

Residual Oil Zones -Phantom Discoveries and Completions

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UTPB/CEED

2009 CO2 Conference

Project Objectives

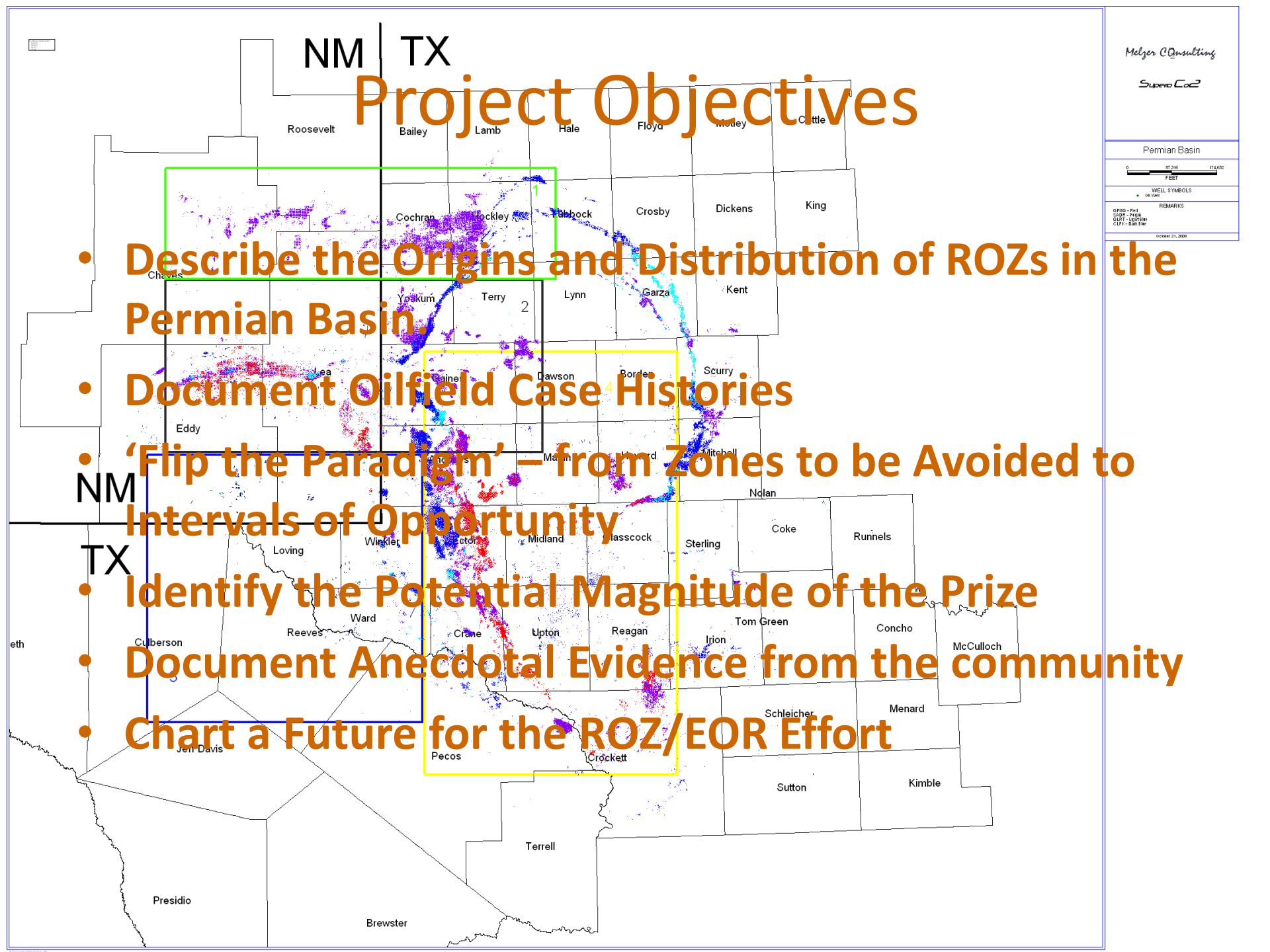
- Describe the Origins and Distribution of ROZs in the Permian Basin.
- Document Oilfield Case Histories
- 'Flip the Paradigm' – from Zones to be Avoided to Intervals of Opportunity
- Identify the Potential Magnitude of the Prize
- Document Anecdotal Evidence from the community
- Chart a Future for the ROZ/EOR Effort

Permian Basin

WELL SYMBOLS
OR USE

REMARKS
CLIP - Perm
CLIP - Perm
CLIP - Perm
CLIP - Perm

October 21, 2009



Thanks go to....

- Steve Melzer
- Arcadis - David Vance, Steve Tischer
- Phil Eager
- Chevron
- Legado
- Edith Stanton
- Hoxie Smith
- Saswati Chakraborty
- All those who have battled with ROZ's in the past.

First basinwide study of Residual Oil Zones (ROZ's) 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 a 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.

- ROZ's appear to be common in Leonardian and Guadalupian carbonates on the Central Basin Platform and Northwest Shelf.
- Exploitation of thick ROZ's associated with many of the major San Andres fields has begun with CO2 projects underway at Wasson, Seminole, Vacuum, Means, Goldsmith, and Hanford Fields, with others planned.
- Production from ROZ's and anecdotal evidence from exploration wells, coupled with the theory/model of the development of Residual Oil Zones (ROZ's), has led to the belief that there are potentially billions of barrels of additional producible tertiary reserves in the Permian Basin and elsewhere.

Calibrating the Oil Recovery Models and EstiTechnically 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.

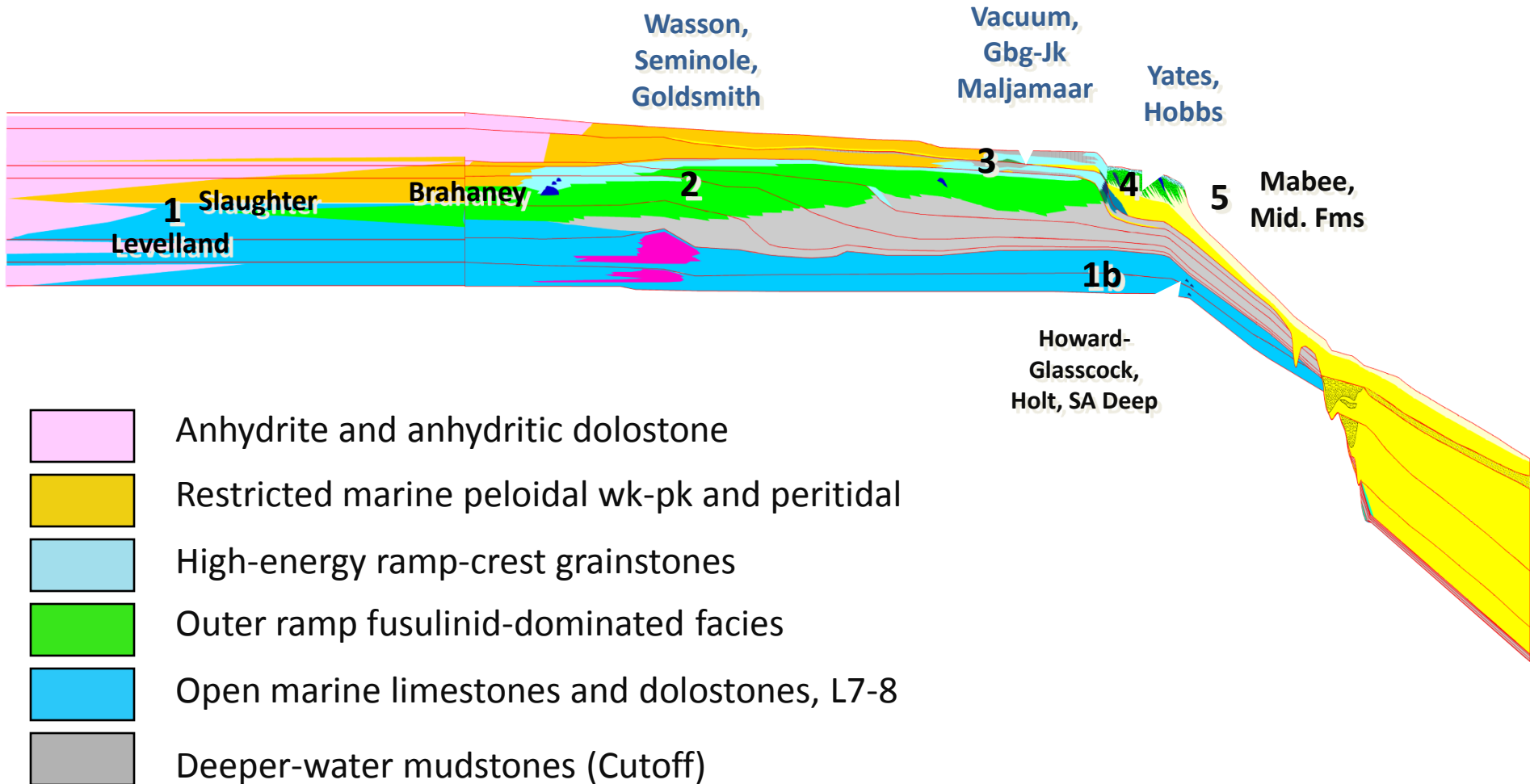
| Field/Unit | MPZ OOIP (BB) | TZ/ROZ OOIP (BB) | No. of Fields | No. of MPZ Fields with CO₂-EOR Projects | No. of Fields with TZ/ROZ CO₂-EOR Projects |
|---|----------------------|-------------------------|----------------------|---|--|
| 1. Northern Shelf Permian Basin (San Andres) | 13.0 | 13.2 | 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

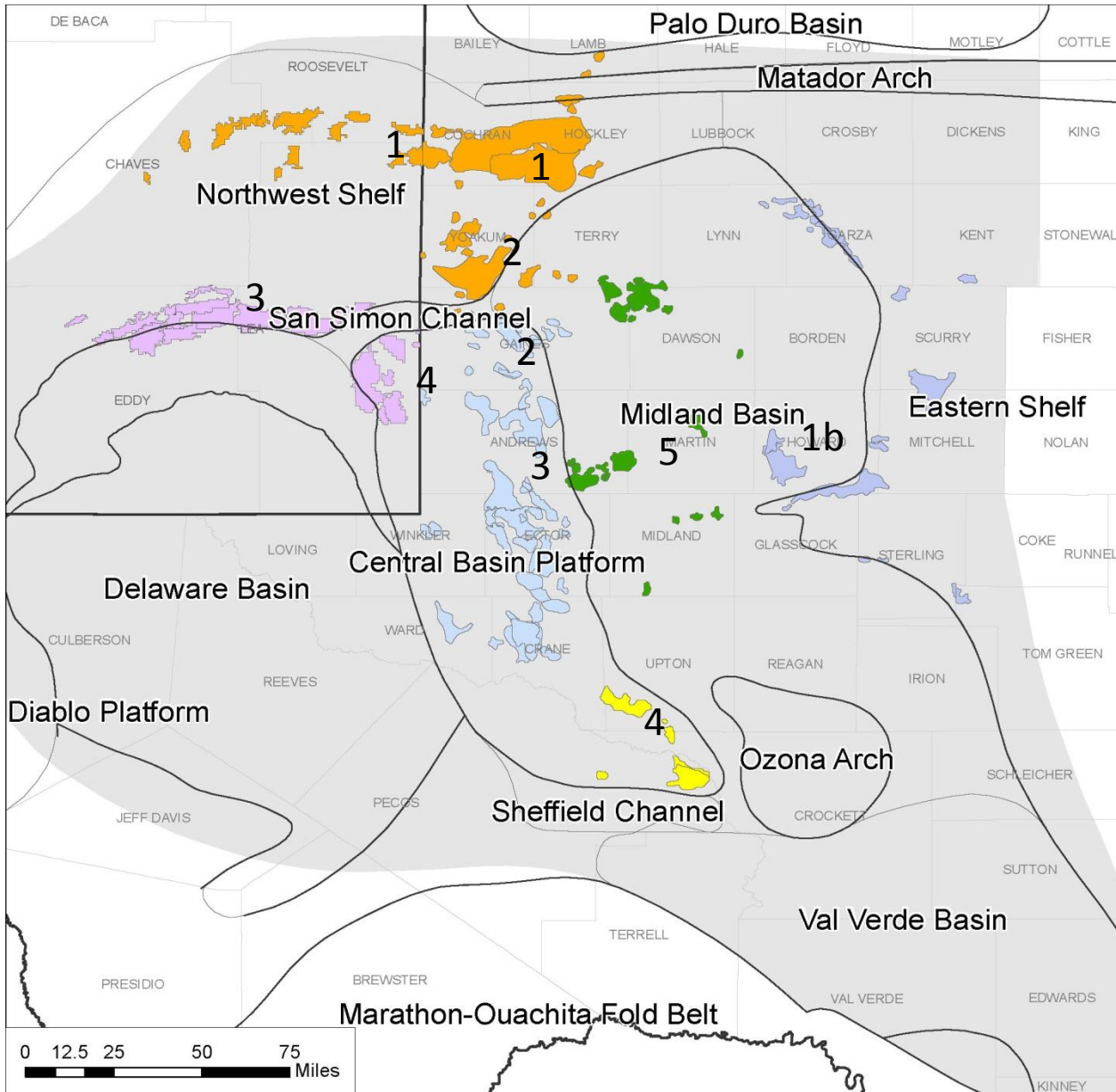
Based on reservoir modeling of applying CO₂-EOR to the TZ/ROZ resources, ARI estimates that 11.9 billion barrels is technically recoverable from the 30.7 billion barrels of TZ/ROZ oil in-place in these five Permian Basin oil plays

| Field/Unit | Total CO₂-EOR (BB) | MPZ CO₂-EOR (BB) | TZ/ROZ CO₂-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 |

San Andres Reservoir Settings. All fields are not alike.



Classification of San Andres Reservoirs on basis of Stratigraphic Setting



Legend

- nw_sanandres_carbonate_nm
- nw_sanandres_carbonate_tx
- upper_sanandres_central_nm
- upper_sanandres_artesia_nm
- e_sanandres_carbonate_tx
- sanandres_grayburg_tx
- sanandres_carbonate_tx
- sanandres_karst_tx

1. L7-8-G1-2 interc. dolo-evap
- 1b. L7-L8, G1? Open shelf and buildups
2. Cyclic G1-4
3. Stacked G8-9 and Gbg G10
4. Karst-modified, anhydrite-free G8-9
5. Oolitic Grayburg lowstand G10

Permian Basin Plays,
Dutton et al (2005)

“Common Knowledge”

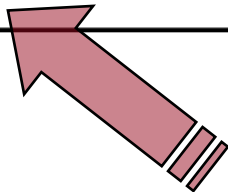
- Where there are tight rocks beneath the oil/water contact, there are longer Transition Zones.
- At the base of these fields, the TZs extend to the Base Of Saturation of Oil (BOSO).
- Some contribution to production can be expected from the uppermost Transition Zone.
- Residual Oil Zones are no different than Transition Zones. It's just semantics.
- There are two periods of oil migration (post-Permian & Cretaceous/Tertiary) commonly proposed for Permian fields in the basin.
- There is a late (Cretaceous) tectonism that “adjusts structure” and created larger closures and reset oil/water contacts.
- Pathway of dolomitizing fluids is perpendicular to the shelf margin and
- Oil was flushed out of the crest of structures down dip into the basin and back.

The new Residual Oil Zone Paradigms

- Swept by “Mother Natures Waterflood” which occurred post/syn oil emplacement.
- Have the same saturation characteristics as mature waterfloods in the swept intervals.
- Often is interpreted/calculated as producible in Exploration Wells, and Primary and Secondary Production Environments:
 - Good Odor, Cut, Fluorescence, and Gas in samples
 - 20 -40 % oil saturations in core
 - Calculate as oil productive on logs
- Produce high percentage of water on DST’s or completions, but not a “deal killer”.
- Originally there were significant ROZ thicknesses (50 to 300’) of producible hydrocarbons in producing fields AND outside the present limits of producing fields.
- This “faux-productive” appearance of ROZ’s is presently found both beneath fields and in areas where there is no, or a minimum, producible oil column.

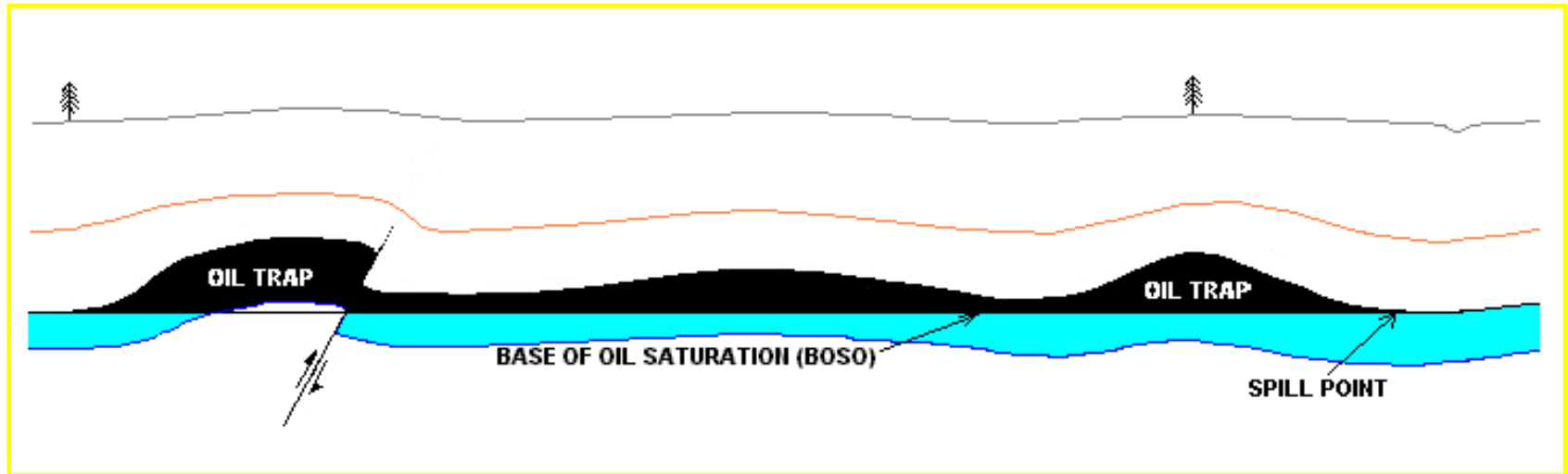
THE ROZ BACKGROUND

| 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) |



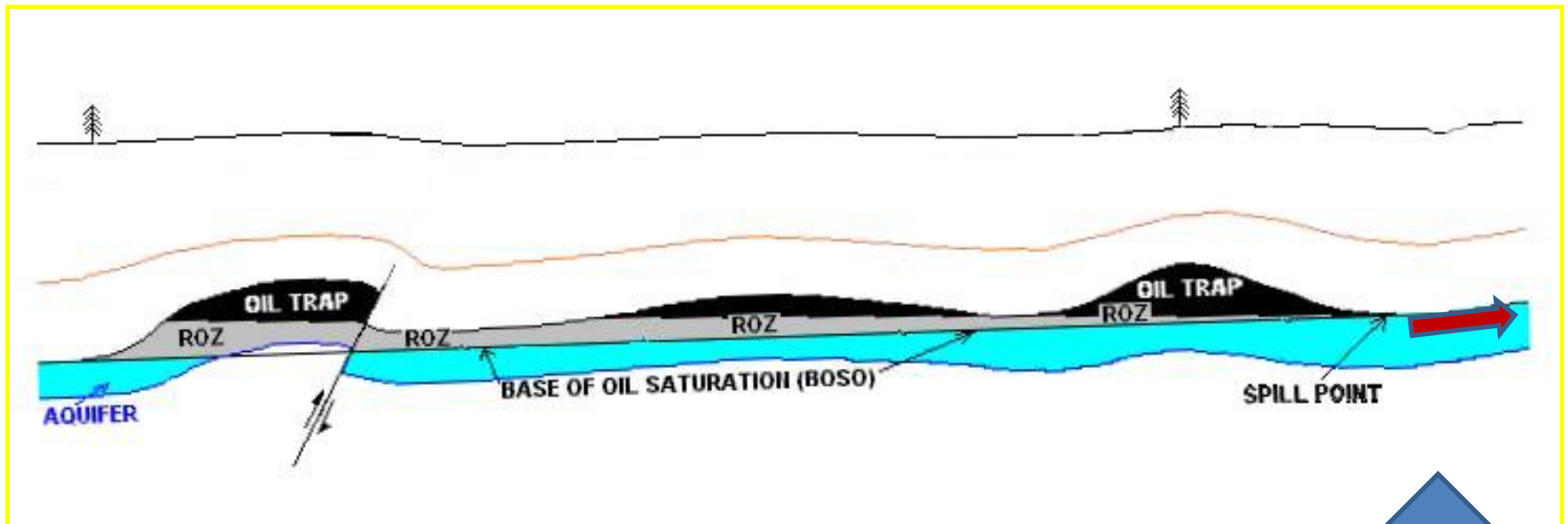
The Evidence suggests Type 3 are common in the Permian Basin

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. Oil would have migrated out of the
basin.

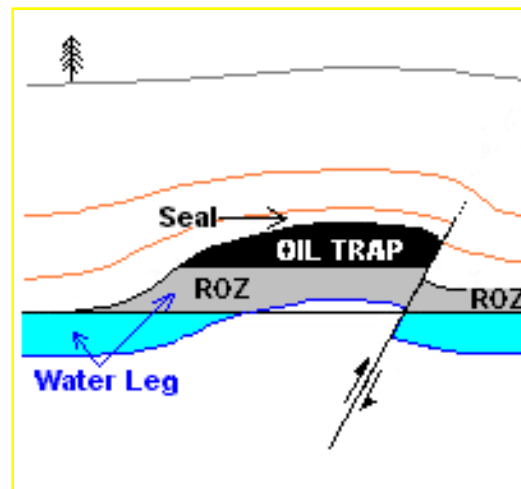
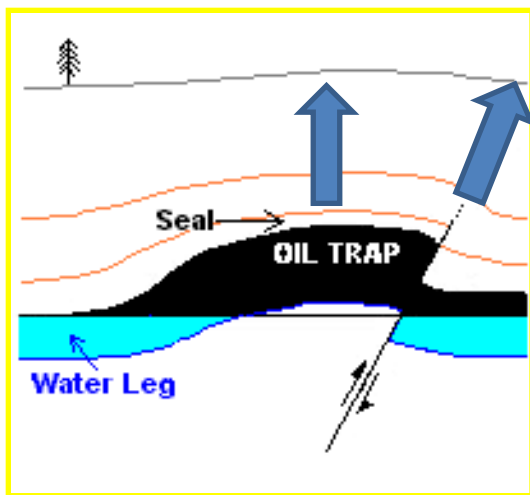


Static System

Original Accumulation with a Breached, then Repaired, Seal, forming a ROZ/TZ, a horizontal O/W contact on the main pay and the ROZ.

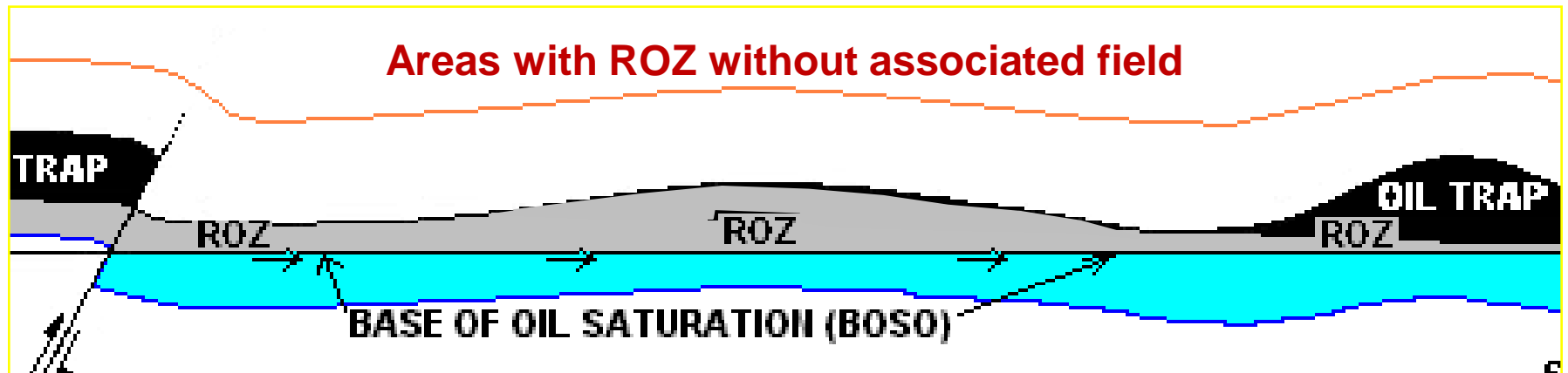
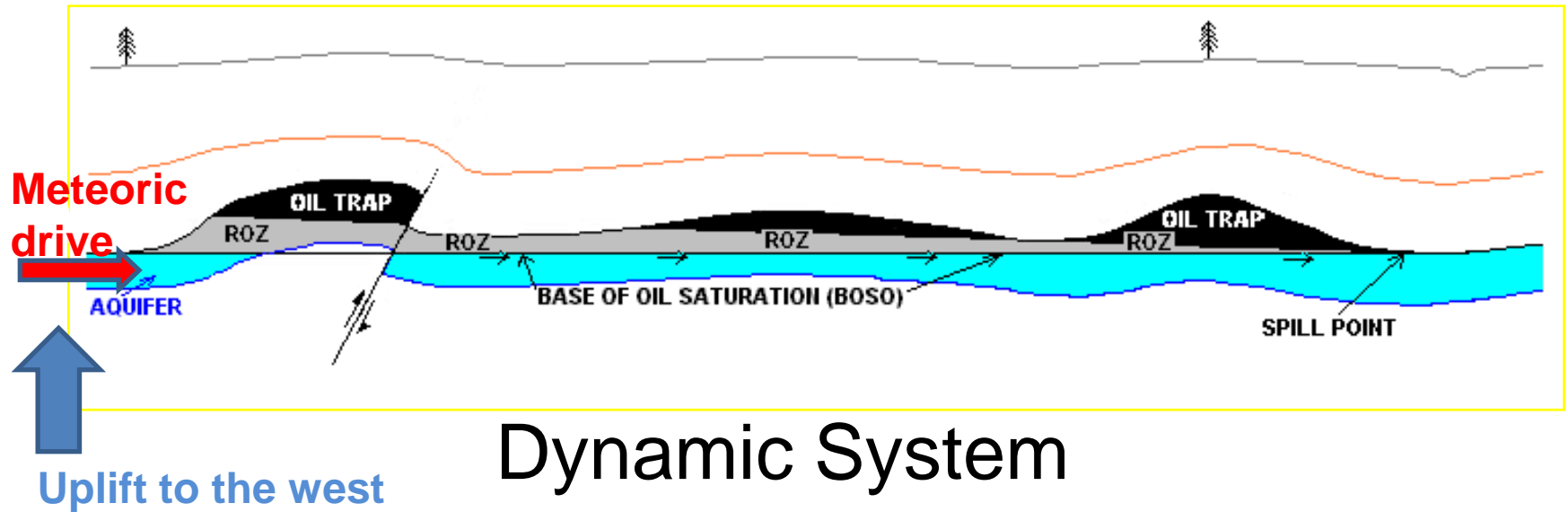
May also “de-gas” the reservoir.

Present in the Permian Basin.



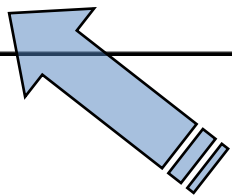
Static System

Change in Hydrodynamic Conditions, Sweep of the Lower Oil Column, Oil/Water Contact Tilt, and Development of a Residual Oil Zone. In the Permian Basin, meteoric flow is from Rio Grande uplift.



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) |



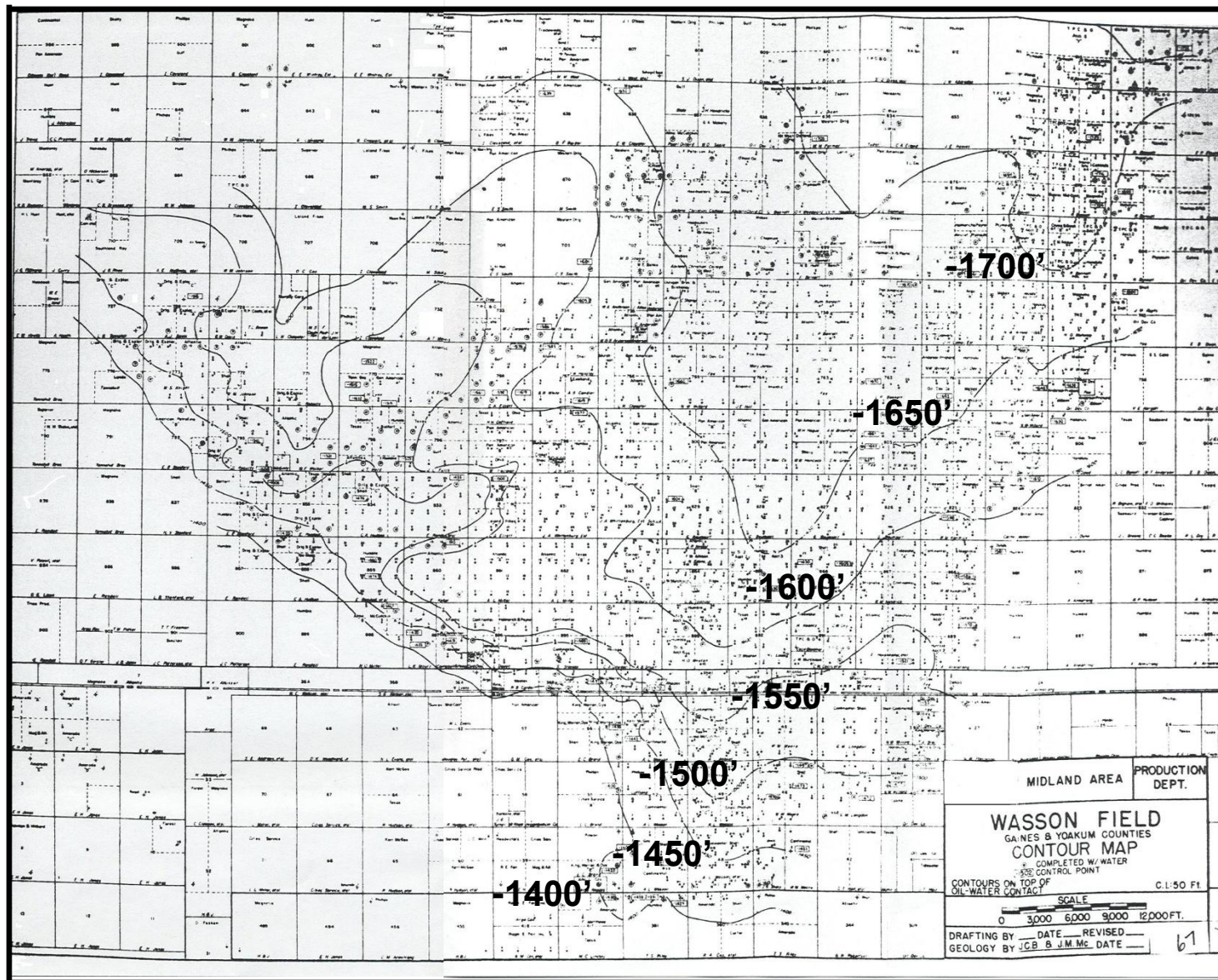
First, Let's Look evidence for OWC Tilt

How did we get here?

Alton Brown and Bob Lindsay

- **Alton Brown** documented the effects of hydrodynamics on Cenozoic oil migration in the Wasson area and elsewhere on the Northwest Shelf.
- Using available data, Alton proposed hydrodynamics as a more reasonable mechanism for the Wasson OWC tilt than capillary effects. And that the hydrodynamic charge model also explains that the ROZ is a relect from previous hydrostatic trapping conditions.
- He documented the tilting of OWC in a number of field on the Northwest Shelf and Central Basin Platform.

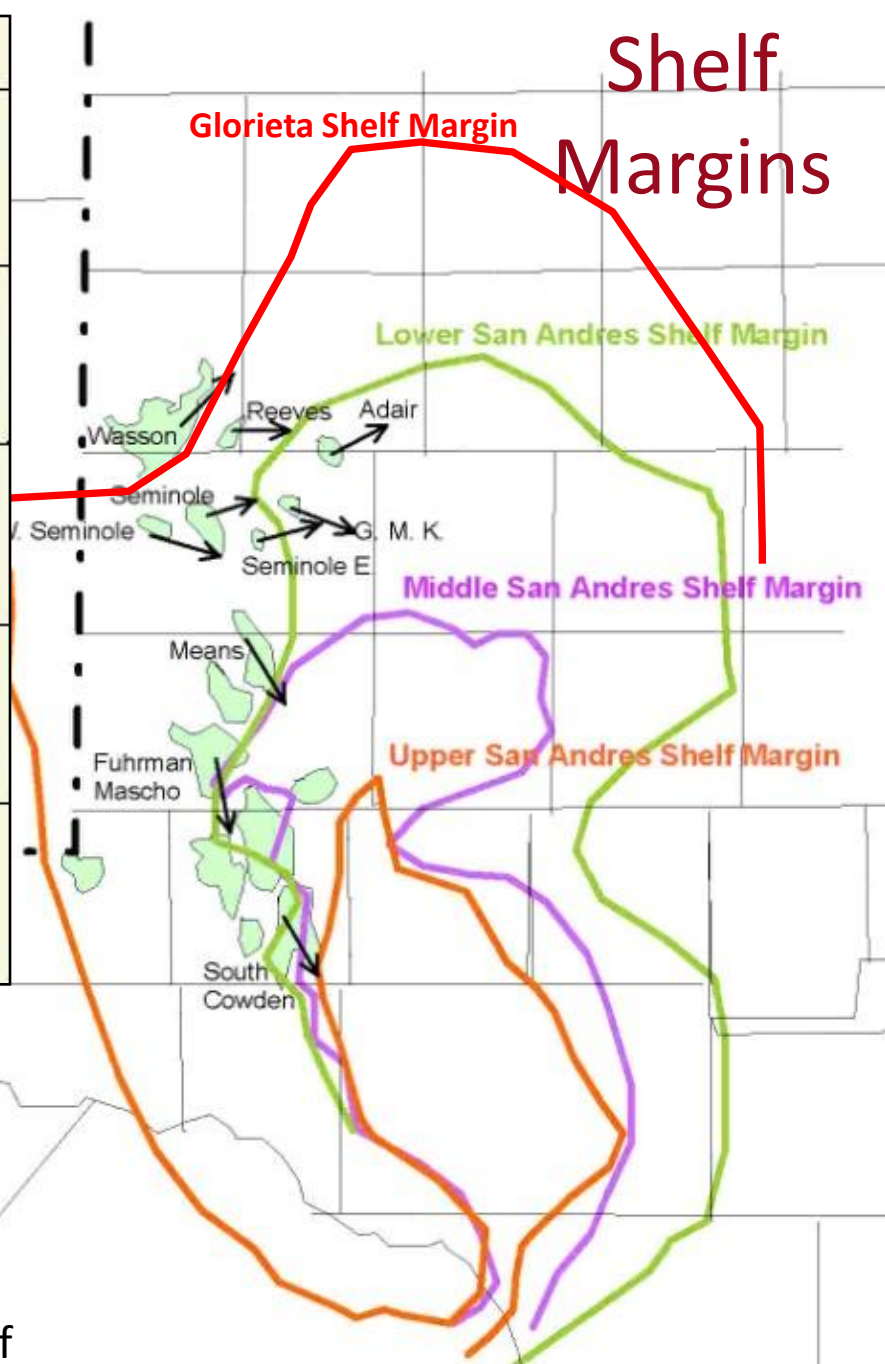
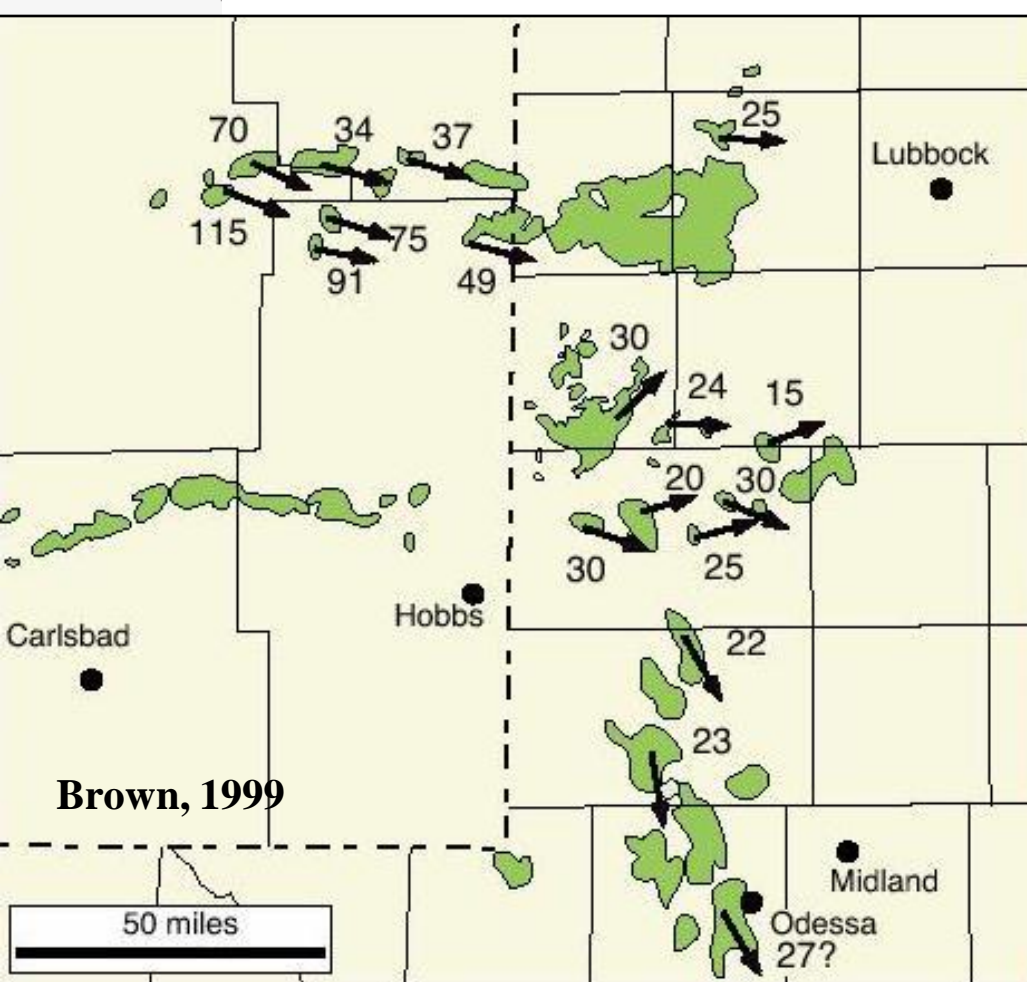
Wasson Field Oil-Water Contact Contour Map – Texas RR Commission Filing, October 1964



Wasson Field Area O/W Contact Structural Contours*



* From Ref 6



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

The direction of OWC tilt may be influenced by the age of the producing interval and its relationship to the shelf margin



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.....find a contract for CO₂.

How did we get here?

Alton Brown and Bob Lindsay

- **Bob Lindsay**, while at Chevron, looked at outcrop-core-production relationships, documented meteoric sweep and the development of Residual Oil Columns in a number of fields on the Central Basin Platform.
- He envisioned massive recharge of meteoric waters into the subsurface during the Mid to Late Tertiary as a result of the uplift in the Rio Grande Rift area. The oil was swept out of the crest of the structures and down dip into the flanks.
- The later extensional development of the Basin and Range structures reduced the “hydraulic head”. Some oil was left behind on the downdip flanks, and the meteoric waters introduced “bugs” which reduced the volume of oil.
- Following the reduction in head, and the enhancement of structure, new oil/water contacts were established in the fields with significant thicknesses of partially oil saturated reservoir now below the oil/water contact.

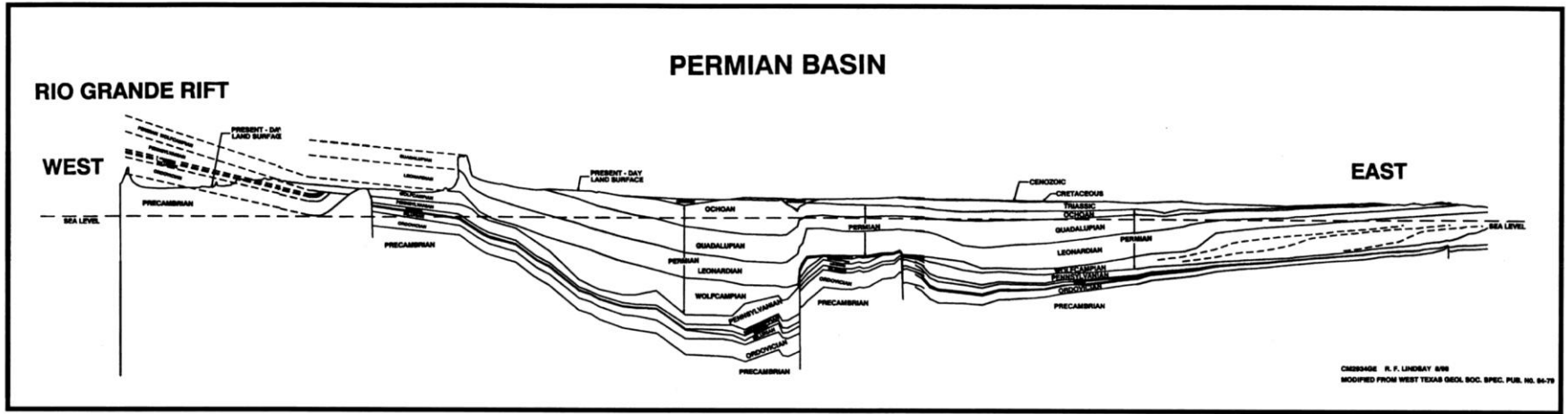


Figure 2. Generalized structural cross section restored to first phase (Late Oligocene to Early Miocene) of uplift, tilting, and extension of eastern limb of the Rio Grande Rift. This large, uplifted land surface to the west provided recharge of massive volumes of meteoric water into the Permian Basin (Modified from Matchus and Jones. 1984)

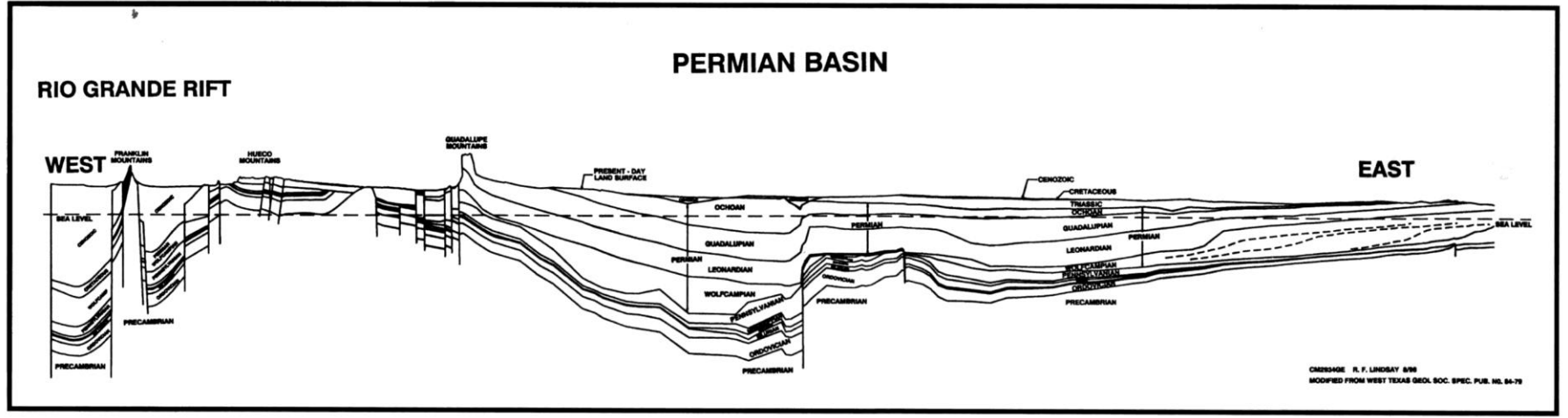


Figure 3. Generalized structural cross section showing present-day structural configuration of the Rio Grande Rife and the Permian Basin. Structures were produced by the second phase (Middle to Late Miocene) of rapid extension of the Rio Grande Rift. This extension created horsts and grabens of the classic Basin and Range province. The third phase (Pliocene to Recent) of slow extension produced deep fluvial incisions in the mountain ranges and stream piracy. The second and third phases of rift development left only small landmasses to recharge much smaller volumes of meteoric water into the Permian Basin (Modified from Matchus and Jones, 1984)

Extensional Phases and Reduction of Hydrodynamic Gradients in the Permian Basin*

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

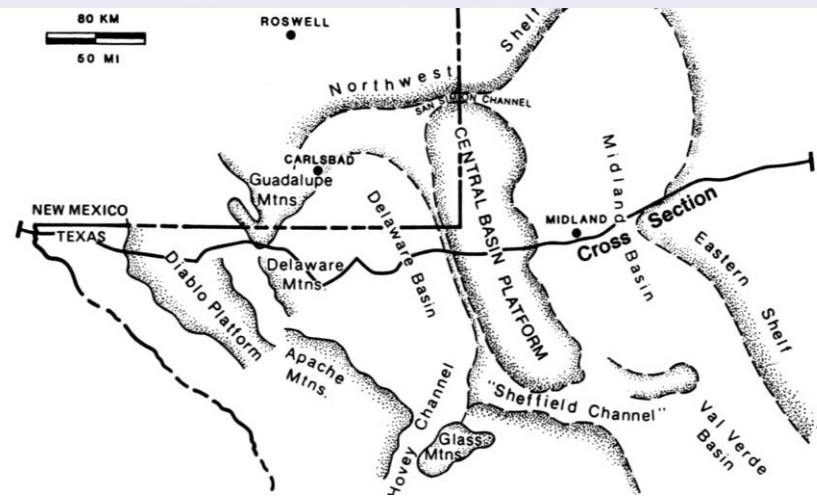
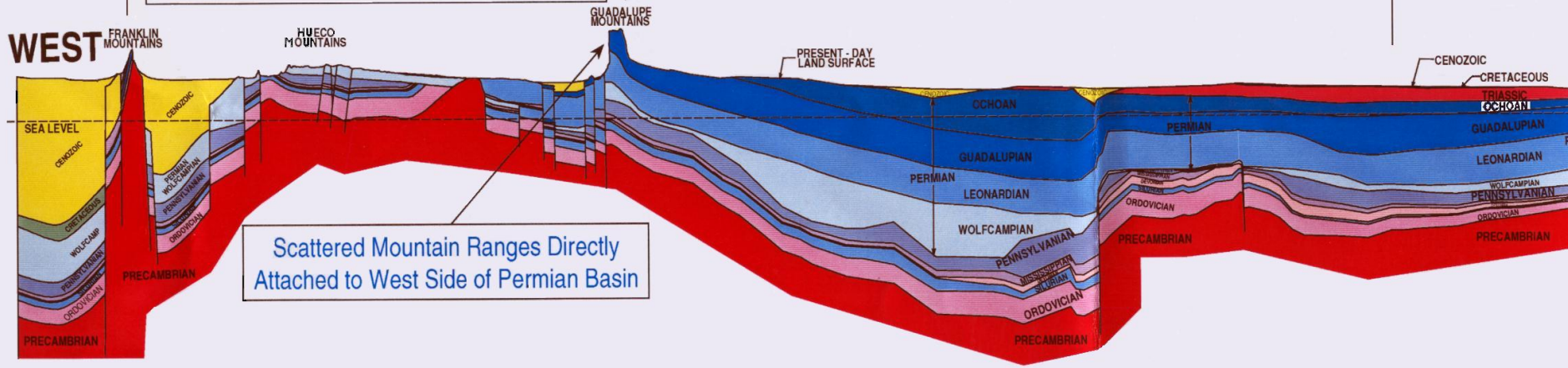
PERMIAN BASIN

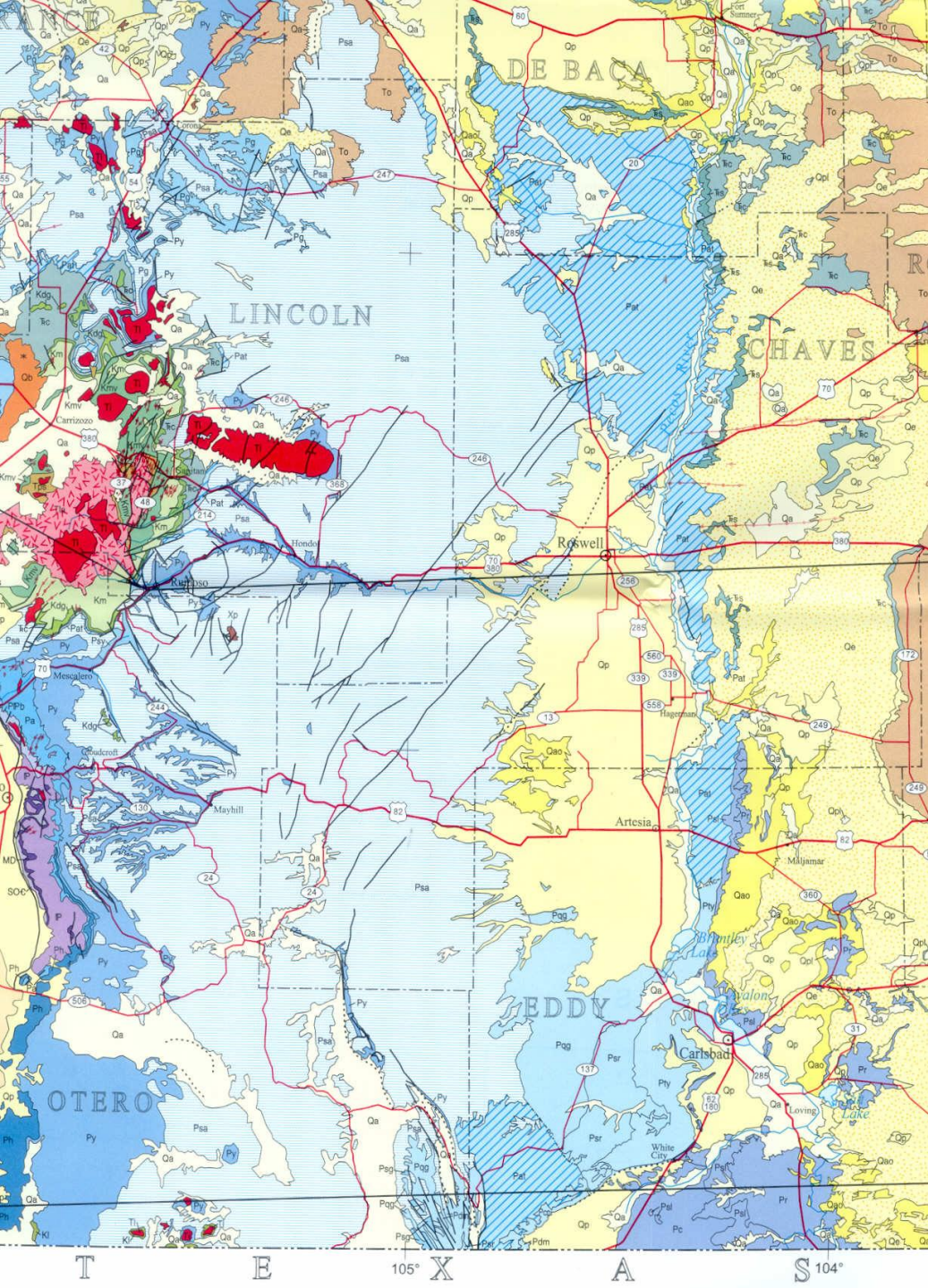
RIO GRANDE RIFT

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

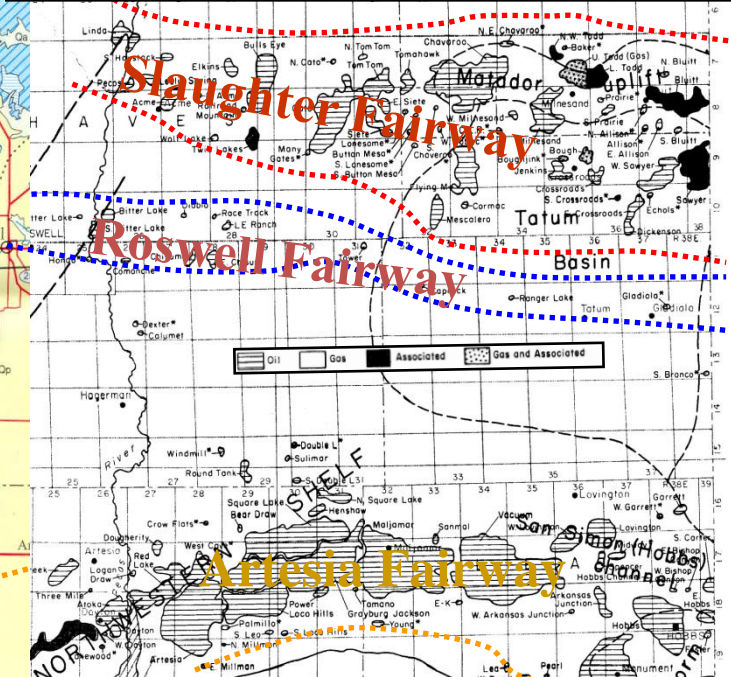
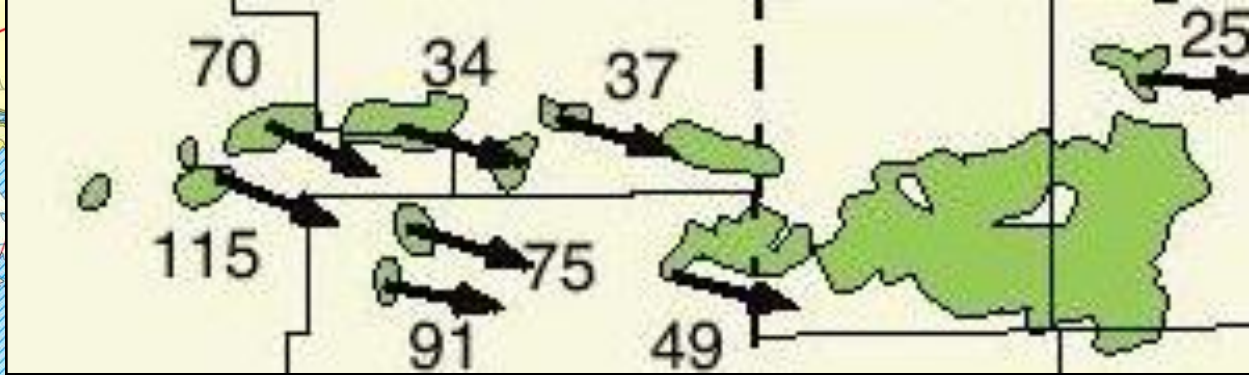
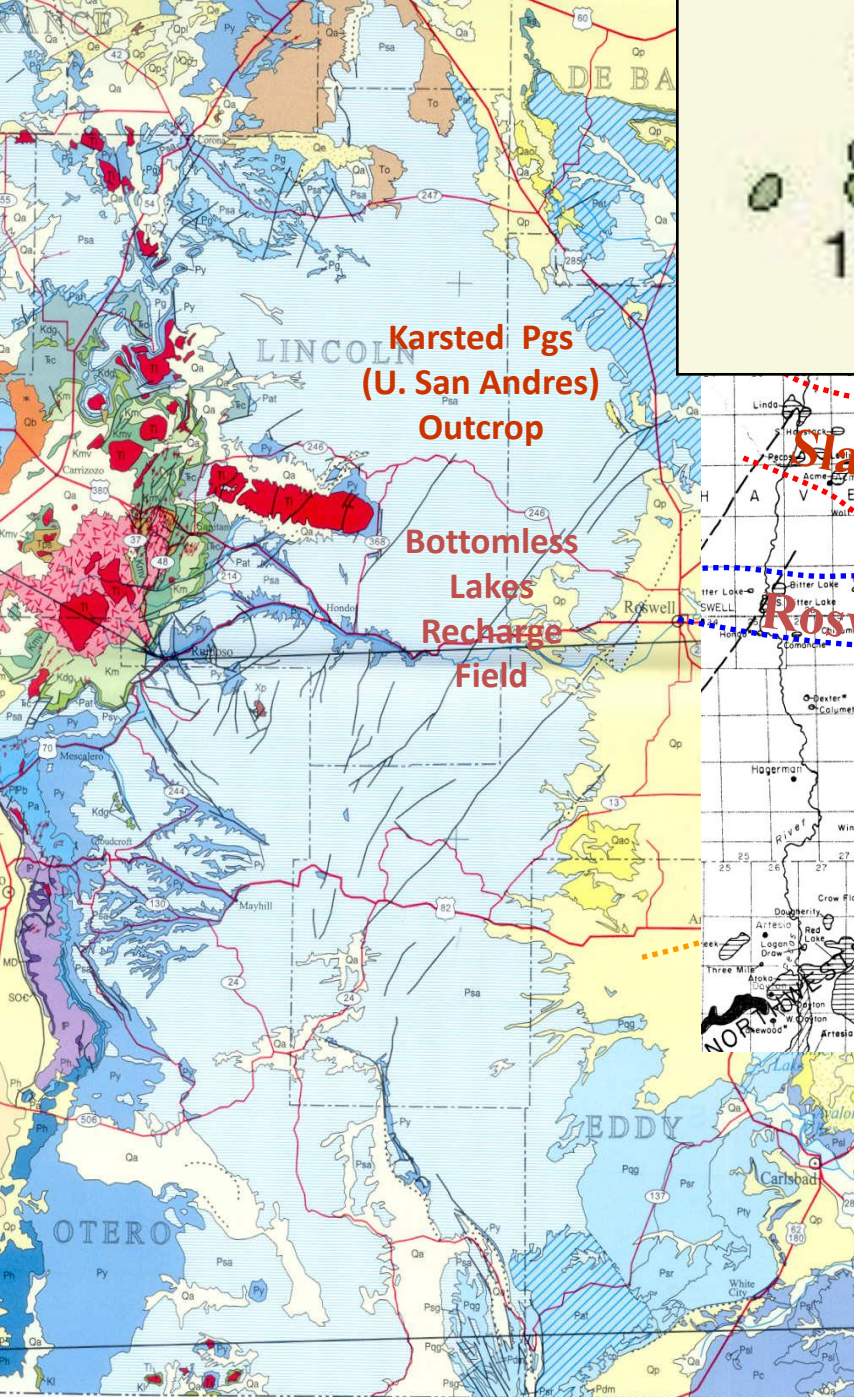
Displaced Oil Columns Resaturate with Oil, Some with Gas,
 & Some Stay at Residual Oil Saturation to Water (S_{orw})

Scattered Mountain Ranges Directly
 Attached to West Side of Permian Basin





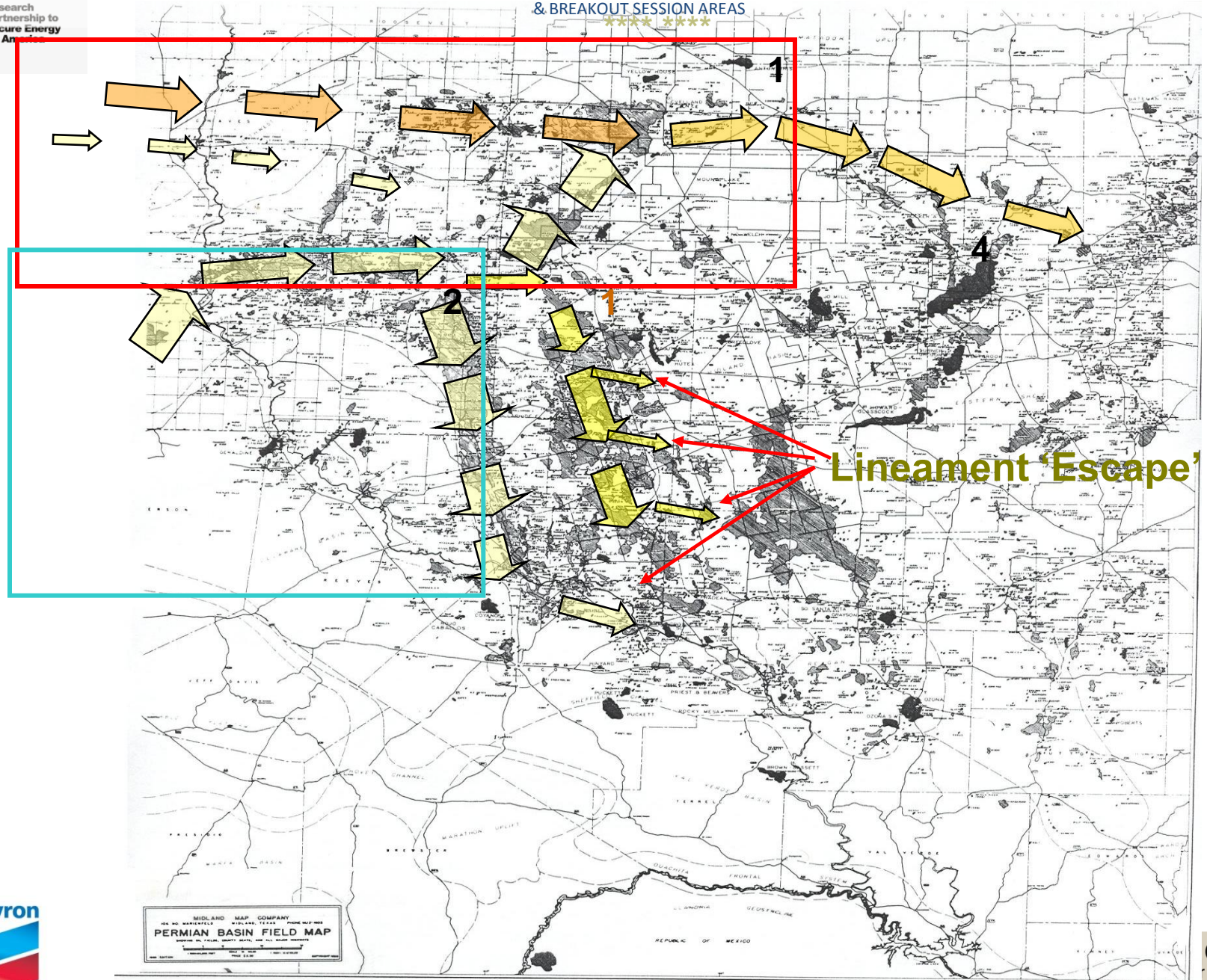
San Andres outcrop (light Blue) is the present day extent of the recharge area for the meteoric water that sustains the tilted oil water contacts in San Andres reservoirs.



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

PERMIAN BASIN FIELD MAP

WITH THEORIZED (U. PERMIAN) HYDRODYNAMIC FAIRWAYS
& BREAKOUT SESSION AREAS

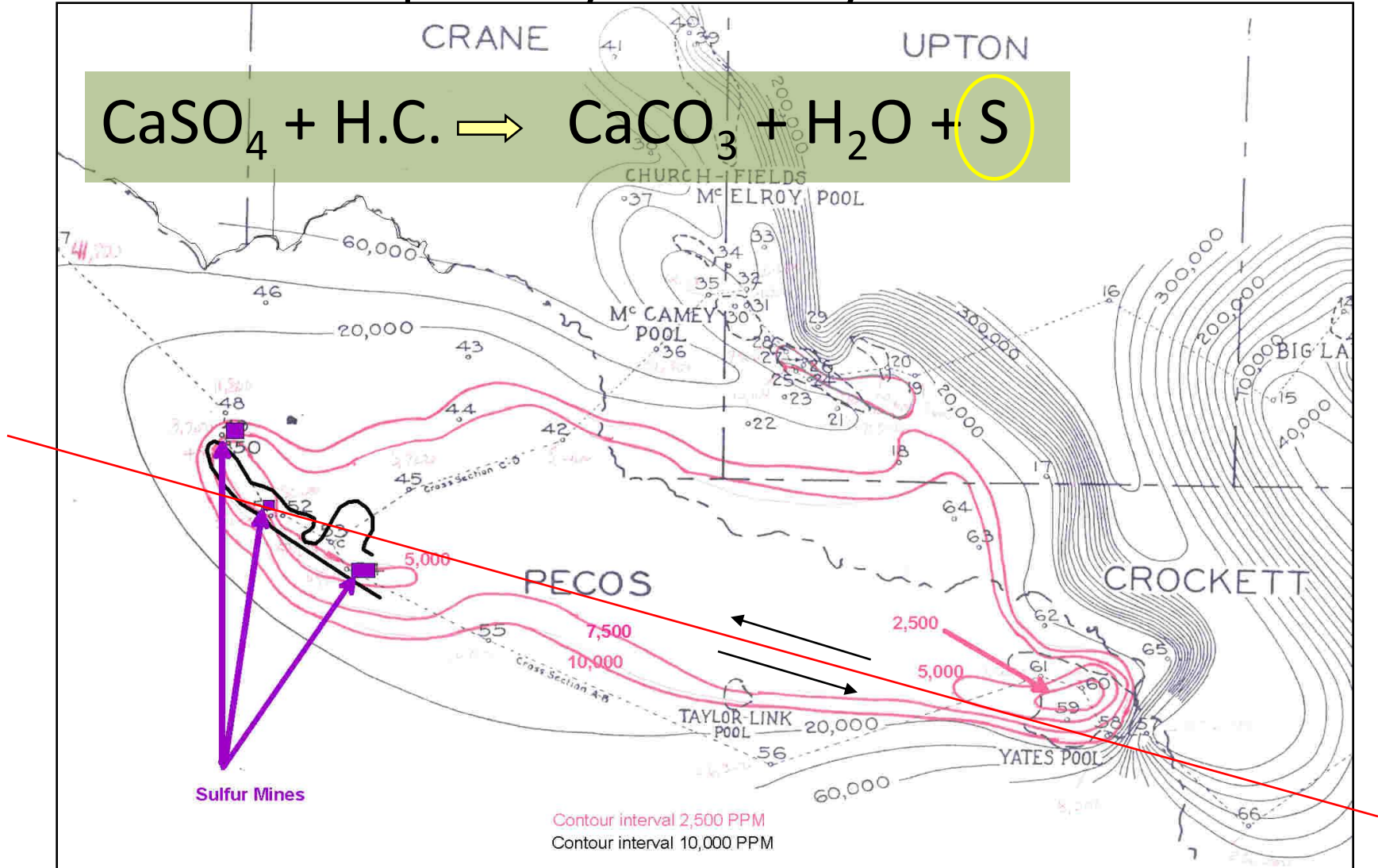
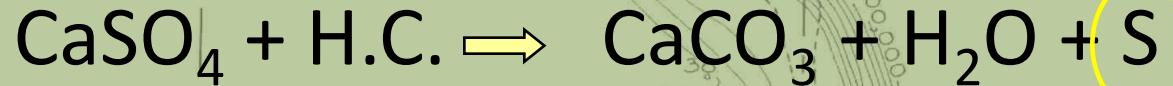


DISCHARGE PATH CONCEPTS (Hose Nozzle)

- 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



San Andres Water Salinities and Sulfur Deposits

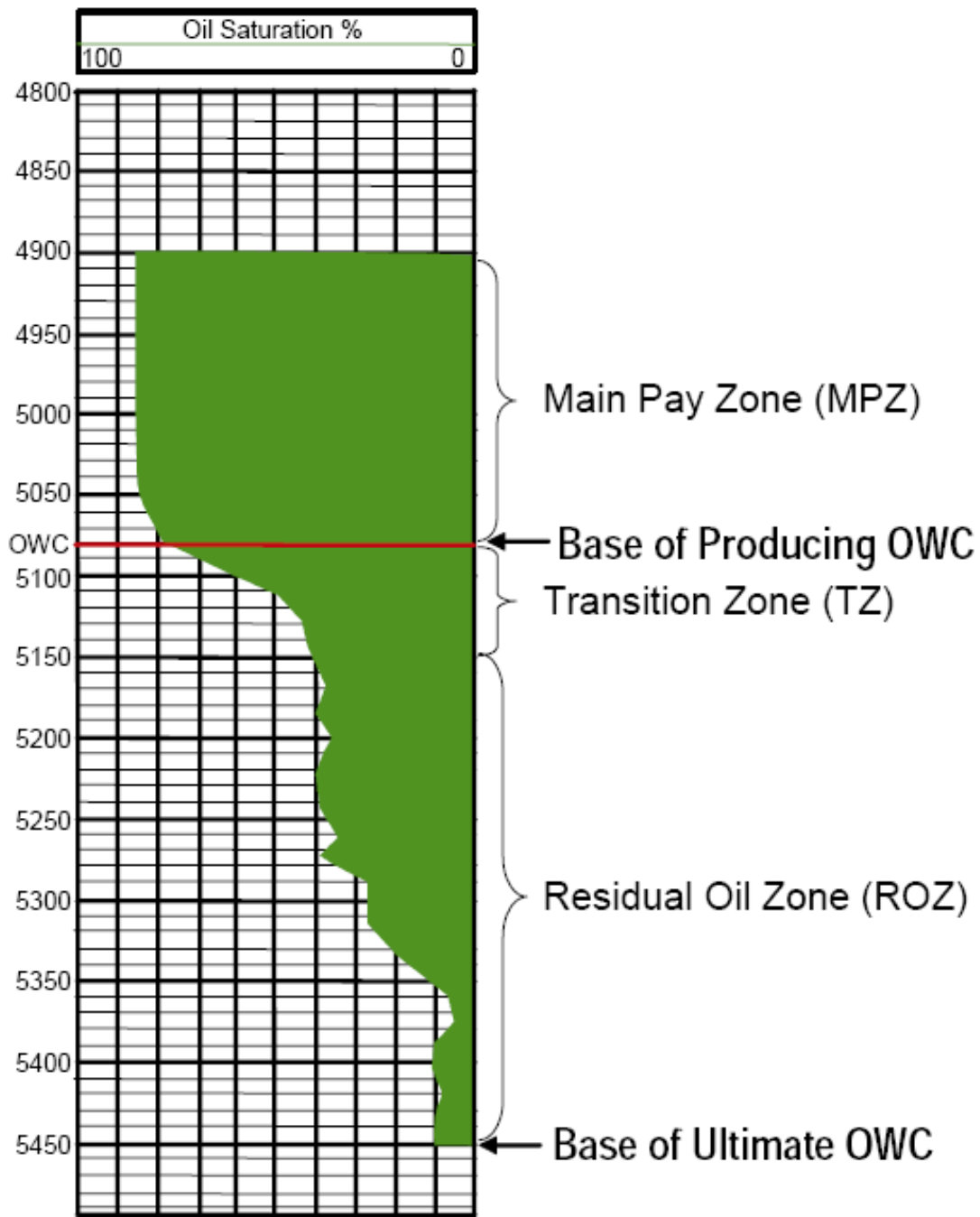
Anecdotal Evidence

- The anecdotal evidence from a growing number of exploration wells documents examples of what can be interpreted as ROZ's where the tests 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:
 - The presence of sulfur crystals associated with gypsum in the carbonates,
 - Enhanced porosity developed as the result of meteoric dissolution of sulfates in the ROZ
 - Sample shows of oil and/or gas,
 - Sulfur water produced on DST's or attempted production tests not salt water,
 - Core with 20-40% oil saturation,
 - Log calculations that suggest producible hydrocarbons. Have sulfur crystals in voids or associated with gypsum.
 - Evaporites may be dissolved or altered in the lower part of the main pay.
 - Porosities and Permeabilities can be higher in the ROZ than in the main pay zone as a result of the meteoric dissolution.

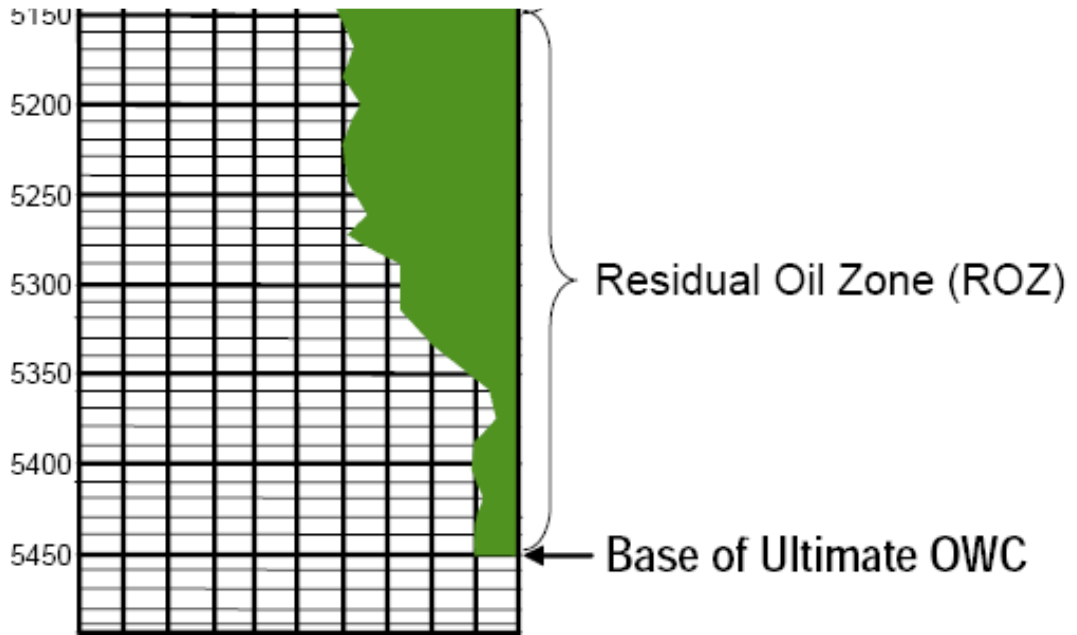
Other Anecdotal Evidence

- 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.
- Modeling of the system that created “Mother Natures Waterflood” will be completed as part of this study.
- Mutual Occurrence of Water, Oil and a Source of Sulfur
 - Water
 - Flushed Oil (Replenishing the Food for the Anaerobes)
 - Sulfur (product-of-reaction, residue)
 - As the Source of H₂S (and Sour Oil)
 - As Proof of Oil ‘Passing By’ & Fairways of Oil Movement
 - As Proof of Oil ‘Consumption’

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



**Your left with a
tertiary recovery
target.**

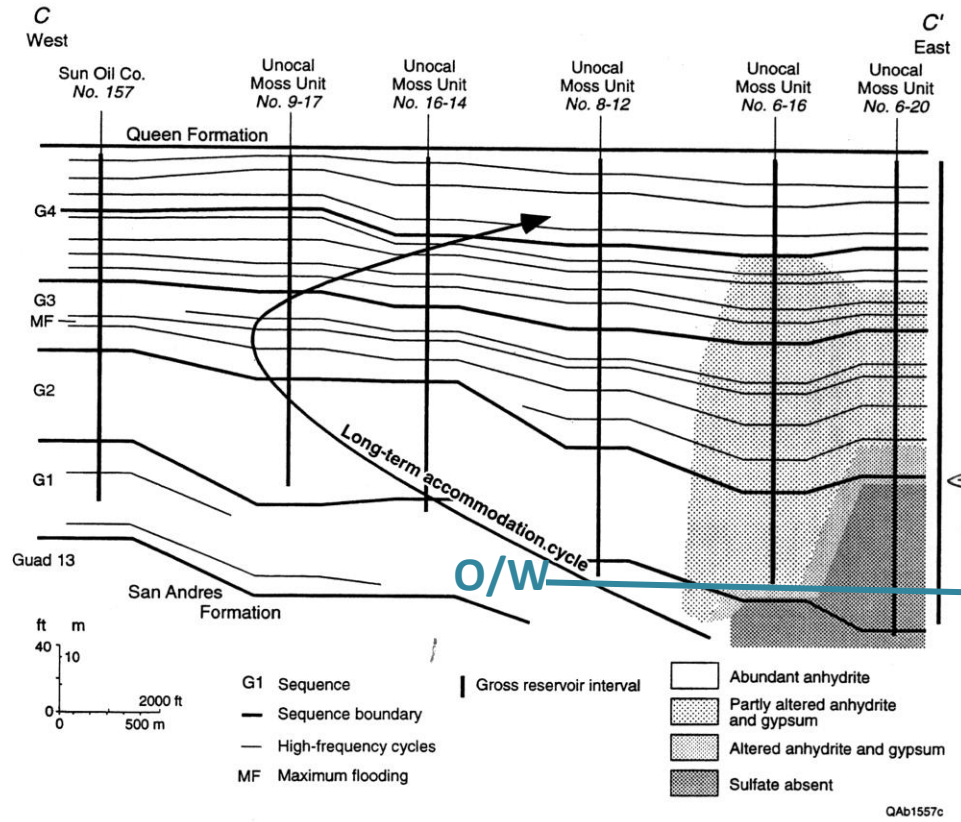
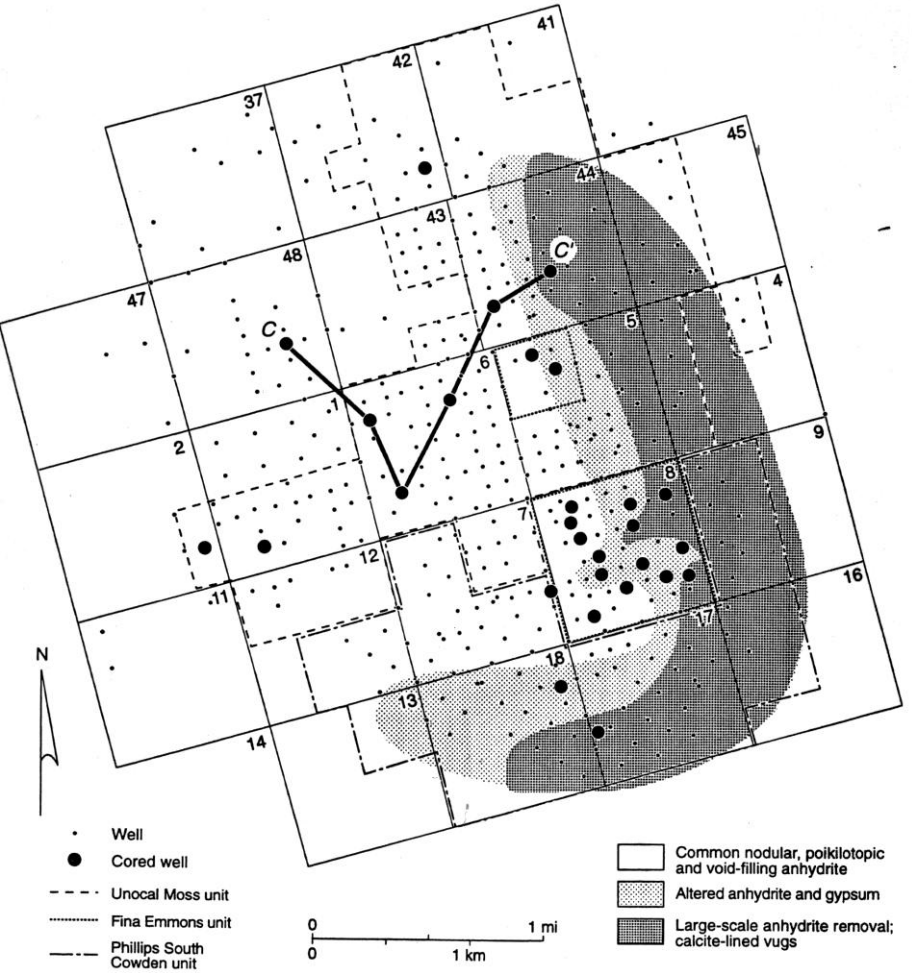


South Cowden

- There appears to be an ROZ in **South Cowden** in the Grayburg, based on BEG work on South Cowden.
- There was “massive sulfate removal mostly below the oil/water contact, an interval of carbonate diagenesis and the zone of altered sulfate.”
- This removal zone is concentrated on the east and south side of the field and is associated with the mud rich, deeper water facies. For the most part, intervals of total sulfate removal are restricted to depths below the estimated field oil/water contact(-1850’).
- Using the ROZ model, a different scenario can be presented that is related to the Meteoric sweeping of the reservoirs from north to south and paralleled the shelf margin and not perpendicular to it.

A. D distribution of altered sulfate & complete removal.

B. Dip section showing distribution and removal.

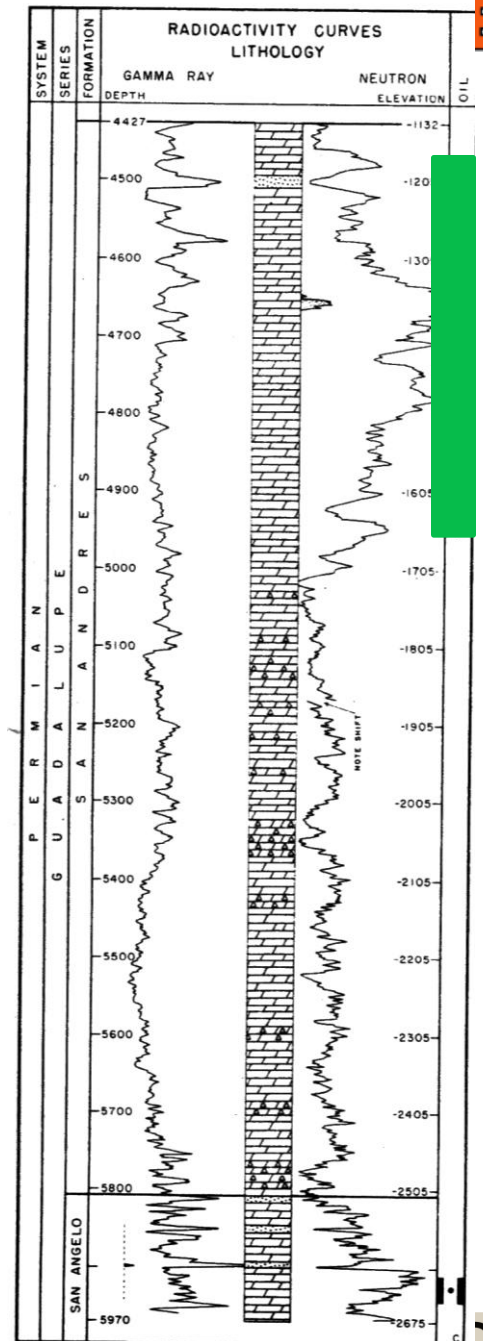


sulfate removal resulted in highest permeability in zone of sulfate removal.

Patterns of vertical and lateral distribution demonstrate that the alteration and removal of sulfate in S. Cowden are related to structural position. Sulfate diagenesis crosscuts facies and stratigraphy in the field.

Evidence from other Fields

- Dune Field - Extremely depleted d13C values typical of calcites produced as a byproduct of sulfate reduction and bacterial oxidation of crude oil in the presence of METEORIC FLUIDS.
- Robertson Field (Right) - Main pay is the Upper Clearfork. There is a minor San Andres pay (25' thick). It has been reported that there is a 250-300' thick oil bearing, non-productive interval. ROZ?



McCamey Field, Oil/Water contacts from core

- Oil/Water contacts from core, McCamey Field

| Well | Fm @ O/W | Depth | Fm @ ROZ | O/W | Depth |
|-------------------------|----------|---------|----------|-----|---------|
| Meridian 3622 "A" Lane | GRBG | +/-320, | SADR | SHR | +/-270, |
| Meridian 51R "A" Lane | SADR | +/-330, | | SHR | +/-280 |
| Meridian #19 Reese N244 | SADR | +/-304 | | SHR | +/-264 |
| BR N353 McCamey Unit | SADR | +/-326 | | SHR | +/-286 |
| BR 549RW McCamey Unit | SADR | +/-340 | | SHR | +/-288 |
| BR #1087 McCamey Unit | SADR | +/-340, | | SHR | +/-240 |
| Meridian 9R "A" Baker | GRBG | +/-385 | SADR | SHR | +/-282 |
| Gulf #16 B Shirk | GRBG | +/-280, | GRBG | SHR | +/-245 |

- Burlington said there are two periods of oil charging at McCamey.
- The thick SHR zone in the SADR is the result of "an early and late oil migration". Using the ROZ model, are we looking at swept oil column?
- Question: is the Grayburg O/W the same as the O/W for the San Andres? Historically, the operators used +/-330 as the O/W contact for the field. Based on SHR in core, +/- 280 is probably the original O/W contact.
- Therefore there was +/-50' of oil column swept at McCamey. 50' covering ~15 sq miles...**9600 acres X 50' X 20% porosity X Sw~20% X 7700 = 575,000,000 BO!**
575,000,000 X .25 (residual to nature's waterflood) = 150,000,000 BO in ROZ
150,000,000 X .66 = 100,000,000 BO potentially recoverable from ROZ.
- Unfortunately, SHR is a poor target for Tertiary Recovery.

North Ward Estes, western margin Central Basin Platform

- Some Production in Glorieta
- In lower San Andres, **H. S. A. #1449** core had good oil stain, but is not productive. Lower SADR producers - **#73, #76, #77, #79 Richter**. 13% or better porosity rhombic dolomite
- Minor production in upper San Andres on H. S. A. lease.
- The complete Grayburg oil column has been swept to Mother Natures Waterflood with no moveable oil for primary or secondary recovery. This area covers a six square miles. The interval has been cored and contained very dark oil saturation where, unfortunately, not a drop of oil was produced.

- What's going on?

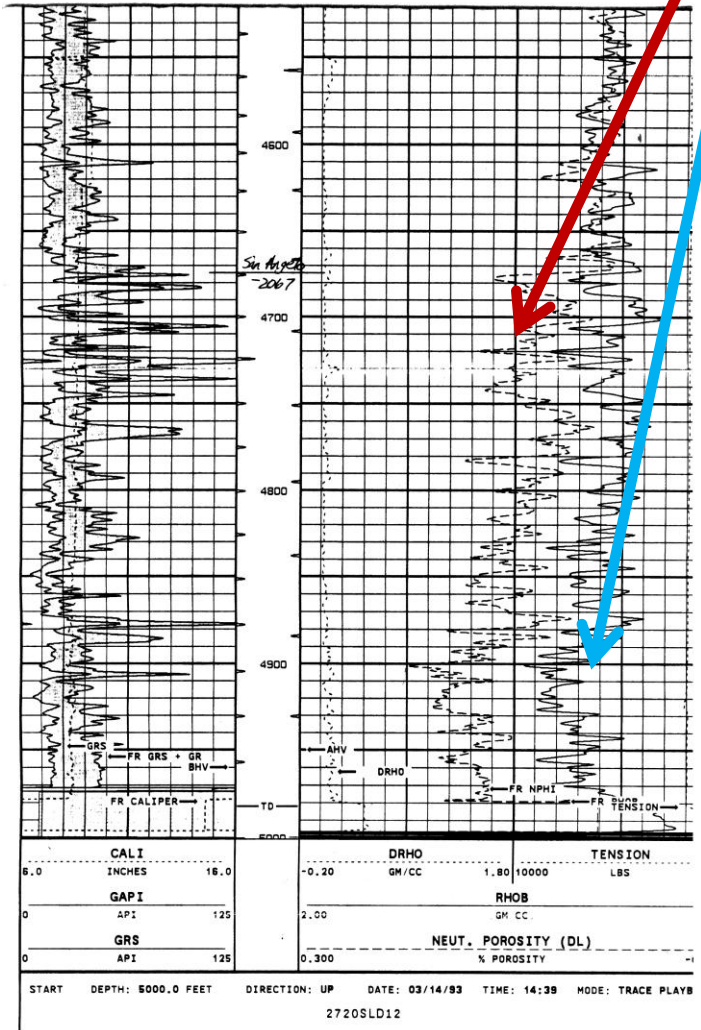
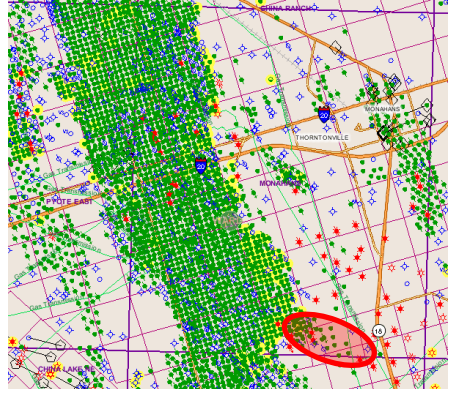
W. A. Estes "Holt" Field (actually Glorieta)

Discovered in 1991, produced over 1MMBO from a small closure with "tight" tidal flat and shallow subtidal carbonates.

Why did it take so long to discover it?

It's a cap for a thick porous dolomite considered to be the "pay" in the area. The interval had shows & calculated as productive, DST's a skim of oil and lots of sulfur water, tested a few times and left alone.

What is going on? It's postulated that the lower, porous portion was swept and only the tight, up-dip facies were left with >70% S_o.



The pay is the upper Glorieta/San Angelo.

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

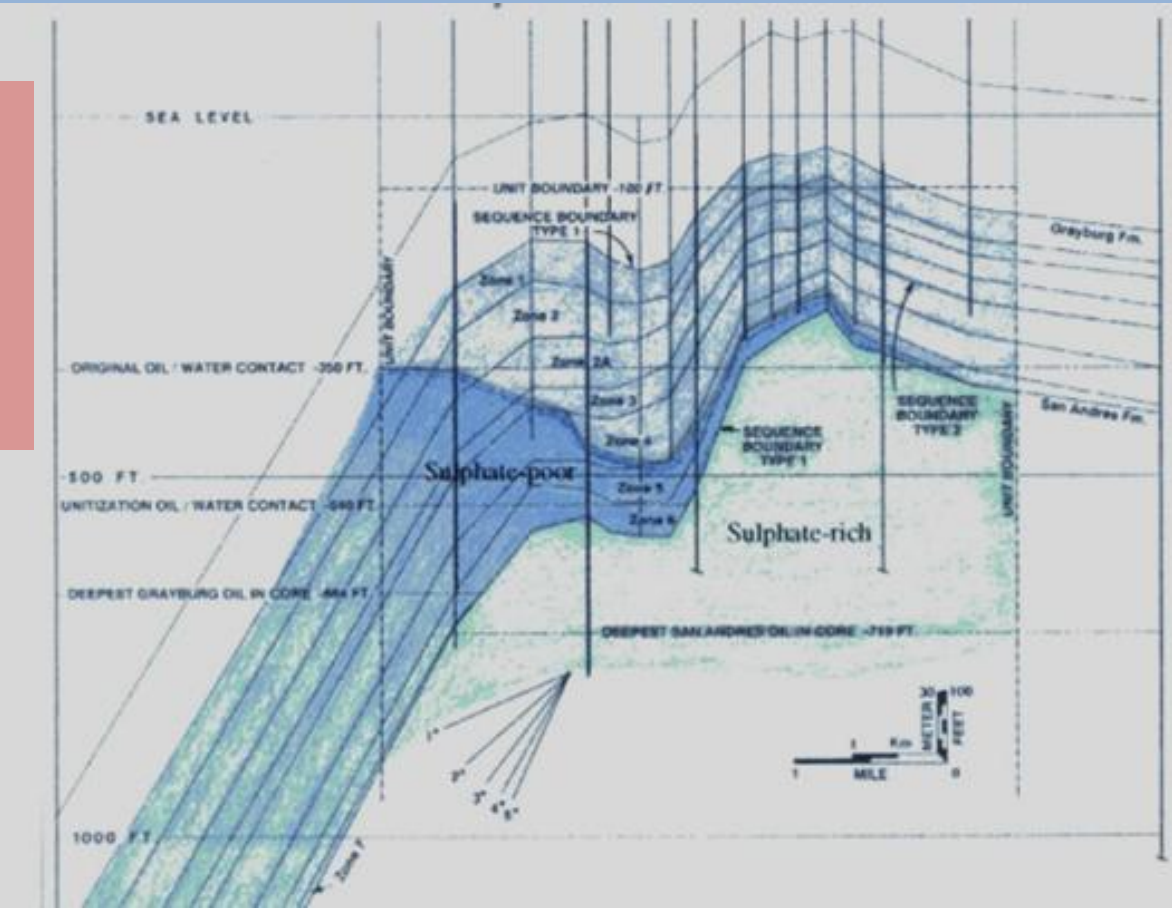
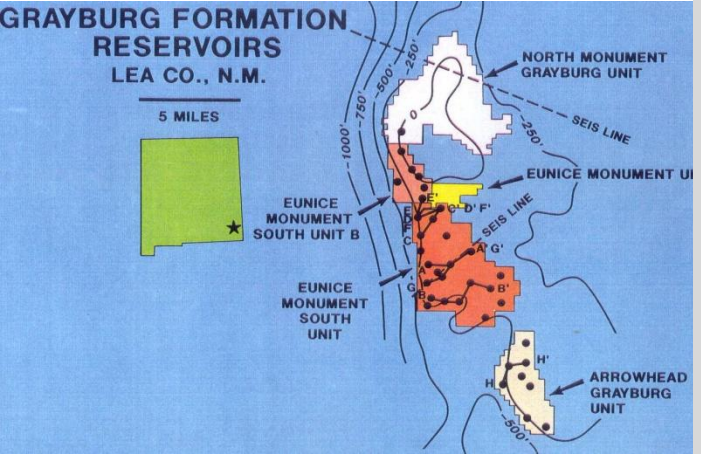
Eunice Monument/South Monument

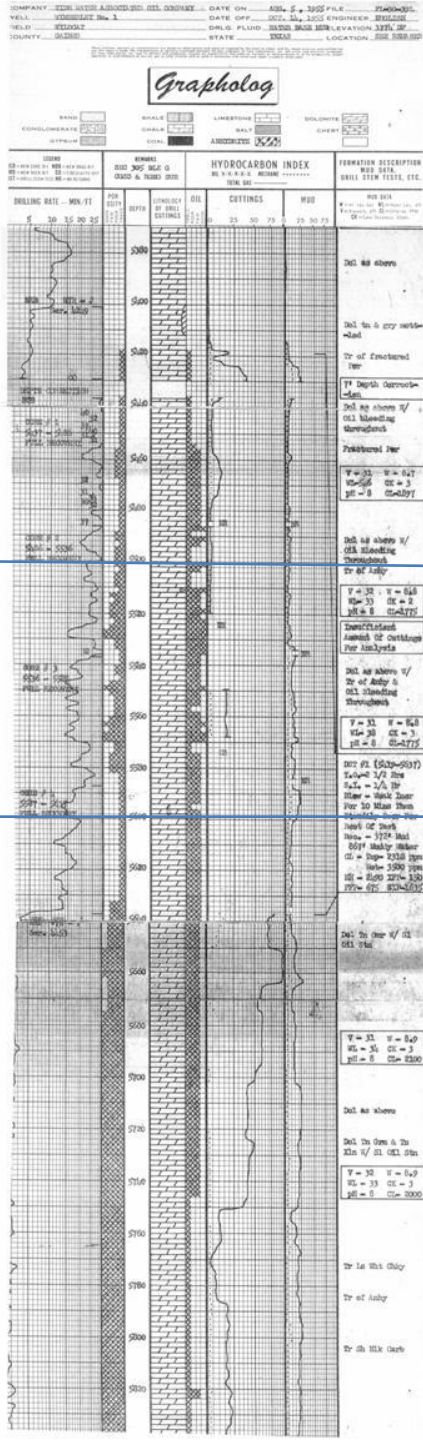
- Grayburg productive with NaCl rich connate water
- San Andres mostly wet with sulfate rich connate water
- Two different sources for the connate waters
- Thickness of San Andres swept reservoir?
- **Eunice Monument South Unit** Productive from the Grayburg with minor production from the underlying San Andres Formation—
 - Discovery Oil/Water contact -350'
 - Unitization Oil/Water contact -540'
 - Deepest Grayburg Oil in core -664'
 - Deepest San Andres Oil in core -719'
- >300' thick SADR w/oil saturation below O/W in Eunice Monument

North Monument Grayburg, Eunice Monument, Eunice Monument South "B", Eunice Monument South, and Arrowhead Grayburg Unit .

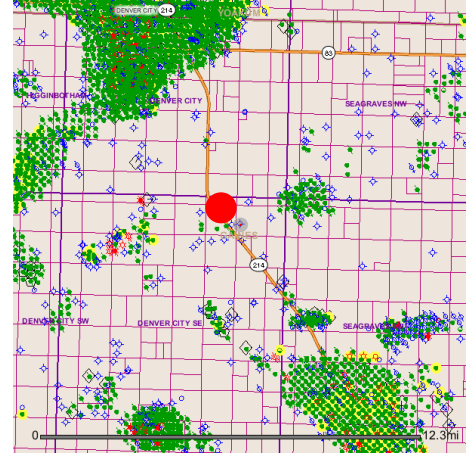
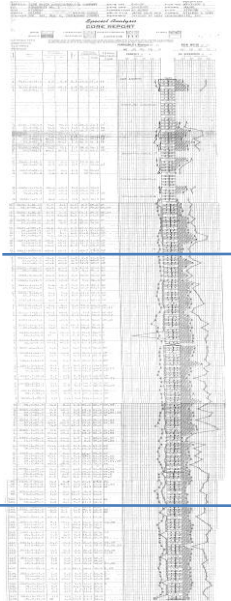
- area combined total of 57 square miles.
- Lindsay suggests the sulfate poor edge water is recharged from the Guadalupe Mountains thru the Goat Seep Reef. The Sulfate-rich bottom water drive in the San Andres is recharged from the Sacramento Mountain thru the evaporite rich San Andres.
- **Eunice Monument South Unit.** The edge water was pulled into the oil leg since production was established in 1929 (from Lindsey, Chevron in-house pubs).
- Structural closures formed by re-activation of existing deep seated faults which folded and fractured the Permian. The structural event increased closure on the reservoir and trapped a larger oil column.

- Eunice Monument
- -150 G/O, -400' O/W (150' below top SADR).
- Na 2000ppm, Cl 2950ppm, TDS 7800PPM (similar to Capitan Reef in Winkler Co.)





ROZ's have been tested for 50 years.



At **Bale East**, Gaines Co., **Tidewater #1 Wimberley**, 305, Blk G CC&RGNGRR.

sec

Is on the east flank of a structure.

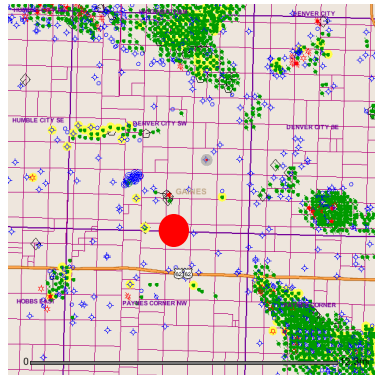
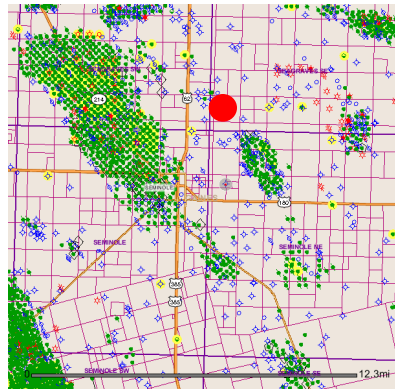
Drilled in **1955**. Cored interval, 5437-5637, had bleeding oil & gas throughout, has 20 to 30% oil saturation throughout the length. DST'd 5419-5637, rec 372' mud, 867' MCSW. Mudlog Sample cut, good bleeding oil to 5745'.

ROZ?

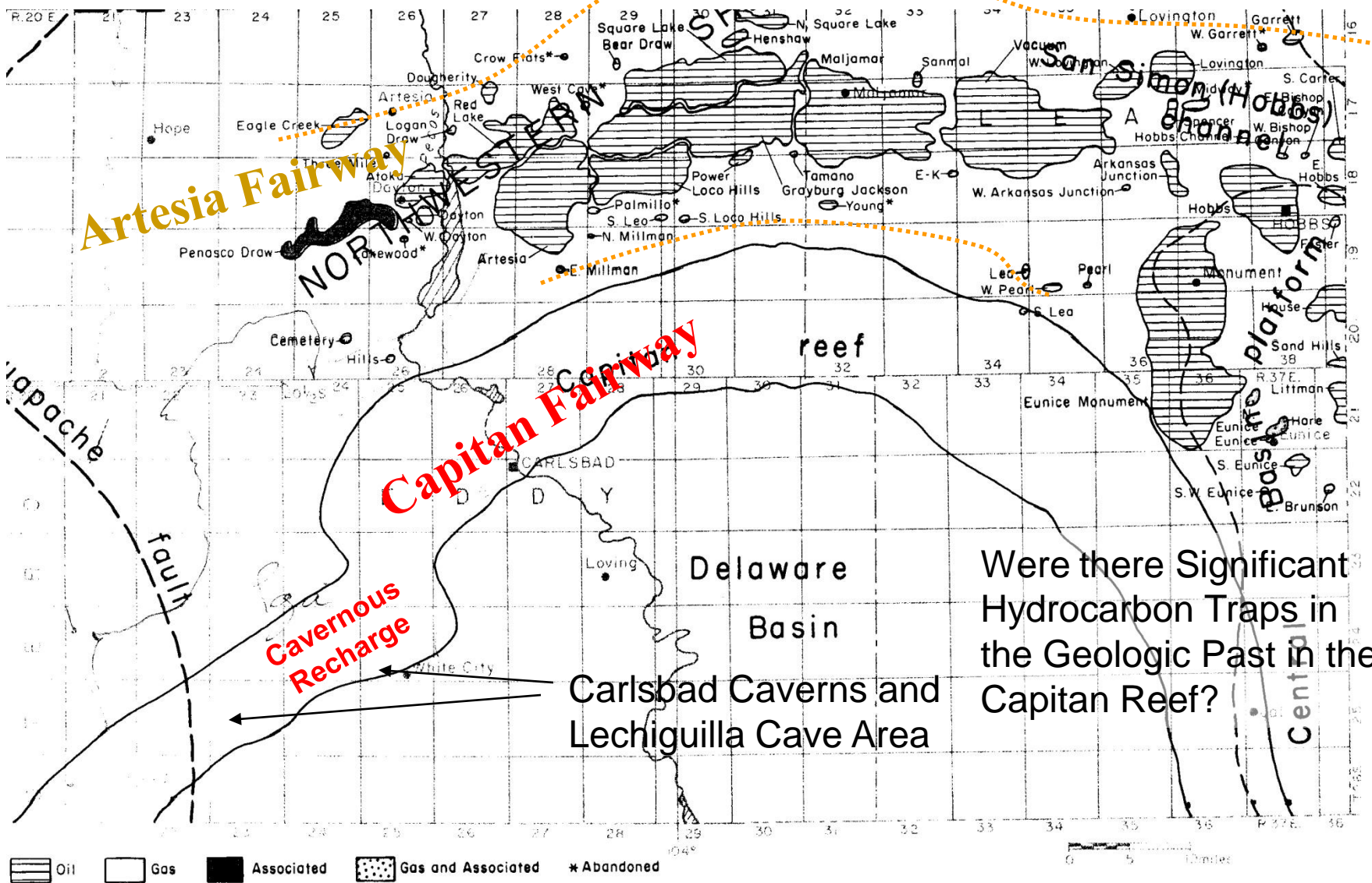
The total length of core and sample shows is 310', from 5437[in core] to 5745[in samples]. DST in the San Angelo (6680-6785) rec 150' muddy Water, 4830' black water (sulfur?).

Gaines, Future Targets or goat pasture?

- A Clearfork test, the **IP #1 Campbell Heirs “158”** set pipe on “WET” San Andres test just south of Seminole.
- All wireline logs, drill time, gas curves and sample said “slam dunk” oil production. Atlas log analyst said it should be a producer.
- 100% water test with barely a sniff of live oil. ROZ?
- **Anschutz #1 Patrick Keating “447”**, drilled for San Andres west of Seminole, had good shows but made only water for a few months before P & A (**3600 BW, 3 BO**). Water analyses show progressive drop in TDS over the two months of production.
- The 2 CORED intervals, from 5464 – 5602, had oil saturations ranging from 15 to 35%, 3 - 12% porosity, & 50-100% fluorescence.



SE NM Grayburg & Upper San Andres Dolomitization Trend



Were there Significant Hydrocarbon Traps in the Geologic Past in the Capitan Reef?

Ref: Future Petroleum Provinces in New Mexico – Discovering New Reserves, Philip R. Grant, Jr. and Roy W. Foster, NM Bur of Mining & Mineral Resources, 1989

Summary

- We've only just begun.
- ROZ's are real and a major tertiary recovery target for today and long into the future.
- Modeling using regional scale groundwater modeling package is underway.
- Documentation of areas/fields with large potential is underway.
- Phase 2 – testing models in the field.