Goldsmith Landreth San Andres Unit (GLSAU) #203R- A CO_2 Oil Bank Caught in the Act*

Robert Trentham[1]

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Abstract

As part of the commingled Goldsmith Landreth Main Pay (MP) and Residual Oil Zone (ROZ) CO_2 flood in the Goldsmith (San Andres) Field, a core was taken in both the MP and ROZ with a partial objective to demonstrate the sweep efficiency of the MP and ROZ flood. The well, #203 RW GLSAU, was a replacement for one of the original injectors in the initial producer-centered five-spot pilot. Oil response was excellent and very rapid in the pilot and, early in the injection history, it was determined that for conformance reasons, it was necessary to plug back from the fast processing lower unit of the ROZ (LROZ), and concentrate the injection in the upper member of the ROZ (UROZ). The operator's most desirable solution was to replace the original well (#203W) and drill and core a replacement well (#203 RW). The new well was drilled ~135' from the original well, just outside the original pattern. Both the MP and ROZ were cored and it became apparent that there were elevated oil saturations (So) in the LROZ when compared to other cores taken before the inception of the CO_2 flood. These elevated So values just outside the pilot pattern serves as proof of oil 'bank' development in LROZ that had provided the fast response inside the pattern and was caught in the act just outside the pilot pattern. As CO_2 had been injected in the lower ROZ for a brief period, the flood front had advanced to the center producer but not moved far beyond the location of the replacement well (#203 RW) outside the injector.

The reservoir portion of the ROZ is composed of two parasequence sets of fusulinid-rich outer shelf mud rich to mud poor packstones (in both the UROZ and LROZ). An interval of deeper water fusulinid dominant wackestone to mudstone separates the two ROZ CO_2 targets. The base of the ROZ is coincident across most of the field with the transition from predominantly limestone below to dolomite above. This transition is often seen to be associated with the base of the ROZ, as is the presence of native sulfur. The faster processing LROZ represents a heavily dolomitized and leached sequence just atop the limey base of the ROZ. The MP is composed of an overall shallowing upward sequence, from open marine to tidal flats, where there are a series of individual shallowing upward individual cycles, many of which have Solid Hydrocarbon Residue (SHR) at the base of the cycle suggesting each cycle acts as a separate flow unit.

GLSAU 203R – A CO2 Oil Bank Caught in the Act

Southwestern AAPG,
May 2014
Dr. Bob Trentham
UT Permian Basin

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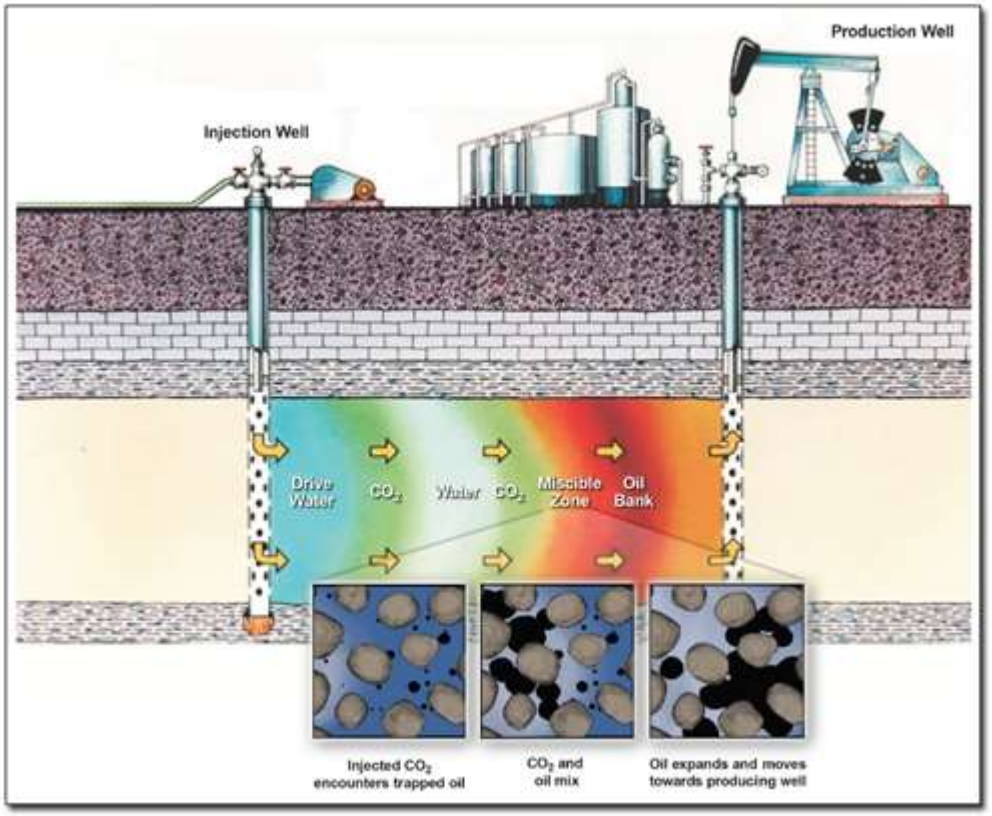
- There is much anacdotal evidence on the sweep efficiency of CO2 in EOR projects. Including many successful ROZ Floods.
- Many people can point to a “twin well” to a CO2 injector where the Oil Saturation has been reduced to less than 5%.
- But, good luck trying to find reports on those wells.
- This is an documented example of “catching a CO2 flood in the act”.

- Discuss:
  - Goldsmith Geology
  - ROZ Development
  - Legado’s Core Program
  - CO2 Pilot
  - 203 RW GLSAU
  - Flood Front and
  - Oil Bank Development



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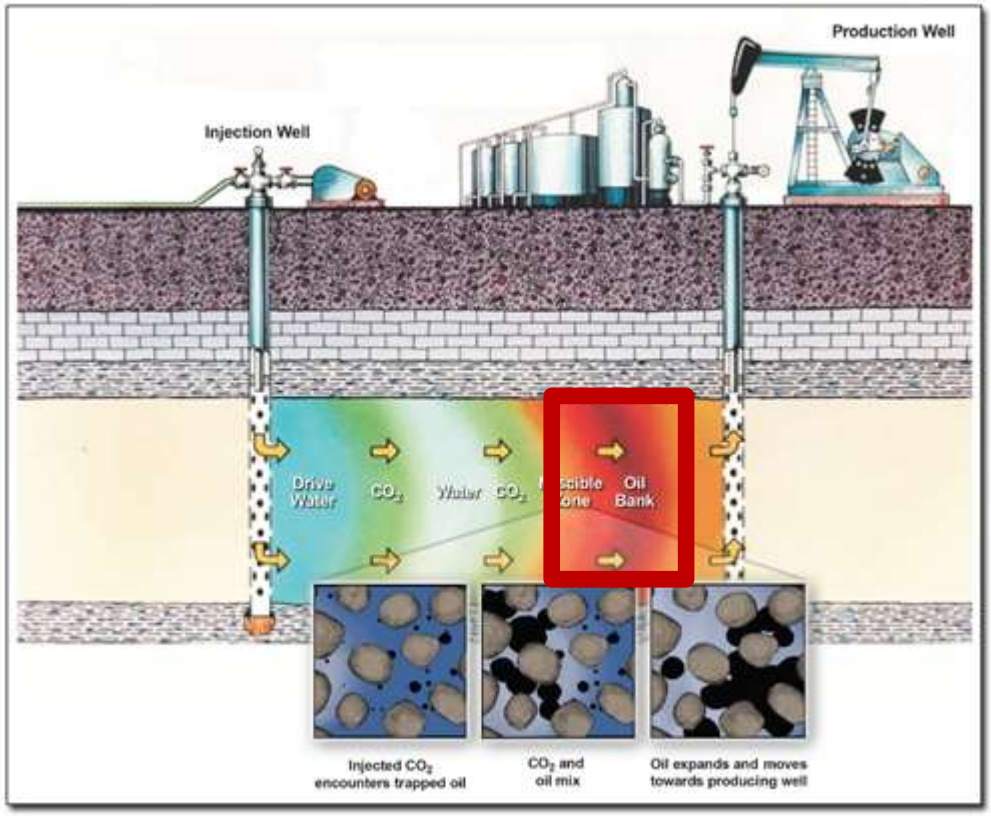
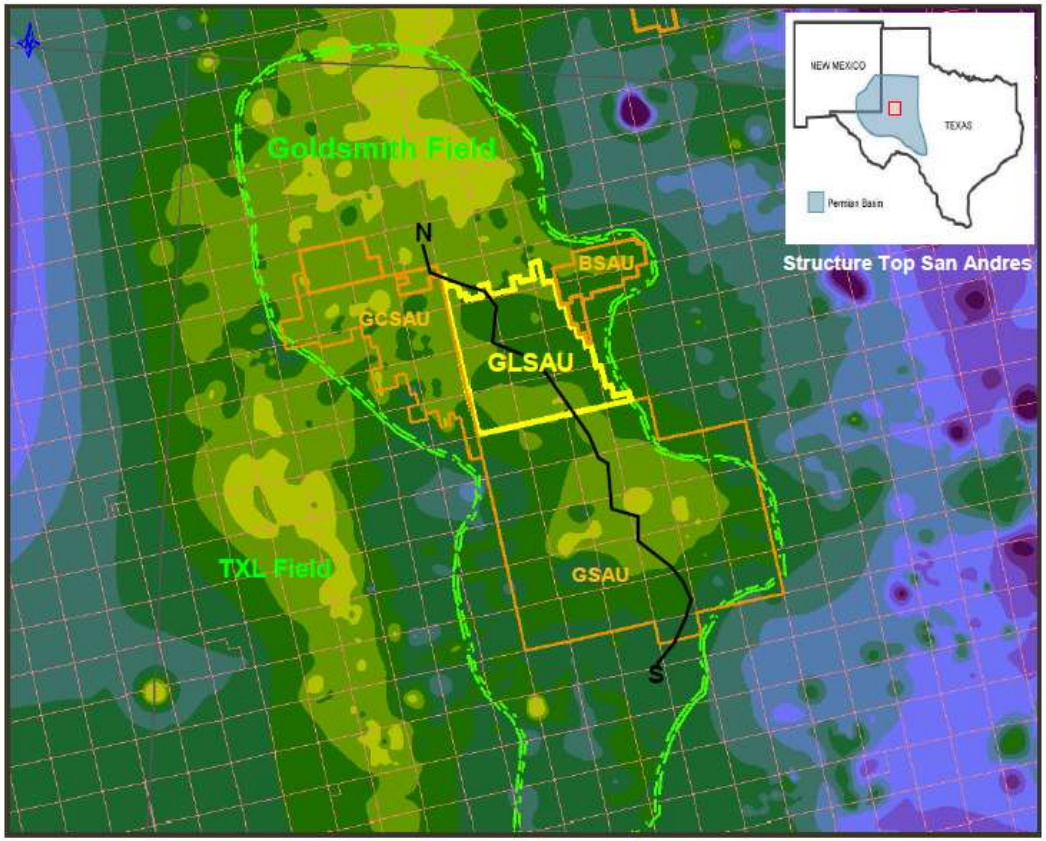


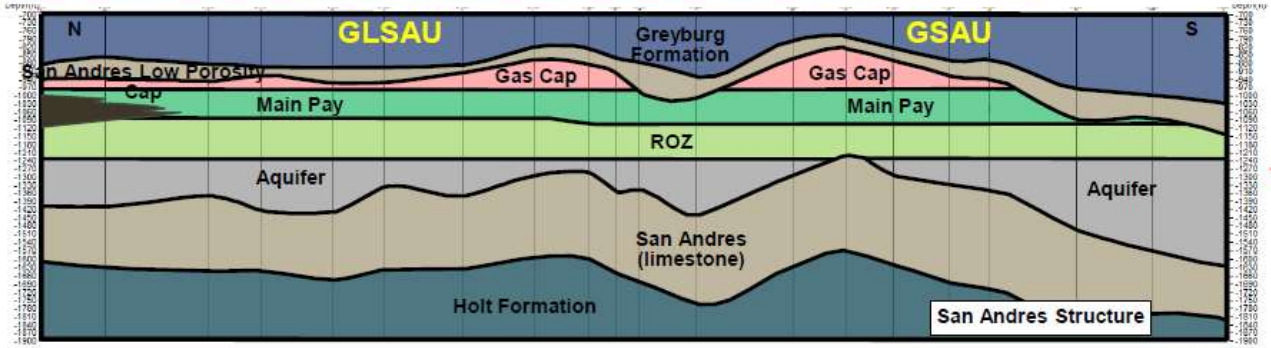
Goldsmith Field Complex

LEGADO resources



Goldsmith Field

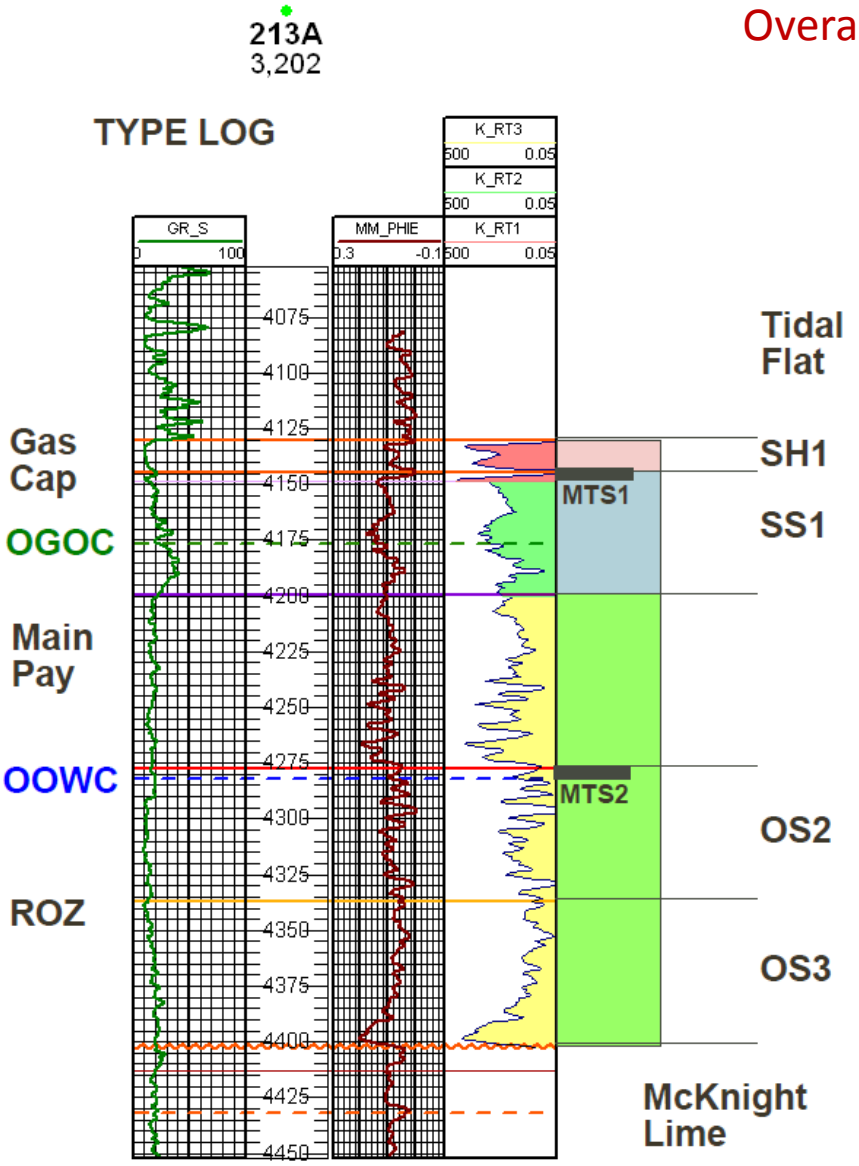
- Discovered 1934 by Davidson-Atlantic
- Production from Permian Grayburg through Ordovician Ellenberger formations
- Complex is a large anticlinal structure with prominent highs to the north and south
- Cum Field Production ~ 780 MMBO
- Primary Producing Zones:
  - Clearfork ~ 385 MMBO
  - San Andres ~ 365 MMBO
- Largest San Andres waterflood units outlined in ORANGE, (GLSAU in YELLOW)



San Andres production is confined structurally on South, East and West. Updip termination at gas cap and ultimate stratigraphic pinch-out to the North.

Stratigraphy – Interval Definition

LEGADO resources

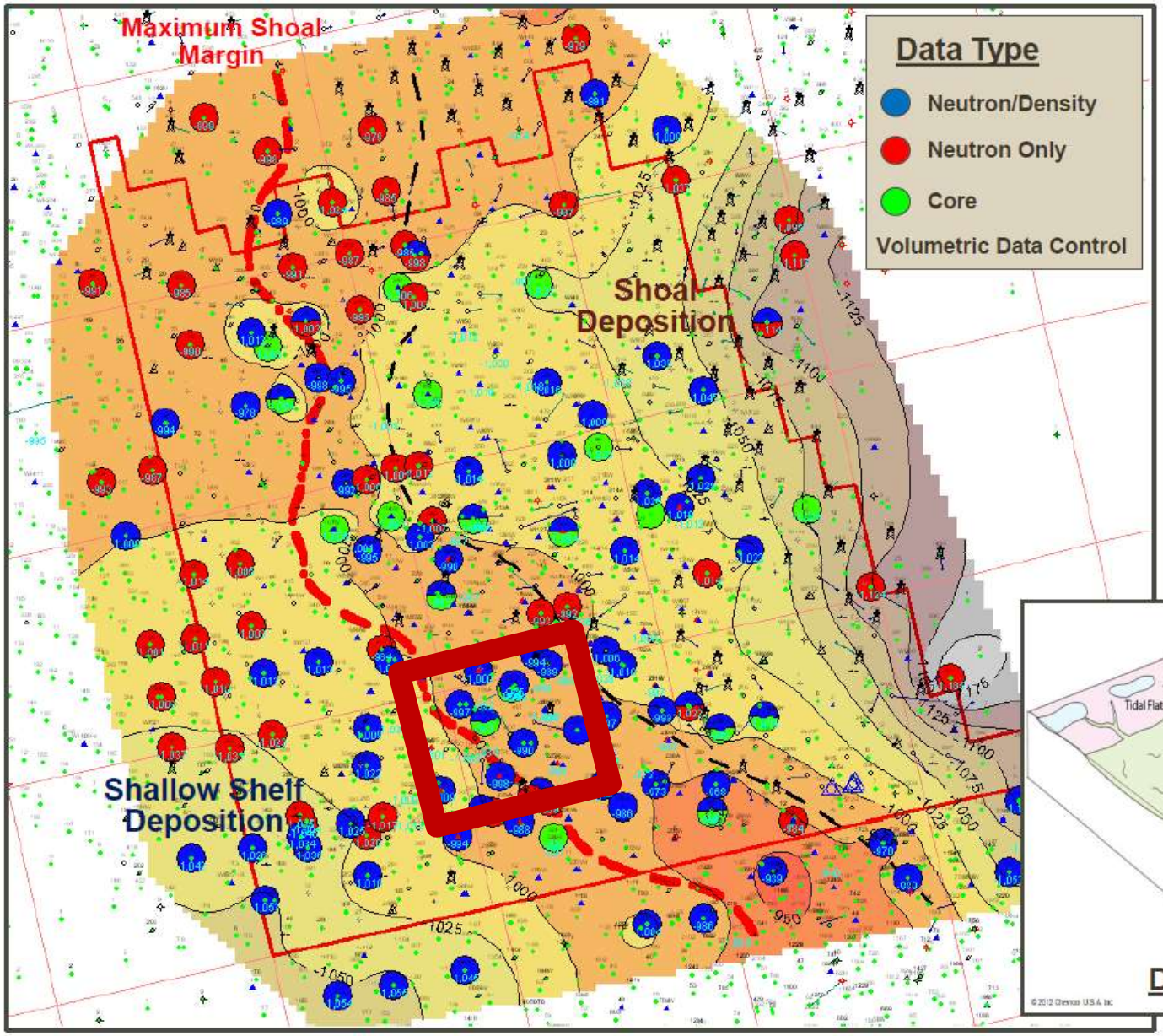


Overall shallowing upward sequence

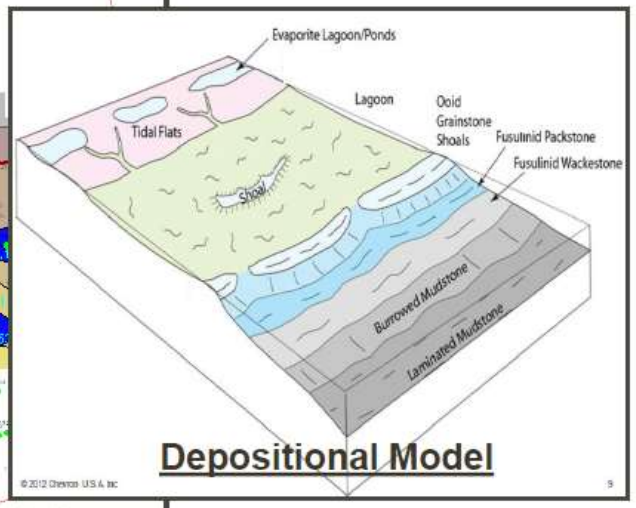
- GLSAU San Andres Reservoir is +/-300':
  - Original Gas cap average 40'
  - Main Pay average 110'
  - ROZ average is 150'
- Key reservoir facies:
  - Capping tidal flat seal (TF)
  - Platform grainstone shoal (SH1)
  - Shallow Platform Packstones and Wackestones
  - Open Shelf packstones and wackestones (OS1, OS2 & OS3)
  - Base of reservoir is marked by transition from San Andres dolomite to limestone (McKnight Formation)
- Reservoir Net Pay Cut-off of 6% porosity corresponding to approximately 0.2 md permeability

Shelf Structure and Depositional Areas

LEGADO resources

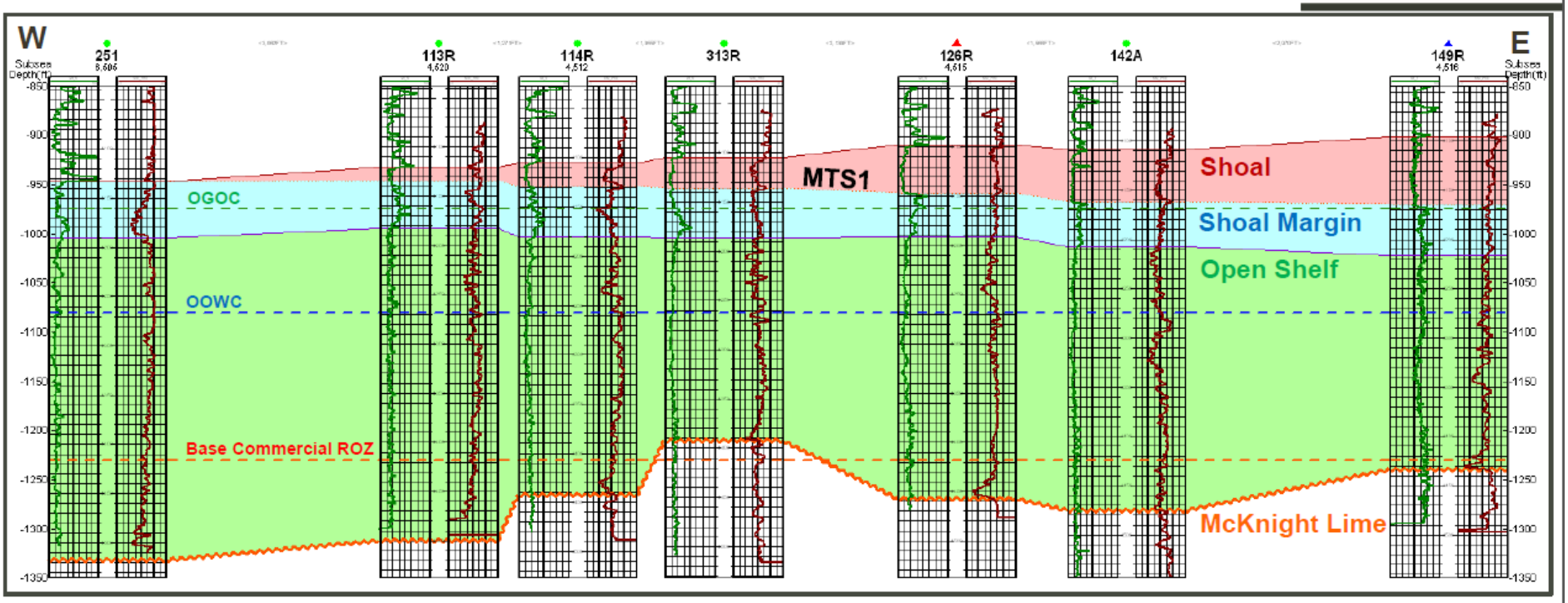


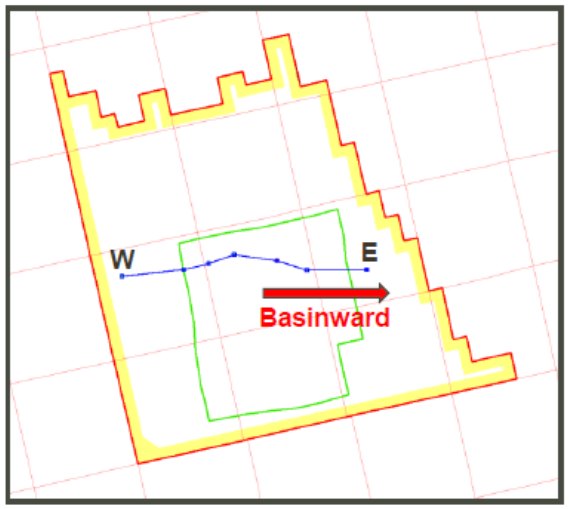
- GLSAU situated between two larger structural highs on the Goldsmith Field anticline.
- Shelf deposition conforms to paleo-structure.
- Open shelf, shallow shelf and shoal margin facies were deposited on eastwardly prograding Central Basin Platform
- Dolomitization of facies enhanced porosity and created reservoir.



Depositional Model

General Reservoir Architecture - Stratigraphy



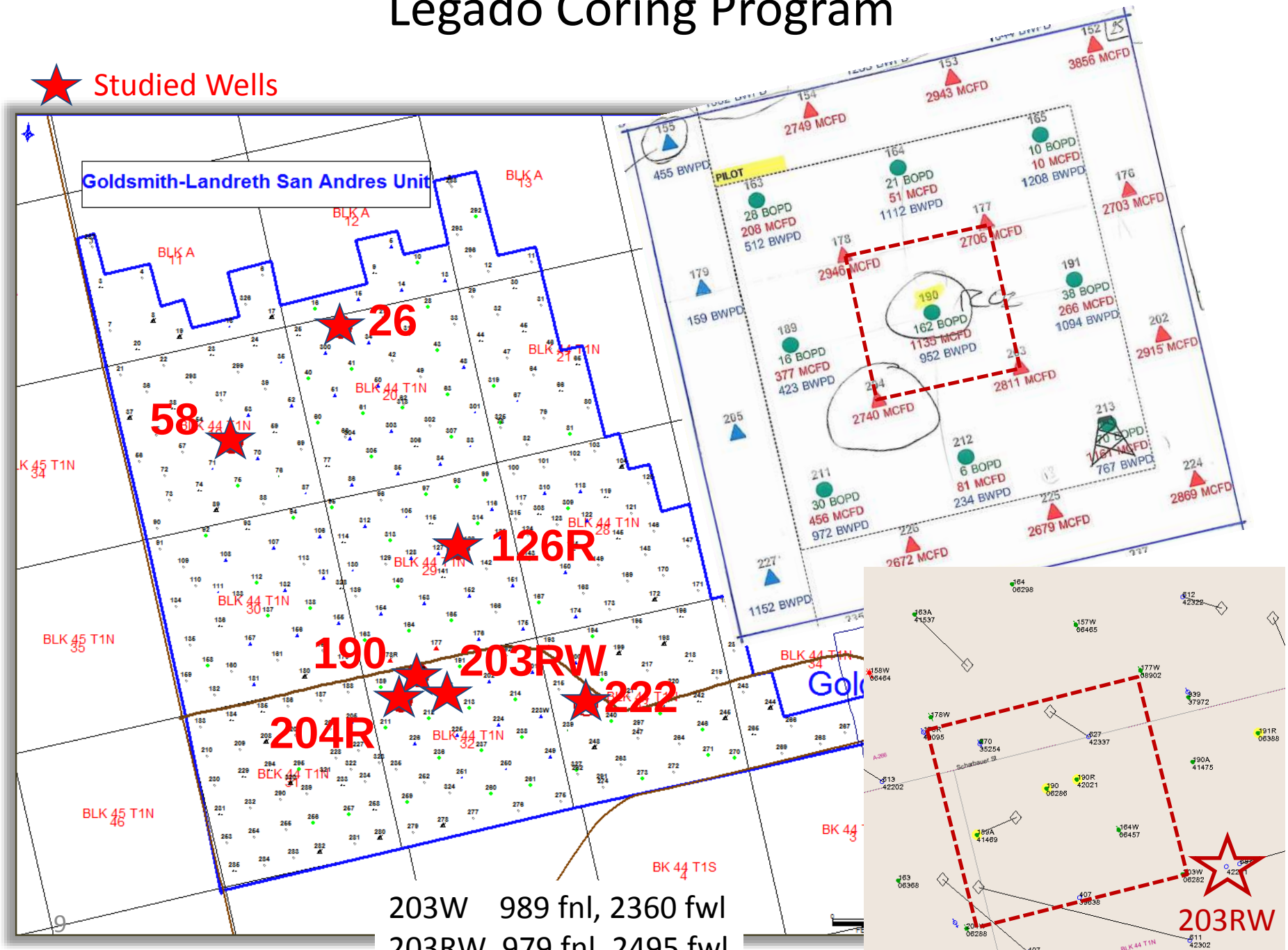


3 Major Reservoir Facies Capped by Tidal Flat

- Shoal – Deposited basinward into accommodation space. Underlied and sealed from deeper zones by Major Transgressive Surface (MTS).
- Shoal Margin/Shallow Shelf – Deposited as trailing edge of overlying shoal and as shallow water shelf.
- Open Shelf – Deposited farther offshore as largest volume reservoir feature
- Mcknight Lime – Transition to limey dolomite reservoir results in oil saturations below commercial threshold. Truncates commercial base in limited portion of the field.

Legado Coring Program

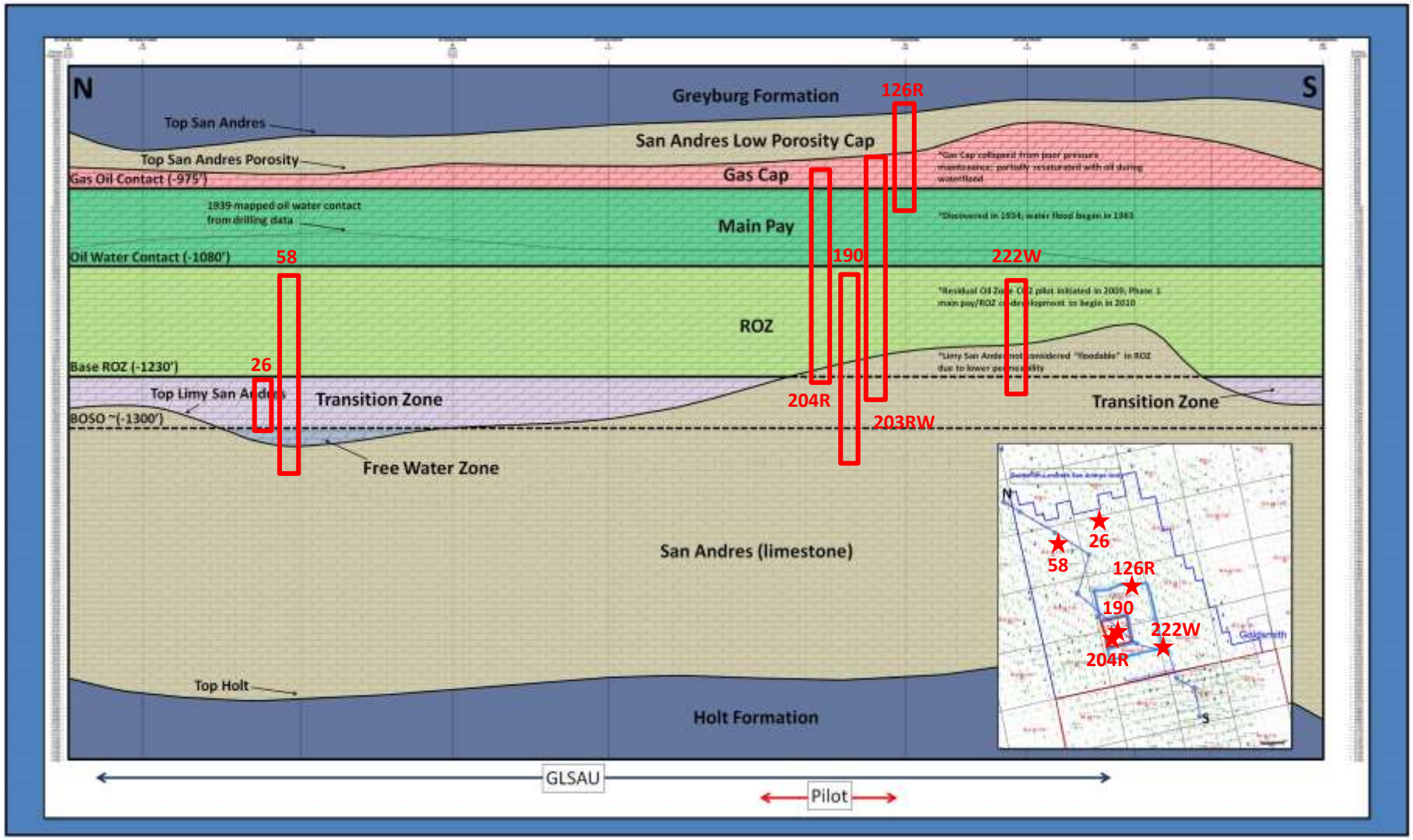
Studied Wells



203W 989 fnl, 2360 fwl

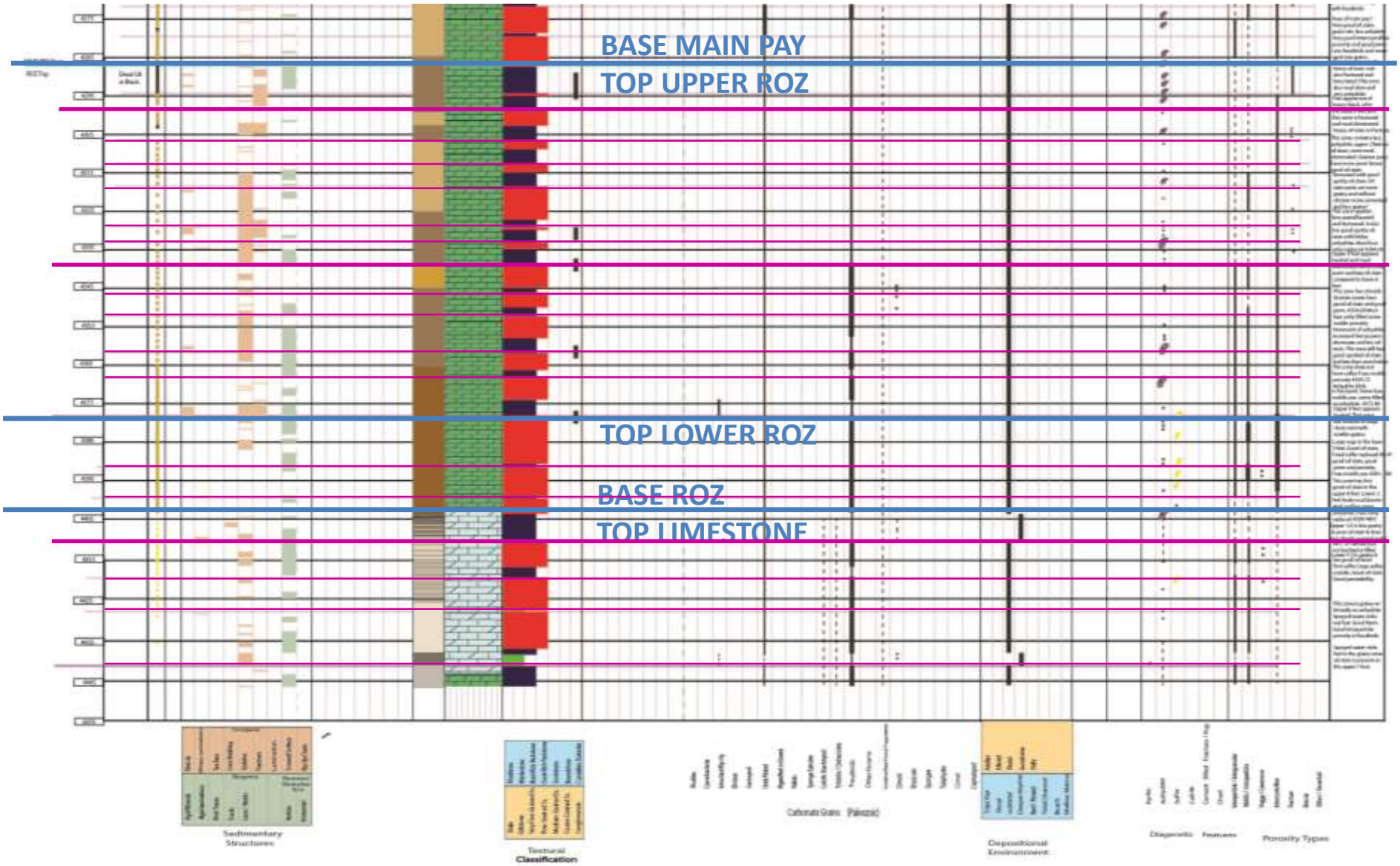
203RW 979 fnl, 2495 fwl

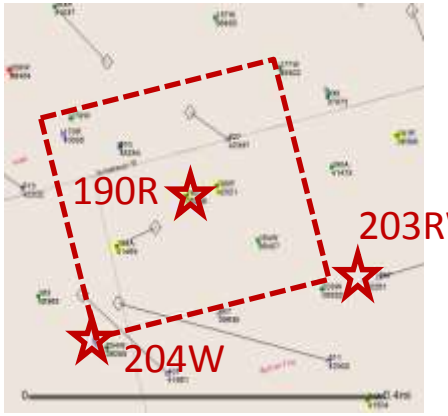
GLSAU Geologic Model



203 RW Core Description ROZ

The ROZ is composed of 15 cycles and 3 Cycle Sets





GLSAU #190

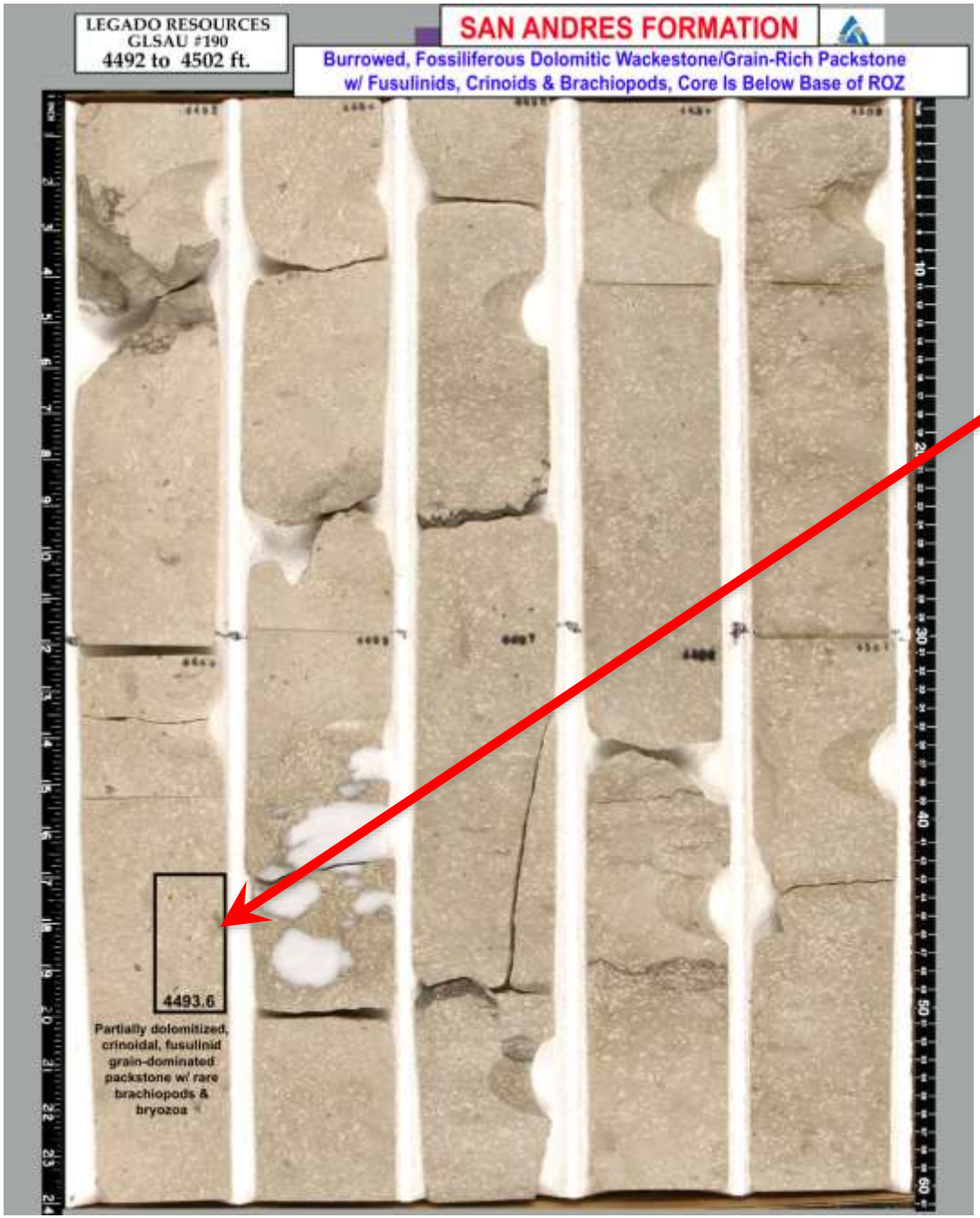
MAIN PAY

UPPER ROZ

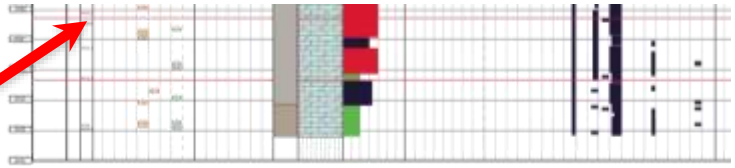
LOWER ROZ

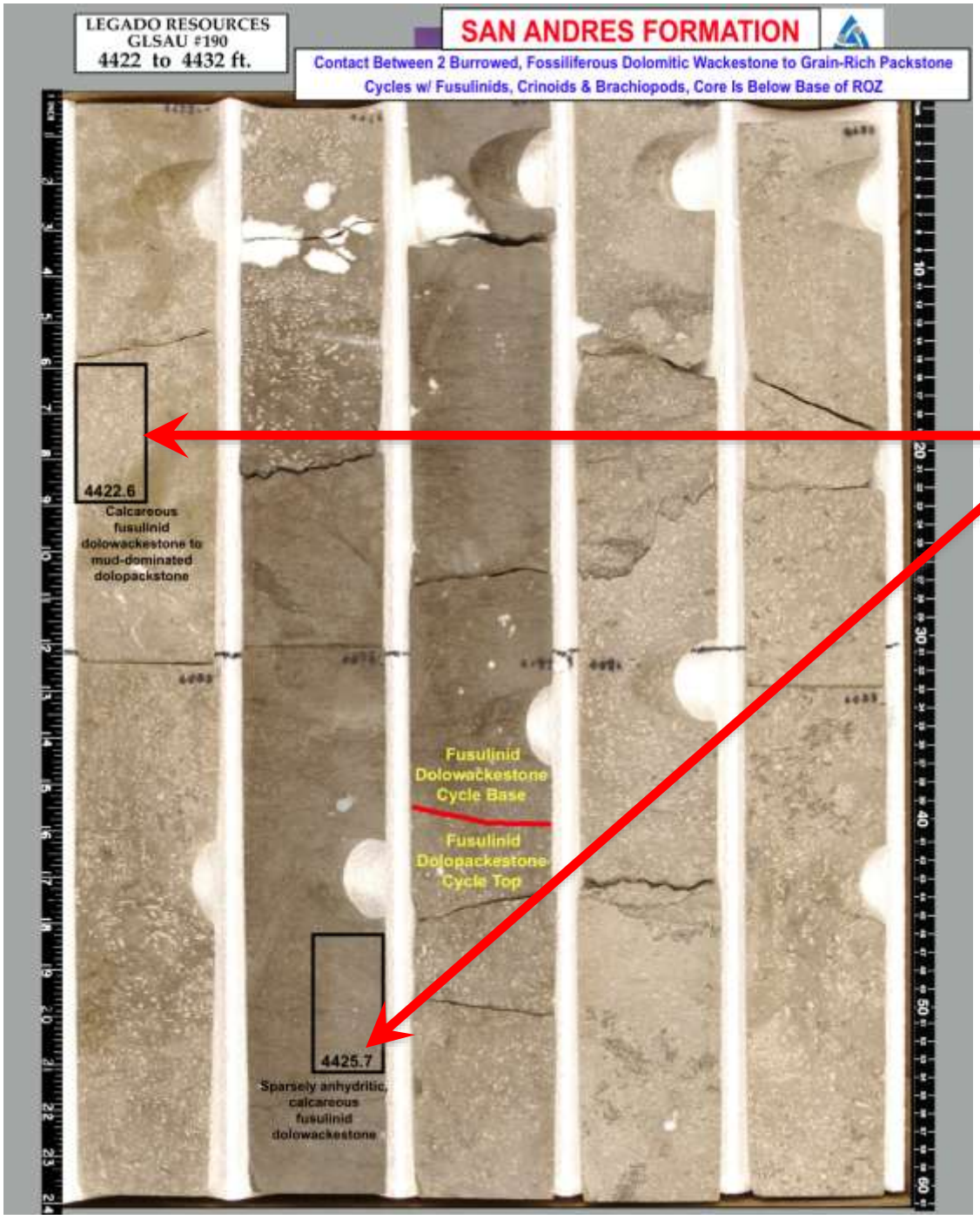
GLSAU #204R

GLSAU # 203RW

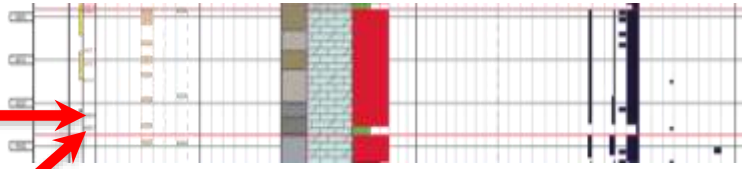


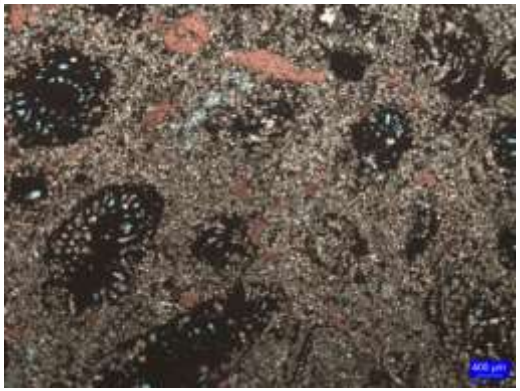
Below the ROZ, partially dolomitized matrix fusulinid/crinoid/brachiopod wackestone to grain dominated packstone. Grains are calcitic, resulting in a “limestone” log signature Porosity is intercrystalline and moldic, averages 10-12%, but contains only water.





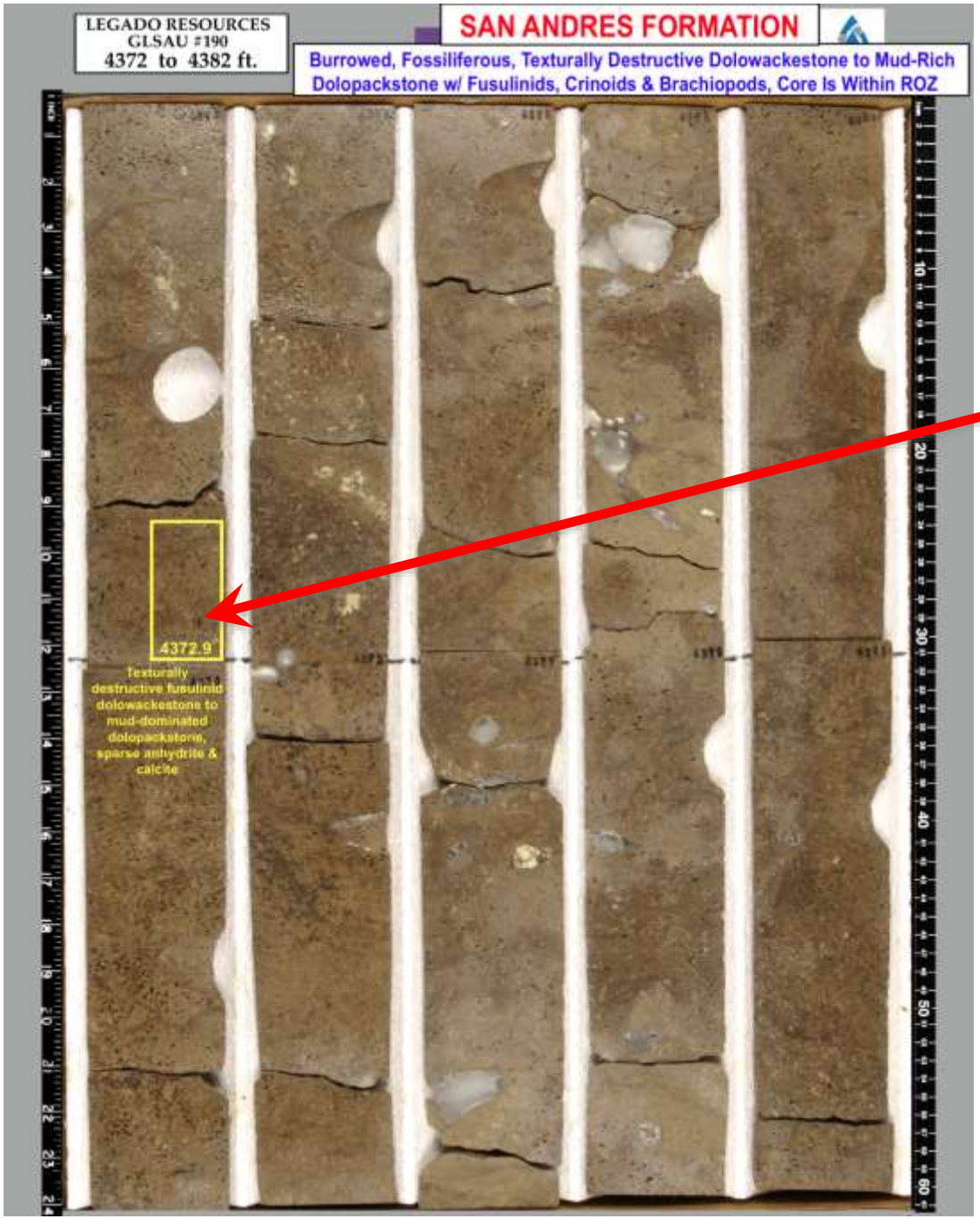
Depositional cycle boundaries are difficult to pick in most of the fusulinid wackestone to grain dominated packstone intervals. However at least two significant dark brown, mudstone to wackestone cycle bases were identified below the ROZ. Hopefully these can be carried around the Landreth Unit.



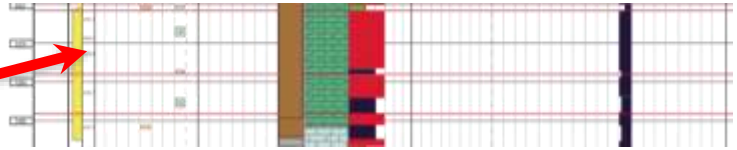


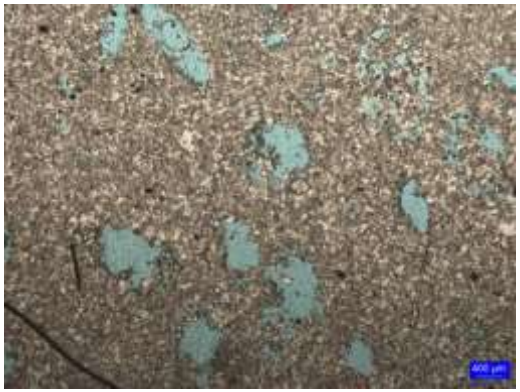
4422.6

4425.7



Lithologies in the ROZ are also fusulinid/crinoidal wackestone to packstone, but they are 90-95% dolomite, with traces of calcite cement or remnant crinoid grains and anhydrite. Fusulinids have been leached, resulting in moldic porosity. Intercrystalline and moldic pores average 5-10%, slightly less than below the ROZ





Ongoing CO_2 ROZ Projects in the Permian Basin

	Field	State, County	Operator	Top MPZ Depth (feet)	MPZ Start Year	ROZ Start Year
1	Vacuum (CVU)	NM, Lea	Chevron	4500	1997	2011
2	Hanford	TX, Gaines	Fasken	5500	1986	2009
3	Seminole Unit - Phase 1	TX, Gaines	Hess	5500	1983	1996
4	Seminole Unit - Phase 2	TX, Gaines	Hess	5500	1983	2004
5	Seminole Unit - Stage 1 Full Field Dev	TX, Gaines	Hess	5500	1983	2007
6	Seminole Unit - Stage 2 Full Field Dev	TX, Gaines	Hess	5500	1983	2011
7	Seminole Unit - Stage 3 Full Field Dev	TX, Gaines	Hess	5500	1983	2013
8	Goldsmith Landreth San Andres Unit	TX, Ector	Kinder Morgan	4200	2009	2009
9	Wasson Bennet Ranch Unit	TX, Yoakum	Occidental	5250	1995	2000
10	Wasson Denver Unit	TX, Yoakum	Occidental	5200	1983	1995
11	Wasson ODC	TX, Gaines	Occidental	5200	1984	2005
12	Salt Creek	TX, Kent County	XTO/ExxonMobil	6300	1993	1996
13	Means	TX, Andrews	XTO/ExxonMobil	4400	1983	2012
14	George Allen (BF&GF) *	TX, Yoakum	Trinity CO2	4900	2012	2012
15	East Seminole	TX, Gaines	Tabula Rasa	5400	2013	2013

Lithologies: Dolomite, Dolomite Anhydrite, except Salt Creek field (SC) which is a limestone

Pay Zones: San Andres (SC = Canyon Lime)

Completion Strategies: Commingle except in Projects # 4-7 (Dedicated Injection into the ROZ) & Project # 13 (Wells were Deepened & Drilled into ROZ)

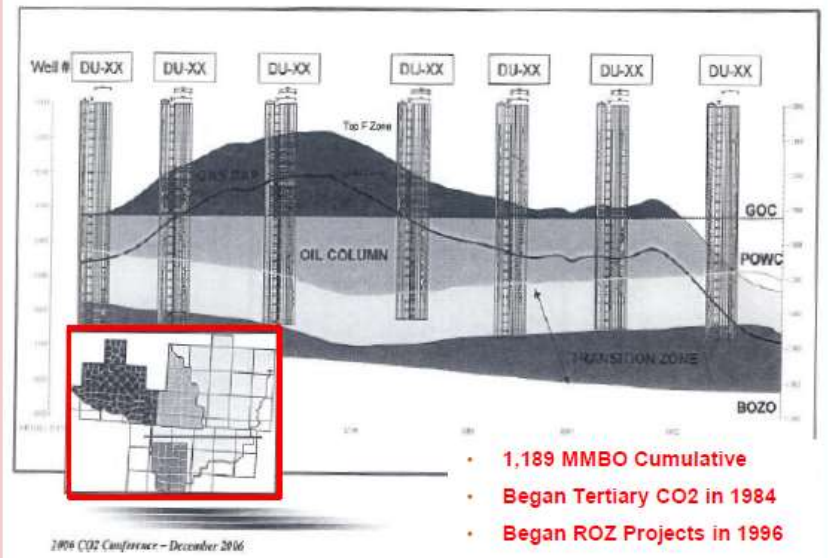
***Brownfield&Greenfield:** All Projects except a portion of George Allen are Brownfields (possess an overlying MPZ; ROZ w/o an overlying MPZ = Greenfield

Sources: SPE 167209, SPE 88770, SPE 81458, CO_2 Flooding Conference Presentations (www.CO2Conference.net)

Structural Comparison of Major Analogs

LEGADO resources

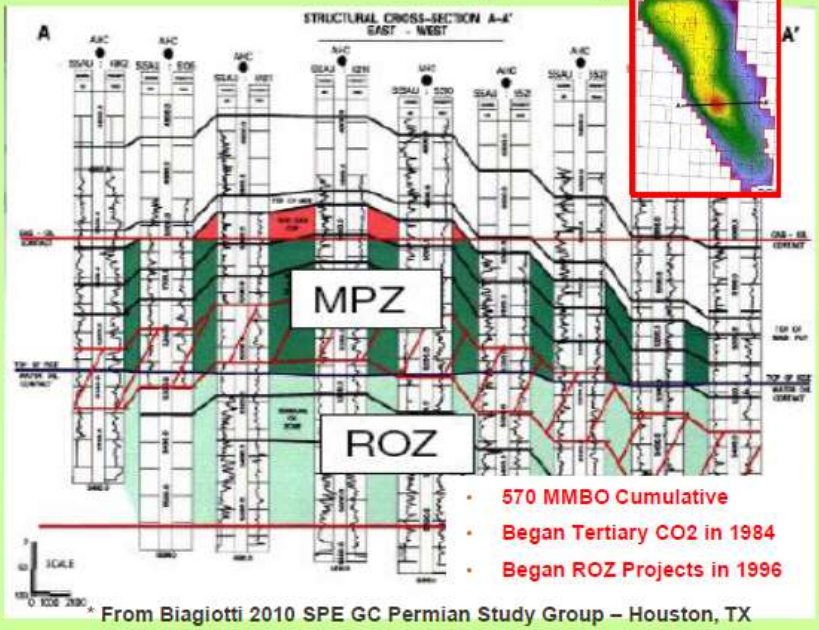
Wasson Field (Denver Unit)



- 1,189 MMBO Cumulative
- Began Tertiary CO2 in 1984
- Began ROZ Projects in 1996

* From Oxy Permian 2006 CO2 Conference – Midland, TX

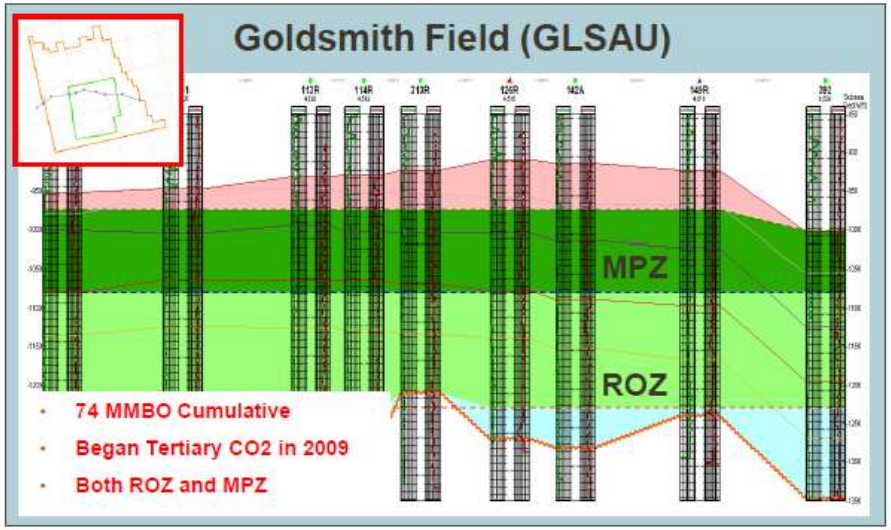
Seminole Field (SSAU)



- 570 MMBO Cumulative
- Began Tertiary CO2 in 1984
- Began ROZ Projects in 1996

* From Biagiotti 2010 SPE GC Permian Study Group – Houston, TX

Goldsmith Field (GLSAU)

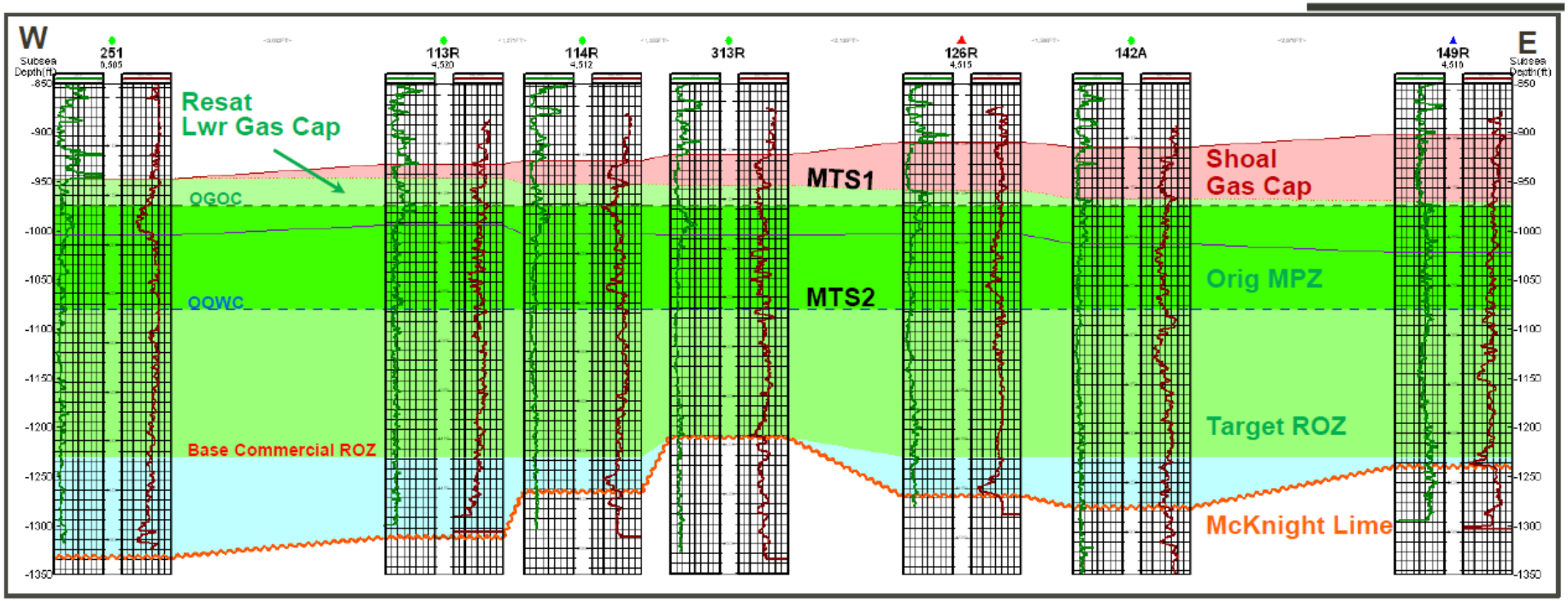


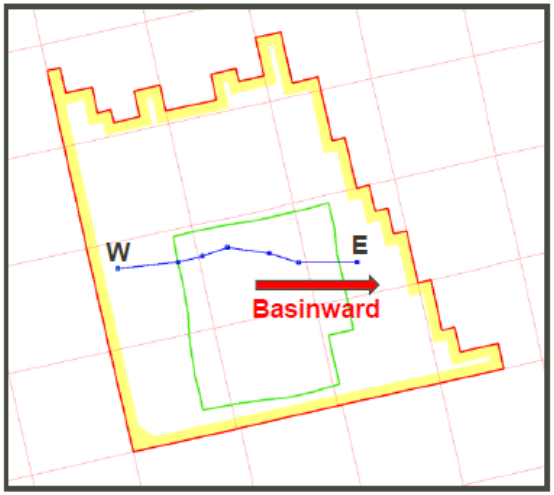
- 74 MMBO Cumulative
- Began Tertiary CO2 in 2009
- Both ROZ and MPZ

Common structural traits:

- Oil columns with overlying gas cap
- Thick hydrodynamic ROZ's
- Anticlinal traps with associated stratigraphic components
- Large surface area footprints
- Significant ROZ projects on-going in all 3 large units

General Reservoir Architecture – Structure and Contacts



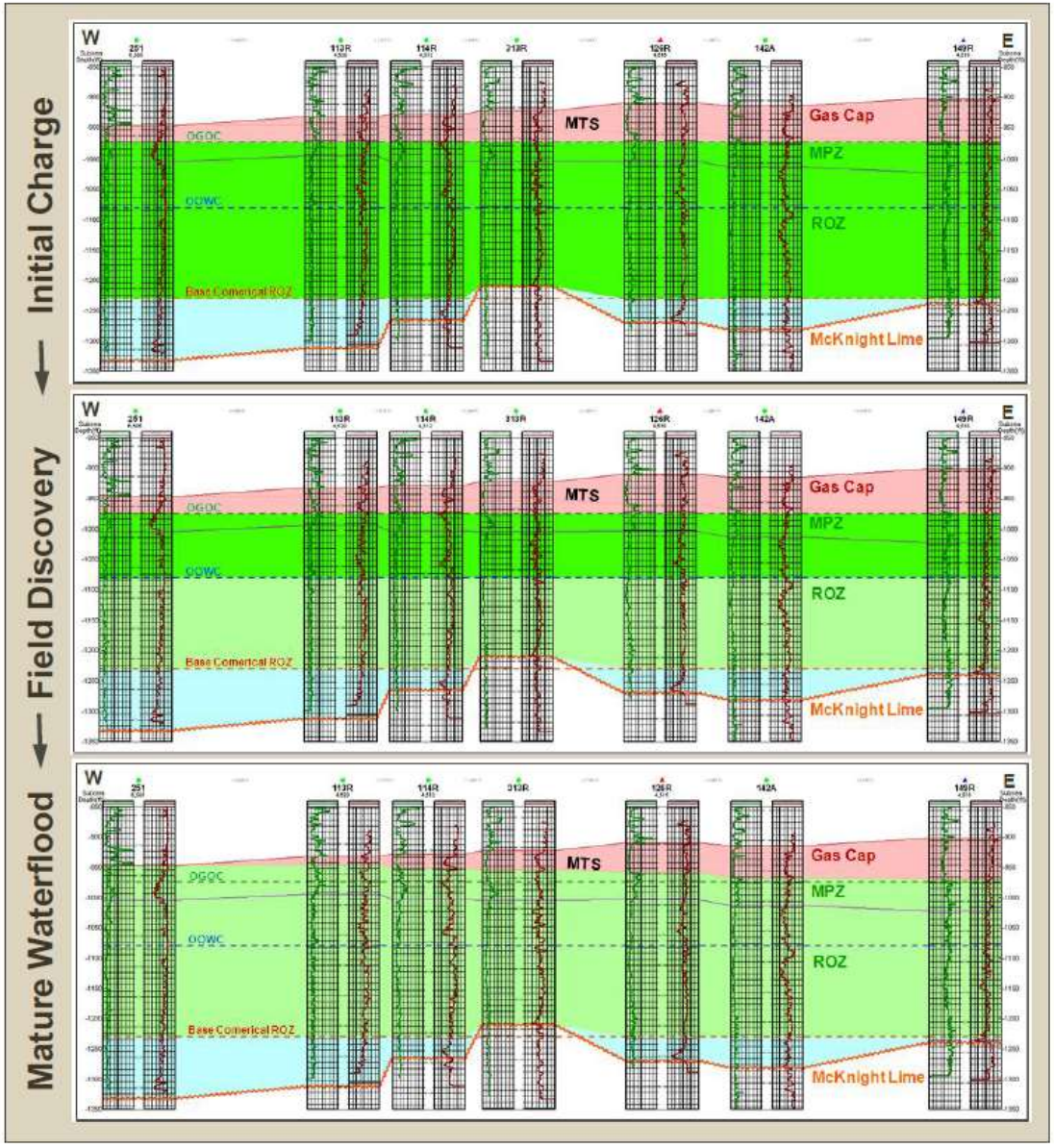


Current Contacts and Structural Flood Intervals

- Shoal Gas Cap (SGC) – Above MTS, hydraulically isolated
- Upper Gas Cap (UGC) – MTS to -950' SS
- Resat Gas Cap (RGC) – -950' to 975' SS oil re-sat zone (80% MPZ Sorw)
- Main Pay Zone (MPZ) – -975' to 1,080' SS
- ROZ – -1,080' to -1,230' SS or truncated by McKnight Lime

Maturation History

LEGADO resources



Initial Charge

- Oil charge and subsequent relaxation
- Formation of initial gas cap and OWC at approximately -1,230' SS except where truncated by underlying McKnight Lime
- **Oil charging (200 – 240 mya), ROZ formed during regional tilting and meteoric derived sweep (10 – 25 mya)**

Field Discovery – 1930's

- Saturated oil zone w/ primary gas cap GOC at approx -975' SS
- Discovery OOWC average depth at -1,080 SS
- Secondary transition zone to ROZ underlying OOWC

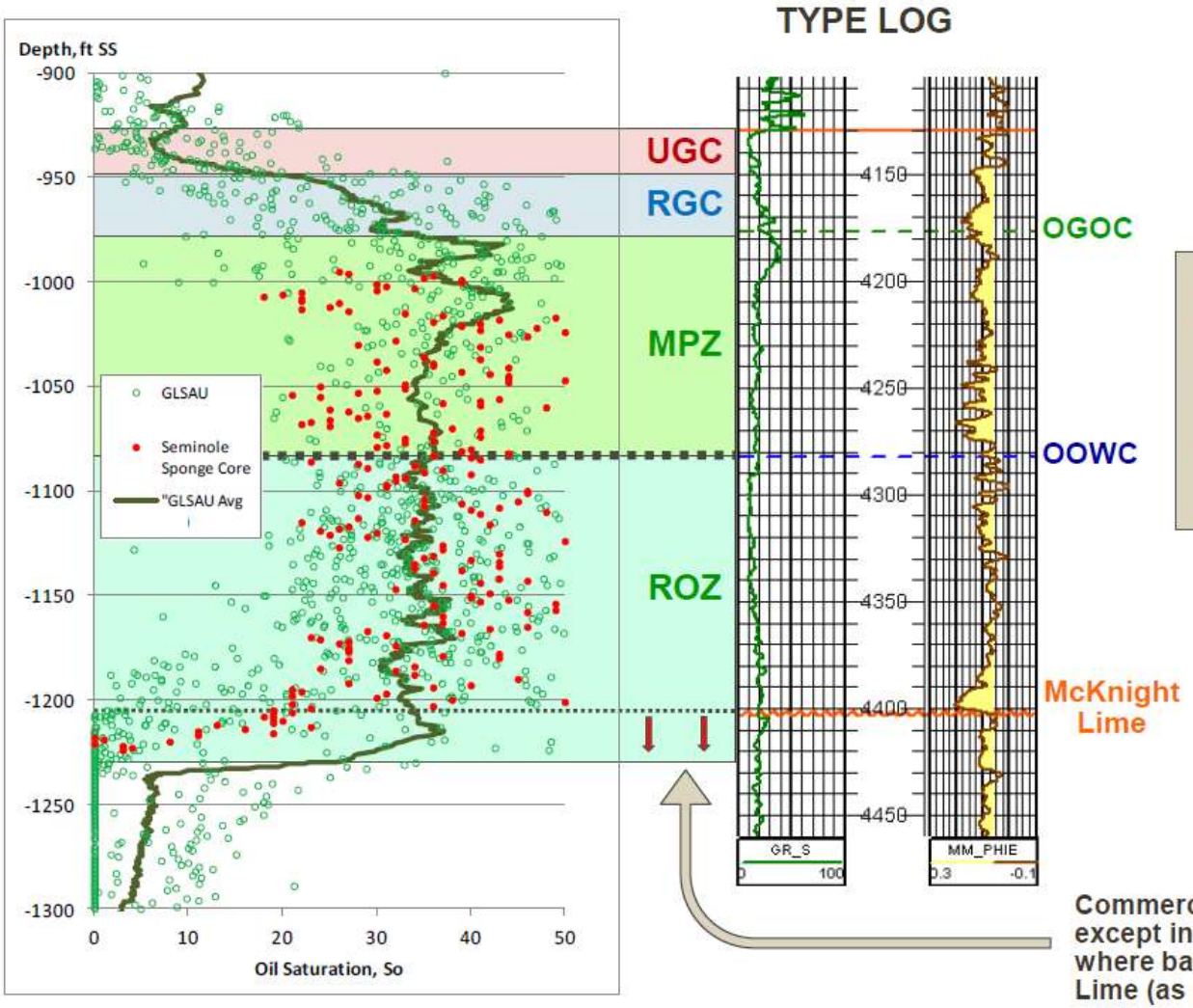
Current – Mature Waterflood

- WF started in 1963. Collapsing of gas cap and filling with water by early 1970's
- Driving of oil into lower gas cap re-saturating to approx -950' SS unless truncated deeper by MTS

GLSAU Oil Saturations GC, MPZ and ROZ

LEGADO resources

- Similar remaining oil saturation in Main Pay and ROZ
- Significant oil volume re-saturated into Gas Cap (RGC) adds to remaining CO2 flood target



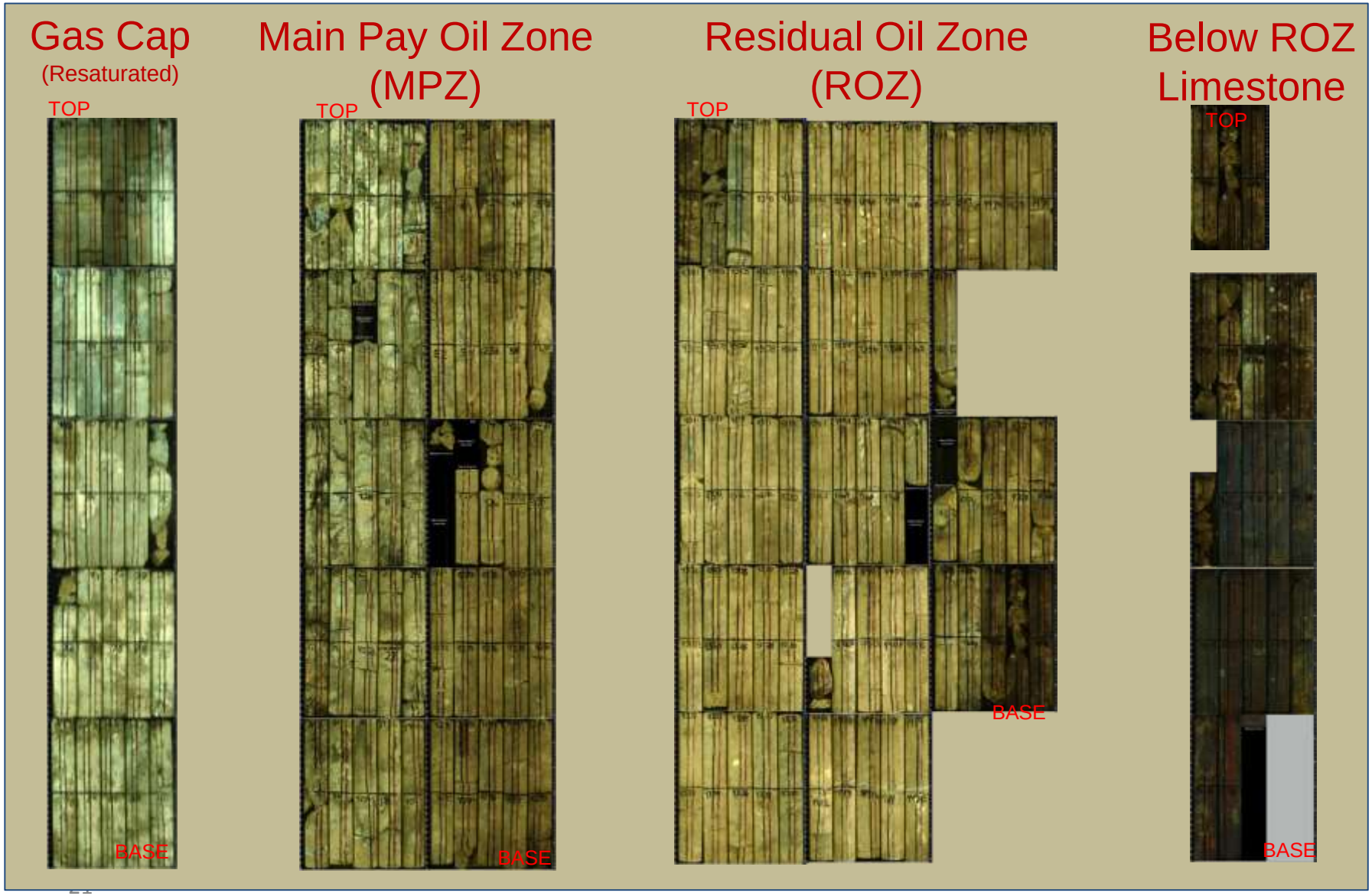
From wells drilled/deepened since 2008

- Core data corrected to in-situ conditions
- Includes 7 recent vintage (since 2009) cores
- Excellent match to Seminole core data

Commercial saturations to -1,230 SS except in structurally high areas where base truncated by McKnight Lime (as depicted in Type Log)

Core Fluorescence – GLSAU 204R

Note similarity between MPZ and ROZ Saturations



Slide courtesy of Legado Resources

GLSAU #203R – Background

- Observed major CO_2 injection into LROZ zone in 203W initial profile (MP+ROZ) from 2009. So?

- Observed oil and gas response from #190 in 2009 prior to having compression in place. OH OH.

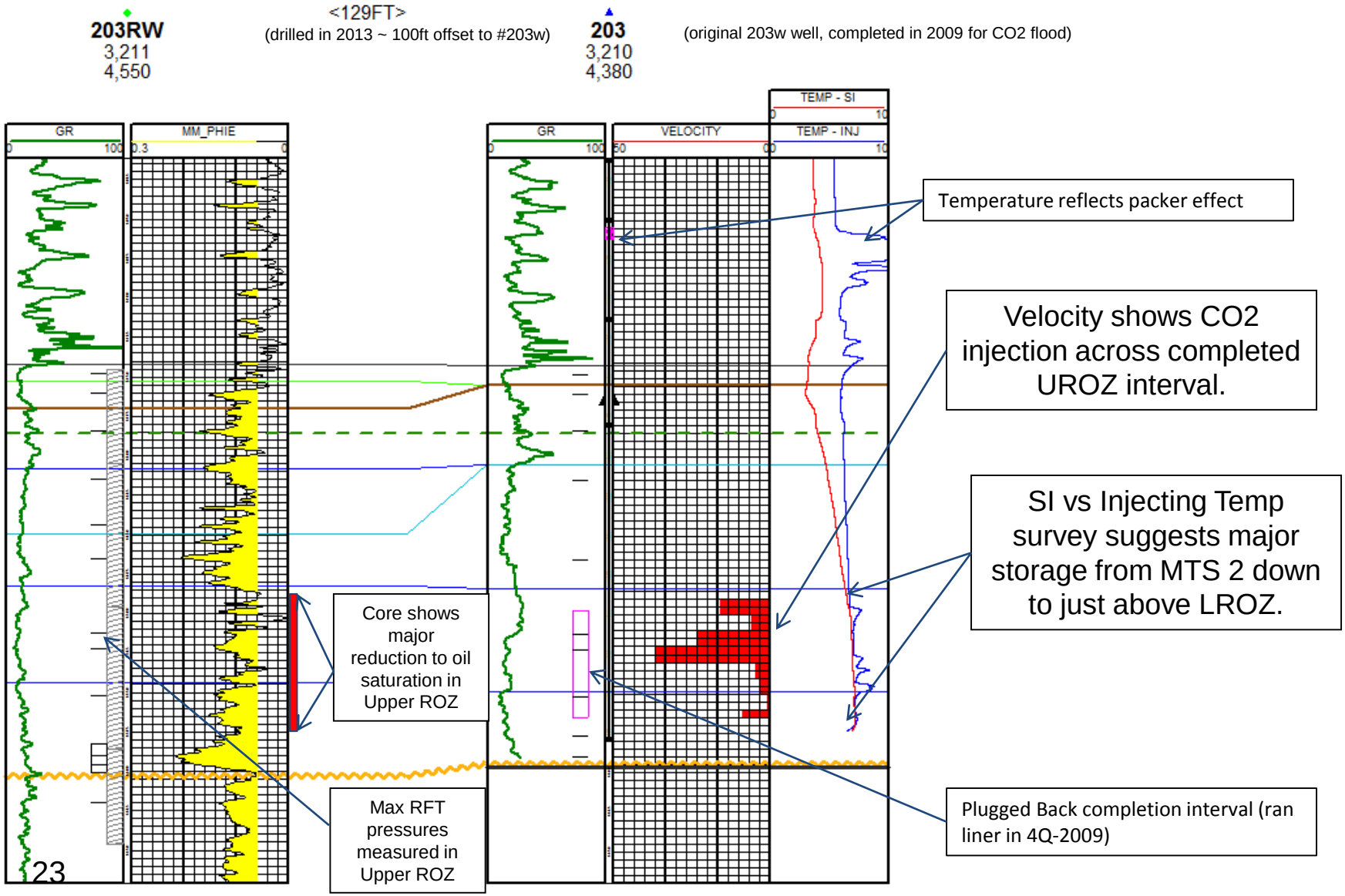
- **Plugged back LROZ** and MP in #203 injector (10/2009) - completed as Upper ROZ only injector.

- Subsequent 203 profiles showed major injection into Upper ROZ.

- Drilled 203 replacement in 2013 for improved wellbore conformance and to re-establish injection into Lower ROZ.

- RFT data from 203 replacement well showed elevated pressures in all zones (confirming general injection support in MP and ROZ for the area), with maximum local pressures occurring in the completed Upper ROZ zone (suggests CO_2 injection remained concentrated in Upper ROZ).

GLSAU #203R & 203w – Completion Intervals & Inj Profile Results



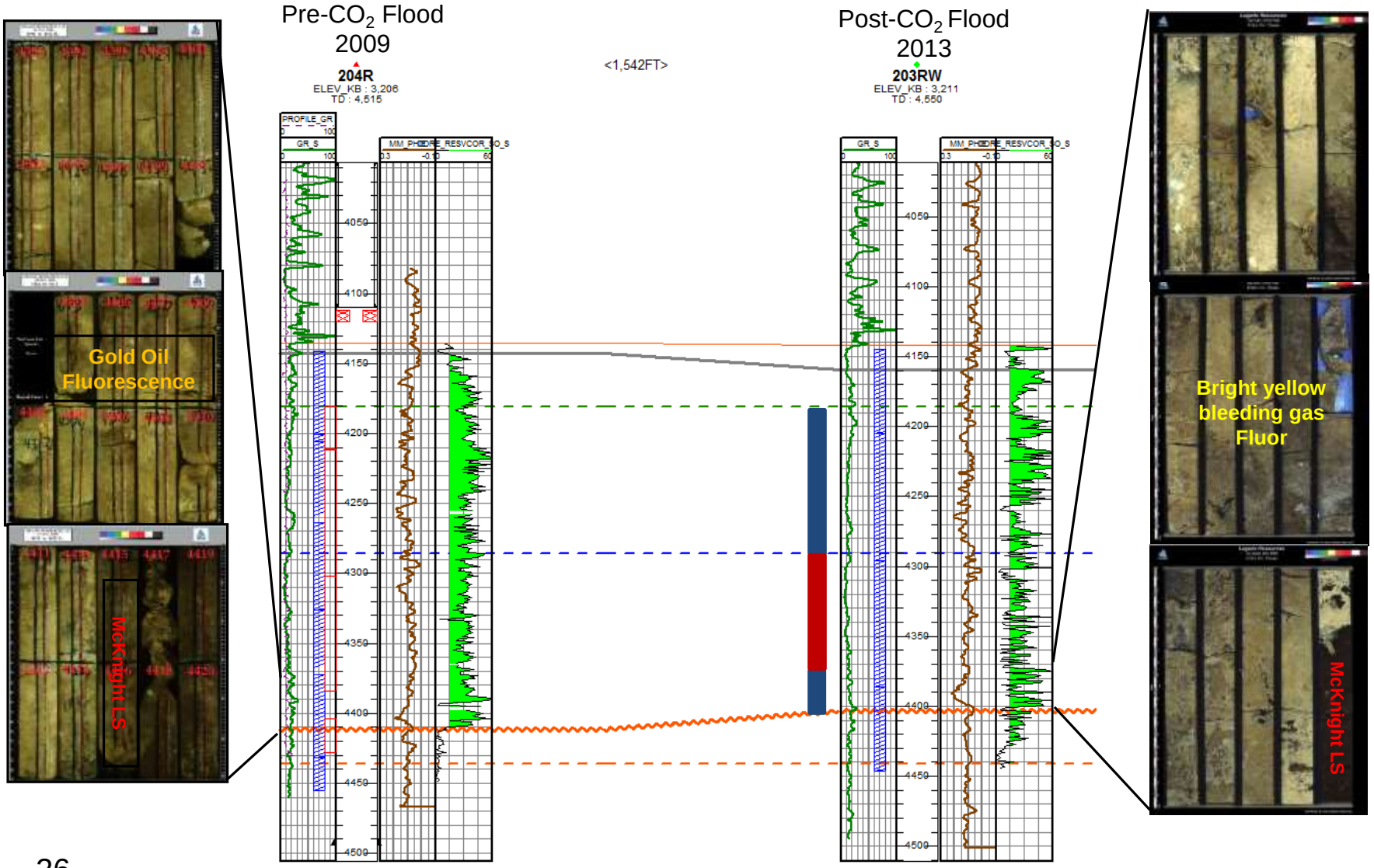
Bubbling Gas and Sweating Oil

- Viewed core as it was being removed from the sleve
- Lower ROZ:
  - Bubbling Gas
  - Sweating Oil
- Gas was CO_2
- Oil saturations higher than seen in other cores.

1. Obtained core from the 203 RW and ran routine analysis using Core Labs.
   - Confirmed significant reduction to oil saturations in the equivalent 203W completed **UROZ** interval (4285-4370) with nearly 40% of the samples being reduced below 15% Sor (versus <2% of pre-CO_2 flood samples measuring below 15%)
   - Saturations in the **UROZ** completed interval were much lower than both the pre-CO2 flood oil saturations and the post-CO_2 flood oil saturations in the non-completed **LROZ** & **MP** intervals.
   - Results suggest the 203W workover to plug back the **LROZ** in 2009 was successful at isolating CO_2 injection from that zone.
2. **Completed the Lower ROZ in 203 RW and tested on 4/22/2013. Flowed ~25 BPH at 5% oil cut with very little gas (FTP 100 psi), confirming isolation from #203W and banked ROZ oil from miscible CO_2 flood process** (typical oil cut prior to CO_2 flood is <1%).

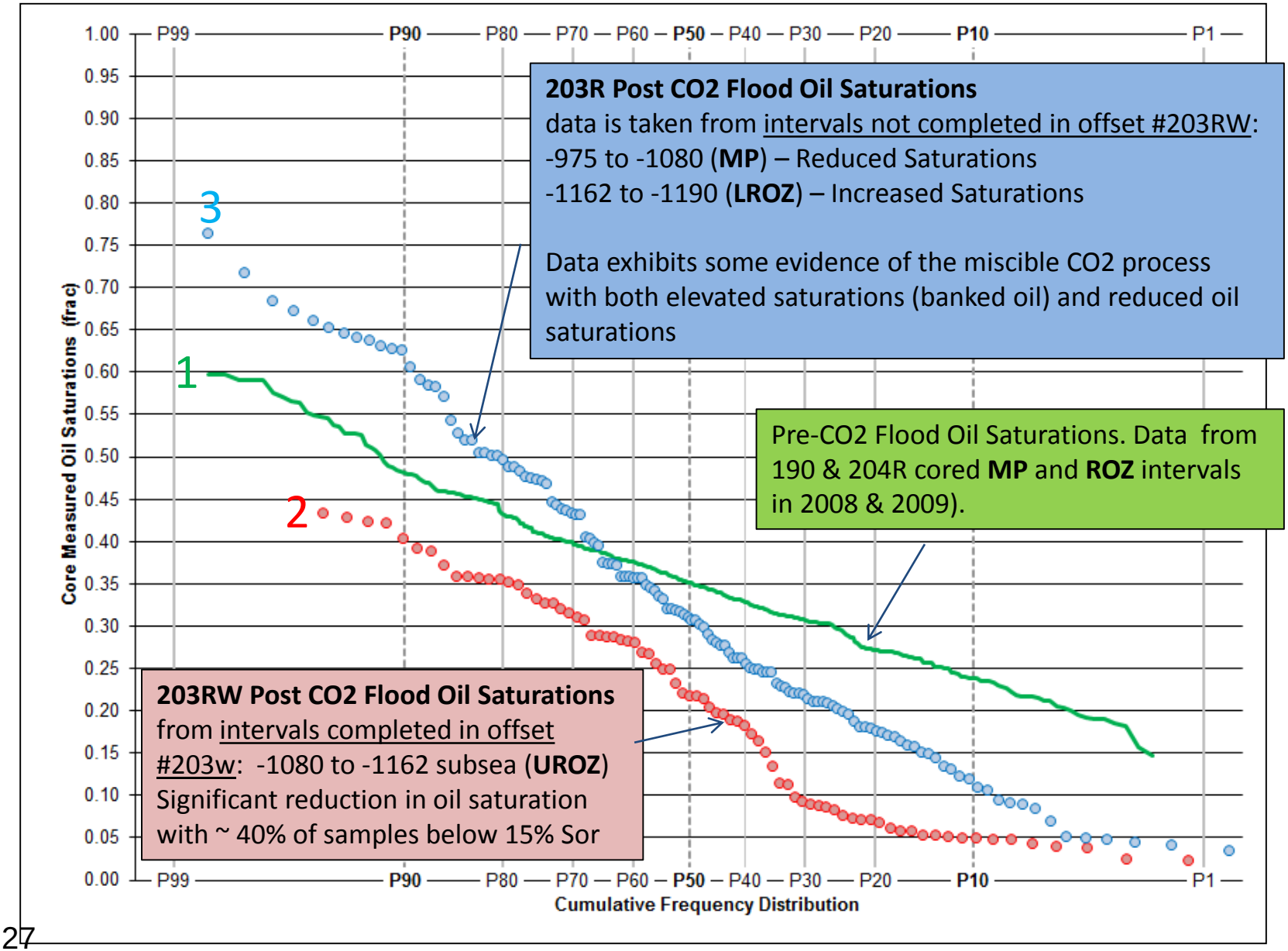
Core oil saturations in the 203R demonstrate varying degrees of miscible displacement maturity throughout the Main Pay & ROZ, corresponding to the offset completed CO_2 injection intervals.

GLSAU 204R and 203RW Saturation Comparisons



Green > 15% Reservoir –corrected Sor

GLSAU #203RW – Post CO_2 Flood S_{or} vs Offset Pre-CO_2 Flood S_{or}



Summary

- Legado Resources proved that an independent operator can take a long-in-the-tooth Waterflood, and associated ROZ and successfully revitalize them with CO_2.
- CO_2 Flood has resulted in raising production from ~100 BOPD to over 1200 BOPD.
- The #203 RW GLSAU provides compelling evidence of successful CO_2 sweep in the Main Pay, and Upper and Lower ROZ.
- Visit our website for more info on Residual Oil Zones – residualoilzones.com.