CO₂ EOR, CCUS and the Horizontal Revolution in the Permian Basin

A Presentation to the

2018 CCUS STUDENT WEEK

Colorado School of Mines
October 18, 2018
CO$_2$ EOR, CCUS and the Horizontal Revolution in the Permian Basin

1. Why all the New Excitement?
2. It’s All About Horizontal Shale Revolution..... But Wait.... “Not So Much”
3. Overview of PB Progress
4. From the Field: Some Fascinating New Realizations/Case Histories
5. Setting the Stage for CCUS
6. Closing
What is all the Buzz About in the PB?
For Maturing Basins...
Things Looked A Bit Dim for the Future Ten Years Ago

In the PB, the Incremental Oil was from EOR and in-fill Drilling
But, Now There is a New Excitement out There?
Why We are Feeling the Excitement

• Producing Unconventional Reservoirs
• Producing Unconventional Oil (More on this Later)
• The Explosion of Innovative Tools for Horizontal Completions
• Better Drilling Rigs and Bits for Faster Drilling
Reservoirs: Feeling the Excitement

“One Horizontal Well in a Section (mi²) is Worth More than 16 Verticals”

This Quote comes from a flood guy and a former disciple for vertical wells

To explain, lateral continuity of a reservoir has always been a big question. With a mile-long lateral, we can now witness the changes in both the oil and rock in a continuous fashion with the new, modern mud logs and Measurement While Drilling (MWD) tools.
Let’s Look at the New Developments

(but We’ll Leave the Shale Excitement i.e., Unconventional Reservoirs) to Others and Concentrate on Conventional Reservoirs with Unconventional* Oil)

* Also Known as Residual Oil
New Discovery (Realization) #1

- Before 2000, the Bottom of an Oil Reservoir had to be a Transition Zone
- We Needed a More General Concept: ‘Residual Oil Zones’
New Discovery (Realization) #1

- Before 2000, the Bottom of a Reservoir had to be a Transition Zone.
- We Needed a More General Concept: ‘Residual Oil Zones’
- So What Causes a Residual Oil Zone?
Types of ROZs

All Three of the Concepts below can be Thought of as Moving Oil and Water around in Conventional Oil Entrapment (Trap) in a Later Stage Tectonic Event after the Initial Oil Entrapment

1st Stage Tectonics: Basin Subsidence, Oil Generation & Migration to a Trap Followed by:

- A Basinwide Tilt (Type 1),
- A Breached (and often Reformed) Seal (Type 2), or
- An Asymmetric Basin Uplift and Lateral Flushing (Type 3)
A Graphical Look at ROZ Creation Mechanics

Type 1: Basinwide Tilt
Type 2: Breached Seal
Type 3: Laterally Swept
How Common are ROZs?
We Are Still Looking for the Oil Basin Without ROZs

• It is Not the Permian Basin
• It is Not the Gulf Coast
• It is Not the Williston
• Nor the Bighorn
• Not the North Sea
• Nor the Cooper-Eromanga
• Not the Baltic
• Nor the Arabian
• And so on.....and on
The Permian Basin San Andres Formation Case History
ROZ Type 3: The San Andres of the Permian Basin

Pre-Laramide

Re: Lindsay, R.F. (2001)
ROZ Type 3: The San Andres of the Permian Basin

Today

Phase III: Slow Extension, Pliocene - Recent
Phase II: Rapid Extension, Middle - Late Miocene

RIO GRANDE RIFT

Formation of Basin & Range Province
Horsts & Grabens
Drastically Reduced Meteoric Recharge Area

PERMIAN BASIN

Displaced Oil Columns Resaturate with Oil, Some with Gas,
& Some Stay at Residual Oil Saturation to Water ($S_{ow}$)

WEST

Scattered Mountain Ranges Directly Attached to West Side of Permian Basin

Re: Lindsay, R.F. (2001)
The net effect was to sweep what was a massively large oil trap in the San Andres. The isolated exceptions to the sweep were closures atop the ROZ (like the Wasson and Seminole fields). In these cases, we call the ROZ below the main pay zone a “Brownfield” ROZ.*

**Residual Oil Zones: Type 3**

Change in hydrodynamic conditions, sweep of the lower oil column, oil/water contact tilt, and development of the residual oil zone.

*To exploit the oil, wells can be deepened.*
If All the Mobile Oil is Swept Out, We Call it a “Greenfield” ROZ Since New Wells Need to be Drilled

Type 3 Residual Oil Zones
Lateral Sweep with ROZs formed beneath a Field and a Greenfield without an Overlying MPZ
Thanks to RPSEA, we were able to Map the Greenfields (aka Fairways of Sweep)

Ref: RPSEA II Report
So How Do You Exploit the Residual Oil?

• EOR Mobilizes the Immobile Oil Just Like it Does after Man’s Waterflood

  And, **Hold on, more breaking news just coming in**...
So How Do You Exploit the Residual Oil?

- EOR Mobilizes the Immobile Oil Just Like it Does after Man’s Waterflood

  And, **Hold on, more breaking news just coming in....**

- If it Retains Enough Gas, Depressuring the Reservoir can Commercially Mobilize Some of the Oil
New Technology (Realization) #2

• Brownfield ROZs are Being Exploited via CO₂ EOR
  • There are 17 CO₂ EOR Projects Deepened into the ROZ at last count
  • All are Within the Permian Basin
  • All but one are San Andres Formation Carbonates

• A Greenfield ROZ CO₂ EOR Project has been Implemented

• We Estimate that over 20,000 bopd are Coming from the ROZ EOR Projects and ROZ Production is Growing Rapidly now

Now Let’s Talk about Depressuring the Upper ROZ (DUROZ)
One Needs to Recognize that not all Residual Oil is Dead Oil
If the Pore Volume Sweep is Minor, the ROZ Oil can have Considerable Solution Gas
Over 200 Laterals are Currently Exploiting the Upper (lightly swept) San Andres ROZ Oil (DUROZ) – Started in 2012
Those Wells Need only a Light Stimulation
DUROZ Wells are Spread out over 6 Counties in the ROZ Fairways and are Making Over 40,000 bopd now and have Accumulated Almost 30 Million BO to Date
There is Some Good Evidence that Other Formations also have ROZs and are Already Being Exploited via Horizontal Wells
The DUROZ Production Process

How Does ROZ Depressuring Work?

The ROZs have Oil Affixed to the Rock Surfaces and, if that Oil Has Gas in it, Depressuring Releases Some of the Oil and Entrained Gas

...and into the flowstream to flow to the well. Lots of water is produced to accomplish the depressuring.
New Concept (Discovery) #4

Why on Earth Would Mother Nature’s Water Floods Leave 30-45% Residual Oil Saturations?

To Explain Why, We Need to Understand Biogeochemistry

Do you Know How Microbes Live and Work?

The Simple Explanation is that they “Broker” electron exchanges between Molecules

An Observation and then a Common Example Will Help Explain
Hmmm?
How Does this Happen?

Data From Near Tall Cotton

The Greenfield CO$_2$ EOR Project
Type 3 ROZ - Related Changes to the Reservoir

- Late Stage Rock Diagenesis
- Solubilizes Components from the Oil During the Sweep
- Souring of Oil
- Wettability Alteration
Key Biogenic Reaction

\[
\text{(aq)} \text{CaSO}_4 + \text{CH}_4 \rightarrow \text{CaCO}_3 + \text{H}_2\text{O} + \text{H}_2\text{S}
\]

- S is +6
- C is -4
- C is +4
- S is -2

- Microbes remove 8 Electrons from the Carbon and transfer them to the Sulfur

- H$_2$S is Often Oxidized Back to Elemental Sulfur S$^0$

- Dolomitization Typically Follows as Well
  \[
  \text{CaCO}_3 + \text{Mg} \rightarrow \text{MgCa(CO}_3\text{)}_2
  \]

Souring the Oil and Gas

When Collecting In a Static Place (like an Attic) - Free Sulfur Deposits

New Dolomite Surfaces Attract Oil over Water, Re: Oil Wettability

Re: Vance, David (2012), RPSEA II Project Chapter 4
Wrapping Things up

How Does All of this Relate to CCUS?

• Storing Large Quantities of CO\textsubscript{2} During CO\textsubscript{2} EOR is Now Widely Known and Better Understood

• Commerciality of CO\textsubscript{2} EOR with Concurrent Storage is On-going but Commercially Challenged on its Own Due to Long Payout Times and Competition for Funding from Higher Rate of Return Projects like the Shale Horizontals

.....\textit{But, Things are Changing}....

• Tax Credits for CCUS in the U.S. are now Available (45Q)

• Huge Reservoir Targets for CO\textsubscript{2} Storage in ROZs are Now Recognized

• The Depressured ROZs Provide Huge Pressure Sinks and Reservoir Targets for CO\textsubscript{2} Injection
Takeways from this Talk?

I hope you are Feeling the Excitement over the “New Day” in Oil and Gas?

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For More Information See: www.CO2Conference.net
www.ResidualOilZones.com
## Key References


The Upcoming CCUS, CO₂ EOR & ROZ Conference
Dec 3-6, 2018 Midland, Texas

• Monday – EOR Carbon Management Workshop
• Tuesday – A Close Look at the New 45Q (CO₂ Storage Tax Credit) Legislation
• Wednesday AM – Field Trip to Kinder Morgan’s Tall Cotton Greenfield ROZ CO₂ EOR Project (a ‘One-of-a-Kind’ Project for the World)
• Wednesday PM Session – Status of Horizontal Well Depressuring of the Upper ROZ and Well Completion Advances
• Thursday Sessions – A Day full of U.S. and International CO₂ EOR Case Histories

To see Agenda Details or Register go to www.CO2Conference.net
Thank you

Time for Questions?