibitor pumped throughout job (polyacrylate / beta phosphate blend)
  - Solid Scale Inhibitor added to sand (Carbo Scale Guard – phosphate based)

Stedman, 2018

Presenter’s notes: Engineering: Landing Depth and Completion have varied wildly over the past few years. High? Low? North to South? East to West? Number of stages? Amount of sand? All these Engineering parameters have changed thru time….how much of the Evolving Target is based on GEOLOGY? We believe that a better understanding of the variability in the reservoir rocks, and fluids can lead to a better drilling and completion design.
DUROZ vs vertical CO₂ EOR in the ROZ

• Having reviewed the importance of the DUROZ components compared to the vertical CO₂ EOR cookbook, the same critical factors in controlling how/where to best complete a vertical CO₂ well: depositional environments, diagenesis, sweep & saturations also apply to DUROZ horizontals, however, the weight of each varies:

  • Fractures
  • GOR’s

• Mass Spec mud logging
• Lateral landing depth
• Sidewall pressure core & analysis
• Oil saturation profiles
• Quantifying gas composition vs depth
• RFT’s
• Logging
• Scale Treatment

• In pilot hole vs. Vertical well hole requirements,
• Completions.

Presenter’s notes: Having reviewed the importance of the DUROZ components compared to the vertical CO₂ EOR cookbook, the same critical factors in controlling how/where to best complete a vertical CO₂ well: depositional environments, diagenesis, sweep, fluids, and saturations also apply to DUROZ horizontals. However, the weight of each varies for vertical to horizontal ROZ completions. There are a number of parameters that vary in importance but two stand out as critical in DUROZ wells: GOR and FRACTURES.
Two Example San Andres Laterals in Yoakum County

- Two one-mile Laterals just less than ½ mile apart
- Landed at the Same Depth
- One has made 60,000 bbls in 10 months
- 2nd has been Shut-in after Making a non-commercial oil cut
- Good well has no significant Gamma Ray throughout lateral
- The non-commercial well has three Gamma “highs”

**Theory:** The Gamma kicks are potential indicators of vertical transmissive fractures

**Conclusion:** Be wary of stimulating into an Interval with a vertical transmissive fracture

Presenter’s notes: Two completions in San Andres Laterals in Yoakum County show significant variations is success based on the presence or absence of FRACTURES. The one-mile Laterals are less than ½ mile apart and landed at the same depth. One of the wells has made 60,000 bbls in 10 months, while the 2nd has been Shut-in after making a non-commercial oil cut. We believe the difference in response to the completion is reflected in the Gamma Ray which is evidence of the presence or absence of fractures. There is no significant Gamma Ray variation throughout the lateral in the good well, while the non-commercial well has three Gamma Ray “kicks” or “highs”.

**Theory** is that the Gamma kicks are potential indicators of vertical transmissive fractures which served as fluid pathways and that the GR response indicated Uranium being deposited by the fluids in the open fractures. [perhaps in “fault gouge”].

**Conclusion** is to be wary of stimulating into an Interval with a vertical transmissive fractures.
Presenter’s notes: The two Gamma Rays of the curve {left end} and the horizontal legs. The two differ only in the presence of the three gamma kicks in the poor-average well which we believe are indicative of open fractures with associated uranium.
• Flexing periodically during the San Andres

• We have numerous Anecdotal reports of barriers [anhydrite filled], lateral movement, and open [transmissive] fracture sets with “fresh water”. Have been seen in SADR waterfloods and CO₂ floods.

• In vertical WELLS, not so important, except where CO₂ losses are high.

• In Horizontal Wells- CRITICAL!!

See: Goldsmith, Alan Hodges, 2017

Presenter’s notes: The theory is that deep {Ouachita-related Structures} with significant throw in the lower Paleozoic-Pennsylvanian sections suffer periodic movement during and after the San Andres. This causes propagation upward of flexures across the deep fault which results in the development of fractures at the point of maximum curvature in the San Andres. We have numerous anecdotal reports of barriers [anhydrite filled], lateral movement, and open [transmissive] fracture sets with “fresh water” having been seen in SADR waterfloods and CO₂ floods which we believe to be the result of this flexing.

In vertical wells this may not be as important, except where CO₂ losses are high, but in horizontal wells the presence of these transmissive fracture sets is CRITICAL!!
How does GOR in Horizontal Well impact production? With increasing Gas the OIP number goes down, but the Recovery goes up.

<table>
<thead>
<tr>
<th>GOR</th>
<th>265</th>
<th>550</th>
<th>900</th>
<th>1150</th>
<th>Scf/stb</th>
</tr>
</thead>
<tbody>
<tr>
<td>Boi</td>
<td>1.13</td>
<td>1.26</td>
<td>1.46</td>
<td>1.59</td>
<td>Res bbl/std bbl</td>
</tr>
<tr>
<td>OIP</td>
<td>1.5</td>
<td>1.4</td>
<td>1.2</td>
<td>1.1</td>
<td>MMBbbls</td>
</tr>
<tr>
<td>WIP</td>
<td>3.4</td>
<td>3.4</td>
<td>3.4</td>
<td>3.4</td>
<td>MMBbbls</td>
</tr>
<tr>
<td>GIP</td>
<td>0.41</td>
<td>0.75</td>
<td>1.08</td>
<td>1.25</td>
<td>Bcf</td>
</tr>
<tr>
<td>“Primary Oil”</td>
<td>0</td>
<td>45</td>
<td>177</td>
<td>191</td>
<td>MMBbbls</td>
</tr>
<tr>
<td>Recovery Factor (RF)</td>
<td>0</td>
<td>3</td>
<td>15</td>
<td>17</td>
<td>% OIP</td>
</tr>
<tr>
<td>“Primary Gas”</td>
<td>0.01</td>
<td>12</td>
<td>77</td>
<td>169</td>
<td>MMscf</td>
</tr>
</tbody>
</table>

Modeling by Koperna and Erdle has demonstrated that with increasing dissolved gas in the system, the Oil In Place number goes down, but the Recovery of Primary Oil goes up. It appears that when initial GOR’s are <350-500, the amount of solution gas drive maybe insufficient to produce significant oil over the life of the well. When GOR’s are >2000, the gas “flashes off” too rapidly leaving the bulk of the oil “stuck” in the reservoir without sufficient drive. So GOR’s ranging from 350 – 2000 represent the “sweet spot” of EUR.

Koperna & Erdle, 2017
Gas to Oil Ratio (GOR’s)

Variation’s in GOR After 1 Year
Why the difference?

Relatively minor tectonism in Yoakum County

Andrews Co wells are related to the Spine of the Platform”

Numerous fields with >80 years of production. Was the pressure reduced in the ROZ enough to reach bubble point & some gas migrated away during Primary Production? Did WF increase pressure and open fractures?

AVERAGE GOR
1,139 scf/stb

AVERAGE GOR
429 scf/stb

Presenter’s notes: Variation’s in Gas to Oil Ratio (GOR’s) for the “Northern” and “Southern” areas after 1 Year are interesting. Why the difference? We suggest that there was relatively minor tectonism associated with the fewer, small deep structures in Yoakum, Cochran, and Lea Counties. In the southern area, Gaines, Andrews, and Ector Counties, the bulk of the horizontal wells are related to what we call the Spine of the Platform” where there are numerous Permo-Penn structures and upper Permian carbonate fields, many with >80 years of production history. This Greenfield ROZ areas may have seen virgin reservoir pressures reduced in the enough to drop below bubble point and for some gas to migrate away during primary production of nearby fields. Coincidently, some wells on the flanks of the older fields may have produced larger volumes of oil than expected as a result of “Incidental ROZ Production”. Over the past decades, waterflooding of these fields could then have resulted in increased pressure and the opening of fractures in the proximal ROZ intervals.
GOR’s
Superimpose the uplifted blocks associated with the Ouachita Orogeny. The lower GOR in Andrews Co wells are in the area where the “Spine of the Platform” with maximum thinning of the SADR and also the potential for periodic flexing associated with movement on the deep structures.

Is there a more mature MNW sweep here?
How does it impact the GOR?

AVERAGE GOR
1,139 scf/stb

AVERAGE GOR
429 scf/stb

Presenter’s notes: When the uplifted blocks associated with the Ouachita Orogeny are superimpose, it is clear that the lower GOR”s in wells in southwestern Gaines Counties, western Andrews, and northwestern Ector are all in the area where the “Spine of the Platform” uplifted blocks are all located. These areas are also located here the maximum thinning of the SADR occurred, and where the potential for periodic flexing associated with movement on the deep structures is maximized.

Questions still to be answered include:
Is there a more mature MNW sweep here?
How does it impact the GOR?
Though the Vertical ROZ CO2 Floods and the Horizontal DUROZ are producing from the same intervals, new thinking needs to evolve for successful DUROZ development.

<table>
<thead>
<tr>
<th></th>
<th>Vertical ROZ</th>
<th>Horizontal DUROZ</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pilot hole vs vertical well</td>
<td>TD at or near base Oil Saturation in ROZ</td>
<td>TD higher in ROZ</td>
</tr>
<tr>
<td>Mass Spec mud logging</td>
<td>Not Critical</td>
<td>Critical</td>
</tr>
<tr>
<td>Lateral landing depth</td>
<td>NA</td>
<td>Critically important</td>
</tr>
<tr>
<td>Oil saturation profiles</td>
<td>From core thru entire ROZ</td>
<td>“frac depth”</td>
</tr>
<tr>
<td>Quantifying gas composition vs depth</td>
<td>No Critical</td>
<td>Critical</td>
</tr>
<tr>
<td>RFT’s</td>
<td>Not Critical</td>
<td>Critical</td>
</tr>
<tr>
<td>Sidewall pressure core &amp; analysis</td>
<td>Important</td>
<td>Important</td>
</tr>
<tr>
<td>Mass Spec mud logging,</td>
<td>Not Critical</td>
<td>Critical</td>
</tr>
<tr>
<td>Logging</td>
<td>Triple Combo</td>
<td>MWD, Spectral Gamma</td>
</tr>
<tr>
<td>Completions</td>
<td>3-4 Stages, Small Frac 70k# sand</td>
<td>20 Stages, Large Frac 205,000# Sand</td>
</tr>
<tr>
<td>Transmissive Vertical Fractures</td>
<td>Important</td>
<td>Critical</td>
</tr>
<tr>
<td>Scale</td>
<td>Inhibitors for Sulfate</td>
<td>Inhibitors &amp; Frequent Cleanouts</td>
</tr>
</tbody>
</table>

Presenter’s notes: Though the Vertical ROZ CO₂ Floods and the Horizontal DUROZ are producing from the same intervals, new thinking needs to evolve for successful DUROZ development. GOR’s and Open Fractures are only two of the critically important components of the DUROZ equation. These and the other components must be studied, documented and addressed if the DUROZ play is to be maximized and extended to other areas where the potential is, as yet, undetermined and the parameters still unknown.
Summary

• DUROZ is a successful, but evolving Horizontal play.

• Landing & stimulating are issues that will successfully be addressed thru a combination of Geology and Engineering.

• The best DUROZ wells seems to be related the relatively gassy ROZ oil intervals (Minimum GORs >300 to 500 cf/bbl) which correlate with moderate porosity, open marine facies (6-11%) & good mud gas shows.

• Encountering vertical (transmissive) fractures can impact success.

• Lateral MWD data, uranium spikes, mass spectrometry shows of helium, & produced water with low salinities are potentially excellent indicators of fractures.

Presenter’s notes: In Summary, the DUROZ is a successful, but evolving Horizontal play. Landing and Stimulating are issues that must be successfully addressed thru a combination of Geology and Engineering. The best DUROZ wells seems to be related the relatively gassy ROZ oil intervals (Minimum GORs >300 to 500 cf/bbl, maximum GOR 1500 to 2000)) which correlate with moderate porosity, restricted, shoal and open marine facies (6-11%) & good mud gas shows. Encountering vertical (transmissive) fractures can negatively impact successful completions. Lateral MWD data, uranium spikes, mass spectrometry shows of helium, and produced water with low salinities are potentially excellent indicators of these fractures.

We still have a long way to go before we have developed a DUROZ “Cookbook” similar to the one that has been developed for the vertical CO2 EOR potential in the ROZ. We need to continue to develop our understanding of the geologic parameters in the play.
References


• Kinder Morgan 2018, Tall Cotton (San Andres) Field. Field Introduction for the 24th Annual CO2-ROZ Conference Field Trip, Seminole, TX. Dec 2018.


• Thurmon, T., 2010, Managing a CO2 Development in a Privately Funded Environment: The GLSAU Project. Presented at the 16th Annual CO2 Conference, Midland TX.


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