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

Bob Trentham[1] and L. Stephen Melzer[2]

Search and Discovery Article #51570 (2019)**
Posted May 27, 2019

*Adapted from oral presentation given at 2019 AAPG Southwest Section Annual Convention, Dallas, Texas, April 6-9, 2019
See similar articles by author Search and Discovery Article #40787 (2011) Search and Discovery Article #10648 (2014) Search and Discovery Article #51259 (2016) Search and Discovery Article #51400 (2017) Search and Discovery Article #70353 (2018)
 DOI:10.1306/51570Trentham2019

[1]The University of Texas Permian Basin, Odessa, TX (trentham_r@utpb.edu)
[2]Melzer Consulting, Midland, TX

Abstract

In 2011 the authors presented a “Cookbook” for outlining the steps utilized to evaluate the potential for successfully CO_2 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 CO_2 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 CO_2 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 CO_2 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’d 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 CO_2 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 CO_2 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 CO_2 EOR, and DUROZ Horizontal development, and the science behind these new resources is presented.

References Cited

Hall, R.K., 2017, Northwest Shelf Horizontal San Andres Play: 23rd Annual CO_2 Conference, Midland, TX, Dec 2017.

Kinder Morgan 2018, Tall Cotton (San Andres) Field: Field Introduction for the 24th Annual CO_2-ROZ Conference Field Trip, Seminole, TX, Dec 2018.

Koperna, G., and J. Erdle, 2017, What Follows Reservoir Depressuring?: 23rd Annual CO_2 Conference, Midland, TX, Dec 2017.

Melzer, L.S., 2018, Residual Oil Drives New Resource Play: American Oil & Gas Reporter, Oct 2018, p. 153-157.

Stedman, S., 2018, Horizontal San Andres – The Evolution of Completion Techniques: 24th Annual CO_2-ROZ Conference, Midland, TX, Dec 2018.

Thurmon, T., 2010, Managing a CO_2 Development in a Privately Funded Environment: The GLSAU Project: 16th Annual CO_2 Flooding Conference, Midland TX, Dec 2010.

Ward, R.F., 1980, Paleogeological Map of Central Basin Platform at Base of Strawn, Wolfcamp, and/or Leonard, personal communication.

Wells, N.E. Jr., 2019, Petrophysical Study of the Lower San Andres in Western Yoakum County, TX: Using Classical Exploration Techniques for Identifying Depressuring Targets in the Upper Residual Oil Zone (ROZ): M.S. Thesis, University of Texas Permian Basin, Odessa, TX.

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

SW AAPG

Spring 2019

Bob Trentham & L. Stephen Melzer

Melzer CO_2nsulting

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

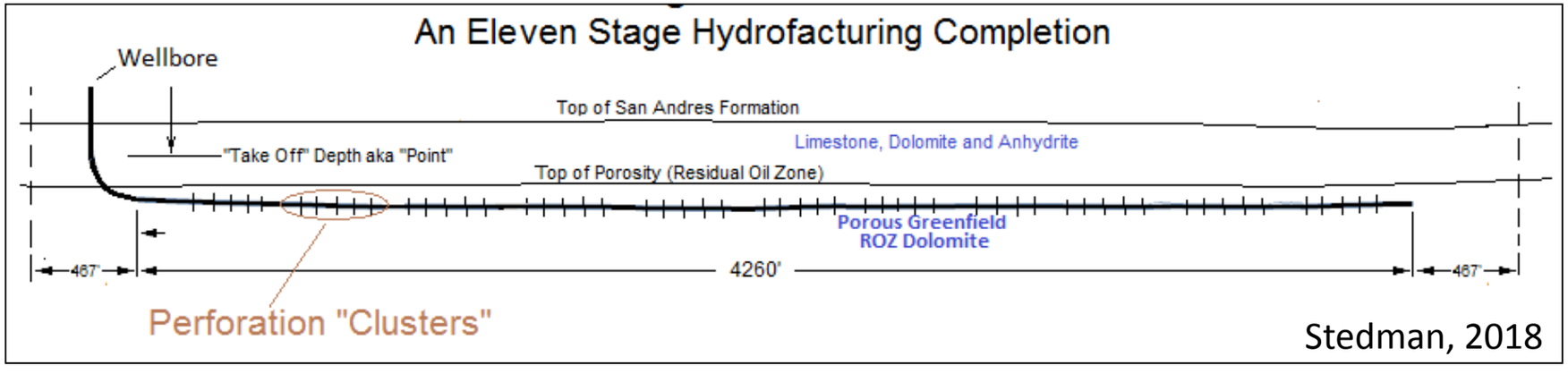
Where are we?

- Company interest in ROZs for 30 years
- First Vertical CO_2 EOR ROZ flood pilots in “Brownfields” 20 years ago
- Research and Documentation of ROZs ongoing for >15 years
- First Full Scale Vertical CO_2 EOR ROZ flood in a “Brownfield” ~15 years ago
- First Vertical CO_2 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 CO_2 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 CO_2 EOR ROZ flood in a “Brownfield” began at Seminole Field ~15 years ago.
The first Vertical CO_2 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 CO_2 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 Zone Studies and Technical Reports

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

- Assessing Technical and Economic Recovery of Oil Resources in Residual Oil Zones. ARI, Melzer, DOE Report, 2006. www.fossil.energy.gov. or http://www.residualoilzones.com website.

Modeling "Mother Natures Waterflood"

- Commercial Exploitation and the Origin of Residual Oil Zones: Developing a Case History in the Permian Basin of New Mexico and West Texas. Trentham, Melzer, Arcadis. RPSEA 08123-19 final report, June 2012. http://www.residualoilzones.com website.

"Brownfield" Goldsmith Case Study

- Case Studies of the ROZ CO2 Flood and the Combined ROZ/MPZ CO2 Flood at the Goldsmith Landreth Unit, Ector County, Texas. Using "Next Generation" CO2 EOR Technologies to Optimize the Residual Oil Zone CO2 Flood. Trentham, Melzer, ARI. DOE DE-FE0005889, Sept 2015. http://www.residualoilzones.com website.

"Greenfield" Regional Reserves and Cookbook Approach to ROZ's

- Identifying and Developing Technology for Enabling Small Producers to Pursue the Residual Oil Zone (ROZ) Fairways in the Permian Basin San Andres. Trentham, Melzer, Arcadis, ARI. RPSEA 10123.17 Final Report, Dec 2015. http://www.residualoilzones.com website.

Presenter's notes: Although these can be found on the NETL or DOE website, the easiest access is thru the residualoilzones.com website.

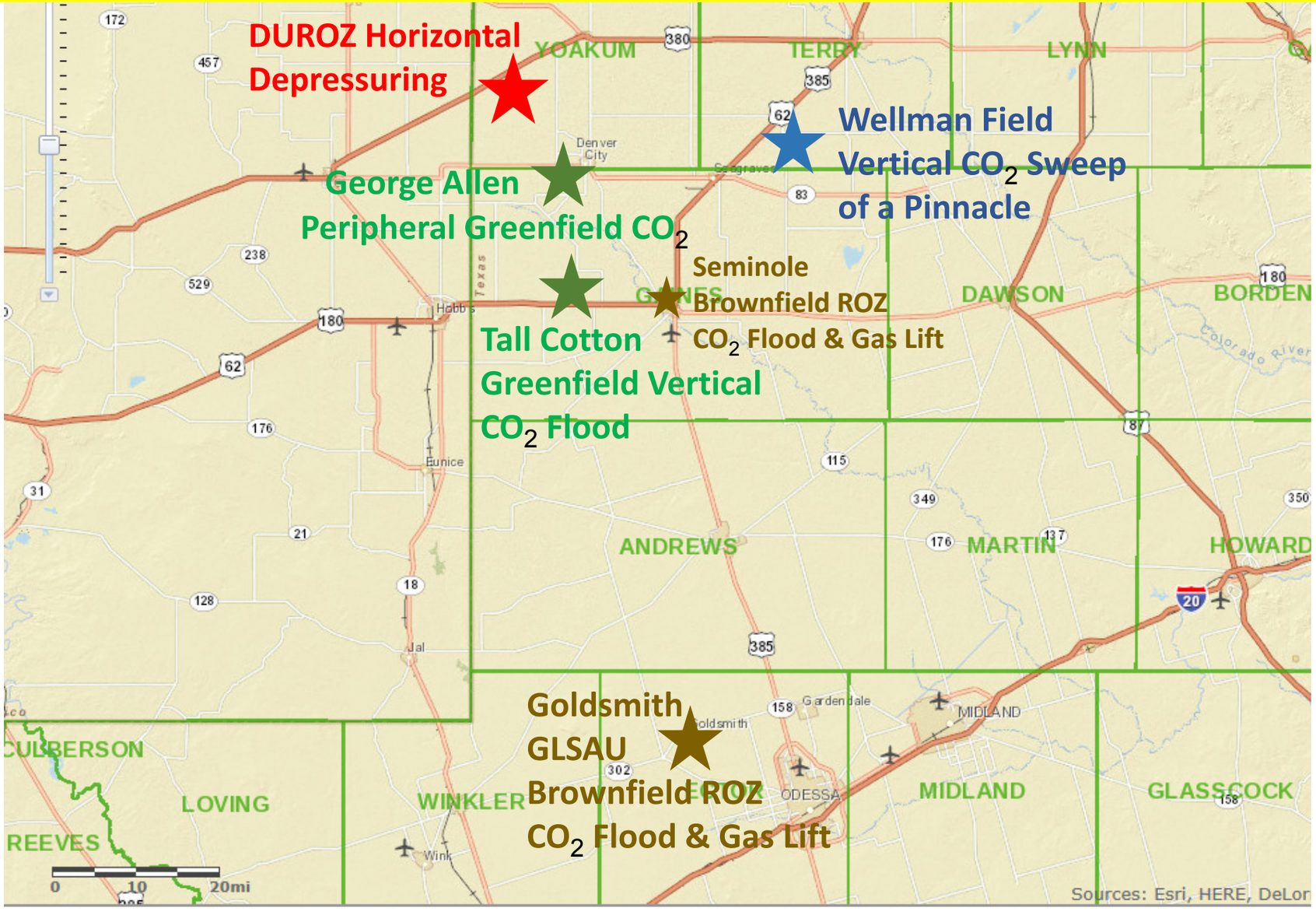
Looking for more geologic background? AAPG Search and Discovery:

- 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, L. Stephen Melzer, 2016, A Cookbook Approach to Exploring for, and Evaluating, Residual Oil Zones in the San Andres Formation of the Permian Basin. #51259.
- R. C. Trentham, 2017, San Andres on the Northwest Shelf: Things You May Not Know. #51400.
- 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 CO_2/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.

Evolution of Residual Oil Zone Development in the San Andres



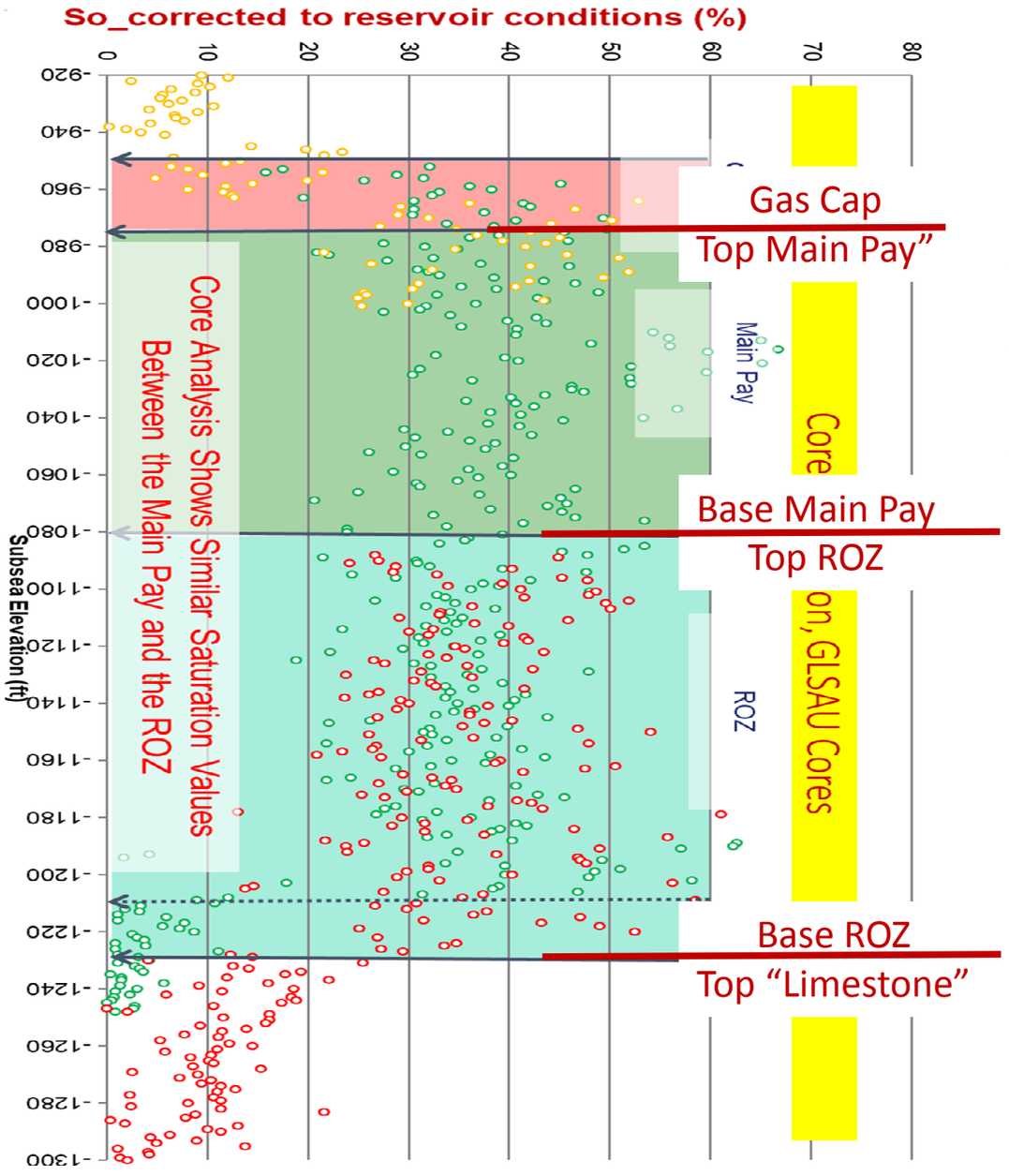
Presenter's notes: The first major deepening to the ROZ and CO_2 EOR development with vertical wells in a "Brownfield" was in the Seminole Field, beginning with a pilot in 1999. The evolution of ROZ continues with the DOE sponsored study of the CO_2 EOR development of the ROZ in the Goldsmith Landreth Unit of the Goldsmith (San Andres) Field. There, vertical wells were deepened thru the ROZ and CO_2 injected into the ROZ in a classic "brownfield".

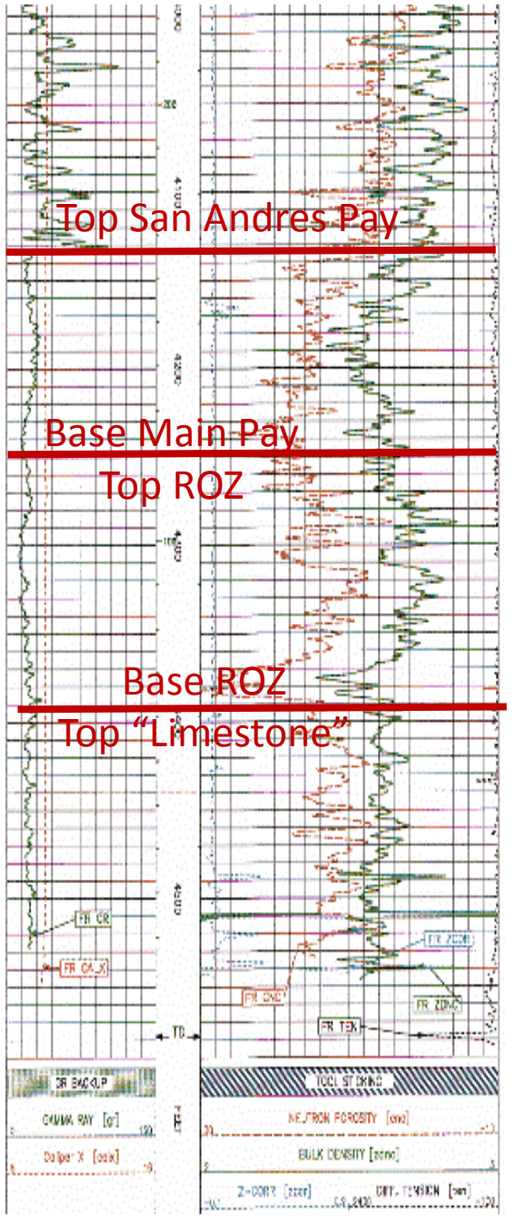
The next major development is the Tall Cotton Field in Gaines County where no economic production from a Main Pay San Andres had been developed prior to the initiation of a Greenfield CO_2 flood.

The George Allen Field, in northern Gaines County, is a Peripheral CO_2 Greenfield development with patterned injection below the O/W contact around the periphery of the Main Pay.

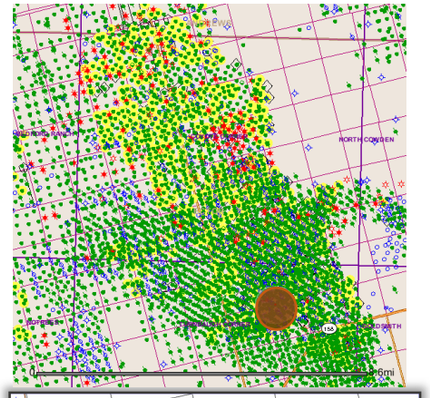
The Welllman Field is an example of a vertical Sweep of a Pinnacle Reef where CO_2 was injected in the crest of the reef and "pushed" the oil down to be produced between the gas column and the O/W contact.

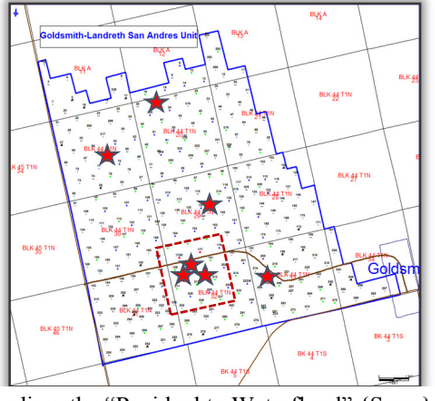
The DUROZ play, centered in Yoakum County, utilizes the depressuring of the reservoir with horizontal wells to produce oil from the ROZ. There is no CO_2 EOR involved in this development. In the future, however, CO_2 may be used.





Goldsmith Landreth San Andres Unit (GLSAU) Proven "Brownfield" ROZ in an 80+ year old field 100 BOPD before >2,000 BOPD after

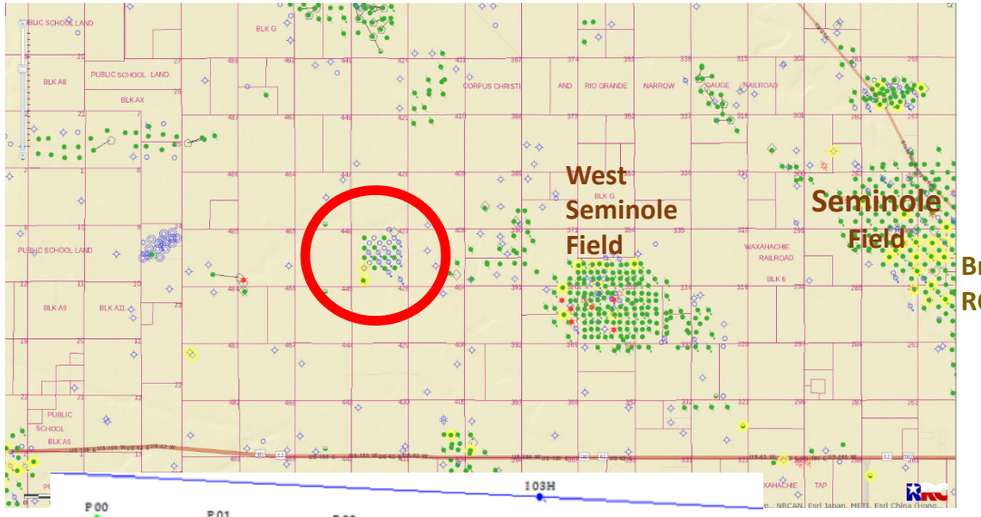




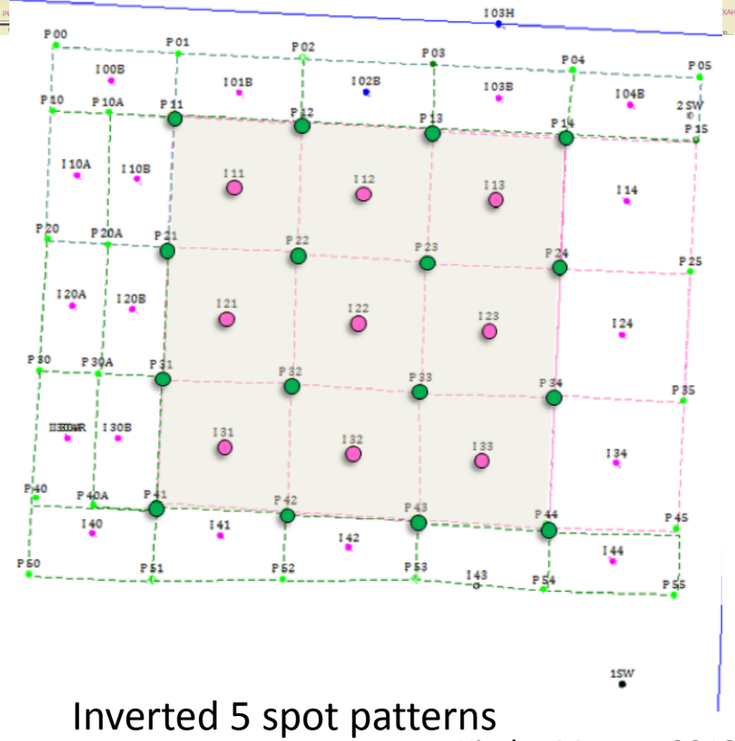
Presenter's notes: The most important takeaway from the GLSAU project is the saturation profile. In this 80+ year old field with a long history of primary production and waterflooding, the "Residual to Waterflood" {Sorw} oil saturation averaging in the 30-40% range is typical of a classic San Andres 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 CO_2 EOR project without an associated Main Pay.

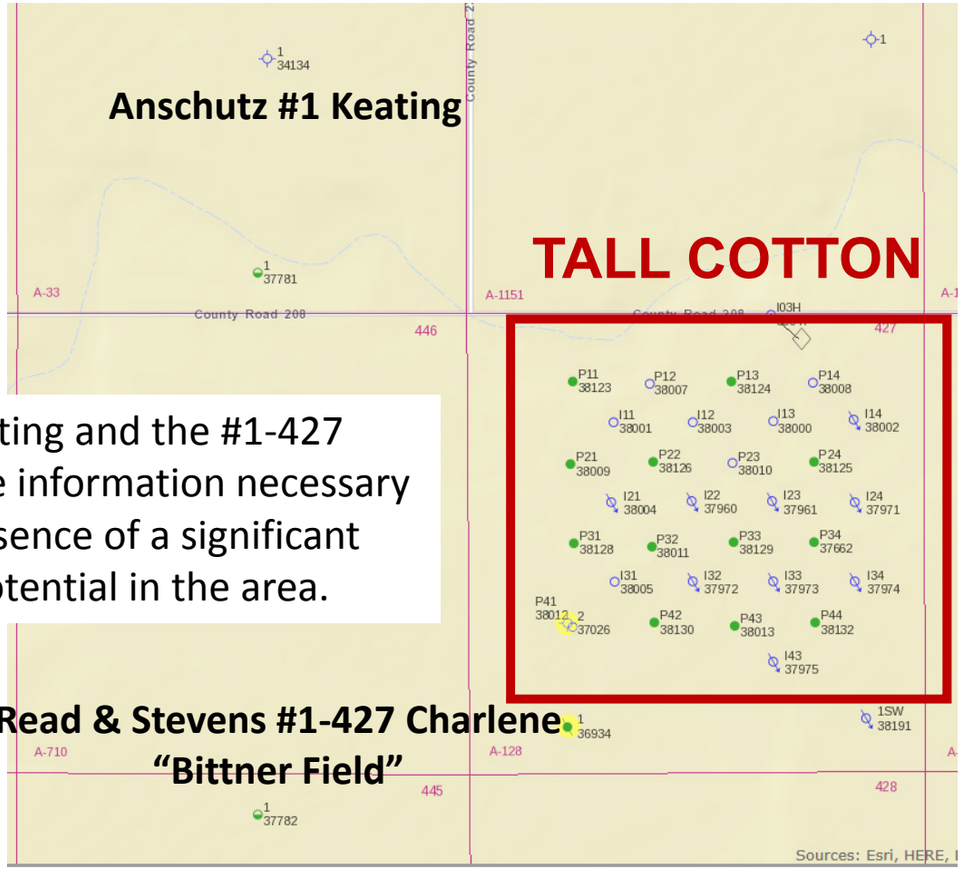


Brownfield
ROZ CO2 EOR



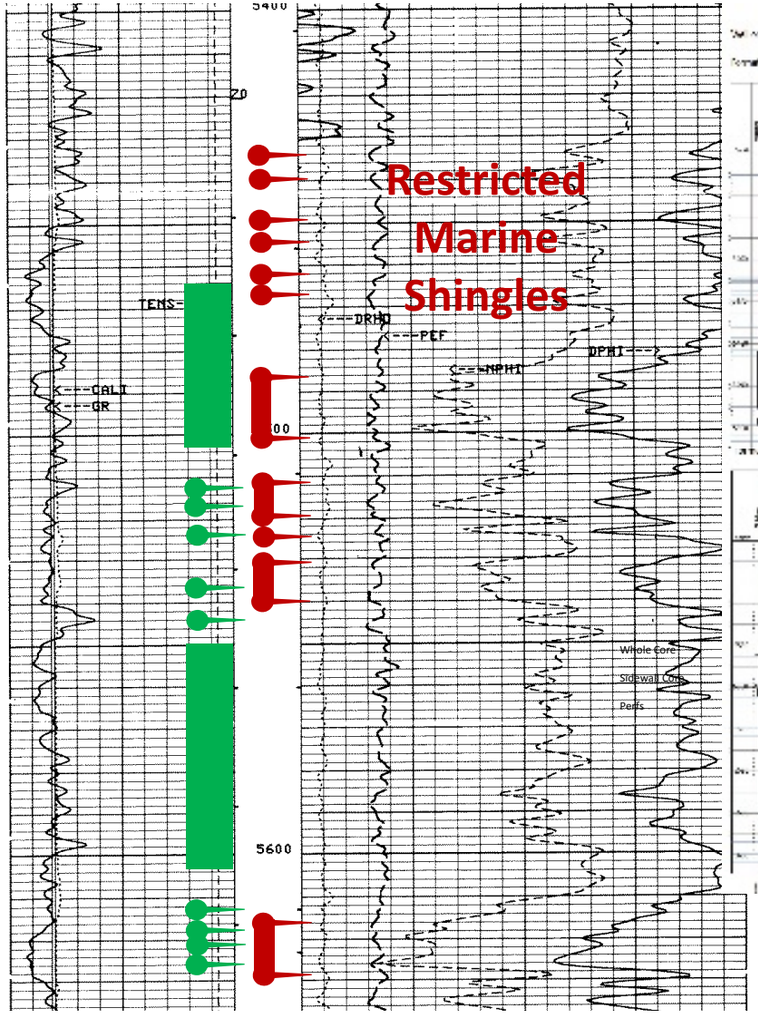
Inverted 5 spot patterns

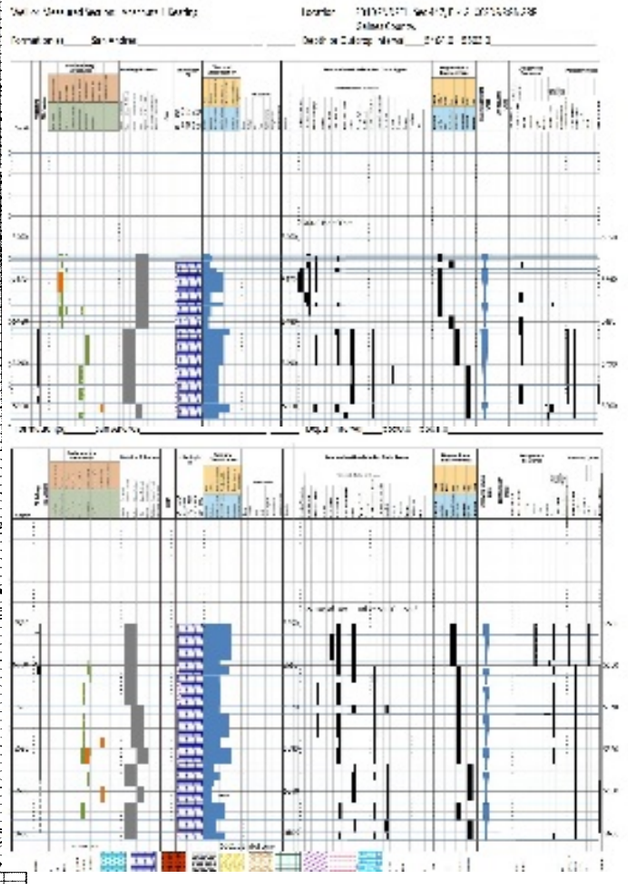
Kinder Morgan 2018

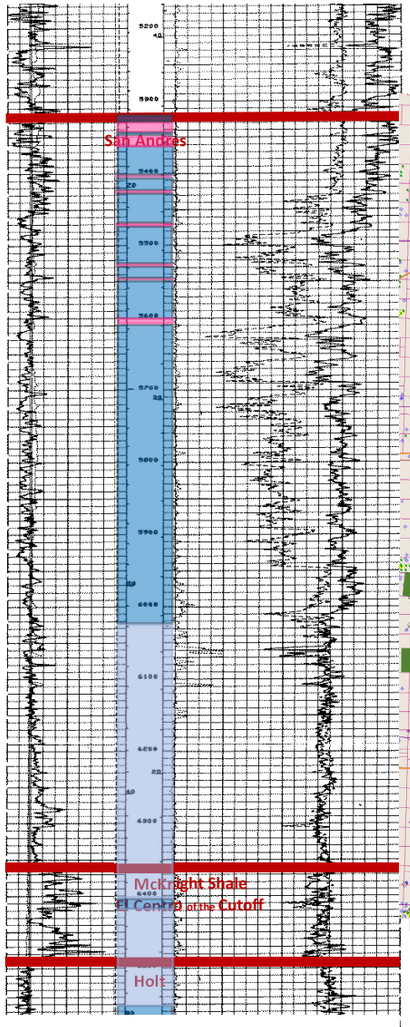


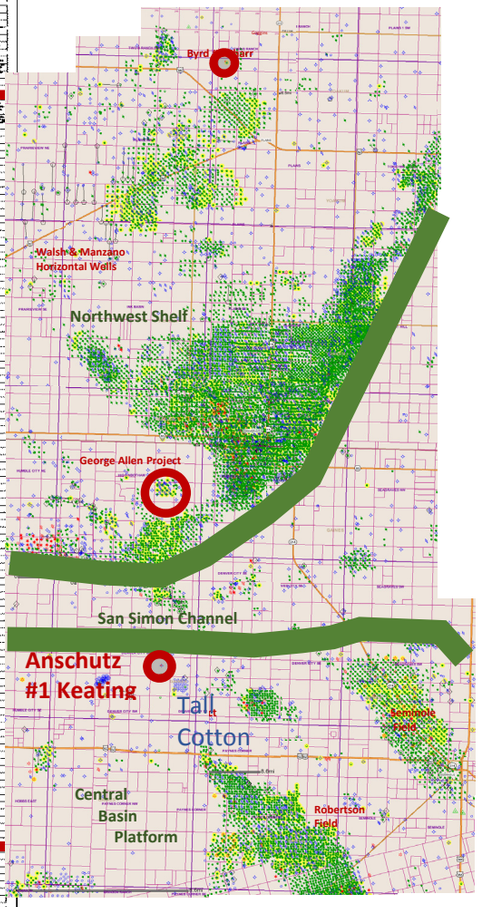
2 wells, the #1 Keating and the #1-427 Charlene, provided the information necessary to establish the presence of a significant Greenfield ROZ potential in the area.

Presenter's notes: The Tall Cotton project, initiated by Kinder Morgan in 2014, is the first Greenfield-only CO_2 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.

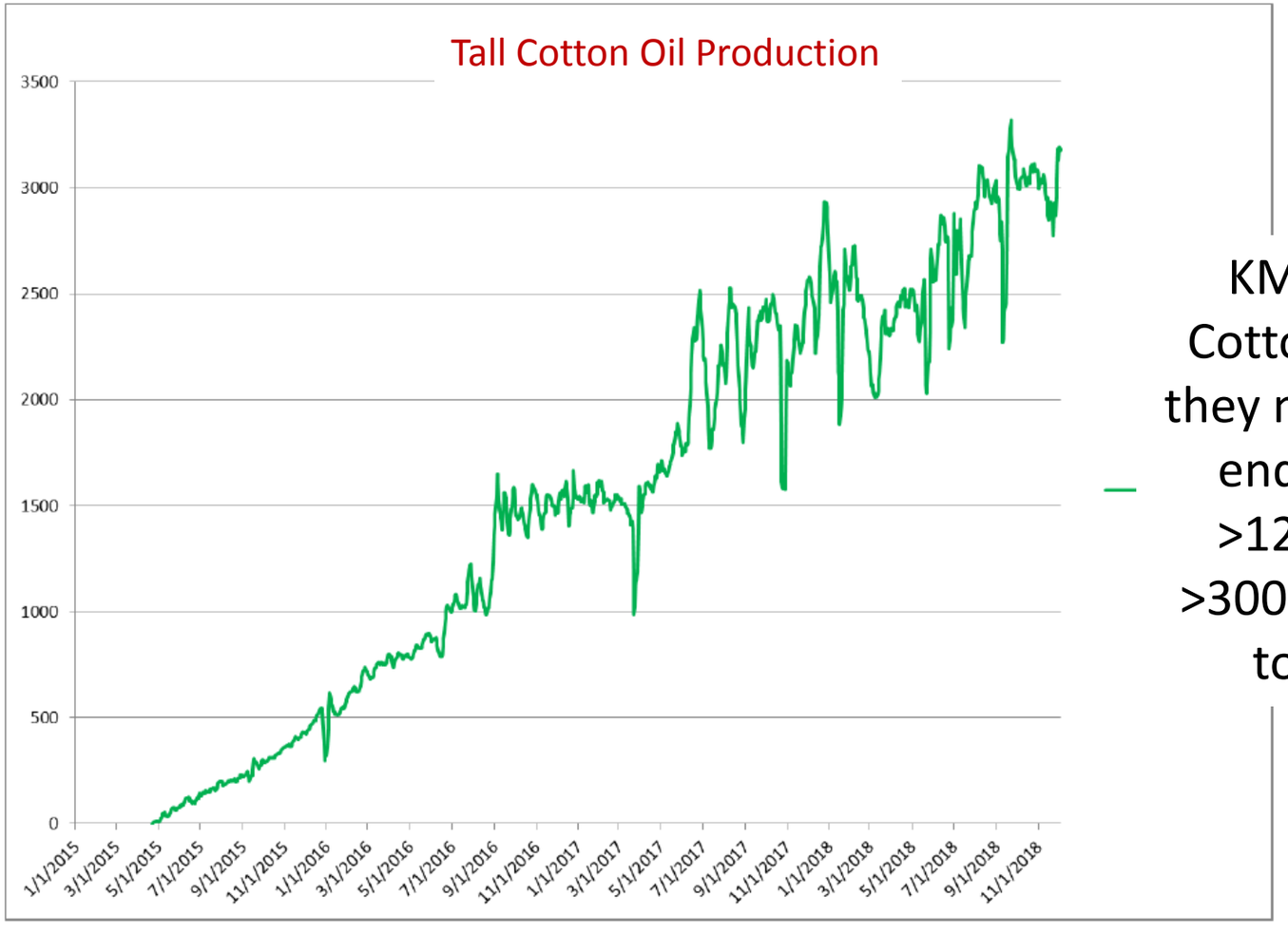
This is a "Classic" ROZ response to an attempted primary completion.

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 CO_2 EOR. The Tall Cotton Field in Gaines County has proven the concept using vertical wells to CO_2 flood a +/-300' San Andres section with variable oil saturations.



KM has been injecting CO_2 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.

KINDER MORGAN 2018

Presenter's notes: KM has been injecting CO_2 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 CO_2 EOR. The Tall Cotton Field CO_2 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.

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

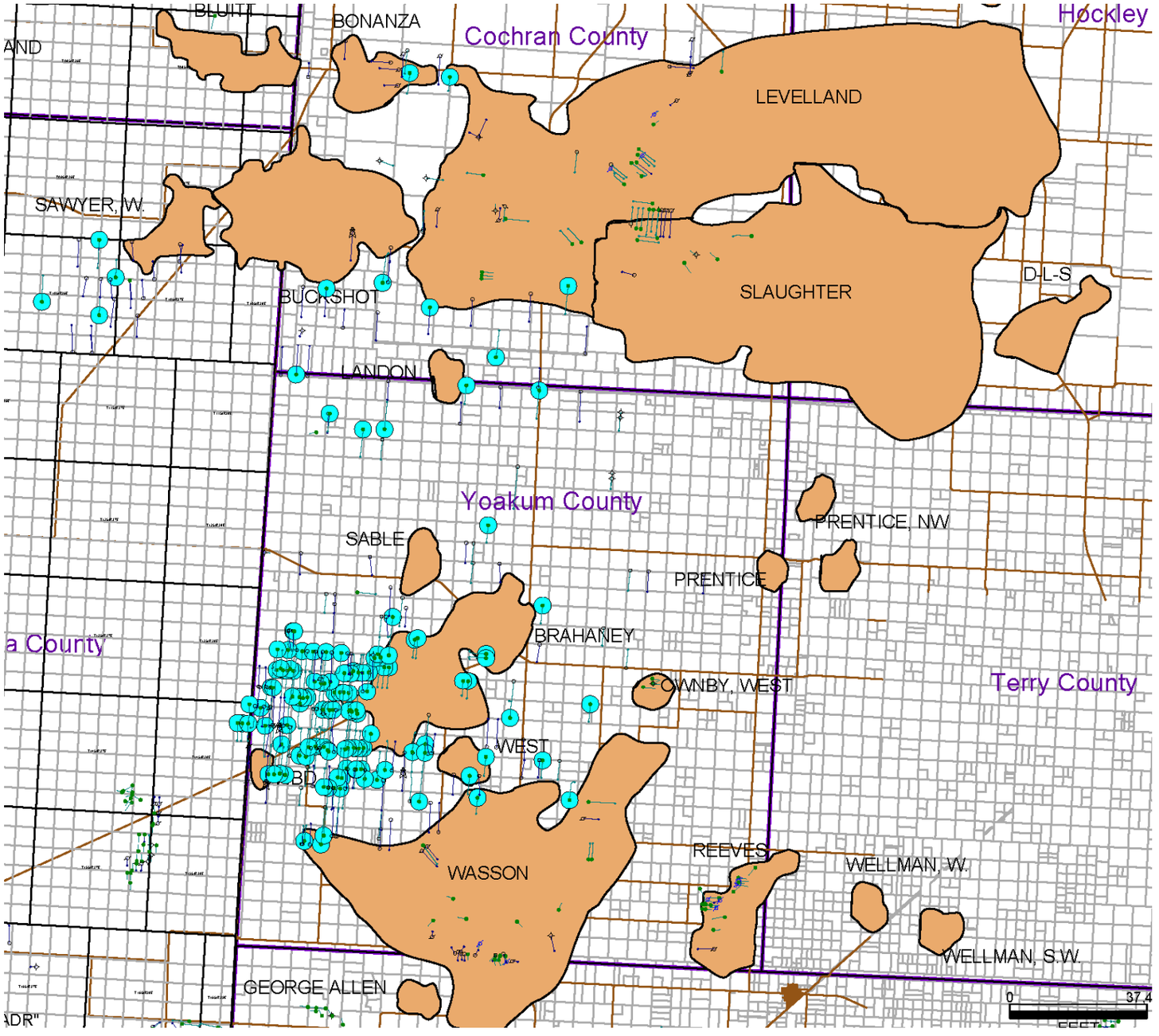
Core Analysis

Completion

We need to shift the paradigm again

To make room For DUROZ Interpretation & Explanation

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 CO_2 EOR projects, but many require a completely new interpretation.

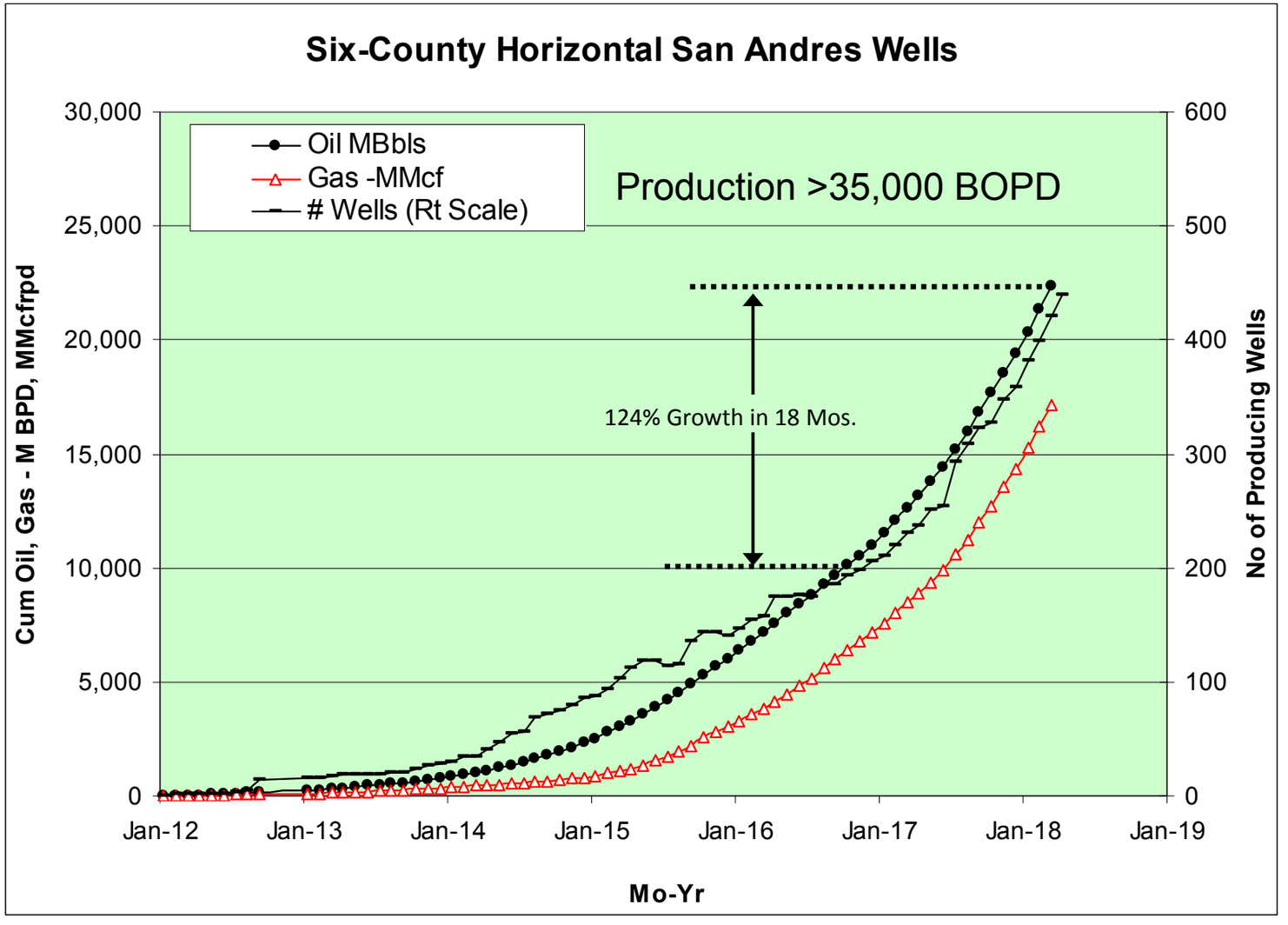


The Second "Horizontal Revolution", centered on Yoakum County, including Yoakum, Cochran, Gaines, Andrews, Ector, and Lea Counties.

Hall, 2017

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

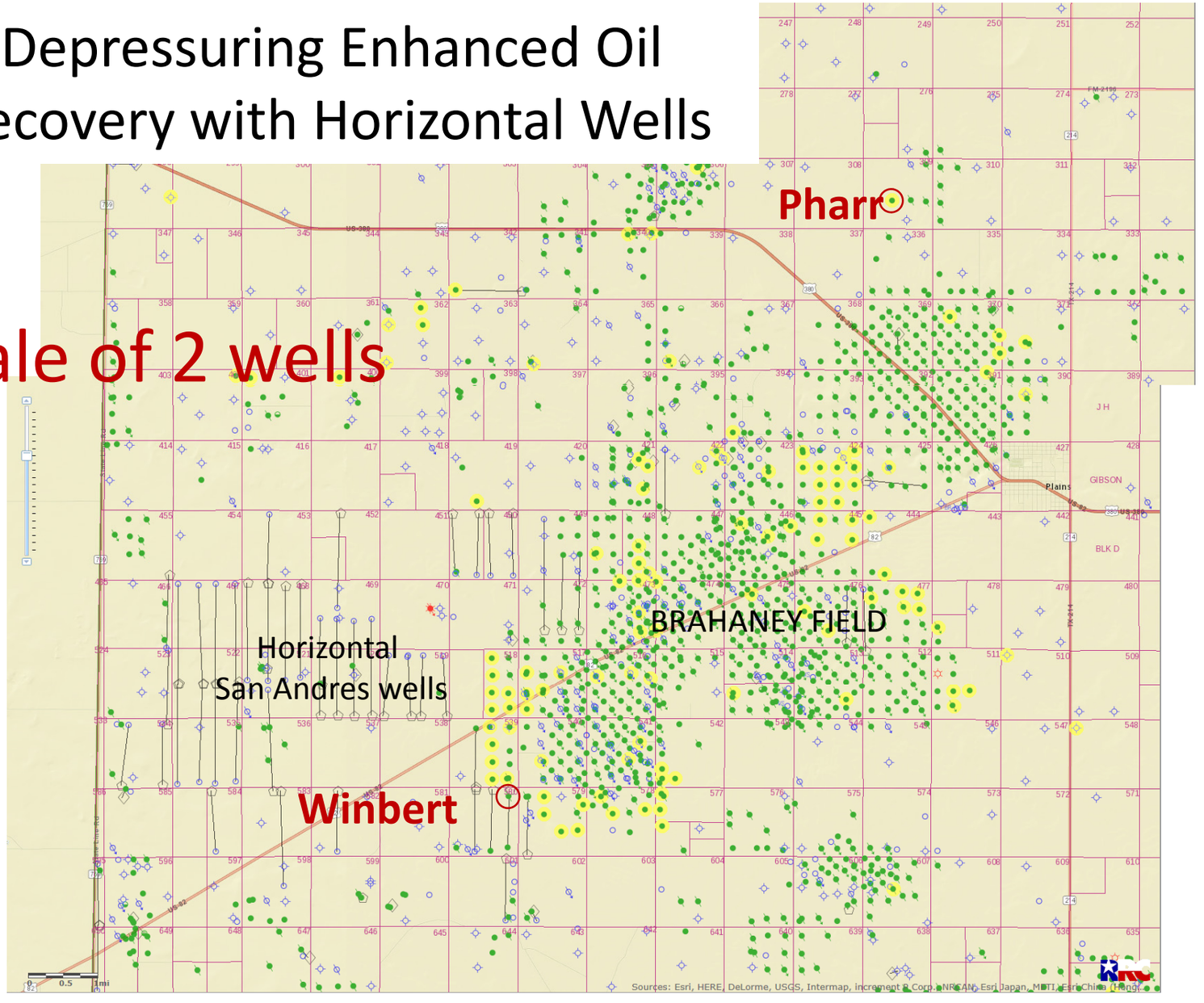


Melzer, 2018

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.

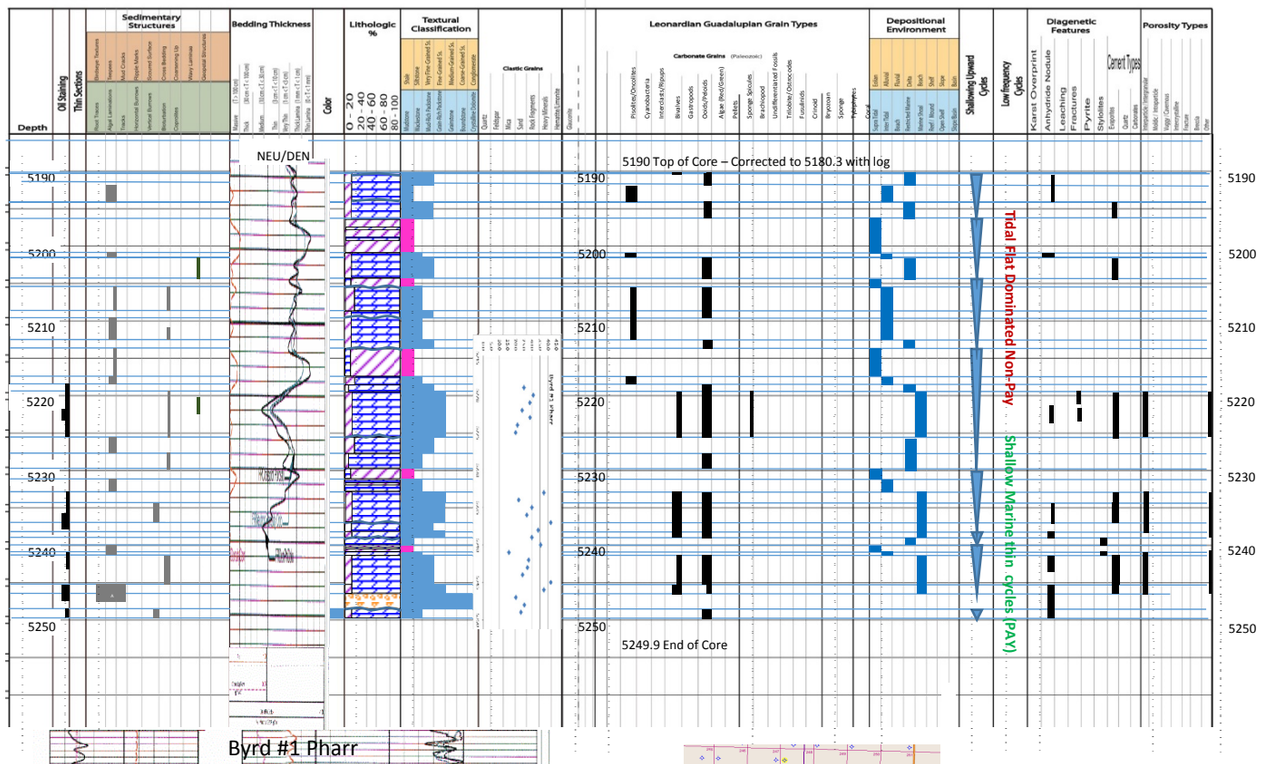
Depressuring Enhanced Oil Recovery with Horizontal Wells

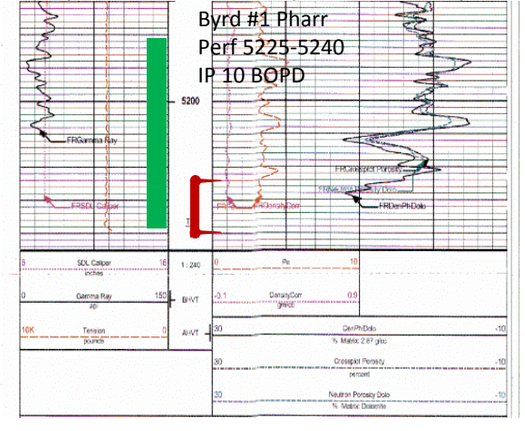
A tale of 2 wells

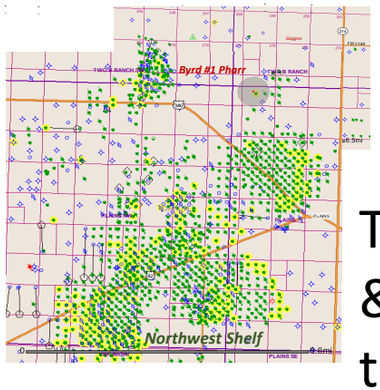


Presenter's notes: The rational for the potential for Depressuring Enhanced Oil Recovery with Horizontal Wells can be seen when comparing the first year's production from a DUROZ horizontal well {#1H Winbert) to an uneconomic to marginally successful vertical well {#1 Pharr} completed in the Main Pay only.

Well or Measured Section:_Byrd #1 Pharr_____ _____ Location_2173 FS & FWL, Sec 309, Blk D, J. H. Gibson Surv, Yoakum Co., TX
ormation(s)_____San Andres_____ _____ Depth or Outcrop interval____5190.0 – 5249.9_____







Byrd	#1 Pharr
42-501-36072	
Date	Production
Oct 2013	296
Nov 2013	307
Dec 2013	140
Jan 2014	381
Feb 2014	307
Mar 2014	416
Apr 2014	349
May 2014	348
Jun 2014	341
Jul 2014	331
Aug 2014	274
Sep 2014	352
Aug 2014	274
Sep 2014	352
Total	3,842

Walsh	1H Winbert
42-501-45999	
Date	Production
Oct 2013	343
Nov 2013	6,172
Dec 2013	8,912
Jan 2014	6,452
Feb 2014	5,361
Mar 2014	6,300
Apr 2014	6,060
May 2014	5,003
Jun 2014	4,365
Jul 2014	4,422
Aug 2014	3,769
Sep 2014	3,711
Total	60,870

The Horizontal well, #1Winbert, 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, #1H 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?

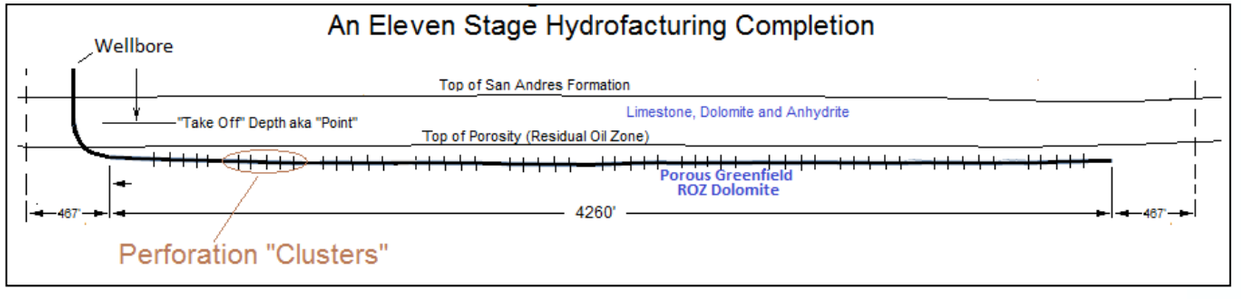
The Bronco frac design has evolved from November 2016 to current day

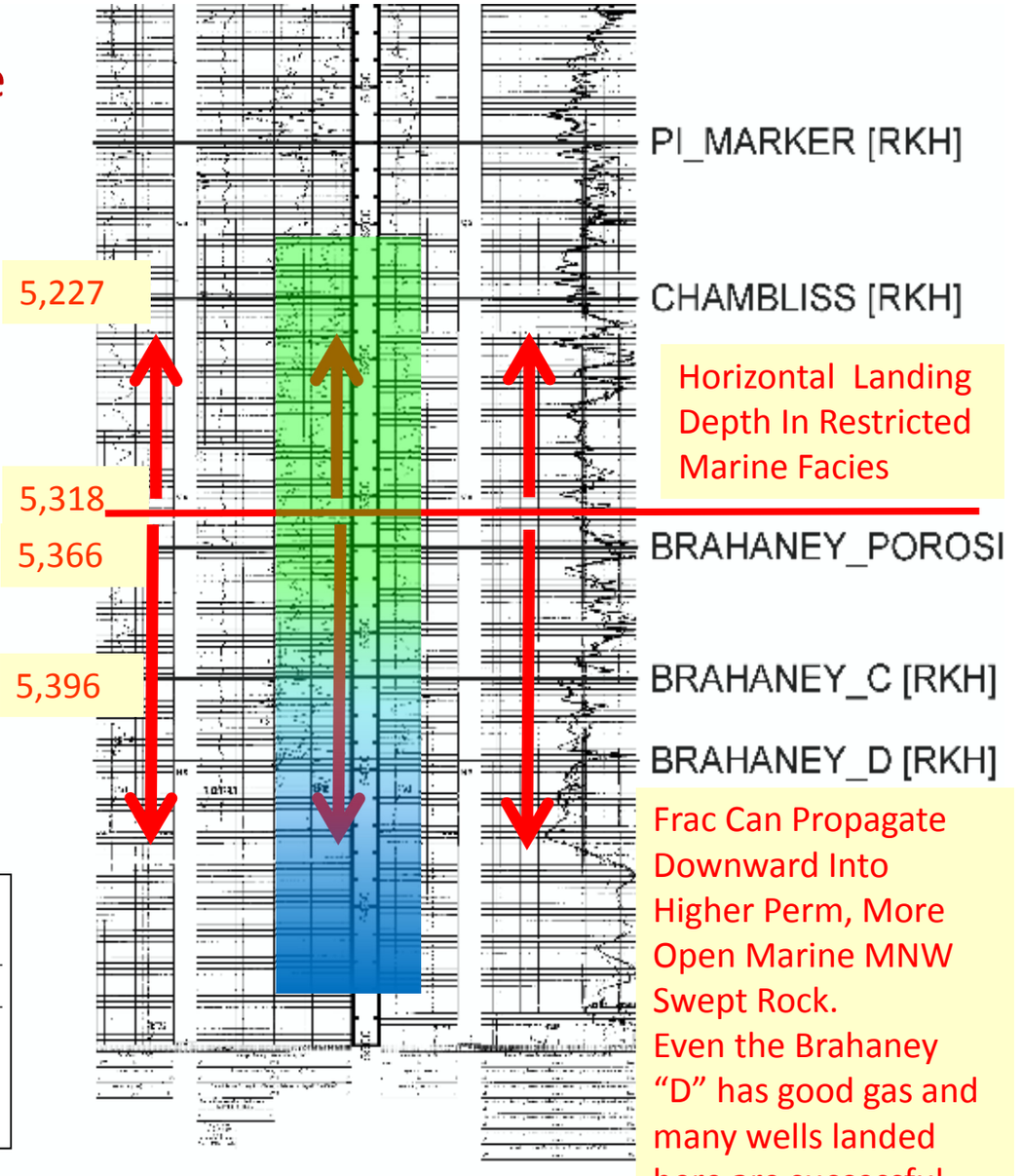
Gen	Date	Lateral Length	Stage Count	Stage Spacing	100 Mesh	Proppant Mesh	Proppant Mass	Slickwater %	Linear %	X-link %	Gel Loading
Pre-ACQ	Oct-16	4100	13	315	45,000	30/50	145,000	45%	40%	15%	12#
1.1	Nov-16	5000	14	357				35%	15%	50%	
1.2	Feb-17		16	313				25%	20%	55%	
2.1	Mar-17		18	278	7,500						
2.2	Apr-17		20	250	5,000			20%	25%		15#
3.1	Jun-17					20/40	205,000		0%	80%	
3.2	Dec-17										18#

Stedman,2018

- 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 cleaned with chlorine dioxide
  - Liquid Scale Inhibitor pumped throughout job (polyacrylate / deta phosphonate blend)
  - Solid Scale Inhibitor added to sand (Carbo ScaleGuard – phosphonate based)





Hall, 2017

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 CO_2 EOR in the ROZ

- Having reviewed the importance of the DUROZ components compared to the vertical CO_2 EOR cookbook, the same critical factors in controlling how/where to best complete a vertical CO_2 well: depositional environments, diagenesis, sweep & saturations also apply to DUROZ horizontals, however, the weight of each varies :

- **Fractures** ⟸
- **GOR's** ⟸

TODAY

- 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 CO_2 EOR cookbook, the same critical factors in controlling how/where to best complete a vertical CO_2 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"

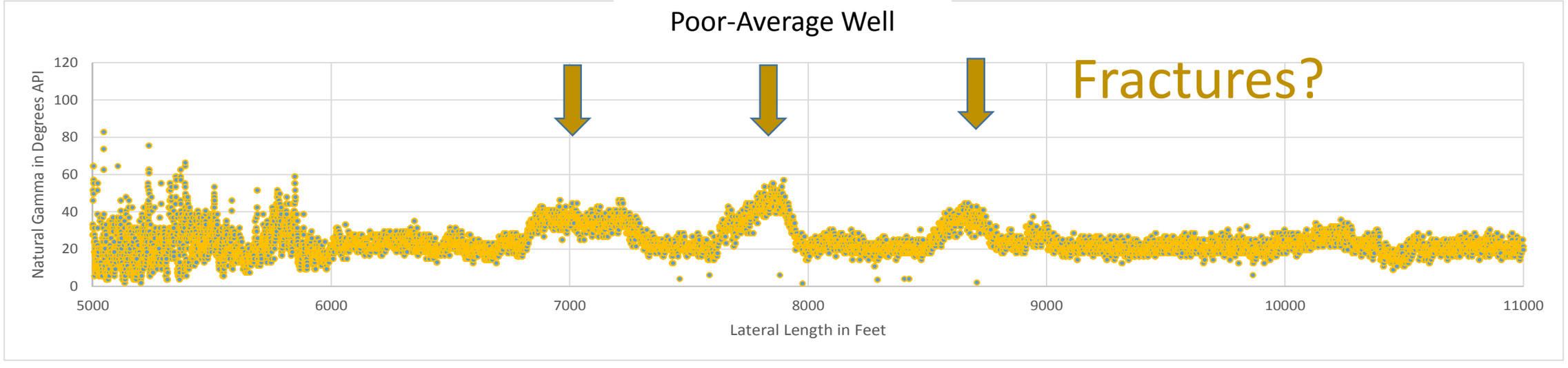
- **Theory:** The Gamma kicks are potential indicators of vertical transmissive fractures

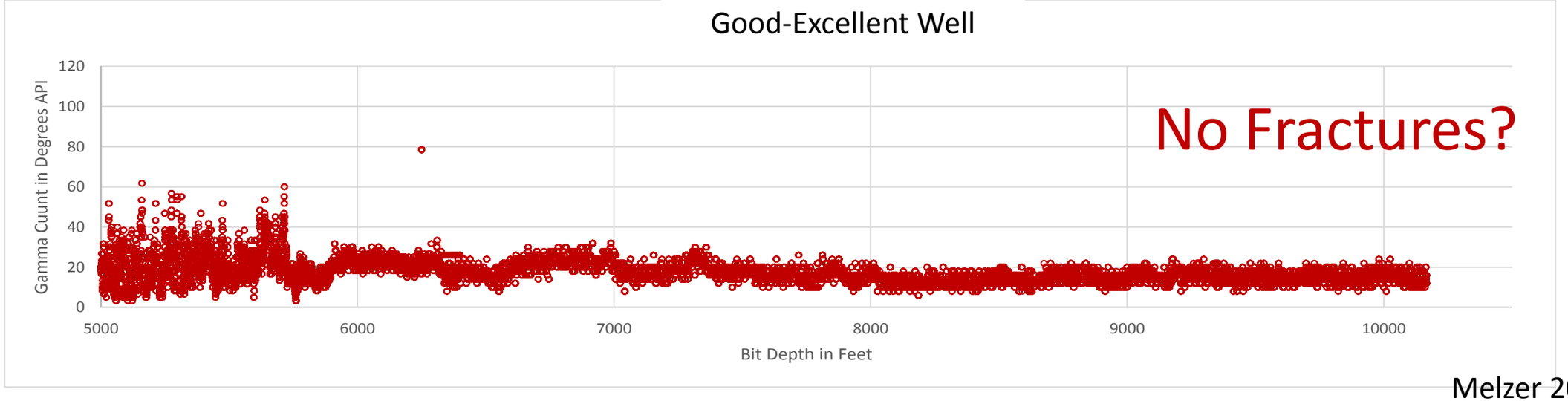
- **Conclusion:** Be wary of stimulating into an Interval with a vertical transmissive fracture

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".
The **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"].
The **Conclusion** is to be wary of stimulating into an Interval with a vertical transmissive fractures.

Yoakum County Horizontal San Andres Wells

Gamma Behind the Bit

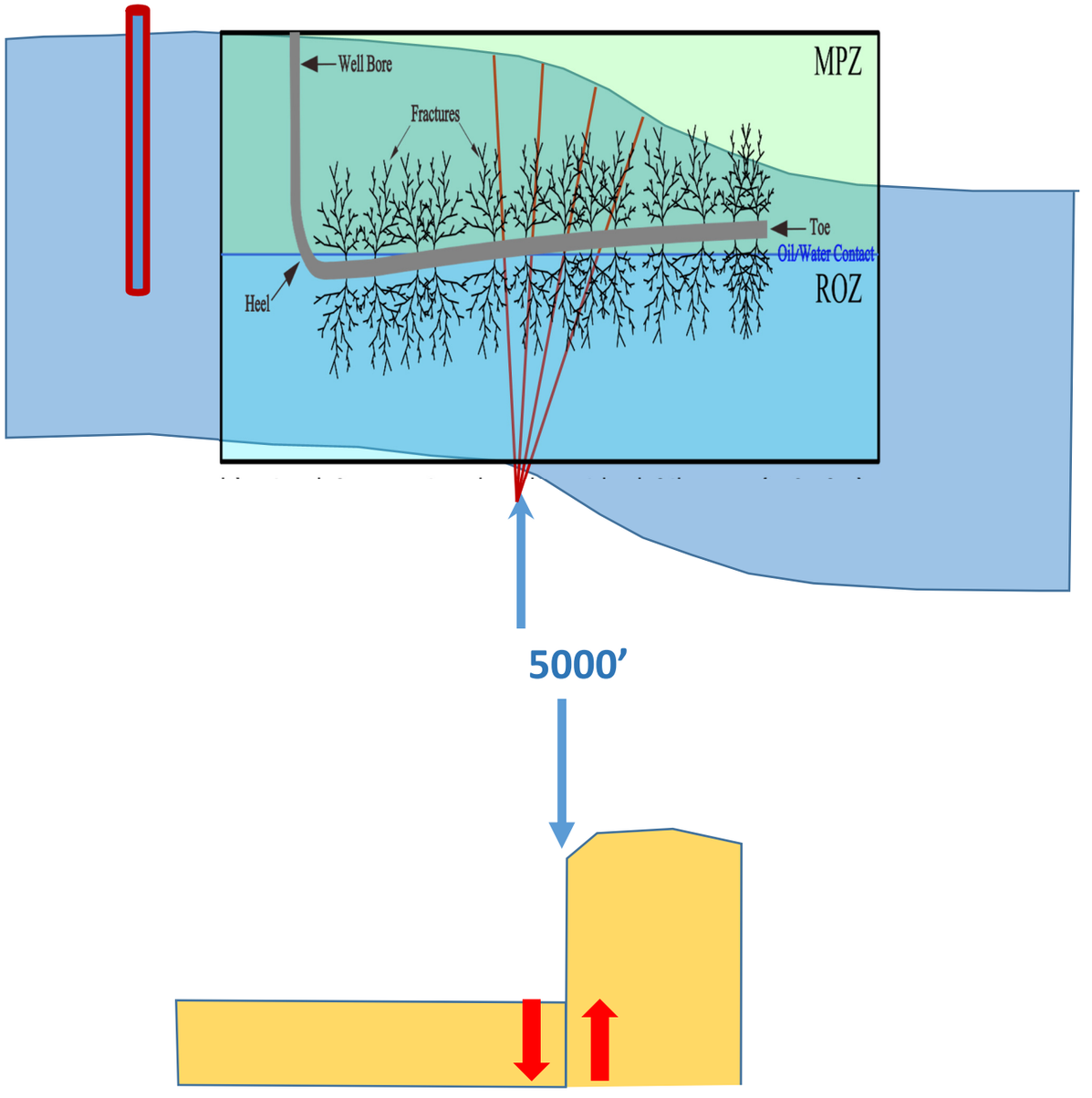




Melzer 2018

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 CO_2 floods.
- In vertical WELLS, not so important, except where CO_2 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 CO_2 floods which we believe to be the result of this flexing.
In vertical wells this may not be as important, except where CO_2 losses are high, but in horizontal wells the presence of these transmissive fracture sets is CRITICAL!!

GOR	265	550	900	1150	Scf/stb
Boi	1.13	1.26	1.46	1.59	Res bbl/std bbl
OIP	1.5	1.4	1.2	1.1	MMBbls
WIP	3.4	3.4	3.4	3.4	MMBbls
GIP	0.41	0.75	1.08	1.25	Bcf
"Primary Oil"	0	45	177	191	MBbls
Recovery Factor (RF)	0	3	15	17	% OIP
"Primary Gas"	0.01	12	77	169	MMscf

How does GOR in Horizontal Well impact production? With increasing Gas the OIP number goes down, but the Recovery goes up.

Koperna & Erdle, 2017

Advanced Resources International, Inc.

Presenter's notes: Moving on to another critical difference between vertical wells in CO_2 floods and Horizontal wells. How does the **GOR in Horizontal Wells** impact production? 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.

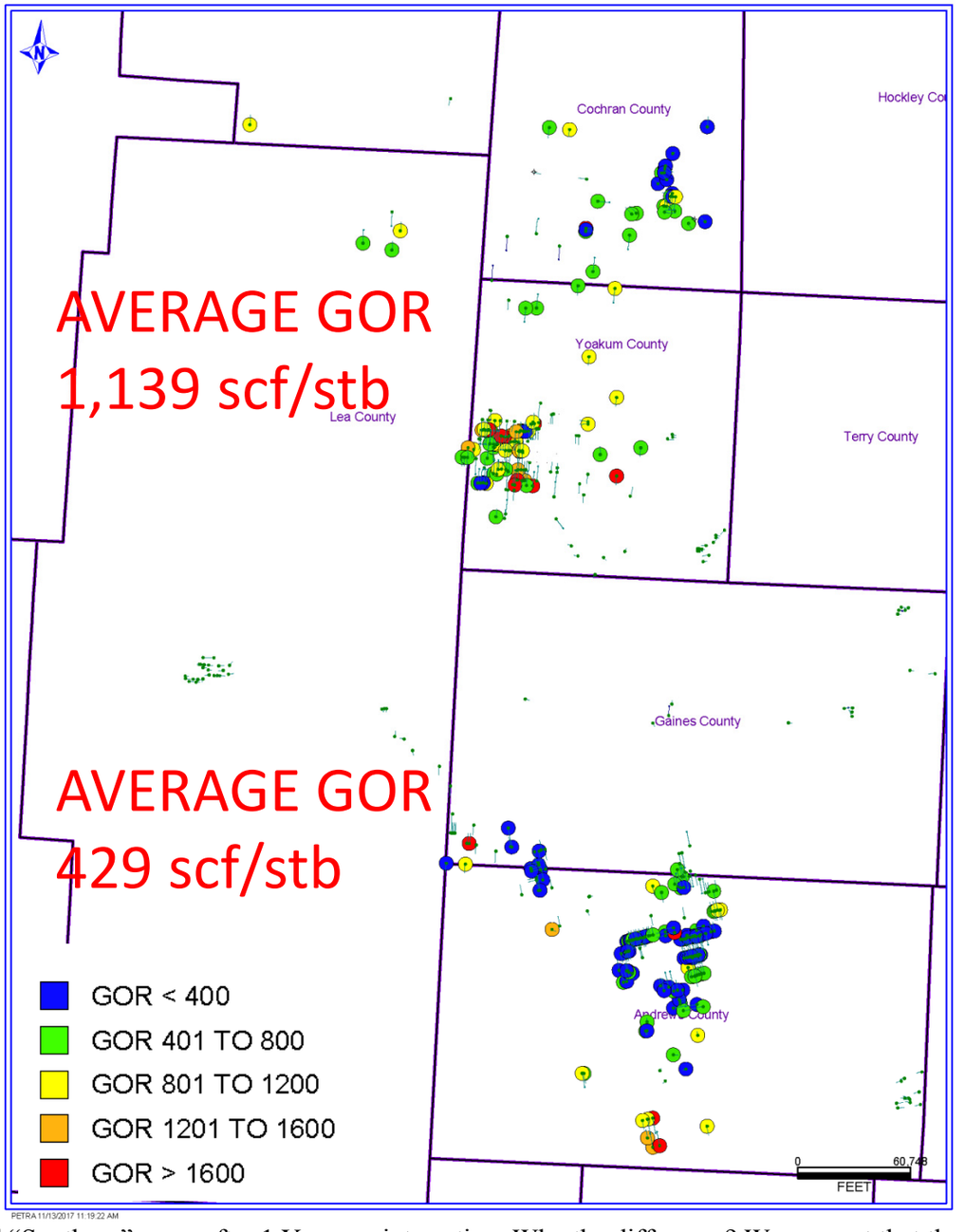
Gas to Oil Ratio(GOR's)

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?



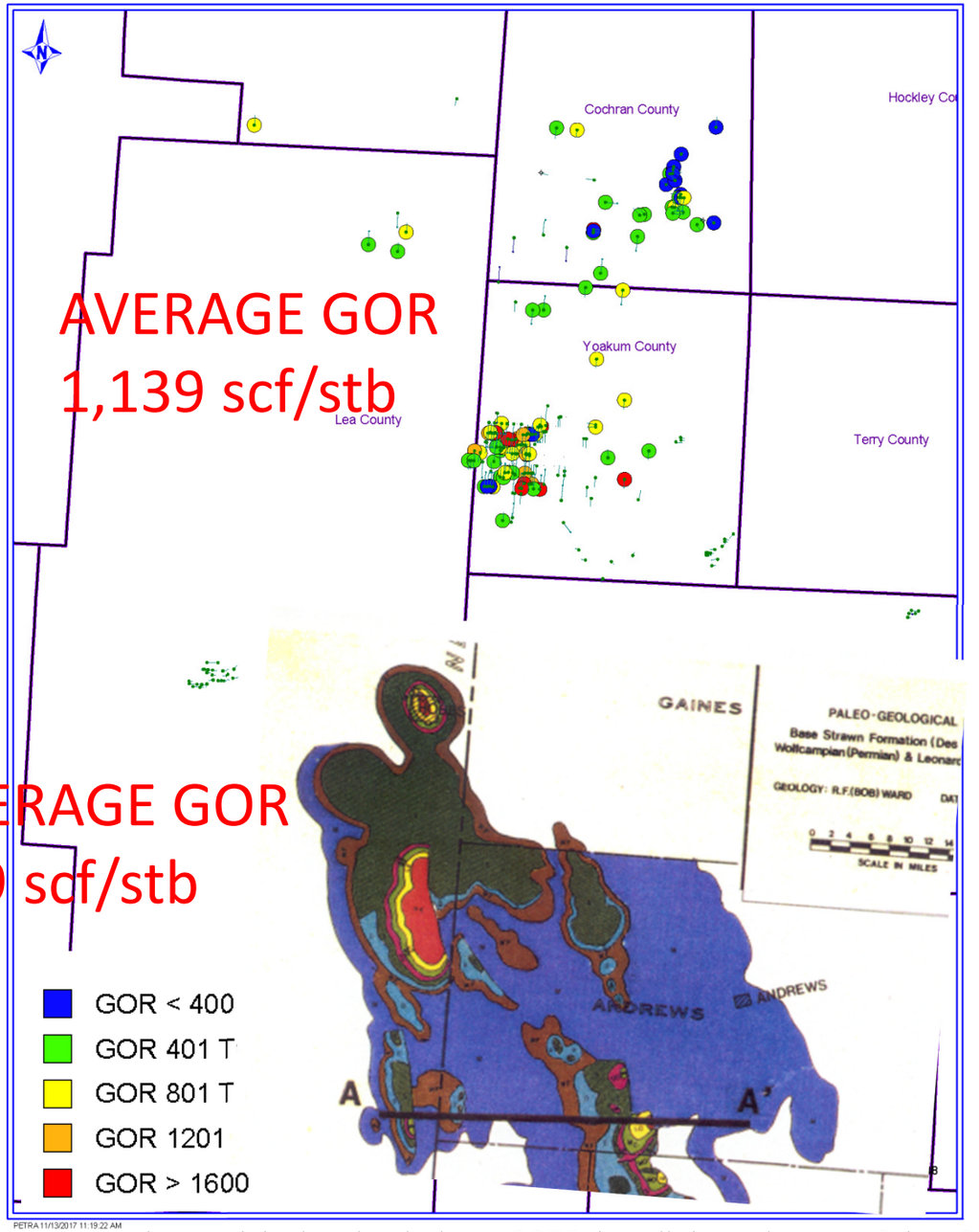
Hall, 2017

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?



Ward, 1980
Hall, 2017

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.

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

Presenter's notes: Though the Vertical ROZ CO_2 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 CO_2 EOR potential in the ROZ. We need to continue to develop our understanding of the geologic parameters in the play.

References

- Hall, R. K., 2017, Northwest Shelf Horizontal Play. Presented at the 23rd Annual CO2 Conference, Midland, TX Dec 2017.
- Kinder Morgan 2018, Tall Cotton (San Andres) Field. Field Introduction for the 24th Annual CO2-ROZ Conference Field Trip, Seminole, TX. Dec 2018.
- Koperna, G., Erdle, J., 2017 What Follows Reservoir Depressuring? Presented at the 23rd Annual CO2 Conference, Midland, TX Dec 2017.
- Melzer, 2018 Residual Oil Drives New Resource Play. *in* American Oil & Gas Reporter, American Oil & Gas Reporter, Oct 2018, P. 153 – 157.
- Stedman, S., 2018, Horizontal San Andres – The Evolution of Completion Techniques. Presented at the 24th Annual CO2-ROZ Conference, Midland, 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.
- Ward, R. F., 1980, Paleogeological Map of Central Basin Platform at Base of Strawn, Wolfcamp, and/or Leonard. Pers. Comm.
- Wells, N. E. Jr. 2019, Petrophysical Study of the Lower San Andres in Western Yoakum County, TX: Using Classical Exploration Techniques for Identifying Depressuring Targets in the Upper Residual Oil Zone (ROZ). University of Texas Permian Basin, M.S. Thesis Defense.

Acknowledgements

- Steve Melzer, Melzer CO_2nsultants
- Russell Hall, Russell Hall and Associates
- George Koperna, ARI
- Norman Wells, McClure Oil
- Scott Stedman, Steward Energy II