SAN ANDRES FORMATION RESIDUAL OIL ZONES
AND THEIR RELATIONSHIP TO THE HORIZONTAL
CARBONATE PLAY ON THE NORTHERN SHELF

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SIPES # 1081
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David Vance, Arcadis

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Abstract

The new understanding of the origins of residual oil zones (ROZs) is providing insights as to the explanation for the growing number of commercial horizontal well exploitation projects in the San Andres formation of the northern shelf area in the Permian Basin. The case will be made that what started out as a tight carbonate play, using production concepts analogous to the shale plays, has morphed into a 'greenfield' ROZ play at considerable distances away from the San Andres fields and in places where the landscape has been dotted with dry or disappointing vertical wells over the course of 60 years.

To understand the targeted reservoir requires a study of the processes involved in the natural sweep (lateral water flood) of a huge paleo oil entrapment in the San Andres formation. The ROZ related studies began as an attempt to explain the abnormal thicknesses and properties of intervals of residual oil beneath main pay zones (MPZs) as in the Seminole and Wasson fields. The studies have now evolved to include the understanding that these residual oil resources exist in large fairways and can be made commercially attractive targets. It was first believed that enhanced oil recovery methods would be required to liberate the oil. And, to that end, several successful projects are underway in the Permian Basin proving the concept of using CO$_2$ as the injectant to enliven and displace the oil via miscible flooding techniques. But more recently, the concept of depressuring the upper ROZ intervals has been introduced, is proving commercial at surprisingly low oil prices, and is offering insights into a process of recovery of immobile oil only conjectured in the past.

What is required for producing residual oil via depressuring are the technologies and commercial developments involved in horizontal drilling and completion methods. The same revolution that occurred in the unconventional shales is being extended into carbonates and into more conventional reservoirs with no mobile oil. An analogous process has been called dewatering in Oklahoma (e.g., Hunton, Mississippian Lime) but is called depressuring here in Texas. The play’s linkage to the ROZ studies in the San Andres formation has occurred and, for that reason, is being dubbed “Depressuring the Upper ROZ” or DUROZ.

The author suspects that the Oklahoma plays were most generally categorized as producing the large volumes of water that freed up the mobile oil to move. Others believed the mobile oil existed in isolated reservoir compartments and that the horizontals intersected enough compartments to make the contacted rock volume commercial. Still others believed both mobile oil and water coexisted in the pore space but that the water moves first by the relative permeability nature of the two fluids. This latter concept can be reframed to the scientific principles involved with reservoir fluid depressuring and that solution gas expansion allows the hydrocarbons to expand in the pore and effectively liberate a portion of the oil and most of the gas. We believe that this scientific formulation, (as contrasted to the mathematical ‘rel perm’ one), forms the basis for explaining how gassy residual oil can be liberated.

Both the EOR and DUROZ projects currently underway and producing residual oil will be presented.
San Andres ROZs

- The Horizontal San Andres Play
- What Kind of a Play is it?
- ROZ Science – Some “New” Processes at Work
- Two Ways to Exploit Residual Oil: Case Histories
W. Yoakum San Andres Horizontal Wells

(as of Jan '16)

Yoakum
Cochran
Lea
Gaines
Brahaney Field

November 24, 2015
1 inch = 24.075 feet

NOTICEDISCLAIMER: Mapping data are provided for informational purposes only. These data are continually being updated and refined. Users are responsible for checking the accuracy, completeness, currency and/or suitability of these data sets themselves. This is not a survey grade product and should not be used to define or establish any boundaries.
Oil Cumulatives of the First Wells in the N Shelf Play
The ‘Players’

- NW Shelf
  - Manzano, Walsh, Riley, Apache, ER Operating, Henry, Silver Creek, Stewart, Element, Wishbone

- Andrews County
  - Forge, Pacesetter
The ‘Big Five’ Operators*

<table>
<thead>
<tr>
<th>Company</th>
<th>bopd</th>
<th>Mcfpd</th>
<th># Wells</th>
</tr>
</thead>
<tbody>
<tr>
<td>Forge</td>
<td>3840</td>
<td>2385</td>
<td>71</td>
</tr>
<tr>
<td>Manzano</td>
<td>3070</td>
<td>3100</td>
<td>14</td>
</tr>
<tr>
<td>Walsh</td>
<td>2150</td>
<td>275</td>
<td>18</td>
</tr>
<tr>
<td>Riley</td>
<td>250</td>
<td>840</td>
<td>4</td>
</tr>
<tr>
<td>Pacesetter</td>
<td>510</td>
<td>220</td>
<td>7</td>
</tr>
<tr>
<td><strong>TOTALS</strong></td>
<td>9820</td>
<td>6820</td>
<td>114</td>
</tr>
</tbody>
</table>

* Stats as of Jan ‘16
Growth in Production from San Andres Horizontal Wells
Andrews and Yoakum Counties

- Oil-BPD
- Gas Mcfpd
- # Wells (Rt Scale)
What is this Play All About?

Is it Just the Carbonate Equivalent to the Shales or Something Else?
The Next Few Slides May Test Your Imagination
DON'T LET SCHOOLING INTERFERE WITH YOUR EDUCATION.

- MARK TWAIN
The “Camps”

1. Compartamentalized Pods of Mobile Oil (Main Payzones)
2. Tight Oil – Some Mobile Oil but Low Perm Rocks
3. Depressuring a Residual Oil Zone (Relative Permeability)

Which Camp are you in?
The ‘Mobile Oil Compartments’ Camp

- Everybody knows carbonates are badly compartmentalized
- A horizontal well is perfectly suited for connecting those compartments
- For Play success, we:
  - Will need to mildly stimulate but in selective intervals
  - Will see oil come quick with minimal water
  - Do not need a gassy oil
The ‘Tight Oil’ Camp

• If we can get oil out of shales, why not out of tight carbonates?

• For Play success, we:
  – Need to find thick zones with same kind of shows as the shales
  – Need to fracture treat like the shales
  – Will see the oil come right away
  – Will see the oil and water deplete pretty rapidly
The ‘ROZ’ Camp

- All the Oil is Immobile!
- As Water is Removed and the Reservoir is Depressured, the Gas in the Oil Expands and the Oil and Gas Occupy Greater %age of the Pore Space
- Some of the Oil Becomes Mobile and Moves into the Flowstream
- Water Dominates all the Production for a Period of Time until the Pressures Fall Past a Threshold Level
- Works Best with a Gassy Oil & Oil- or Mixed-Wet Rocks
- Can be Modeled with Relative Permeability Curves
A Frame of Reference
Fractional (Water) Flow as a Function of Oil/Water Saturation

No oil Moves if Oil Saturation less than this (30%)
150 Years of Looking for These Reservoirs!
Our Industry Has Moved Beyond the “Conventional” Into Two “New” Camps
Fractional (Water) Flow as a Function of Oil/Water Saturation

Really? Camp #3?
So what can cause the oil to start moving?

No oil Moves if Oil Saturation less than this (30%)
Depressuring Production Mechanics

The pore Fluids

De-pressured State

Pore Space

Rock

Oil

Water

Oil

Water

\[ P_i = 2000 \text{ psi (in-situ)} \]

\[ P_i = 2000 \text{ psi (in-situ)} \]

\[ P_n = 1000 \text{ psi (in-situ)} \]

Melzer CQsulting
Fractional (Water) Flow as a Function of Oil/Water Saturation

Oil Begins to move as the Oil Volume Grows
Cautionary Note:
That Fractional Flow Curve was Idealized!

The Critical ("Irreducible") Sor Value can Vary Due to Variable Reservoir and Fluid Properties

In Other Words, Water Flooding Can Leave Behind a Lot of Oil in the Swept Zone and the Sorw Values Left Will be a Function of the Reservoir and Oil Properties

It is that Sorw that we are Targeting and, if it was Mother Nature’s Water flood, the Oil has Never Been Depressured
"The ROZ Camp"

- All the Oil is Immobile
- As Water is Removed and the Reservoir Depressured, the Gas in the Oil Expands and the Oil and Gas Occupy Greater %age of the Pore Space
- Some of the Oil becomes Mobile and Moves into the Flowstream
- Water Dominates all the Production for a Period of Time until the Pressures fall Past a Threshold Level
- Works Best in Gassy, Oil- or Mixed-Wet Rocks
- Can be Modeled with Relative Permeability Curves
Case History: Water Cut vs. Time

* North Shelf Discovery Well (Lea Co.)
# DUROZ Case Histories

**Pressure Characteristics**

**DUROZ WELLS: YOAKUM CO., TX**

<table>
<thead>
<tr>
<th>Well</th>
<th>Initial Intake Pressure</th>
<th>First Oil Cut Intake Pressure</th>
<th>Lateral Length</th>
<th>Days Until First Production</th>
<th>Ave BOPD since 1st Oil Cut</th>
<th>Initial Intake Pressure</th>
<th>First Oil Cut Intake Pressure</th>
<th>Lateral Length</th>
<th>Days Until First Production</th>
<th>Ave BOPD since 1st Oil Cut</th>
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<tr>
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<td>What A Melon 1H</td>
<td>1745</td>
<td>1225</td>
<td>1 mile</td>
<td>393</td>
<td>26</td>
<td>166</td>
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<tr>
<td>2</td>
<td>Well #2</td>
<td>2120</td>
<td>1315</td>
<td>1 mile</td>
<td>378</td>
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<td>202</td>
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<tr>
<td>3</td>
<td>Well #3</td>
<td>1700</td>
<td>1270</td>
<td>1 mile</td>
<td>195</td>
<td>6</td>
<td>203</td>
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<td>4</td>
<td>Well #4</td>
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<td>1090</td>
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<td>170</td>
<td>32</td>
<td>313</td>
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<td></td>
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<td>5</td>
<td>Well #5</td>
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<td>1200</td>
<td>1 mile</td>
<td>151</td>
<td>22</td>
<td>126</td>
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<td></td>
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<tr>
<td>6</td>
<td>Well #6</td>
<td>2225</td>
<td>1150</td>
<td>1 mile</td>
<td>122</td>
<td>32</td>
<td>243</td>
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<td>7</td>
<td>Well #7</td>
<td>2053</td>
<td>1260</td>
<td>1 mile</td>
<td>83</td>
<td>25</td>
<td>228</td>
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<td>8</td>
<td>Well #8</td>
<td>2110</td>
<td>1635</td>
<td>1 mile</td>
<td>42</td>
<td>30</td>
<td>142</td>
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<tr>
<td>9</td>
<td>Well #9</td>
<td>1820</td>
<td>No Oil Cut Yet</td>
<td>1.5 mile</td>
<td>20</td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>10</td>
<td>Well #10</td>
<td>2040</td>
<td>No Oil Cut Yet</td>
<td>1.5 mile</td>
<td>20</td>
<td></td>
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<tr>
<td>11</td>
<td>Well #11</td>
<td>1750</td>
<td>No Oil Cut Yet</td>
<td>1 mile</td>
<td>1</td>
<td></td>
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</tr>
</tbody>
</table>

*Note Also the Trend to Longer Laterals – Some 2-mile Laterals now*
ROZs and EOR

A Progress Update
SSAU FIELD HISTORY
Original & Post Waterflood Seminole Field Saturation Profile

- Main Pay Zone (MPZ)
- Original & Waterflood Swept Zone Saturation
- Usual Depth Interval of Original Well Completions
- Zone of "Quaternary" Oil Recovery Potential
- Paleo Transition Zone

- Water Saturation (%)
- Oil Saturation (%)
- Height

$S_o = \text{Oil Saturation} (%)$
SSAU CO\textsubscript{2} EOR & ROZ Era Production

SSAU TERTIARY & QUATERNARY (CO\textsubscript{2}) PHASE OIL PRODUCTION AND ANALYSES

- TOTAL EOR Oil-bopd
- Main Pay Baseline
- ROZ Ph I PROD (Rt Scale)
- ROZ Ph II (Rt Scale)
- ROZ Stage 1&2 (Rt Scale)

- Stage 1,2,&3-56 Injectors
- Ph 2 - 9 Injectors
- MAIN PAY ZONE 160 INJECTORS
- Ph 1 - 4 Injectors

Incremental ROZ Project Production - bopd
PB ROZ Research

Forming a ROZ

Greenfields and Fairways
Within a Hydrocarbon Basin

• First Stage
  – Deposition and Burial
  – Generation of Hydrocarbons, Expulsion of Some Oil/Gas from the Source Rock
  – Migration to a Trap

• Second Stage
  – Moving Oil and Water Around within a Trap (Mother Nature’s Waterflood)

• And Sometimes….third…fourth Stages

Is this all that happens in a Basin?
Types of Second Stage Adjustments

1. Basin-wide Tilt
2. Basement Readjustments and/or ‘Leaky Seals’
3. Asymmetric Uplift and Lateral Sweep
   – Reservoir Outcrop and Meteoric Derived Water Sweep (aka Lateral Sweep)
   – Salt Diapirs
Residual Oil Zone Fairway Mapping with Superimposed Major Permian and Pennsylvanian Oilfields and Showing the First Pure ROZ Greenfield ROZ CO₂ Project

Source Waters for Lateral Sweep
Residual Oil Zone Fairway Mapping with Superimposed Major Permian and Pennsylvanian Oilfields and Showing the First Pure ROZ Greenfield ROZ CO₂ Project

San Andres Greenfield ROZ Assessment Study

Kinder Morgan’s Tall Cotton Project
What is a Greenfield ROZ?

The classic CO₂ enhanced oil recovery and WAG schematic with a commingle residual oil zone deployment.

- Injection wells (MPZ & ROZ) isolated within well or via separate wells
- Carbon Dioxide Pipeline
- Produced Fluids (Oil, Gas, and Water) Separation and Storage Facilities
- Water Injection Pump

X NO MPZ!

-----OWC-----

Greenfield ROZ
KM's Tall Cotton Pure Greenfield ROZ Project Production History

- **Oil Production in Bbls/Day**
- **Producing Well Count (Rt Scale)**

CO₂ Injection Begins (11/14)
Back to the Horizontals
The Upper Bow
San Andres Horizontals and the “Camps”

<table>
<thead>
<tr>
<th>Prod Characteristic</th>
<th>Pods Camp 1</th>
<th>Tite Res Camp 2</th>
<th>ROZ Camp 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Offset Wells</td>
<td>A new Ball Game</td>
<td>Variable Results</td>
<td>Consistent</td>
</tr>
<tr>
<td>Onset of Oil</td>
<td>Immediate</td>
<td>Quick</td>
<td>Delayed</td>
</tr>
<tr>
<td>Need for Gassy Oil</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Requires Dolomites</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>Requires Sour Oil</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>Resource* Play</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
</tr>
</tbody>
</table>

* My Definition – not SPEE’s
Thankyou

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