‘UNCONVENTIONAL’ EOR TARGETS

Residual Oil Zones

The Wyoming Enhanced Oil Recovery Institute’s Conference Entitled
“Recovering Stranded Oil through Improved and Enhanced Oil Recovery Technologies”
September 13 – 14, 2010
Snow King Resort
Jackson, WY
Past Thanks Go to:

- Some of the Early Pioneering Work Done in Wyoming & the Rockies Looking at Reservoir Hydrodynamics
- King Hubbert – circa 1950’s
- The UTPB ‘Team’ in Midland/Odessa
- The Research Partnership to Secure Energy for America (RPSEA)
- The U.S. DOE and Advanced Resources, International

*Much Work Remains so....*

Future ‘Thanks’ Likely to Go to:

- RPSEA
- USDOE
- Cooperating Industry Partners
- EORI
But First.............

Bob suddenly realized his geologist coworker had fallen off his horse, which was quite a relief to him as just an hour earlier he thought he'd gone deaf.
RESIDUAL OIL ZONES
A GAME CHANGER?
WHERE ARE THEY AND HOW FORMED?

Origins of Residual Oil Zones and Identification Methodology

• ROZ Origins (…..Sorry if this is Repetitive)
• The Fascinating ROZ Science – State of the Knowledge
• ROZ Types – Examples
• The Anecdotal Evidence
• Screening Methodology
• A Southern Williston Example
• A Wyoming Example
• We’ve Only Just Begun – So Much Work Yet to be Done
The Stage is Set for the Age of EOR

Example Quotes:

“Kuwait Researchers Forecast Global Conventional Crude Oil Production Will Peak in 2014”

“The End of Cheap Oil?” (Former Shell President)

“The New Cycle of Resource Nationalism is Bad News” (‘Universal’ Concern)
A Lot of Folks have Looked at EOR Targets Like we Looked at Waterflood Targets (i.e., Main Pay Zones only)

*Let’s Re-examine (Challenge) that Perspective*
Original Oil Accumulation Under Static Aquifer Conditions (A Hypothetical Example)
Original Accumulation Subject to a Westward Regional Tilt

TYPE 1 ROZ
Original Accumulation with a Breached then Reformed Seal

ORIGINAL

POST BREACH

TYPE 2 ROZ
Change in Hydrodynamic Conditions, Sweep of the Lower Oil Column, Oil/water Contact Tilt, and Development Of The Residual Oil Zone
All Three of those Post Entrapment Adjustments (Scenarios) Lead to Pay Zone Flushing

**Attributes of the ROZ Types**

<table>
<thead>
<tr>
<th>ROZ TYPE</th>
<th>Oil-Water Contact</th>
<th>Base of Oil Saturation</th>
<th>Other Characteristics</th>
</tr>
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<tbody>
<tr>
<td>Regional Tilt (1)</td>
<td>Horizontal</td>
<td>Tilted</td>
<td>Wedge with thin side Downdip</td>
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<td>Breached Seal and Reaccumulation (2)</td>
<td>Horizontal</td>
<td>Horizontal</td>
<td>Stratified Tar Mats, Anomolously Low GOR</td>
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<tr>
<td>Hydrodynamic Tilt (3)</td>
<td>Tilted</td>
<td>Horizontal</td>
<td>Wedge with thin side in Direction of Flow (to Spill Point)</td>
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</table>
Case History: Region 1

*Let’s Talk a bit about the Permian Basin*
San Andres (Permian Guadalupian)
Post-Subsidence (Entrapment) Phase* of Permian Basin Development**

* Dated at Late Permian through Cretaceous

** Adapted from Lindsay, R.F. (2001), W. Tx Geological Society Fall Symposium, Oct 01, Midland Tx USA
Extensional Phases and Reduction of Hydrodynamic Gradients in the Permian Basin*

* Ref: Lindsay, R.F. (2001), W. Tx Geological Society Fall Symposium, Oct 01, Midland Tx USA
A Curious Exploitation ‘Thing’ Has Quietly Moved Forward in the Permian Basin
There are 9 total ROZ projects now with two more scheduled for start by early ‘11

Rumor has it there is a Chemical EOR ROZ pilot underway and another one in design

* Adapted from Sagnak (2006), Chevron Presentation at the 12/06 CO₂ Flooding Conference
(Anecdotal) Evidence of ROZs
OIL SHOWS WITHOUT PRIMARY (OR SECONDARY) PRODUCTION

• Residual Oil in Cuttings
• Utility of Mud logs
• Drill Stem Tests
SWEEP WATER* ATTRIBUTES

• Updip Origins
  – Surface Caverns
  – Karst

• Evidence of “Connection” to Petroleum Sources and Entrapments
  – Fairways
  – Lineaments
  – Sulfur, H₂S, Reservoir ‘Alchemy’

• Discharge (Corrosive Zones)

• Temporal Effects
  – Mixing Zones (think both laterally and vertically)
  – OWC Tilts

* The “Flushing Water” - Most of these Relate to Type 3 ROZs: Lateral Sweep Origins
Another “Anecdote”

OWC Tilts
(\textit{Type 3 ROZs})
Distribution of San Andres Tilted Oil-Water Contacts in the Northern Shelf and Central Basin Platform Areas of the Permian Basin*
But OWC Tilts Occur Elsewhere

Permian Basin Stratigraphic Chart (Permian Only)

### STRATIGRAPHIC CHART

<table>
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<tr>
<th>SYSTEM</th>
<th>SERIES</th>
<th>DELAWARE BASIN</th>
<th>CENTRAL BASIN PLATFORM</th>
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Melzer Consulting
OWC Tilts Occur Elsewhere
Abo Cross-Section Through Major NM Fields

Note: Tilted OWC

After Lemay (1960), Southwestern Federation of Geological Societies Transactions, Oct 12-14, 1960
And Yet......Other ‘Anecdotal’ Evidence
DOLOMITIZATION

- Magnesium Rich Flush Waters
- Porosity/Perm Enhancements
- Pervasive Zonations
- Geological Timing (Late Stage, Biogenic)
- Anhydrite Conversion
Reservoir ‘Alchemy’

Biogenic Reaction

\[ \text{CaSO}_4 + \text{HC} \rightarrow \text{CaCO}_3 + \text{H}_2\text{O} + \text{H}_2\text{S} \]

Non-Biogenic Chemical Reactions

\[ \text{CaCO}_3 + \text{Mg} \rightarrow \text{MgCa(CO}_3)_2 \]

Zero Porosity Rock

Picked up as Flush Water Moves through Mg Salts

Reservoir Rock
Northern Central Basin Platform Area

- DST 486' Sulfur H₂O
- First Currings Sample Shows = 5330'
- Base of Cuttings ‘Strong’ Flour = 5620'
- PDI*
- ROZ

* Pervasively Dolomitized Interval
A Sidebar Thought

If Anhydrite Conversion Pervasively Occurs in the ROZ

Does this Offer a Greater Application of Chemical (SP) Technologies?
WATER SALINITIES

- Sulfur Water Occurrence
- Source to Discharge Mixing
- Evidence of Pathways
SULFUR ACCUMULATIONS

• Biological Processes
  – Aerobic
  – Anaerobic

• Associations

• Geographical Occurrence

• Quantitative Estimates of Petroleum ‘Consumption’

• Did the Flushed Oil all Get Consumed?
  – Strat Traps Down-gradient
  – Heavy Oil and Tar Sands Down-gradient
But….at least in the PB, a Lot of Oil Stayed in Place
## (SCOPING PHASE) PERMIAN BASIN RESIDUAL OIL ZONE STUDY*

<table>
<thead>
<tr>
<th>Field/Unit</th>
<th>TZ/ROZ OOIP (BB)</th>
<th>No. of Fields</th>
<th>No. of MPZ Fields with CO2-EOR Projects</th>
<th>No. of Fields with TZ/ROZ CO2-EOR Projects</th>
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<tbody>
<tr>
<td>1. Northern Shelf Permian Basin (San Andres)</td>
<td>13.2</td>
<td>13</td>
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<td>2. North Central Basin Platform (San Andres/Grayburg)</td>
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<td>3. South Central Basin Platform (San Andres/Grayburg)</td>
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**ACRONYMS USED:** OOIP = Original Oil in Place; BB = Billion Barrels, TZ = Transition Zone; ROZ = Residual Oil Zone, MPZ = Main Pay Zone

Ho Hum.....I work in the Rockies so what do I care about the Permian Basin?

Let’s Look Outside
WILLISTON BASIN

ROZ METHODOLOGY
SOUTHERN WILLISTON BASIN

ROZ PLAYS?
Why Look for ROZs in the Southern Williston Basin?

• The Source Rock for the Ordovician Reservoirs is Thermally Mature to Overmature at the Basin Center, and Pinches Out On the Basin Flanks. Winnipeg Shale and Marine Shales of the Red River Formation are Thought to be the Primary Source Rock. *Hydrocarbon Generation and Migration is Estimated to Have Begun in Late Paleozoic Time*\(^1\) (*entrapment stage*).

• The Black Hills uplift is a large, *rather simple, doubly plunging anticlinal uplift of Laramide age* (*second stage*) and appears to be related to faulting at depth\(^2\).

• The Area Thus Meets the Requirements of at least two stages of tectonics.

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2) Geomorphology from Space, NASA Ref http://disc.sci.gsfc.nasa.gov/geomorphology
Regional Structure of the Mission Canyon Fm. and Location of Important Oil Fields and Greater Billings Nose Study Area, Williston Basin *

Williston Basin Stratigraphic Column

Mississippian: Mission Canyon Formation

Ordovician: Red River Formation
Regional Production and Shows for the NW South Dakota Region. The Map Shows Both the Areas of Oil and Gas Production and Areas Where Hydrocarbon Shows in ‘Dry Holes’ were Encountered. The Colors Correspond to the Stratigraphic Formation or Interval in which the Production or Show is Associated (After United States Geological Survey, 1996).
### Red River Oil Fields in NW So. Dakota

#### Lantry Field Parameters
- **Formation:** Ordovician Red River
- **Lithology:** limestone / dolomite
- **Average Depth:** 5000 feet
- **Porosity:** 10%
- **Permeability:** unknown
- **Oil / Gas Column:** unknown
- **Ave. Net Pay Thickness:** 30 feet
- **Other Formations w/ Shows:** Mission Canyon, Stony Mtn, and Red River

#### Buffalo Field Parameters (an example of Cedar Creek Anticline production)
- **Formation:** Ordovician Red River
- **Lithology:** limestone / dolomite
- **Average Depth:** 8600 feet
- **Porosity:** 20%
- **Permeability:** unknown
- **Oil / Gas Column:** unknown
- **Ave. Net Pay Thickness:** 15 feet
- **Other Formations w/ Shows:** Charles and Red River

Other Information: initial IP 24 BOPD; gravity 22 API; 62 BWPD; cumulative production (1995) 135 MBO, 5.2 MMBW, 1 well; Dewey County; primarily a structural / stratigraphic trap; also produces large volumes of 140 degree formation water.

Other Information: initial IP 80 BOPD; gravity 30 API; 200 BWPD; cumulative production (1995) 19.8 MMBO, 47.2 MMCF, 93 wells; Harding County; primarily a stratigraphic trap.
Example Log for a Red River Formation Hydrocarbon Show. Taken from a well within the Standing Rock Indian Reservation Boundary (after Howells, 1982)
The Nature of the Red River Formation

General Characteristics: The Red River Formation is the second most productive formation in the Williston Basin. Reservoirs are dolomites and dolomitic limestones formed from bioclastic mounds and tidal flat deposits. Cyclic episodes of carbonate, evaporite, and organic rich shale provide reservoir, source and seal.

Major MPZ accumulations are found on structural noses such as Nesson and Cedar Creek Anticlines. Smaller fields are found in fold structures draped over basement fault blocks, or small, carbonate mounds. Accumulations in Harding County, SD are thought to be primarily stratigraphic (hydrodynamic?) traps.

Source rock is thermally mature to overmature at the basin center, and pinches out on the basin flanks. Winnipeg shale and marine shale of the Red River Formation are thought to be the primary source rock. Hydrocarbon generation and migration is estimated to have begun in Late Paleozoic time.

The only non-Harding County Red River production in So. Dakota is 115 miles NE of Rapid City Dewey County and about the same distance SE of the Buffalo Field in Harding County. Shows are present in most wells penetrating the Red River in the region and include oil staining in core, and gas and oil cut mud and water on DST's.
LET’S INTRODUCE SOME TERMINOLOGY

IT’S TIME TO TALK ABOUT SWEEP IN TERMS OF BROWNFIELDS* AND GREENFIELDS

Greenfield

TYPE 3 ROZ

* Residual Oil Zone Beneath a Main Pay Zone
For Our Final Journey Down the ROZ Methodology ‘Highway,’

Let’s Look at a Wyoming Example*

* Disclaimer: I don’t claim to be an expert on Reservoirs in Wyoming (wish I were) – this is all about ROZ methodology and how one might start a study on ROZs (BTW, thanks to EORI staff with their help here already)
Frannie Oil Field, Big Horn Basin Illustrating the SW OWC Tilt of ~600 ft/mi*

Fig. 25.—Structural contour map of Murphy Dome and Northwest Lake Creek fields in Big Horn basin showing hydrodynamic “tilt contours” on oil-water contacts.
Wyoming Big Horn Basin
and
the Goose Egg Field
Wyoming
(Big Horn Basin)
Stratigraphic Column

Permian: Phosphoria Formation
Pennsylvanian: Tensleep Formation
Location of Oil Fields, Structure and Direction of Hydrodynamic Flow, Big Horn Basin, Wyoming*

From Technical Oil Recovery Potential from Residual Oil Zones: Big Horn Basin, Advanced Resources Intern'l U.S. DOE Report, Feb '06

**DISCOVERY WELL**

**Name:** Tenite-Dzwenski et al., 1-33 Government  
**Location:** NWNE (860 S/N, 1980 W/E) 33-55N-85W  
**Date of Completion:** September 16, 1975  
**Initial Production:** 115 BOPD  
**Total Depth:** 2381 Phosphoria  
**Elevation:** 4045 KB  
**Casing:** 9 5/8 @ 122 w/120 sir; 7 @ 3211  
**Perforations:** 2318-2340 plus 19 feet open hole  
**Treatment:** Frac w/10,500 gal. acid, 4500 lbs sand  
**Pressure:** 509 psi casing pressure, 100 psi FTP (22/64 choke) 9/75

**GENERAL FIELD DATA**

**Regional Setting:** Northeast Plains, Big Horn Basin  
**Other Formations with Shows:** Stone-stone-Pennsylvanian  
**Exploration Method Leading to Discovery:** Surface geology (Goose Egg is a classic breached "sheepherder anticline")  
**Trap Type:** Structural, anticline  
**Surface Formation:** Frontier, Nowry, Muddy-Cretaceous  
**Oldest Formation Penetrated:** Madison-Mississippian  
**Well:** Dzwenski, Prussel and Hughes, Aquitane 5-33  
**Govt. NESE 33-55N-85W**  
**Spacing Order:** None developed on 40 acre spacing  
**Logging Practices:** DLI, FIC-GR, HKD, EM  
**Completion Practices:** Both natural and acidized  
**Productive Area:** 240 acres  
**Number of Producing Wells:** 8  
**Number of Abandoned producers:** 0  
**Number of Dry Holes:** 1 (drilled to Madison within one year of field discovery date)  
**Number of Shut-in Wells:** 1  
**Number of Disposal Wells:** 0  
**Number Pressure Maintenance Injection Wells:** 0  
**Market for Production:** Murphy Oil Co., truck  
**Major Operators:** Carl D. Underwood Oil & Gas Co.

**RESERVOIR DATA**

**Porosity:** 11.2% average  
**Permeability:** Unknown  
**Average Pay Thickness:** 8 feet  
**Oil/Gas Column:** 555 feet  
**Gas/Oil/Water Contact:** Between +2156 & +2099  
**Gas Oil Ratio:** 1292:1  
**Initial Pressure:** 500 psi casing pressure, 100 psi FTP (22/64 choke)  
**Present Pressure:** Unknown  
**Drive Mechanism:** Fluid expansion
‘Anecdotes’ for Goose Egg

- Two (maybe more) Stages of Tectonics
- Tilted OWC (100-200’/mile)
- Shows in Wells Off-Structure

Just Touching the Surface here – More Work to be Done

- Look at Core, Cuttings
- Estimate Oil Saturation in ROZ
Summary (1)

• The Day has Arrived when EOR can Compete with Conventional Oil Recovery

• EOR Opens up the Scope of Reservoir Targets to Residual Oil Zones – we have got to quit thinking EOR is limited to MPZs (think Brownfields and Greenfields)

• Lots of Understanding is Needed for these ROZs, Organizations Like EORI can help Tremendously (already have!)
Summary (Cont’d)

• There are Processes at Work in the ROZs that are not at Work in the MPZs  
  – e.g., microbial, sulfur conversion

• Many of the Processes at Work in the ROZs have affected the MPZs  
  – e.g., $H_2S$ generation

• The Advancement of Understanding ROZs is Clearly Multi-disciplinary  
  (get the geologist back on the horse)
The End

(Before the Questions: a Couple of ‘Mentions’)

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If this ROZ Work Strikes your Fancy

Please Catch Me Later….We need some good help!!!!