

The Concept of Hybrid Reservoirs: Deep Saline Formations + Residual Oil Zones as EOR and CCS Target Expansions

USGS EOR-CO₂ Sequestration Workshop



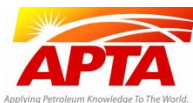
May 10-11, 2011

Stanford University



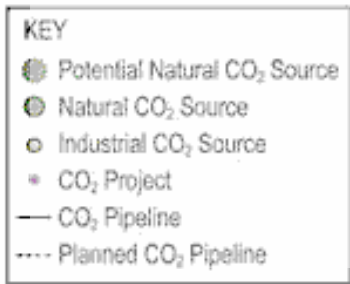
L. Stephen Melzer

Melzer CO₂ Consulting



**Thanks to the USGS and our Host,
Stanford University**

**The Concept of Hybrid Reservoirs: Deep Saline
Formations + Residual Oil Zones as EOR and CCS
Target Expansions**



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For a Very Long Time.....

- We Viewed the Zones Beneath Oil/water Contacts as Transitional Zones
- We Generally Avoided Drilling into the Zones for Fear of the Costs of Water Disposal
- Our Understanding of Their Origins and Distribution was, therefore, Limited and Biased

RESIDUAL OIL ZONE

DEFINITION:

a) An interval that will produce water and noncommercial quantities of oil on Primary or Secondary Recovery but has (immobile) residual oil present

b) a Target for Enhanced Oil Recovery

Includes the intervals often referred to as transition zones

STRANDED OIL IN THE RESIDUAL OIL ZONE

PREPARED FOR ADVANCED RESOURCES, INTERNATIONAL
AND THE U.S. DEPARTMENT OF ENERGY, OFFICE OF OIL AND
GAS PROGRAMS

May 2005

L. Stephen Melzer
Melzer Consulting

Results to Date for the ROZ Studies

Observations

- **Very Thick Residual Oil (Transition) Zones Occur in the San Andres Formation of West Texas {up to 300' in Thickness}**
- **Tilted Oil/Water Contacts (OWCs) Occur in the Same Fields**
- **Industry Project Work Shows Residual Oil Zones {also in the San Andres formation} are Commercial under Tertiary (CO₂) flooding**
- **Ubiquitous and Thick San Andres ROZs & their Large OOIP Numbers can Dramatically add to CO₂ EOR Reserves and Storage Capacity**
- **Preliminary Investigations Suggest Significant ROZs are Present in Other Basins (Commerciality Undemonstrated)**

Builds on:

***Hydrodynamic Displacement Work (Refs 11, 12) &
Work at Chevron by Brown and Lindsey Refs (6,9,10)
CO₂ Work at Shell, Lynn Orr, Hess Corp...and many others***

HYBRID RESERVOIRS

aka RESIDUAL OIL ZONES

- 1) Science to Commercial Exploitation
- 2) On-Going Pilot and Demonstration Project Results
- 3) Can this be a Permian Basin Peculiar Concept?Considerable Need for Further Documentation and Study

GEOLOGIC ORIGINS OF THE ROZ

(From Science to Commercial Exploitation)

*Warning: So Far, This Study has a Strong
Permian Basin Bias*

First Public Study of Residual Oil Zones (ROZs) in the Upper Permian Carbonates in the Basin

- It is supported by the Research Partnership to Secure Energy for America (RPSEA) and industry partners
- ROZ's have historically been interpreted as being long Transition Zones. Although the upper portions of TZ's/ROZ's have long been assumed to contribute to production in some fields, until recently their potential as an EOR (e.g., CO₂ recovery) target has not been exploited.
- Development wells, scheduled to test deeper horizons, have often been drilled through zones with good shows in samples, porosity and oil saturation in core, and where the zones are calculated to be oil productive. These wells, however, have a poor record of successful completions.

Translation: Zones of Frustrating Completion Failures



Calibrating the Oil Recovery Models and Estimating Technically Recoverable ROZ Oil – MPZ and TZ/ROZ Oil in Place

56 fields in five major Permian Basin oil plays that have potential for significant TZ/ROZ resources were identified by ARI. The TZ/ROZ OOIP in these 56 fields is estimated by at 30.7 billion barrels.

Field/Unit	MPZ OOIP (BB)	TZ/ROZ OOIP (BB)	No. of Fields	No. of MPZ Fields with CO ₂ -EOR Projects	No. of Fields with TZ/ROZ CO ₂ -EOR Projects
1. Northern Shelf Permian Basin (San Andres)	13.0	13.2	13	5	1
2. North Central Basin Platform (San Andres/Grayburg)	2.9	2.6	6	2	1
3. South Central Basin Platform (San Andres/Grayburg)	9.9	7.9	16	5	0
4. Horseshoe Atoll (Canyon)	5.4	2.9	10	4	2
5. East New Mexico (San Andres)	2.3	4.1	11	2	0
Total	33.5	30.7	56	18	4

Calibrating the Oil Recovery Models and Estimating Technically Recoverable ROZ Resources - Technically Recoverable Resources from the MPZ and ROZ

Based on reservoir modeling of applying CO₂-EOR to the TZ/ROZ resources, ARI estimates that 11.9 billion barrels is technically recoverable from the 30.7 billion barrels of TZ/ROZ oil in-place in these five Permian Basin oil plays

Field/Unit	Total CO ₂ -EOR (BB)	MPZ CO ₂ -EOR (BB)	TZ/ROZ CO ₂ -EOR (BB)
1. Northern Shelf Permian Basin (San Andres)	8.3	2.8	5.5
2. North Central Basin Platform (San Andres/Grayburg)	1.5	0.6	0.9
3. South Central Basin Platform (San Andres/Grayburg)	4.6	1.7	2.9
4. Horseshoe Atoll (Canyon)	2.7	1.4	1.3
5. East New Mexico (San Andres)	1.7	0.4	1.3
Total	18.8	6.9	11.9

The New Residual Oil Zone Paradigms (1)

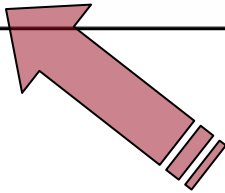
- The So-called Transition Zones Should be More Accurately Called Residual Oil Zones
- Transitional Oil Saturations are Observed at the Top and Base of the ROZs
- Where >20 feet in thickness, a Zone of ~Constant Oil Saturation is Observed (Middle Interval)
- The Middle Interval in the ROZs have ~ same oil saturation characteristics as the Swept Intervals in mature waterfloods (30-40% Sorw)
- These Intervals were Swept (“Mother-natures Waterflood”) which occurred in a second tectonic adjust, i.e., post basin subsidence and oil emplacement

The New Residual Oil Zone Paradigms (Cont'd)

- ROZs are Often Interpreted/Calculated as Oil Productive in Exploration Wells
 - Good Odor, Cut, Fluorescence, and Gas in samples
 - 20-30 % oil saturations in core
 - Calculate as oil productive on logs
- If Drill Stem Tested or in a Well Completion, Produce Only Water or, Occasionally, a Very Slight Amount of Oil
- These ROZs Represent a Paleo Entrapment That Has Been Laterally or Vertically Flushed
- ROZs Exist Below Current Oil Fields (“Brownfields”) and Exist Outside the Present Limits of Producing Fields (“Greenfields”)

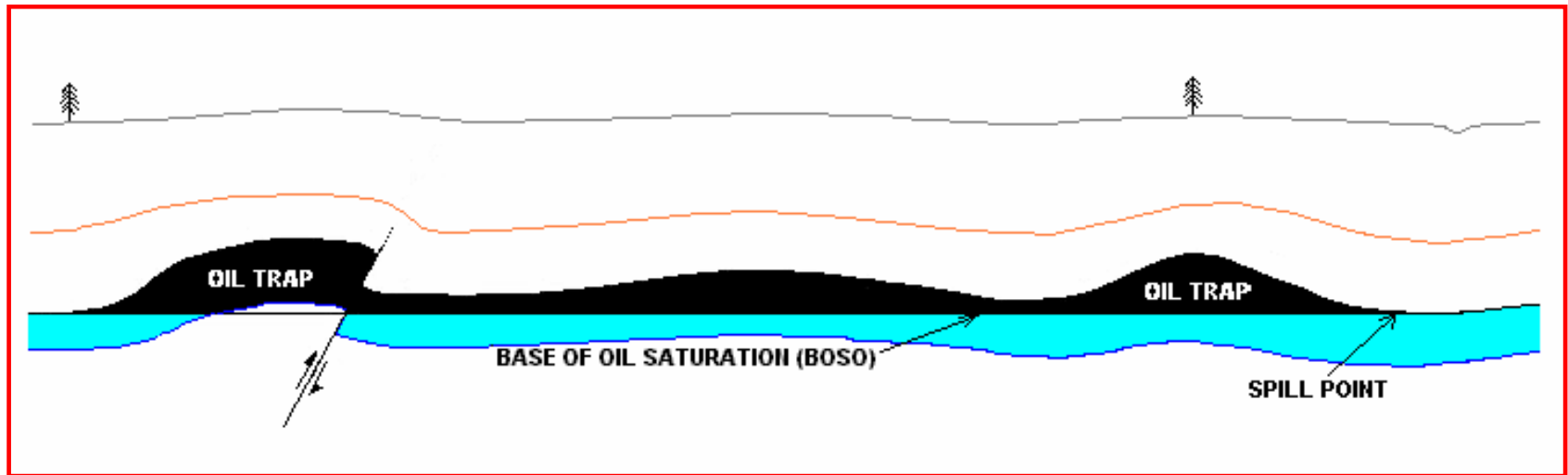
ROZ SCIENCE

ROZ TYPE	Oil-Water Contact	Base of Oil Saturation	Other Characteristics
Regional Tilt (1)	Horizontal	Tilted	Wedge with thin side Downdip
Breached Seal and Reaccumulation (2)	Horizontal	Horizontal	Stratified Tar Mats, Anomolously Low GOR
Hydrodynamic Tilt (3)	Tilted	Horizontal	Wedge with thin side in Direction of Flow (to Spill Point)

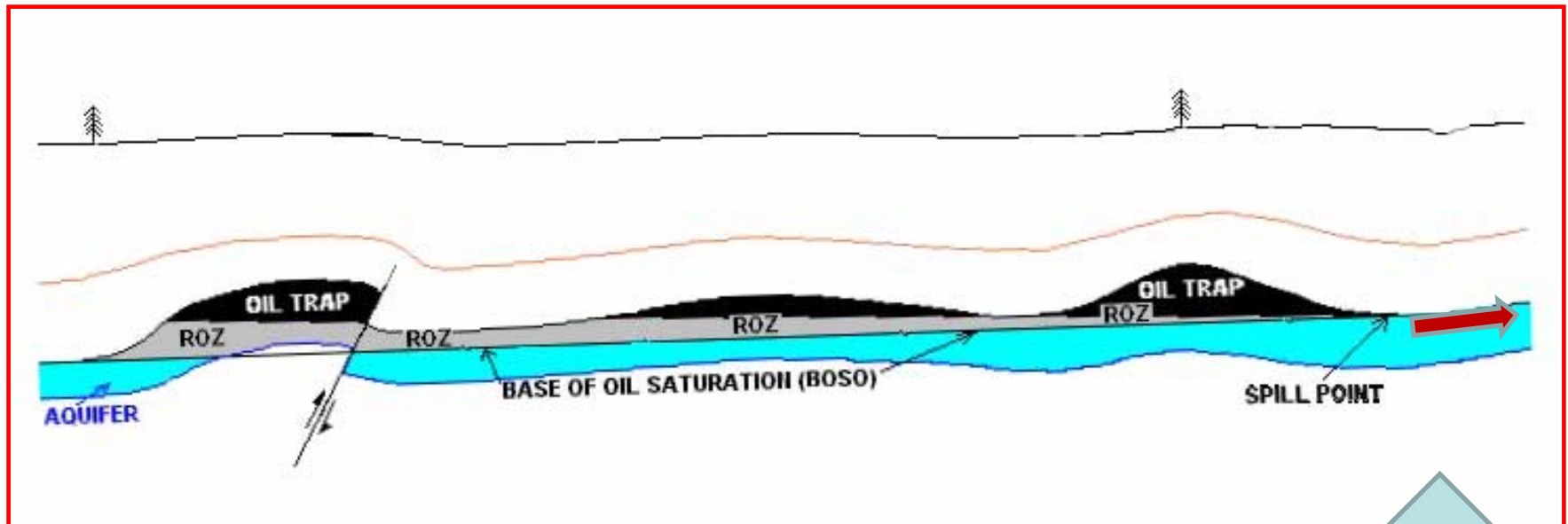


The Evidence suggests Type 3 are very common in the Permian Basin

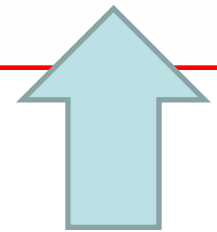
Original Oil Accumulation Under Static Aquifer Conditions (A Hypothetical Example)



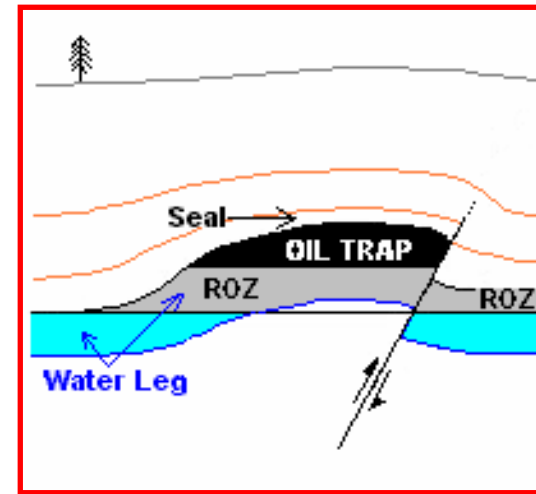
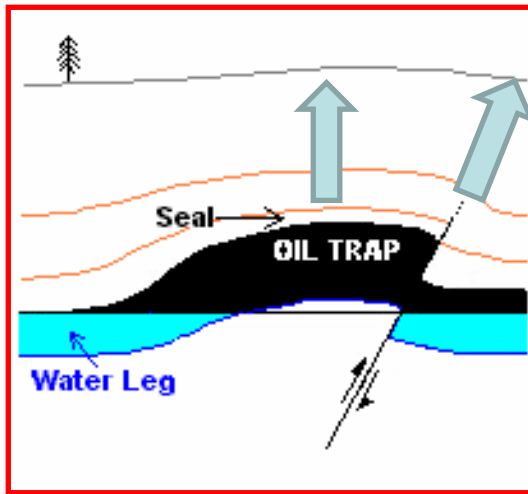
**Original Accumulation Subject to a Eastward Regional Tilt & Forming a ROZ.
The O/W Contact Is Horizontal, the Base of the ROZ Is Tilted.**



Modern Day Static System

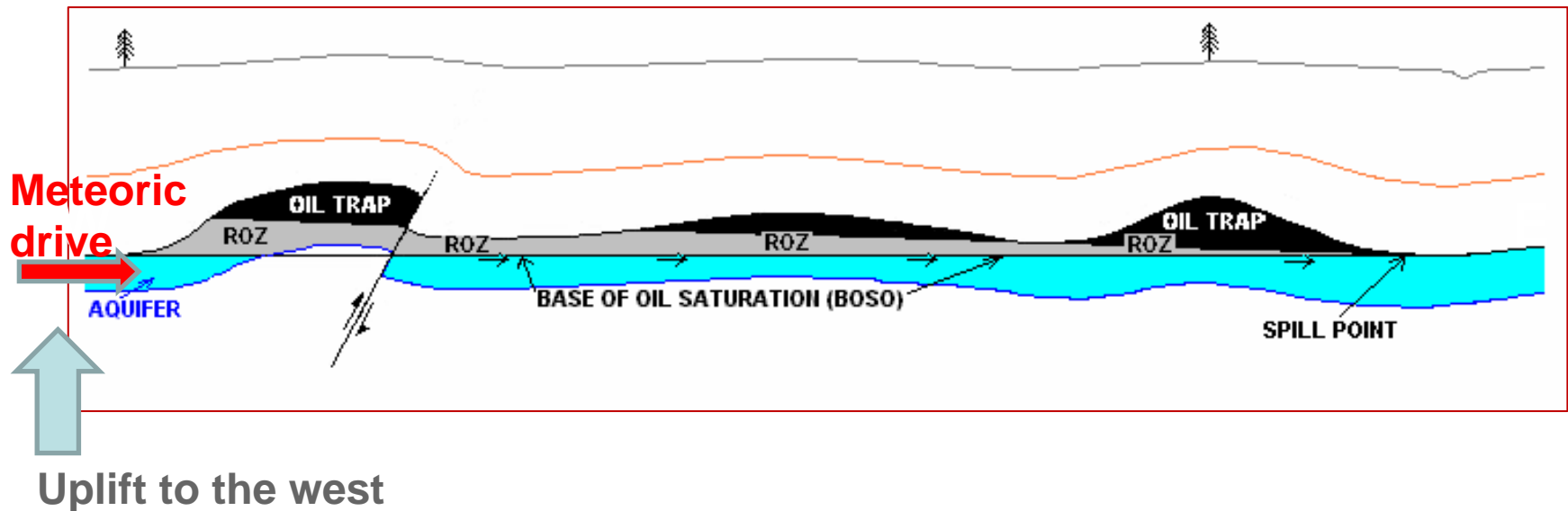


Original Accumulation with a Breached, then Repaired, Seal, forming a ROZ/TZ, a horizontal O/W contact on the main pay and the ROZ.
May also “de-gas” the reservoir.
Present in the Permian Basin.



Modern Day Static System

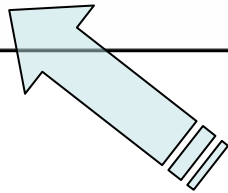
Change in Hydrodynamic Conditions, Sweep of the Lower Oil Column, Oil/Water Contact Tilt, and Development of a Residual Oil Zone



Modern Day Dynamic (but very slow) Flow System

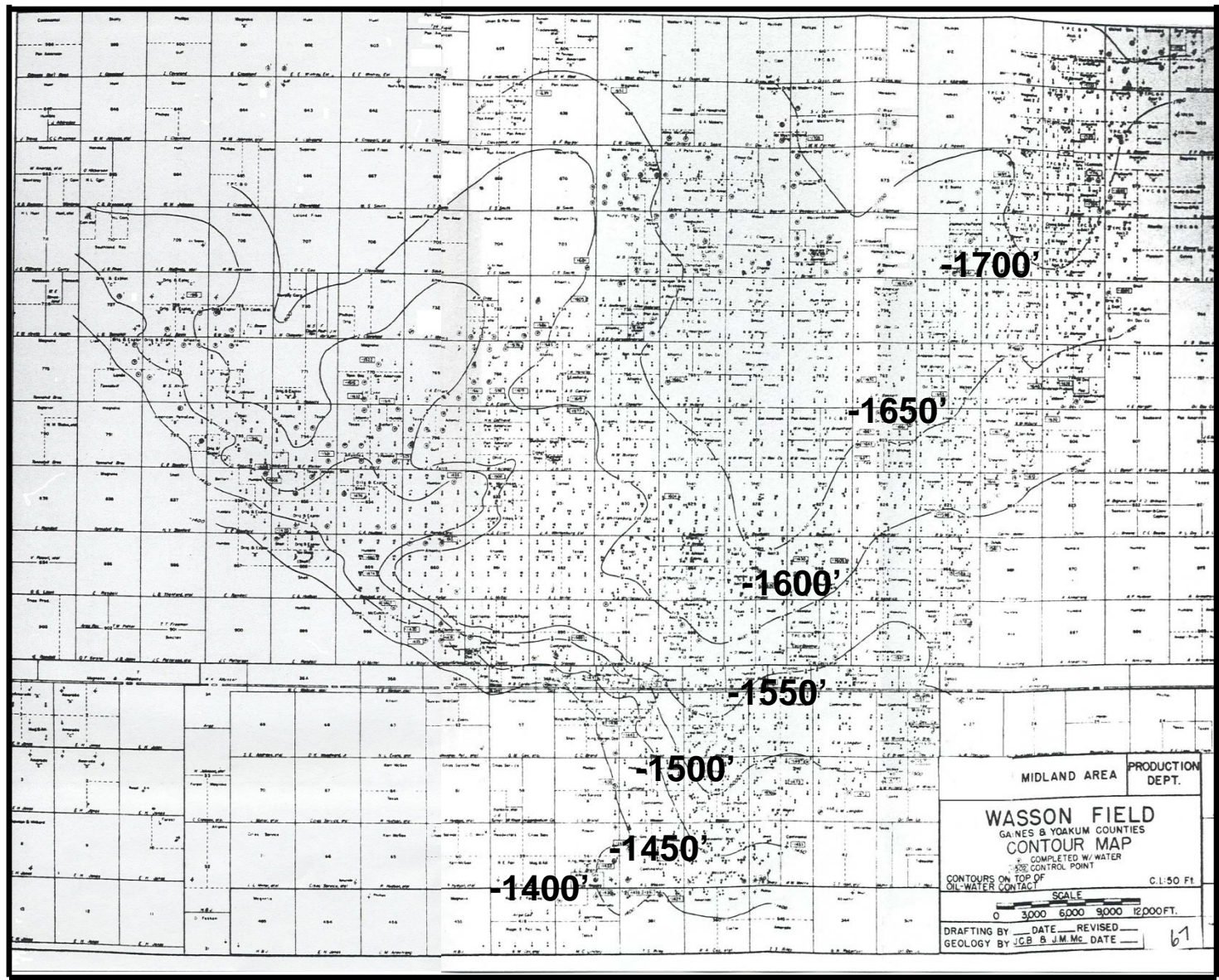
Attributes of the ROZ Types

ROZ TYPE	Oil-Water Contact	Base of Oil Saturation	Other Characteristics
Regional Tilt (1)	Horizontal	Tilted	Wedge with thin side Downdip
Breached Seal and Reaccumulation (2)	Horizontal	Horizontal	Stratified Tar Mats, Anomolously Low GOR
Hydrodynamic Tilt (3)	Tilted	Horizontal	Wedge with thin side in Direction of Flow (to Spill Point)

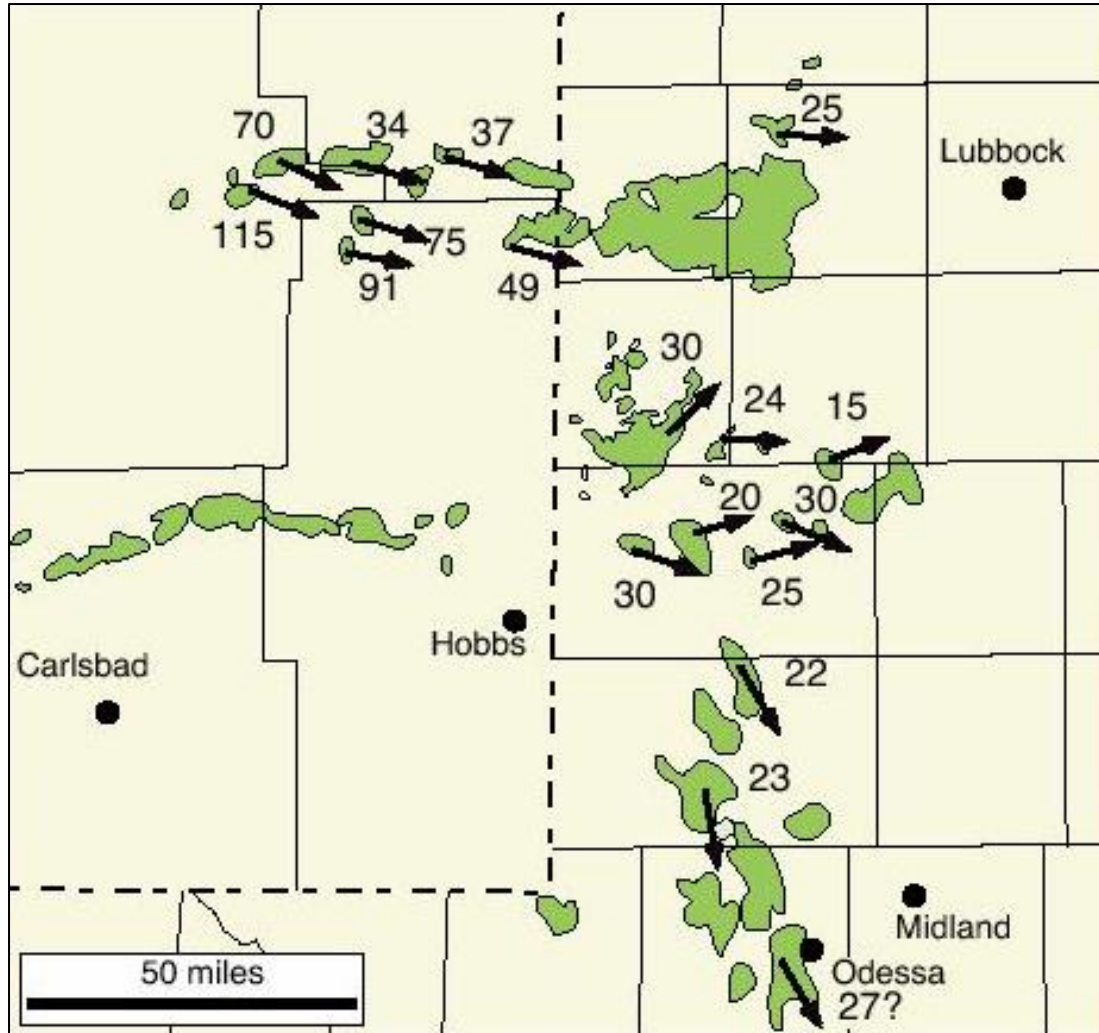


First, Let's Look Evidence for OWC Tilt

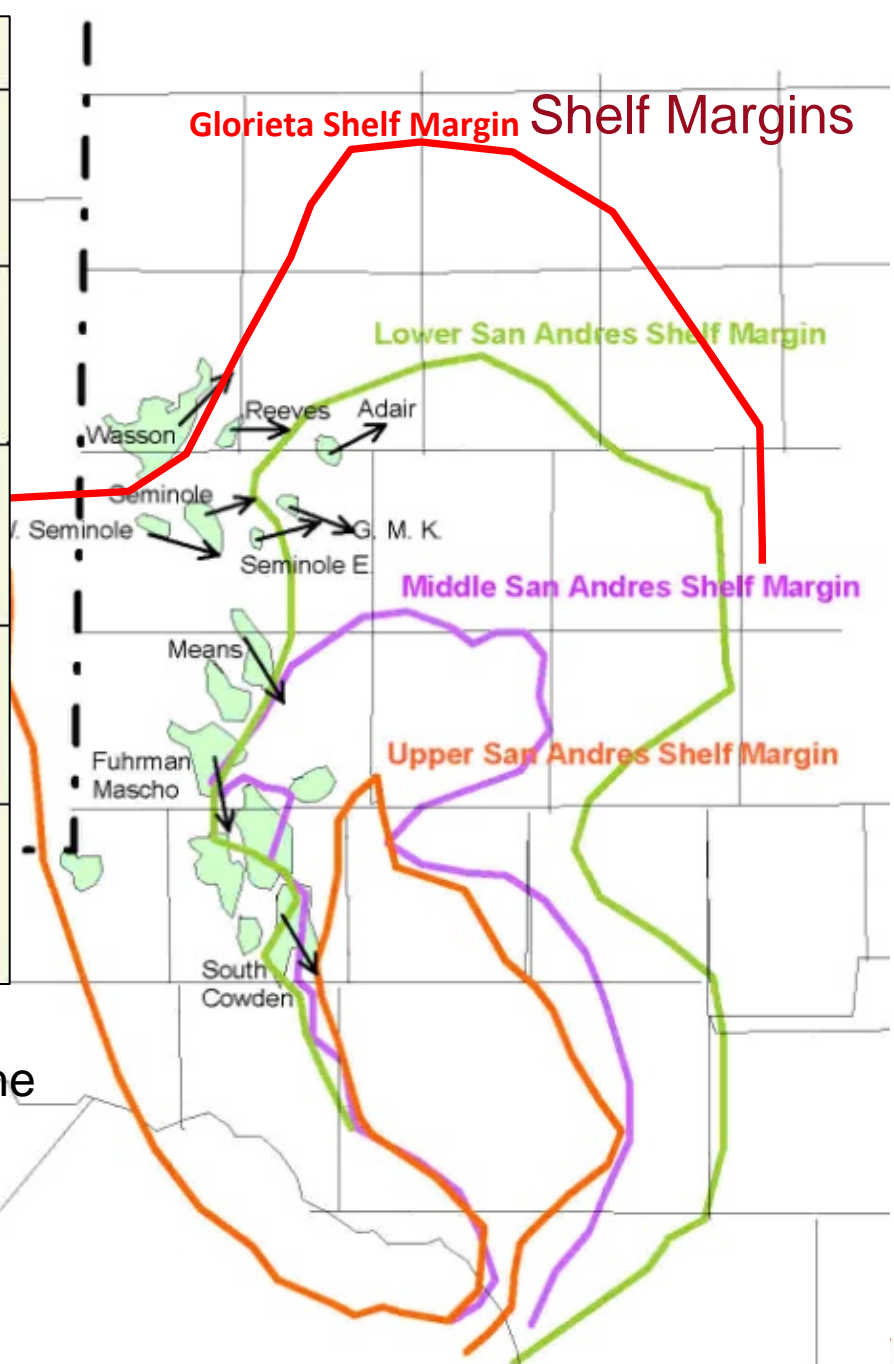
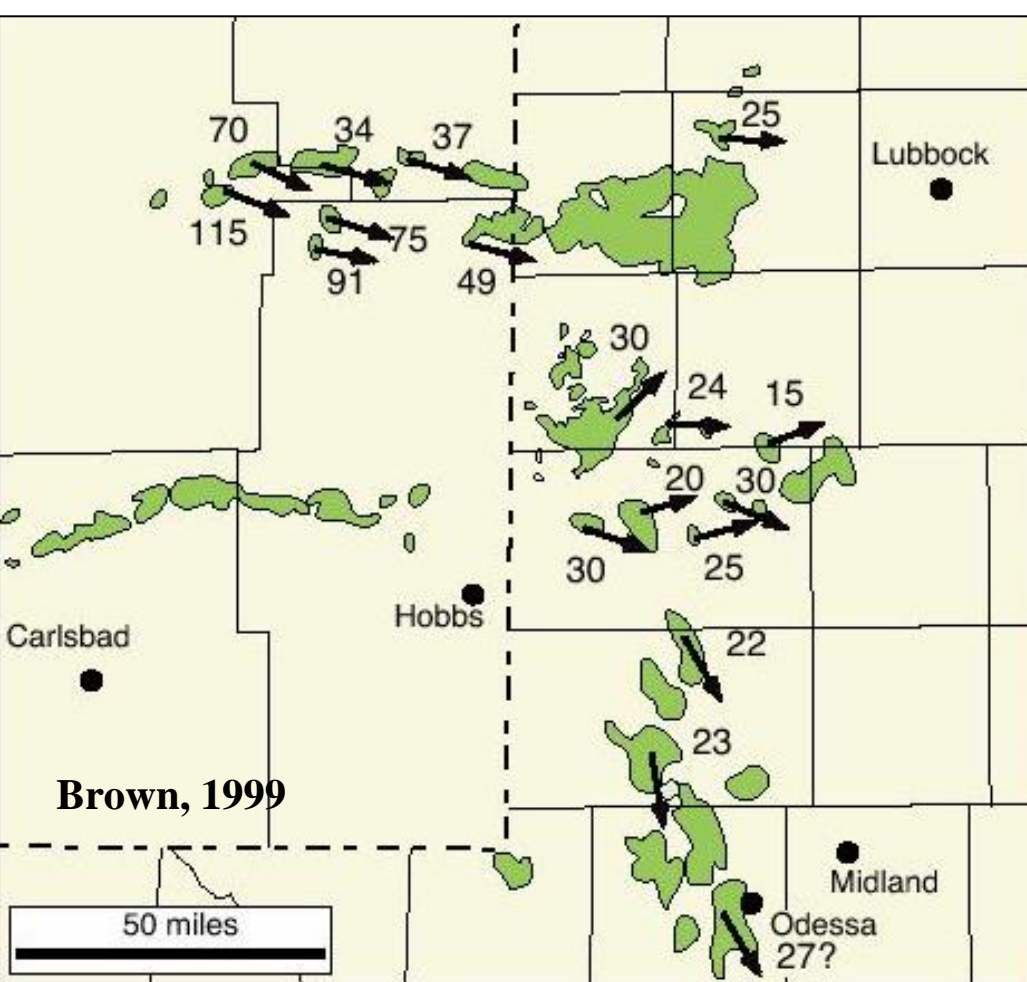
Wasson Field Oil-Water Contact Contour Map – Texas RR Commission Filing, October 1964



Distribution of Tilted Oil-Water Contacts in the Northern Shelf and Central Basin Platform Areas of the Permian Basin*



Brown, 1999

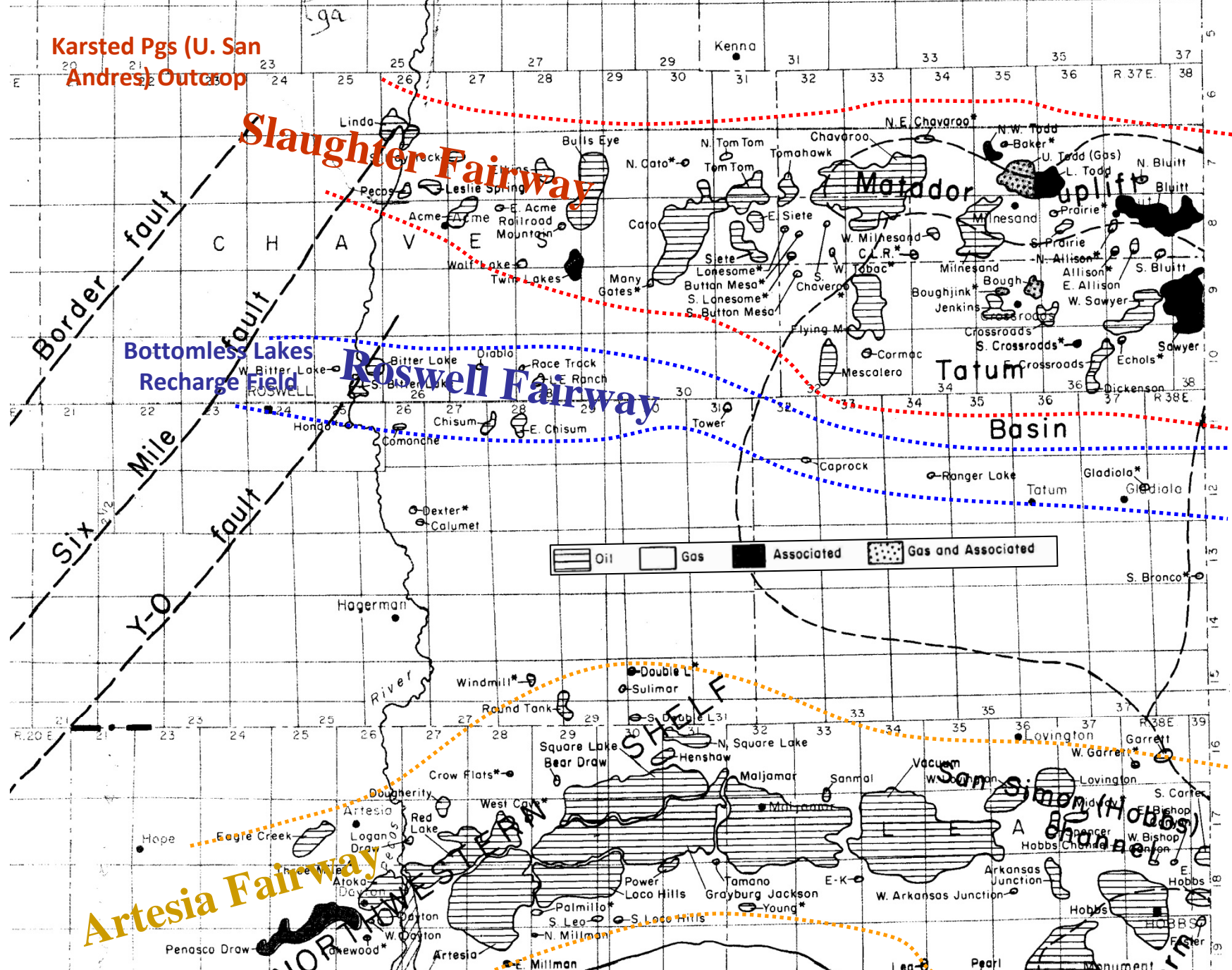


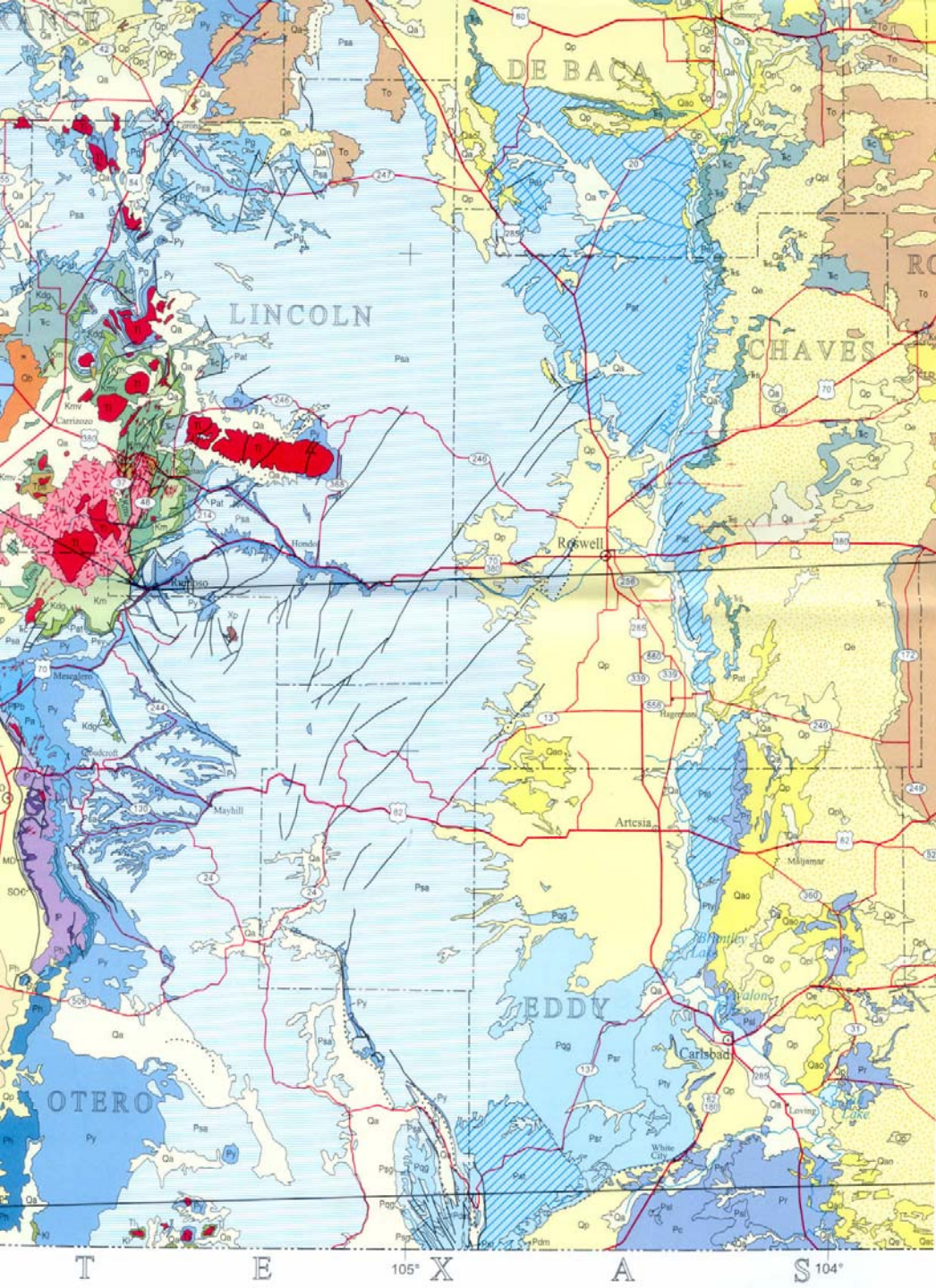
Distribution of Tilted Oil-Water Contacts in the Northern Shelf and Central Basin Platform Areas of the Permian Basin*

Tilted Oil Water Contacts

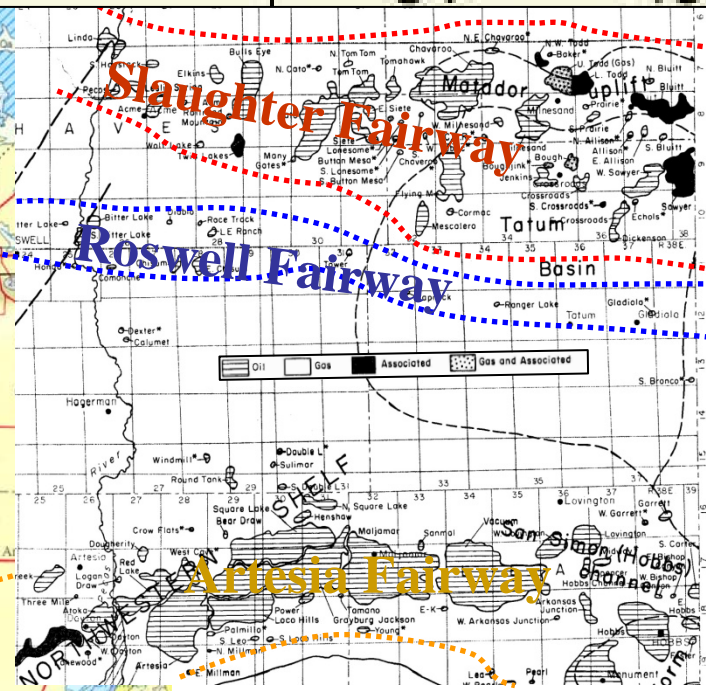
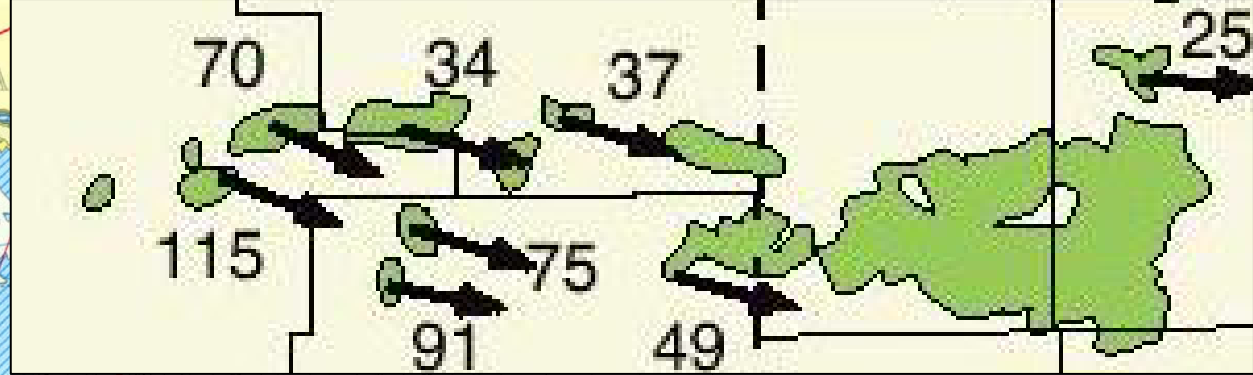
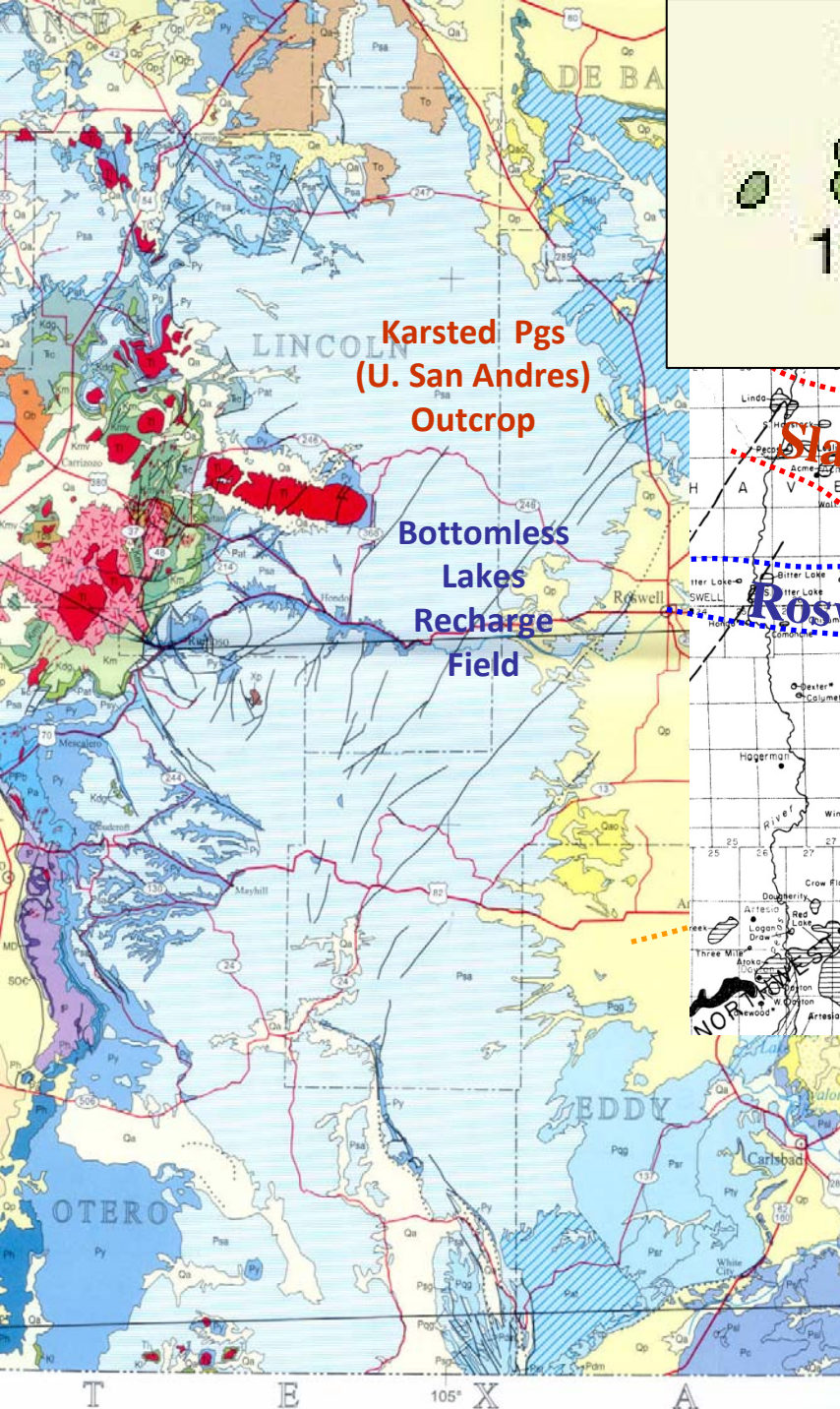
- New Axiom – “ If you have an tilted oil/water contact in the San Andres, you have a ROZ.
- If you have an ROZ.....go find a contract for CO₂.

SE NM San Andres Dolomitization Trends



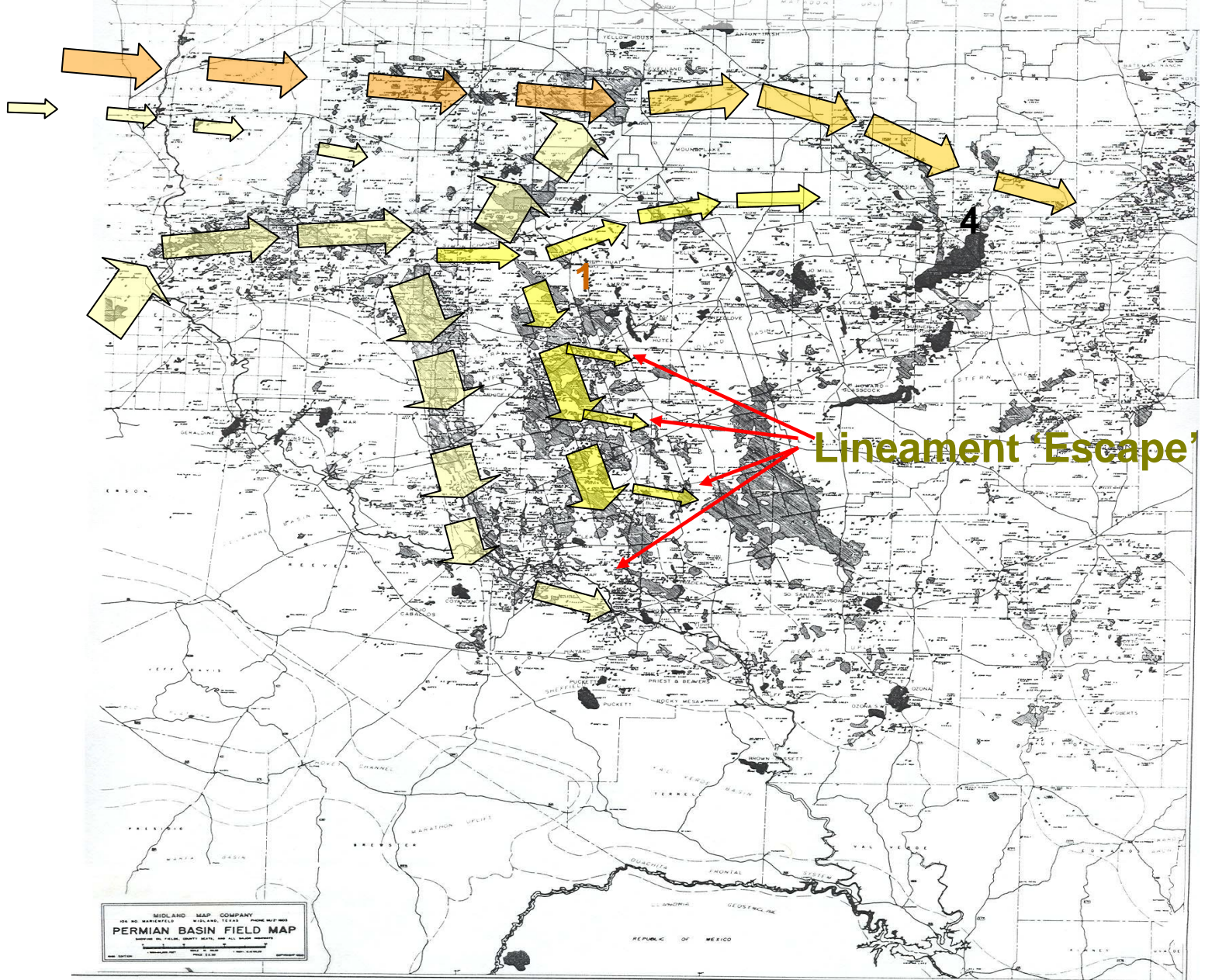


San Andres outcrop (light Blue) is the present day extent of the recharge area for the meteoric water that sustains the tilted oil water contacts in San Andres reservoirs.



Relationship of San Andres outcrops and San Andres Fairways in New Mexico.

PERMIAN BASIN FIELD MAP WITH SIMPLIFIED, THEORIZED (U. PERMIAN) HYDRODYNAMIC FAIRWAYS



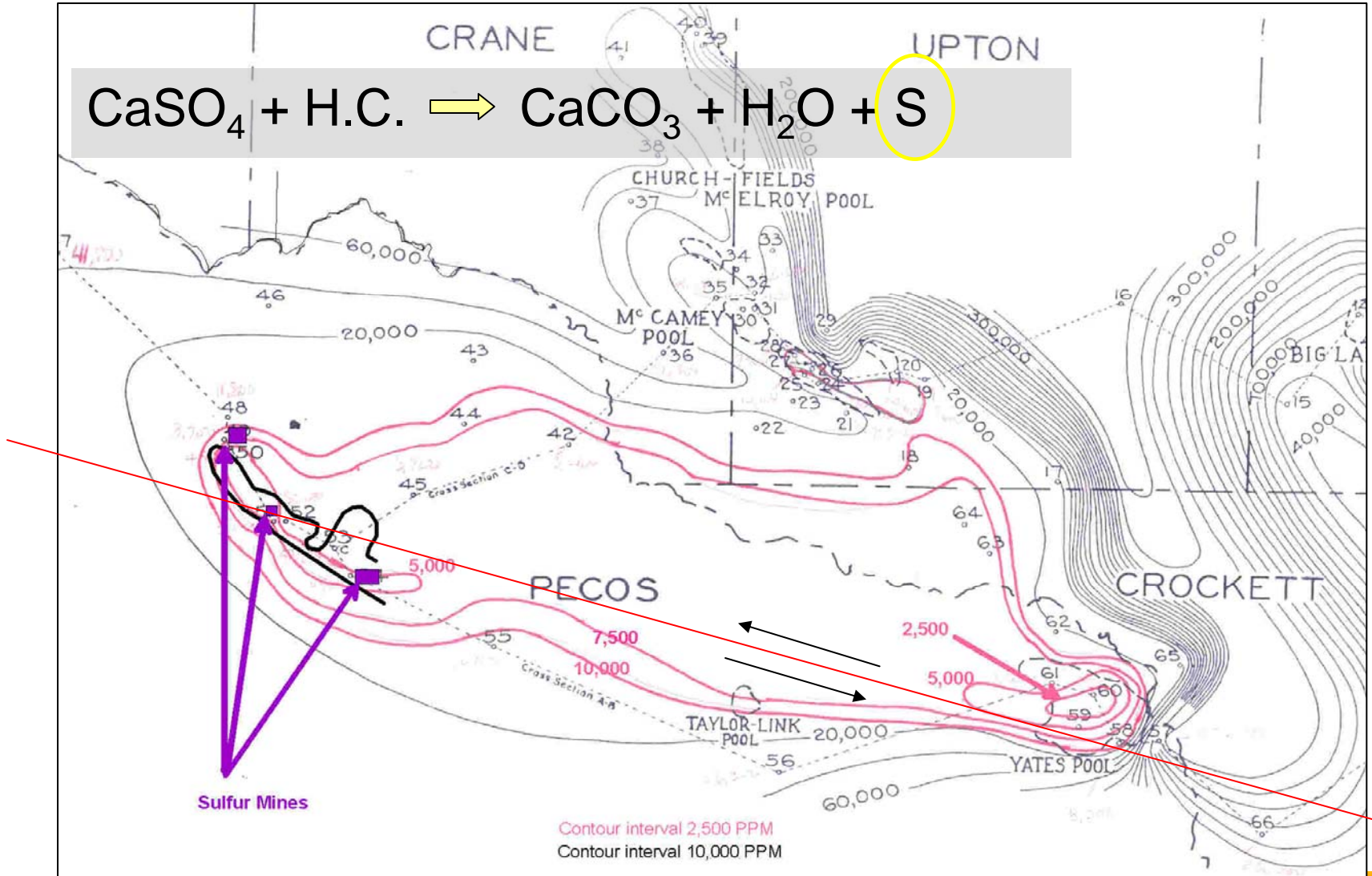
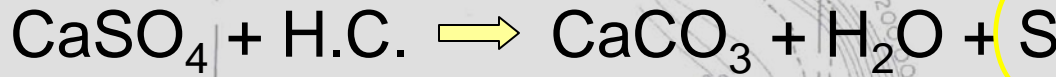
YOU HAVE A SOURCE, YOU MUST HAVE AN EXIT

DISCHARGE PATH CONCEPTS (Hose Nozzle)

- We have a source of the water, we also need discharge points in order to have movement of the meteoric water.
- Direction of OWC tilt is evidence of both Movement and Direction.
- Do we have other pathway clues?



The 'Heel Of The Boot' Of The Central Basin Platform Also The Location Of Sulfur Mines Which Document Exit Pathways For The System



The Body of Anecdotal Evidence

- The anecdotal evidence from a large number of exploration wells documents examples of what can be interpreted as ROZ'. The wells were unsuccessful as there was no associated primary production. From discussions with a number of explorationists and review and reinterpretation of research articles on Permian Basin fields, a set of common ROZ characteristics is developing:
 - Enhanced porosity and permeability developed as the result of alteration of limestones, conversion of anhydrites in the ROZ
 - Sample shows of oil and/or gas,
 - What is typically referred to as sulfur water produced on DSTs or attempted production tests (contrasted with higher salinity connate, salt water)
 - Conventional Core with 10% oil saturation or higher,
 - Log calculations that suggest producible hydrocarbons,
 - Porosities and Permeabilities are most often slightly higher in the ROZ than in the main pay zone – we believe this to be as a result of the “overlay of late (sweep stage) dolomitization” – ‘bow shape’ logs are common
 - The presence of free sulfur associated with anhydrite nodules in the swept zones of the carbonates.

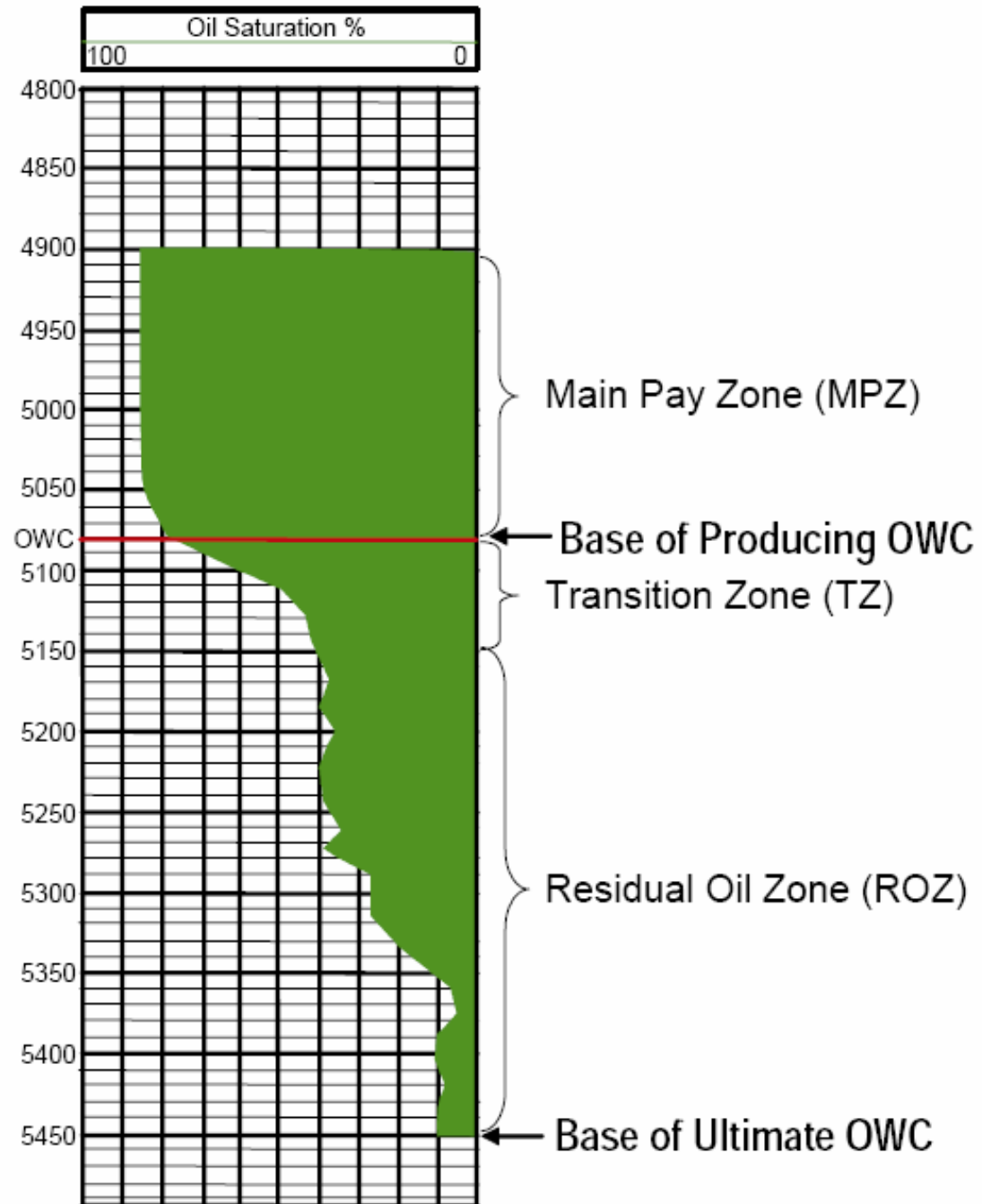
Modeling of the System That Created “Mother Natures Waterflood” Will Be Completed As Part of This Study

- The large sulfur deposits in northern Pecos County are believed to represent one exit point on the Central Basin Platform for the flushed oil and meteoric waters.
- These deposits are the result of the mutual occurrence of Water, Oil and a Source of Sulfur
 - Water – from the meteoric system
 - Flushed Oil (Replenishing the Food for the Anaerobes)
 - Sulfur – from anaerobic bacterial reformation of anhydrite
 - As the Source of H₂S (and Sour Oil)
- The Sulfur Deposits (product-of-reaction, residue)
 - Are Proof of Oil ‘Passing By’
 - Fairways of Oil Movement
 - As Proof of Oil ‘Consumption’

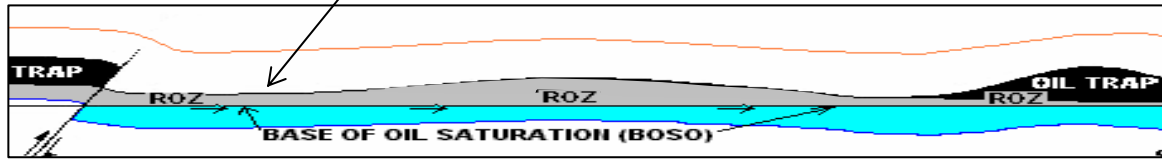
One More New Concept

‘Greenfields’ and ‘Brownfields’

What happens when the entire oil column is swept by Mother Nature?



Areas with ROZ without an associated field

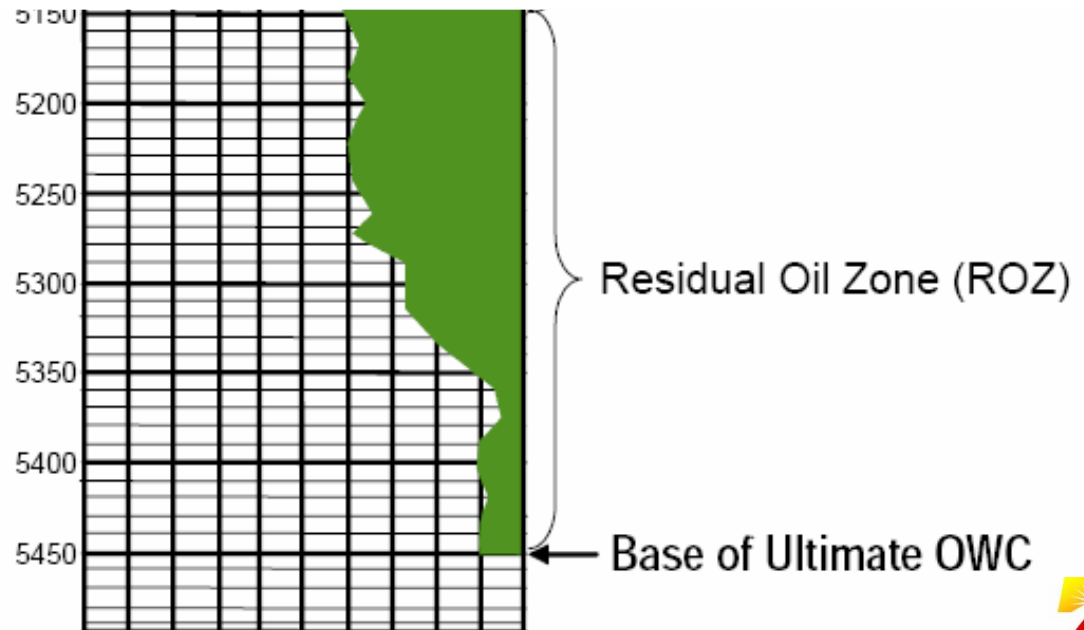


TYPE 3 ROZ

It is a 'Greenfield'

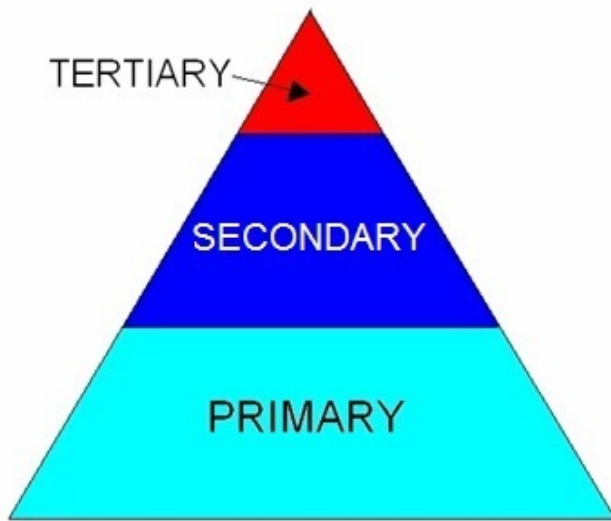
(Wouldn't Produce Oil in Primary or Secondary Production)

You're left with a tertiary
recovery target.



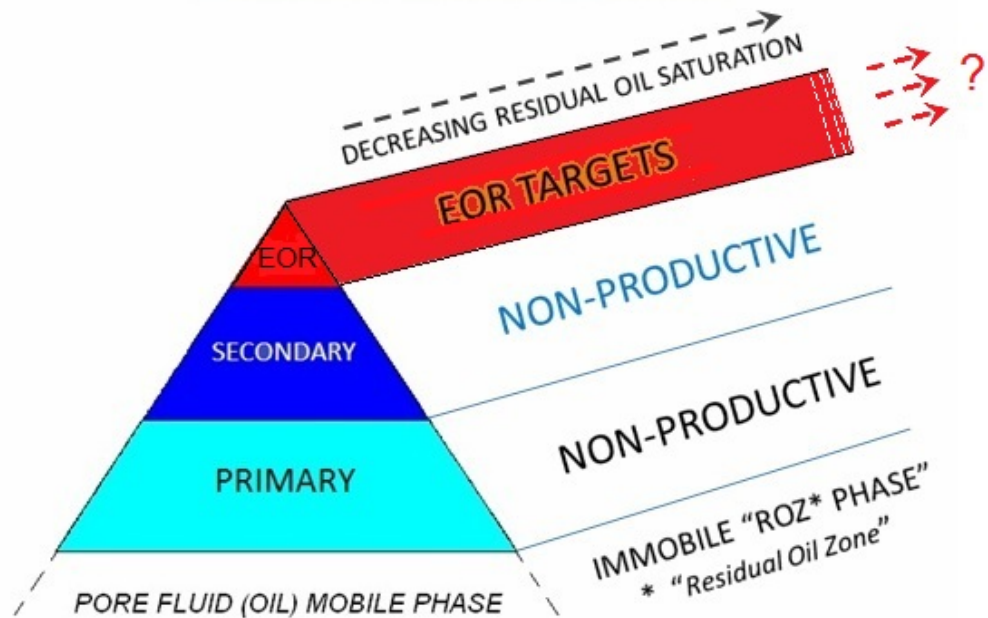
AN EMERGING NEW APPROACH FOR OIL RESOURCE DEVELOPMENT WITH CARBON CAPTURE & STORAGE

CONVENTIONAL VIEW OF RECOVERABLE OIL RESOURCES



TERNARY VIEW

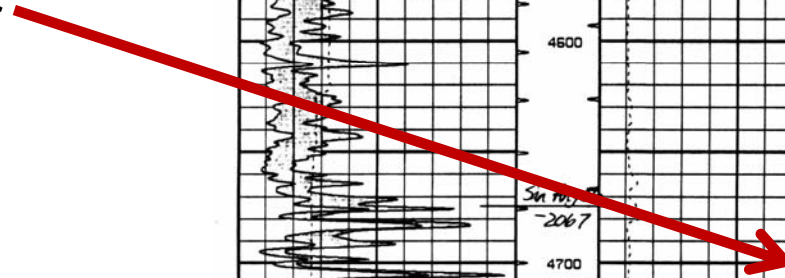
REVISIONARY VIEW OF RECOVERABLE RESOURCES



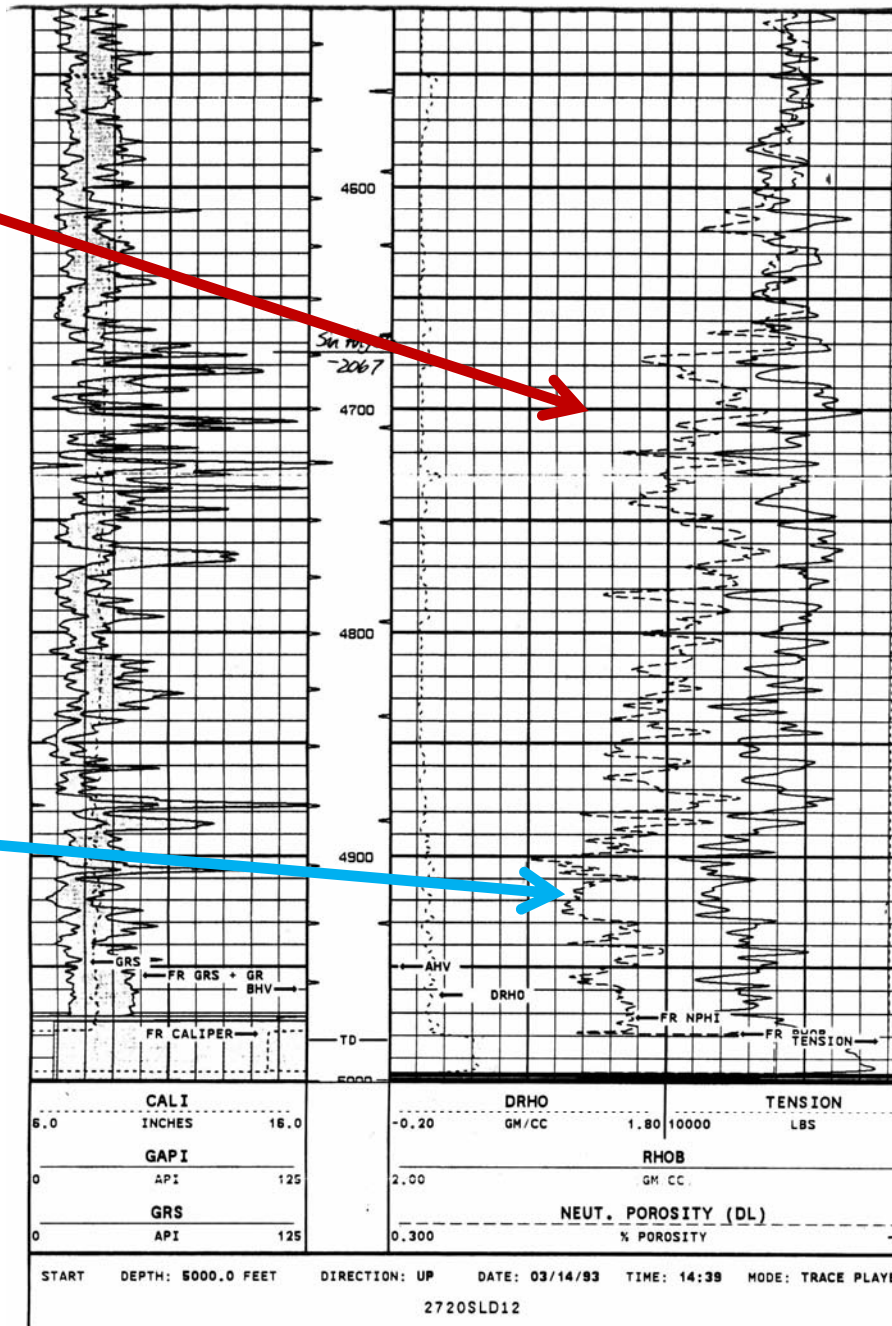
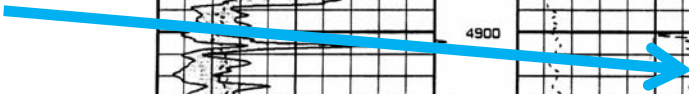
"QUATERNARY" VIEW

Melzer Consulting

The pay is in the tighter upper Glorieta/San Angelo.



The more porous lower section calculates as productive on logs and is oil stained BUT 100% sulfur water productive.



Gamma Ray

Neutron Log

DST 486' Sulfur H₂O

First Currings Sample Shows = 5330'

ROZ

5500'

Base of Cuttings 'Strong' Flour = 5620'

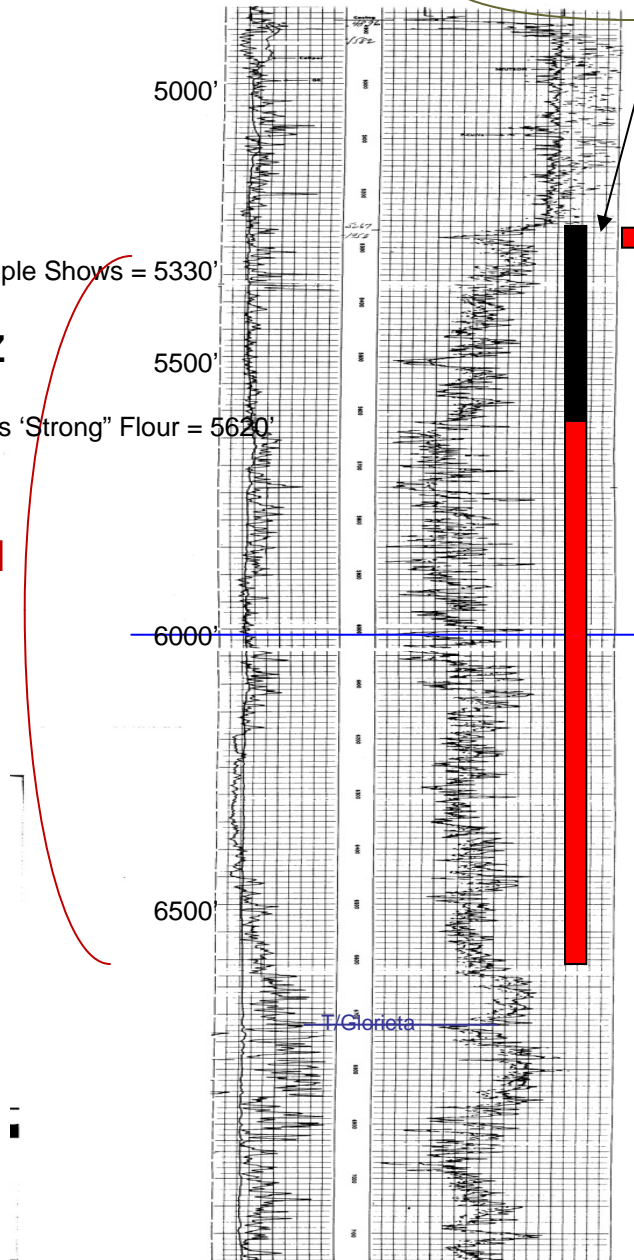
PDI

6000'

6500'

T/Glorieta

Pervasively Dolomitized Interval,
Northern Central Basin
Platform Area



ROZ Science Summary

- We've only just begun to understand the areal distribution of these reservoirs
- ROZ's are a real and major EOR target for today and long into the future
- Pervasively Dolomitized Intervals, Devoid of Residual Oil, are Present in Many Locales
- Documentation of Areas/Fields with Large Oil and Storage Potential is Underway

Interesting Science but....Can We Say this
Is of Commercial Interest?

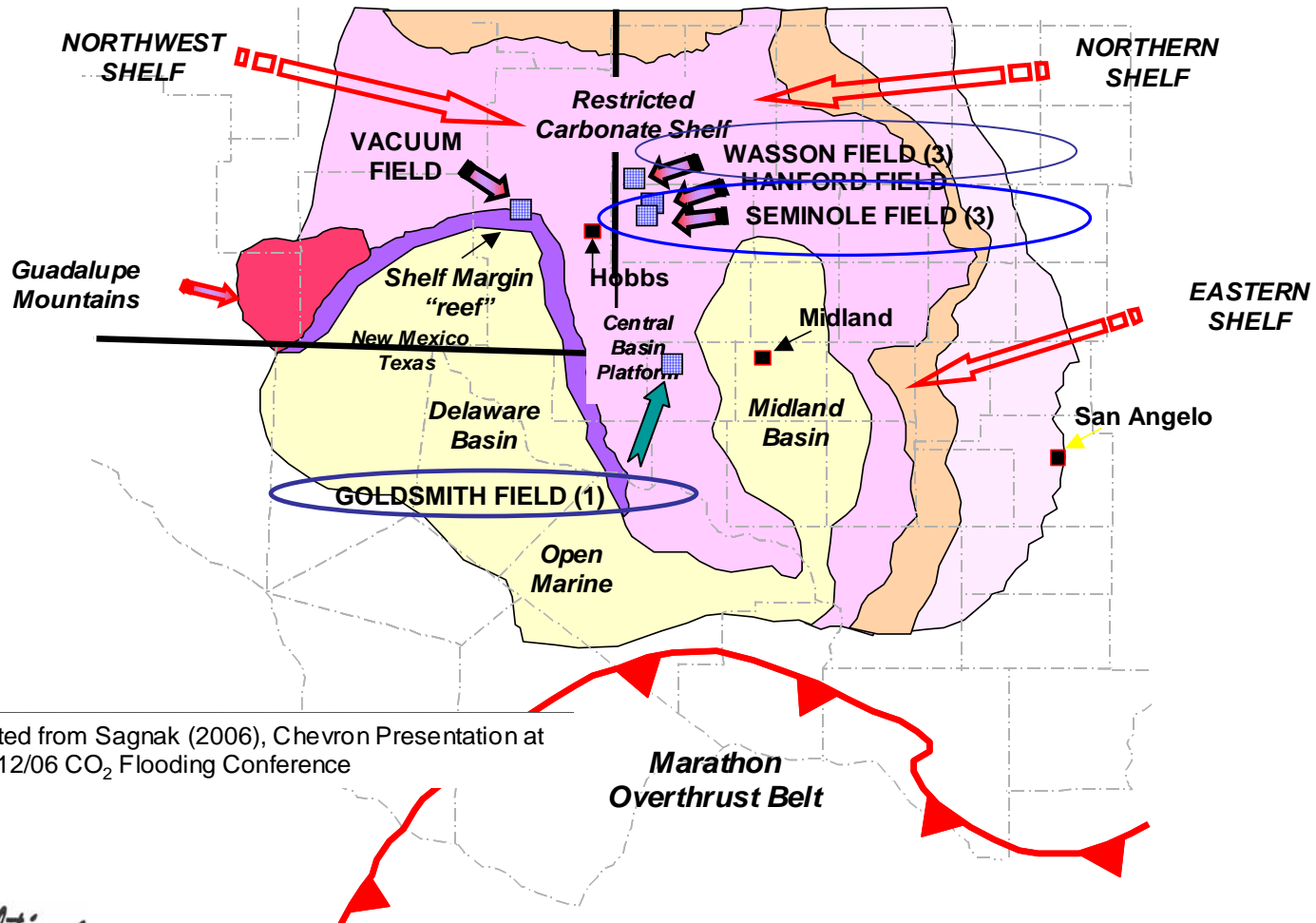
RESIDUAL OIL ZONE CO₂
FLOODING DEMONSTRATION
PROJECTS

COMMERCIALIZING THE ROZ

ACTIVE RESIDUAL OIL ZONE CO₂ EOR PROJECTS IN THE PERMIAN BASIN

MIDDLE SAN ANDRES PALEOGEOGRAPHY

with Location of Industry Documented ROZ Zones/Fields*

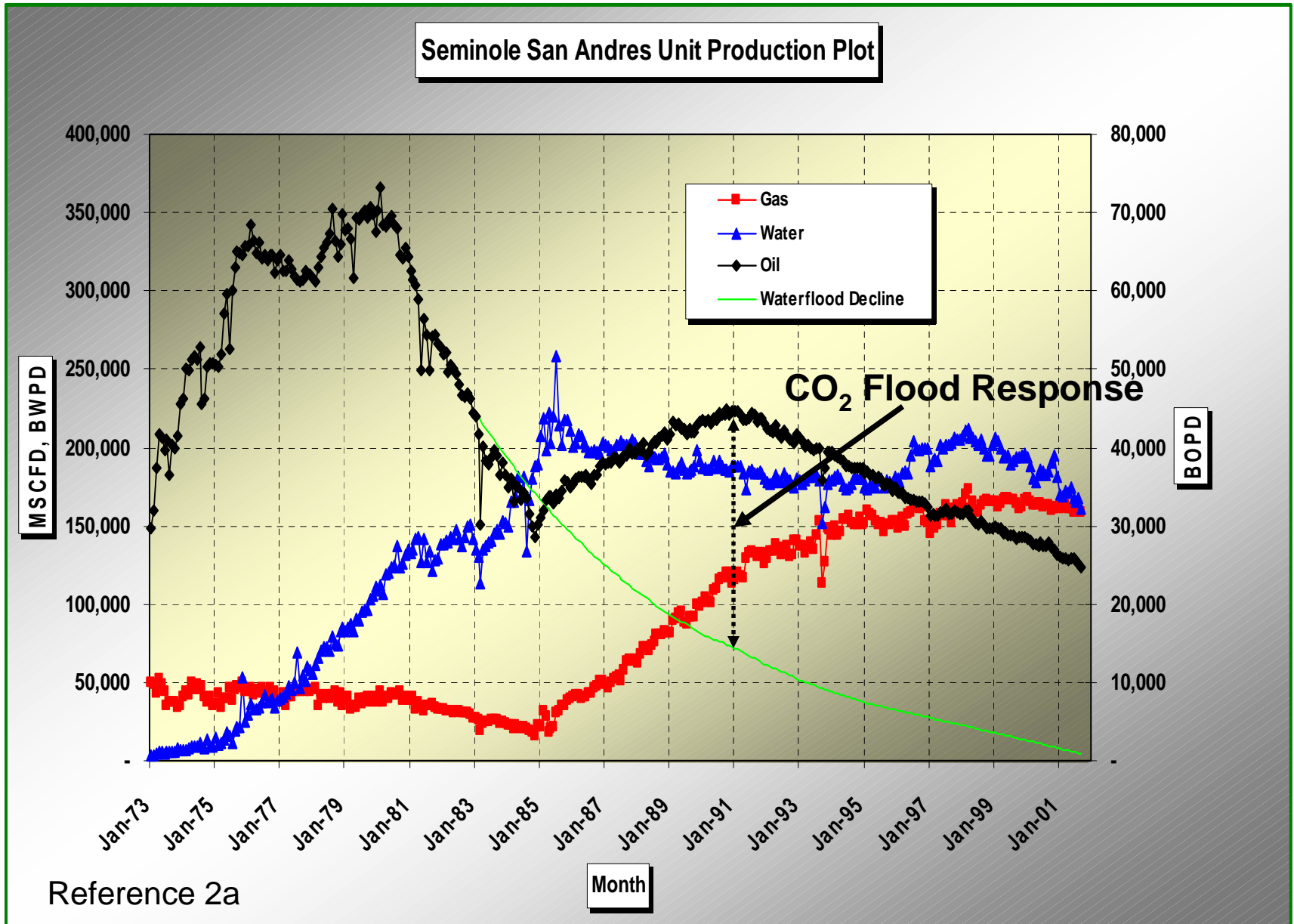


* Adapted from Sagnak (2006), Chevron Presentation at the 12/06 CO₂ Flooding Conference

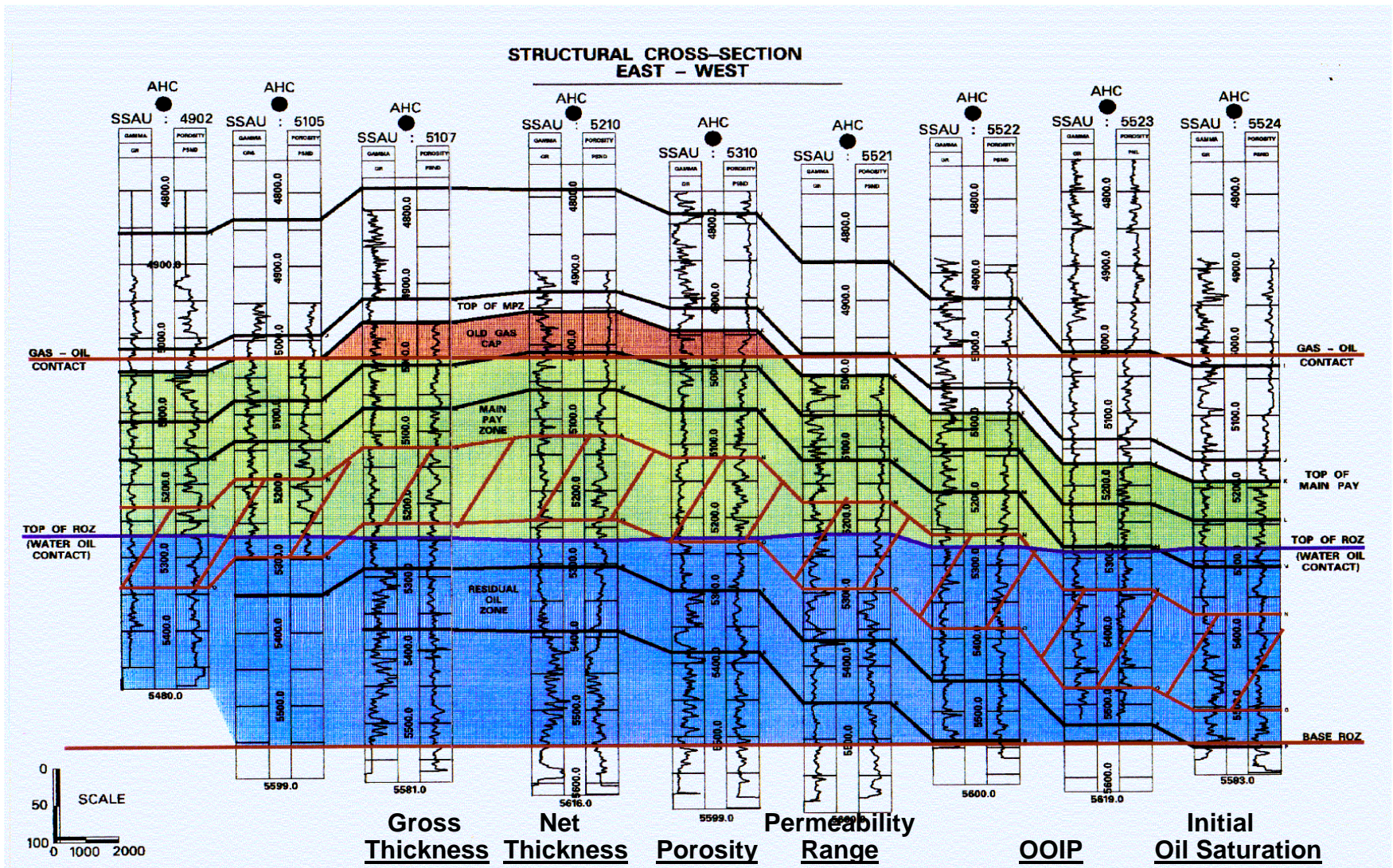
Active ROZ Floods in the Permian Basin

Type and operator	Field	State	County	Top MPZ Depth, ft	Pay zone
Active CO₂ miscible					
Chevron	Vacuum San Andres Grayburg Unit	NM	Lea Co.	4,550	San Andres/Grayburg
Fasken	Hanford	Tex.	Gaines	5,500	San Andres
→ Hess	Seminole Unit-ROZ Phase 1	Tex.	Gaines	5,500	San Andres
→ Hess	Seminole Unit-ROZ Phase 2	Tex.	Gaines	5,500	San Andres
→ Hess	Seminole Unit-ROZ Stage 1 Full Field Dev	Tex.	Gaines	5,500	San Andres
→ Legado	Goldsmith-Landreth Unit	Tex.	Ector	4,200	San Andres
Occidental	Wasson Bennett Ranch Unit	Tex.	Yoakum	5,250	San Andres
→ Occidental	Wasson Denver Unit	Tex.	Yoakum	5,200	San Andres
Occidental	Wasson ODC	Tex.	& Gaines	5,200	San Andres

Production History of the SSAU

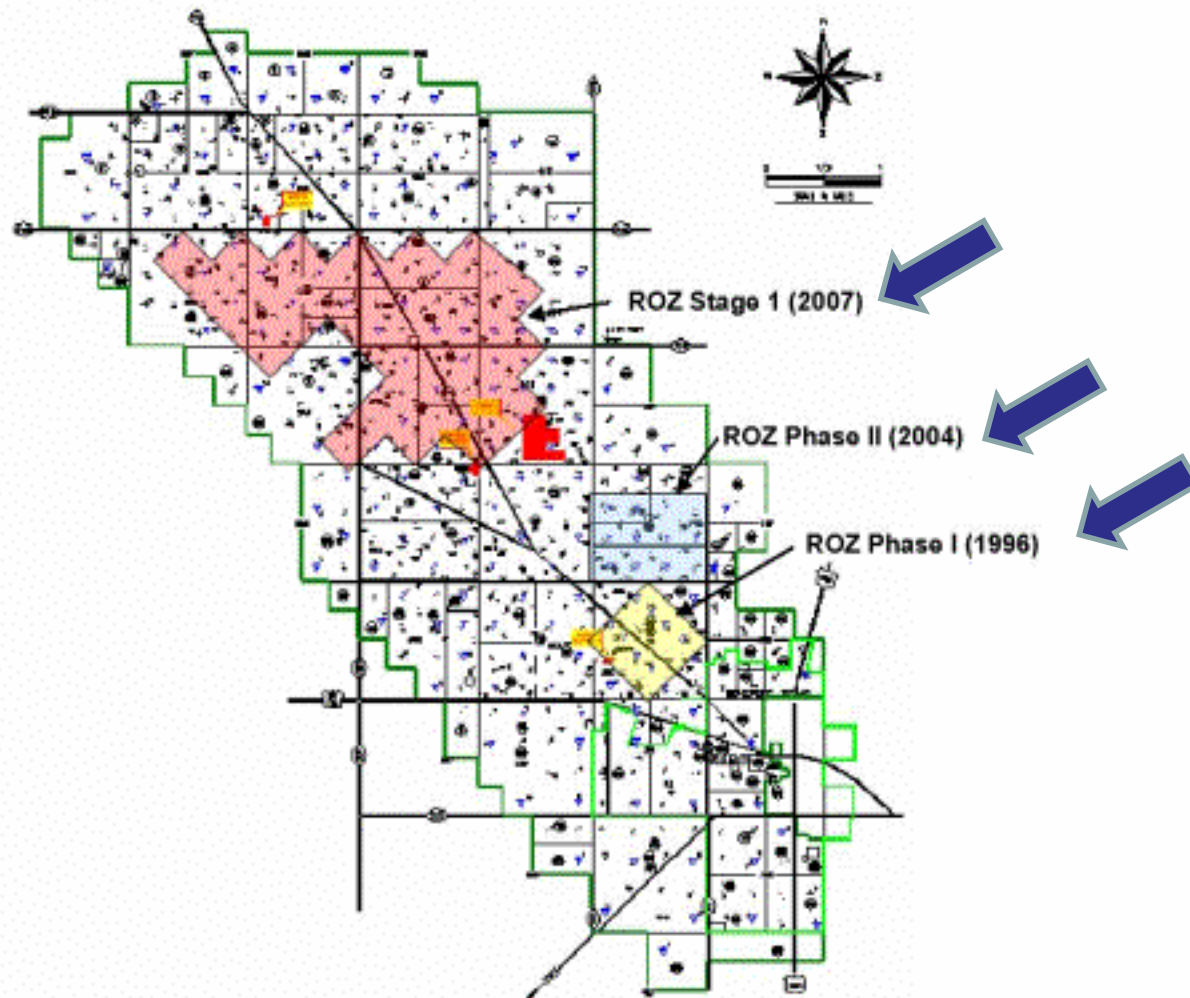


SSAU MPZ & ROZ Crosssection and Zonal Attributes



Main Pay Zone (MPZ): 160' 126' 12% 0.8-120 md 1 billion stbo 0.84

Residual Oil Zone (ROZ): 246' 197' 12.6% 0.5-270 md 960 million stbo 0.32

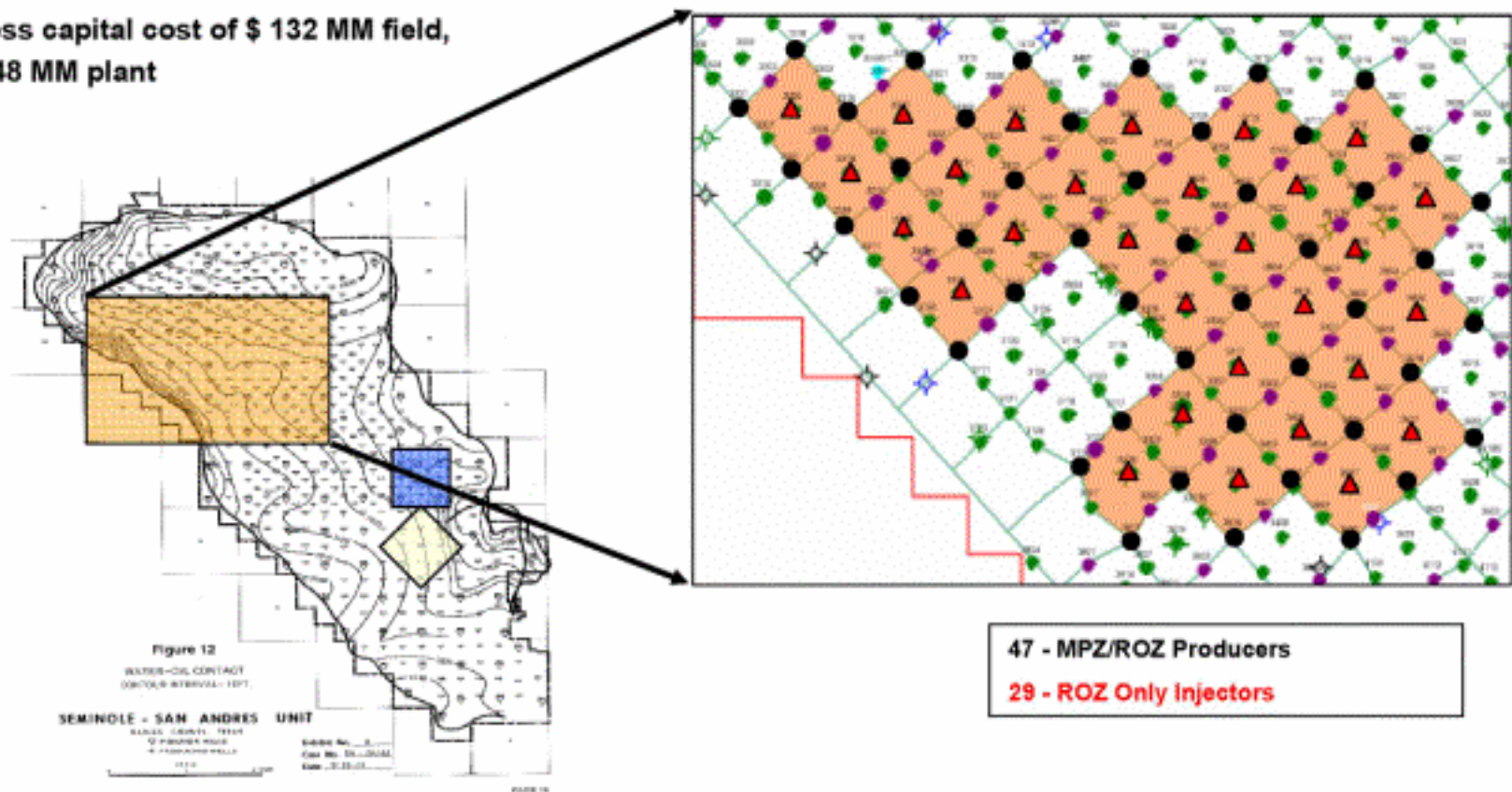


Seminole San Andres Unit

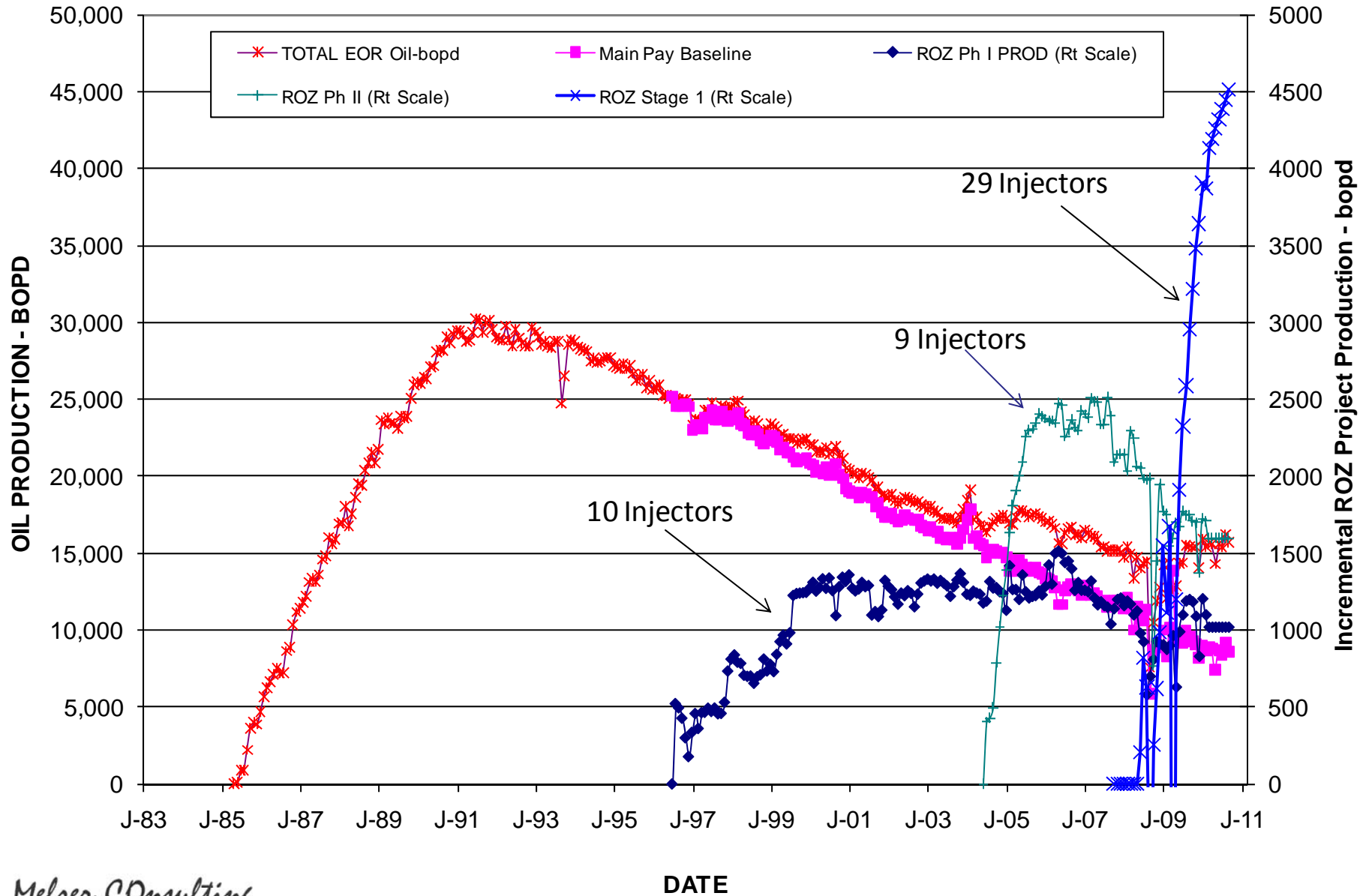
Stage 1 Project Area



- Objective: Begin full field development of the Residual Oil Zone
- Twenty-nine 80 acre patterns with inverted five-spots
- Injection commenced October 31, 2007
- Plant Expansion of 70 MMSCFD (Complete Q2 2009)
- Gross capital cost of \$ 132 MM field, \$ 148 MM plant



SSAU TERTIARY & QUATERNARY (CO₂) PHASE OIL PRODUCTION AND ANALYSES



Update from CO₂ Conference Field Trip

(as of Dec 7, 2010)

- Stage 1 (29 injection patterns) Making >4000 bopd and climbing *(further update: 5000 bopd last month)*
- Several Wells Now Making >400 bopd
- Approvals Circulating to Move to Stage 2 (12 more injection patterns)
- Oil Quality Not Perceptibly Different from Main Pay Zone Oil

Legado's Goldsmith Landreth Unit CO₂ Flood

Now a Part of a DOE Study

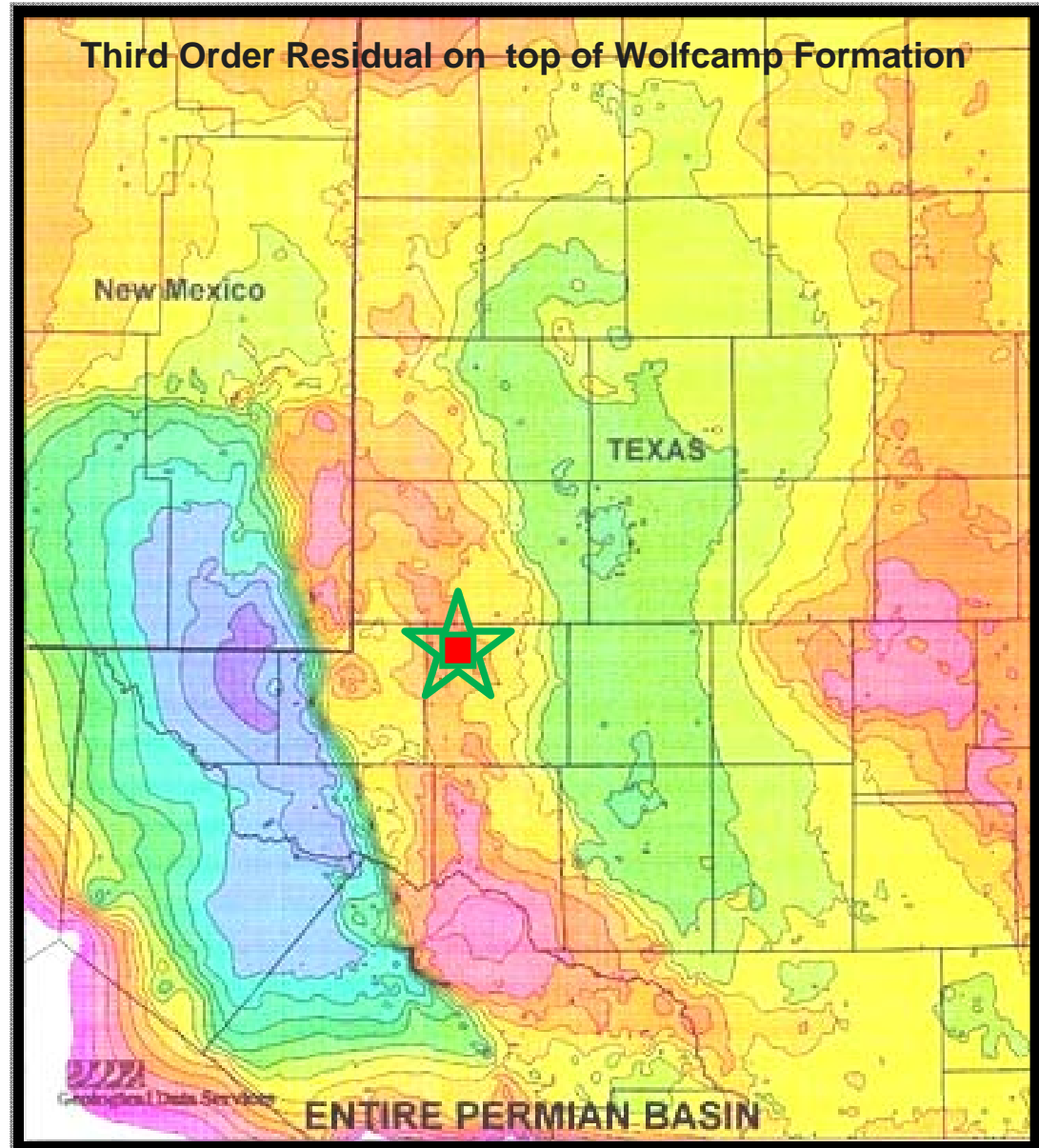
<http://www.netl.doe.gov/technologies/oil-gas/EPAct2005/Projects/SPR/0812319-UTexasPermian-Abstract.html>

Project Placement – GLSAU Location

Placement Alone Addresses Several Management Goals:

- ✓ Process – More CO2 Flood Projects Than Anywhere Else in the World. Almost “SOP” Here.
- ✓ Cost – Nearby Access to Worlds Most Extensive PL Network. Top Quality Service Infrastructure.
- ✓ Performance – Vast Array of Analog Information. Highly Refined Range of Outcomes.

LEGADO
resources



DOE Contract with UTPB and ROZ Team + ARI

- Work has Just Begun (Kicked off in March '11)
- Will Use Legado's Goldsmith Field as the Case History for Study
- Legado has agreed to Contribute 1150' of Core taken in the GC, MPZ, and ROZ
- Will Look at Response of Pilot (dedicated ROZ) and Phase I Area (Commingled MPZ+ROZ)
- Will Examine Water and Oil Looking for Differences in Chemistry (U of H/Martin Cassidy)

ROZ FLOOD RESPONSE CONCLUSIONS

- ROZ CO₂ Flooding Now Proven For San Andres Formation
- Brownfields (Vertical Expansions): Economically Proven
- Greenfields (Requiring All New Wells): Not Demonstrated As Yet

KEY ROZ REFERENCES (1)

- 1) Oxy Permian Ltd., (2005), Personal Communication and Presentation Slides, February 2005)
- 2a) Bush, J. (2001), "The Seminole San Andres Unit Residual Oil Zone (ROZ) CO₂ Flood," Presentation Slides, CO₂ Flooding Conference, Midland, Tx., Dec 2001 (www.utpb.edu/ceed)
- 2b) Biagiotti, S. (2008), Presentation Slides, "Seminole San Andres Unit ROZ Review," Presentation Slides, CO₂ Flooding Conference, Midland, Tx., Dec 2008 (www.utpb.edu/ceed)
- 2c) Thurmond, T (2010), "Managing a CO₂ Development in a Privately Funded Environment: The GLSAU Project," Presentation Slides, CO₂ Flooding Conference, Midland, Tx., Dec 2008 (www.utpb.edu/ceed)
- 3) Kosco, K. (2005), Personal Communication, February 2005.
- 4) Exxon Means Presentation at the 2004 CO₂ Conference, Dec 2004
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