Residual Oil Zones
from Science to Commercial Exploitation

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UTPB/CEED

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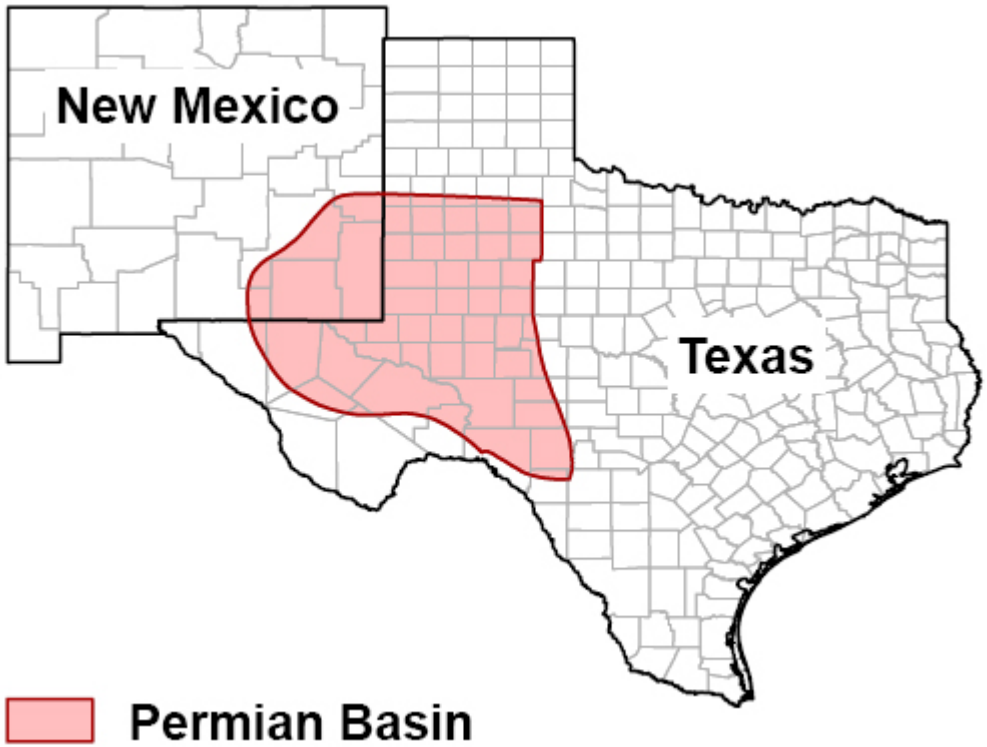
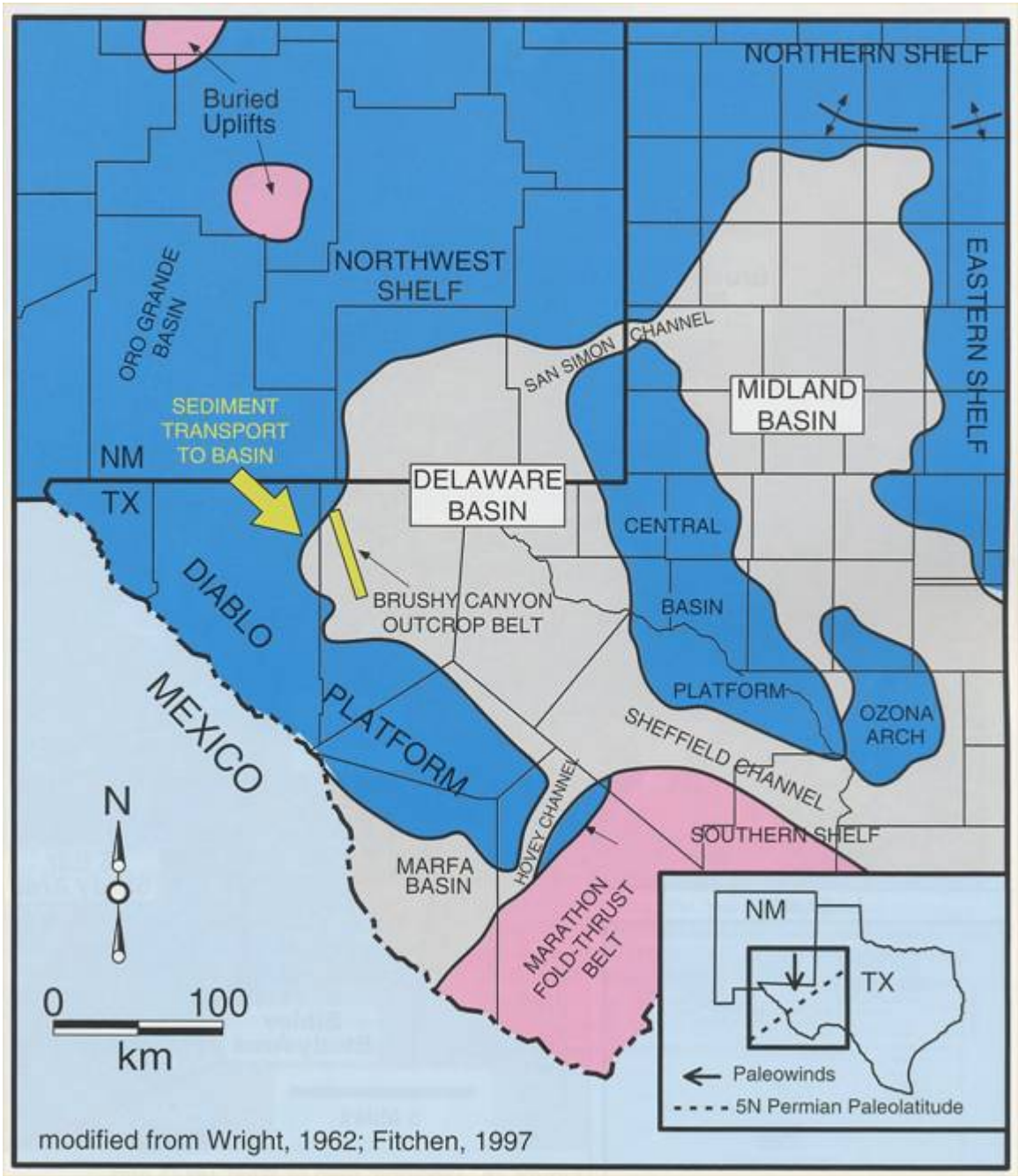
Rocky Mountain Section – AAPG

Presented by W. Hoxie Smith


New Mexico
Texas
Permian Basin


Buried Uplifts
NORTHERN SHELF
NORTHWEST SHELF
ORO GRANDE BASIN
EASTERN SHELF
SAN SIMON CHANNEL
MIDLAND BASIN
SEDIMENT TRANSPORT TO BASIN
NM
TX
DELAWARE BASIN
CENTRAL
BASIN
PLATFORM
BRUSHY CANYON OUTCROP BELT
DIABLO PLATFORM
MEXICO
OZONA ARCH
SHEFFIELD CHANNEL
HOVEY CHANNEL
SOUTHERN SHELF
MARFA BASIN
MARATHON FOLD-THRUST BELT
N
0
100
km
NM
TX
Paleowinds
5N Permian Paleolatitude
modified from Wright, 1962; Fitchen, 1997

First Basin-wide Study of Residual Oil Zones (ROZ's)

- Support: Research Partnership to Secure Energy for America (RPSEA), UTPB, Chevron, Legado
- ROZ's have historically been interpreted as being long Transition Zones.
- Upper portions of ROZ's have long been assumed to contribute to production in some fields, only recently have they been exploited w/CO2 injection for EOR.
- Development wells have often been drilled through ROZ's with good shows, porosity and oil saturation in core, and in zones calculated to be oil productive. But, with a bad record of successful completions.

Melzer CO_2nsulting

Project Objectives

- To describe the origins and distribution of ROZ's in the Permian Basin.
- To document oil field case histories.
- To flip the paradigm – from zones to avoid to intervals of opportunity.
- To identify the magnitude of the prize.
- To collect anecdotal evidence from the Permian Basin oil and gas community.
- To chart a future for the EOR/ROZ effort.

Where we are today

- ROZ's are 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 at Wasson, Seminole, Vacuum, Means, Goldsmith, and Hanford Fields.
- Production from ROZ's, anecdotal evidence from exploration wells, and the theory of the development of Residual Oil Zones, has led us to believe there are potentially billions of barrels of additional producible reserves in the Permian Basin and elsewhere.

	Formation	Area	Field
Guadalupian	Queen		
	Grayburg	C. B. P. N. W. S.	N. & S. Cowden Maljamar
	U. San Andres	C. B. P. N. W. S.	Means Hanford N.M.F.U.? Eunice Mon.?
	M. San Andres	C. B. P. N. W. S	Seminole Vacuum Goldsmith Robertson?
Leonardian	L. San Andres	N. W. S. C. B. P.	Wasson Yates? McCamey?
	Glorieta	N. W. S.	
	U. Clearfork	C. B. P.	Robertson?
	Tubb Sand		
	L. Clearfork	C. B. P	Sand Hills?
	ABO	N. W. S.	Empire?

Calibrating the Oil Recovery Models and EstimatingTechnically Recoverable ROZ Oil

ROZ OOIP in these 56 fields – 5 Permian Basin oil plays - estimated to be 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 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

Technically Recoverable Resources from the MPZ and ROZ

By applying CO_2-EOR, ARI's reservoir modeling estimates that **11.9 Billion BO is technically recoverable from the 30.7 Billion BO of TZ/ROZ oil in-place**

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

“Common Knowledge”

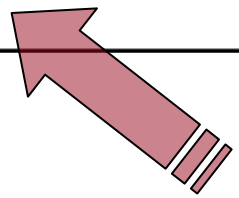
- Where there are tight rocks beneath the oil/water contact, there are longer Transition Zones.
- Some contribution to production can be expected from the uppermost Transition Zone.
- Residual Oil Zones are no different than Transition Zones. It’s just semantics.
- There are two periods of oil migration (post-Permian and Cretaceous/Tertiary) commonly proposed for Permian fields in the basin.
- There was a late Cretaceous tectonism that “adjusted structure” and created larger closures, resetting oil/water contacts.
- The 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.

Residual Oil Zone Paradigms

- Large intervals and areas have been swept by “Mother Nature’s Waterflood” which occurred post/syn oil emplacement.
- ROZ’s have the same saturation characteristics as mature waterfloods in the swept intervals.
- ROZ’s often are interpreted/calculated as producible in exploration wells:
  - good odor, cut, fluorescence, and gas in samples
  - 20-40 % oil saturations in core
  - calculate as oil productive on logs
- ROZ’s produce high percentage of water on DST’s or completions.
- Usually found where there are significant thicknesses (50 to 300’) of producible hydrocarbons in producing fields, but they are outside the present limits of producing fields.
- This “faux-productive” appearance of ROZ’s is presently found both beneath producing fields and in areas where there is no, or a minimum, producible oil column.

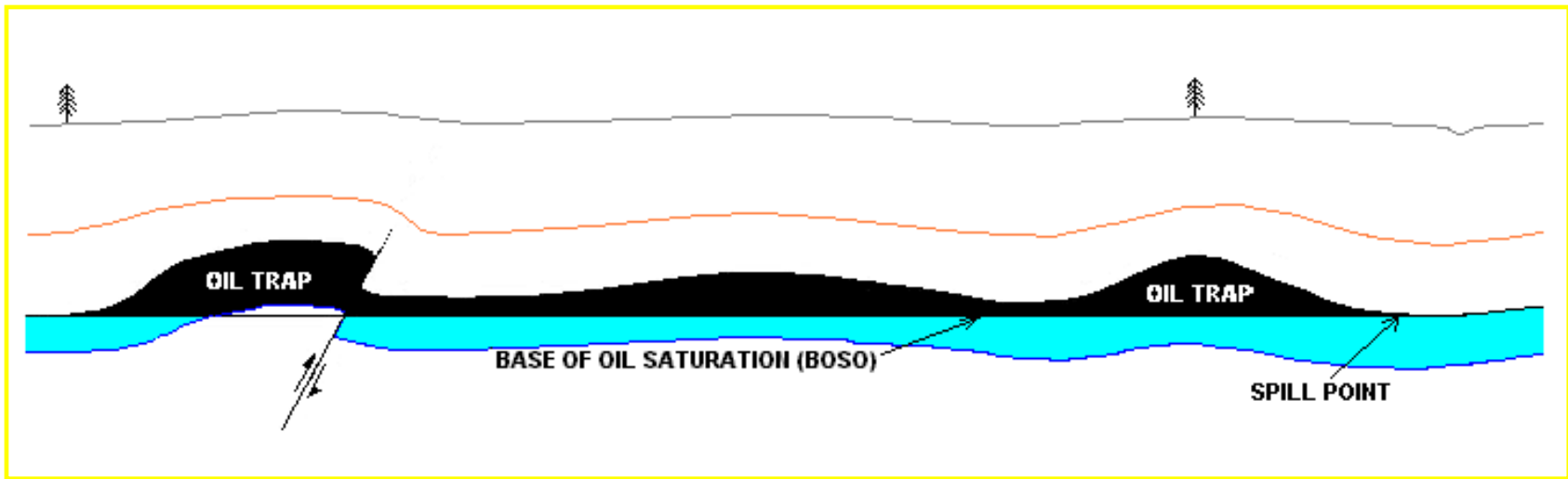
ROZ BACKGROUND
The 3 types of Residual Oil Zones

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)

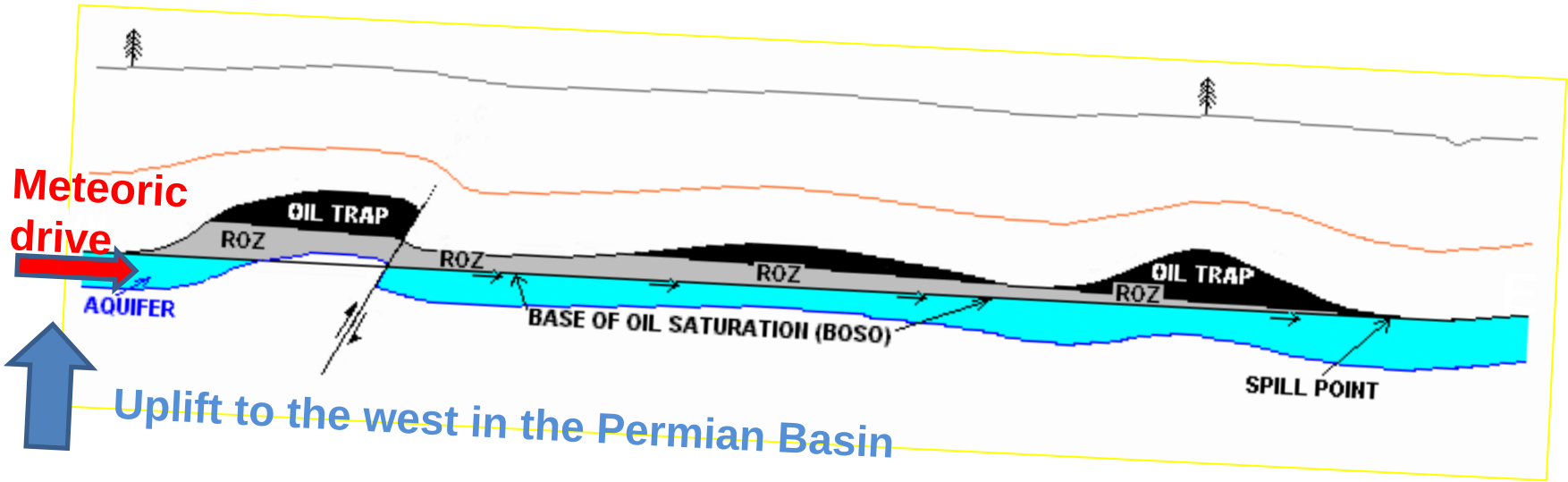


The Evidence suggests Type 3 are common in the Permian Basin

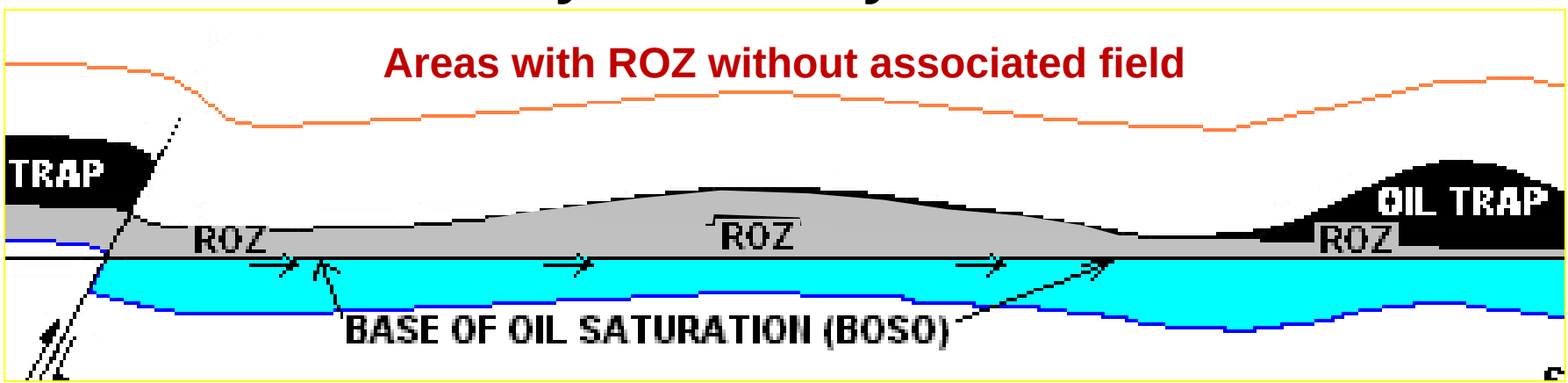
Original Oil Accumulation Under Static Aquifer Conditions
(A Hypothetical Example)

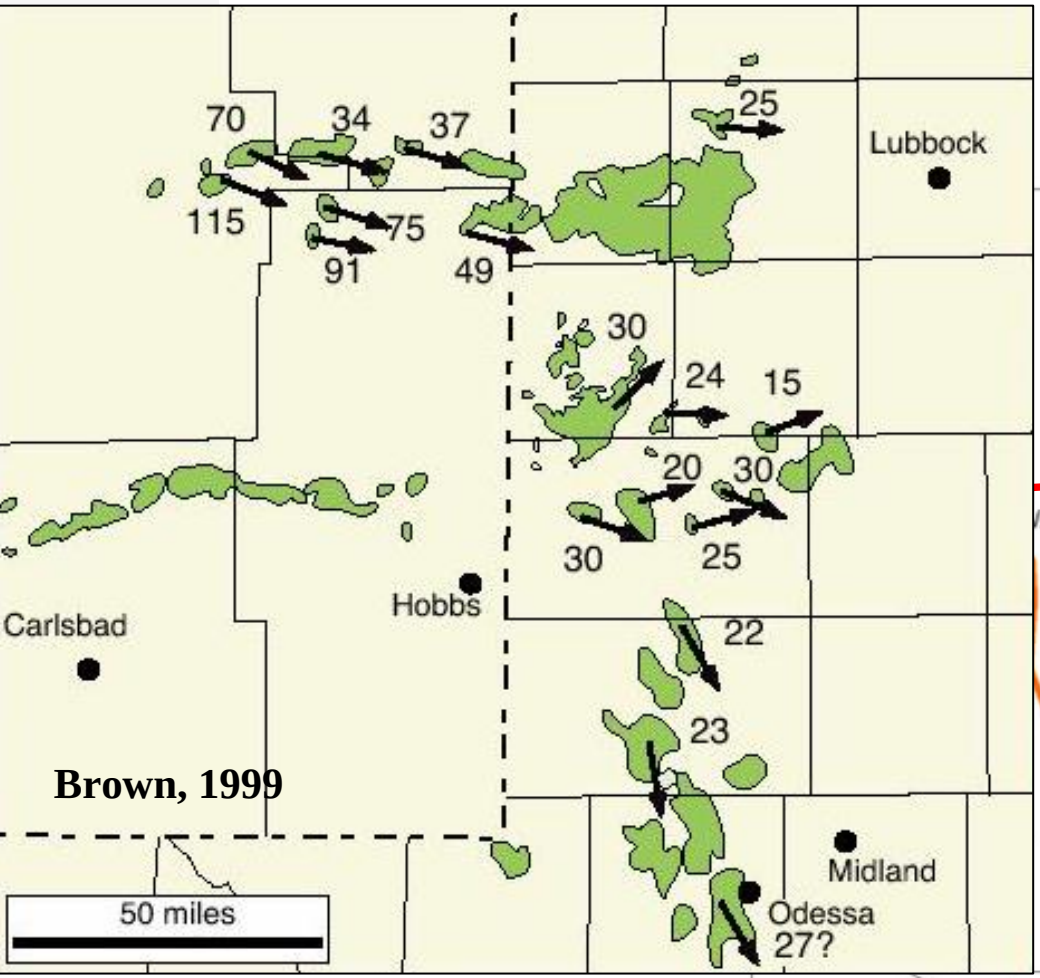


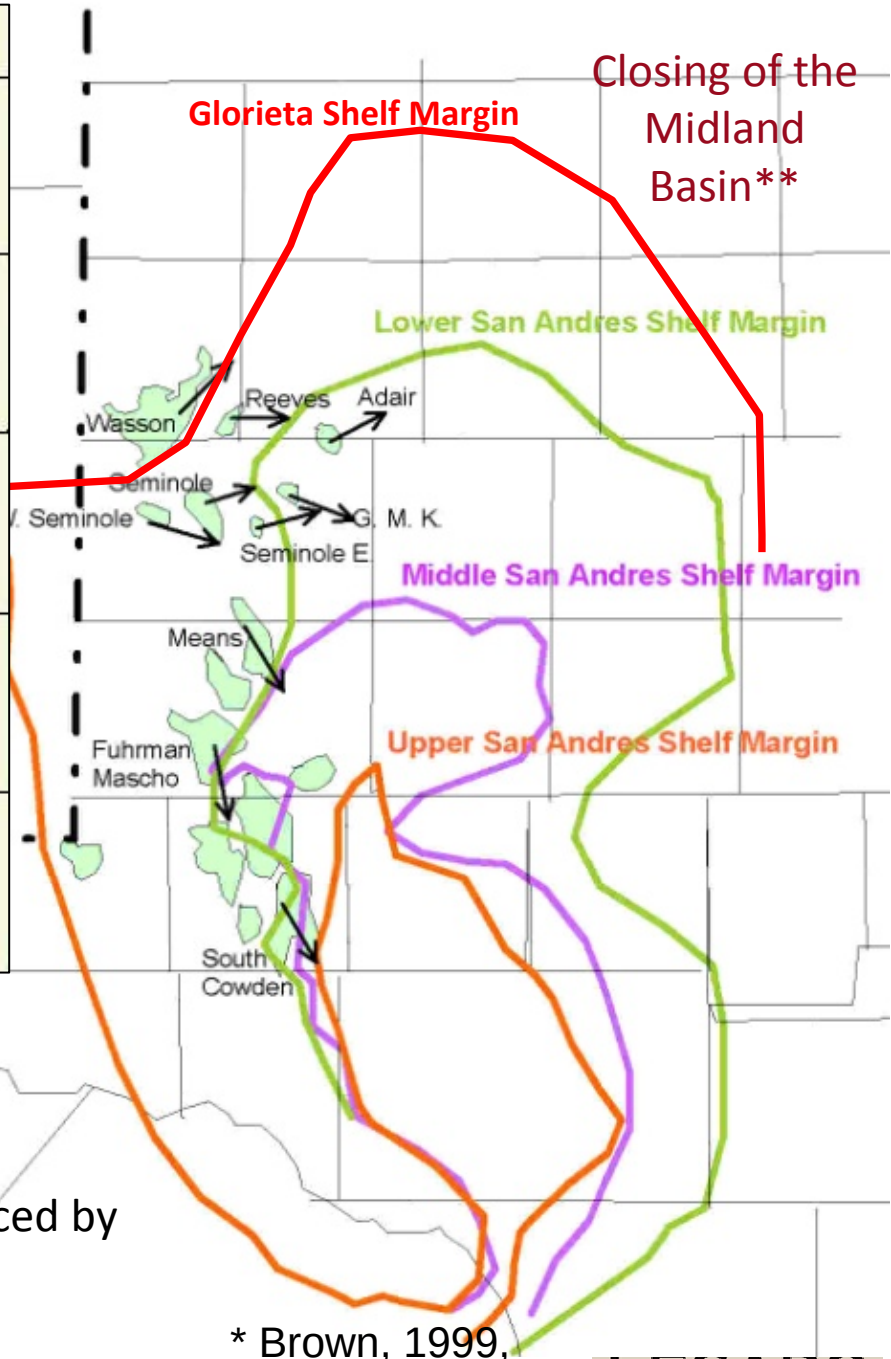
TYPE 3: Change in hydrodynamic conditions, sweep of the lower part of the oil column and development of a residual oil zone. Oil/water contact is tilted. Base of the ROZ locally almost flat, regionally tilted.



Dynamic System







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

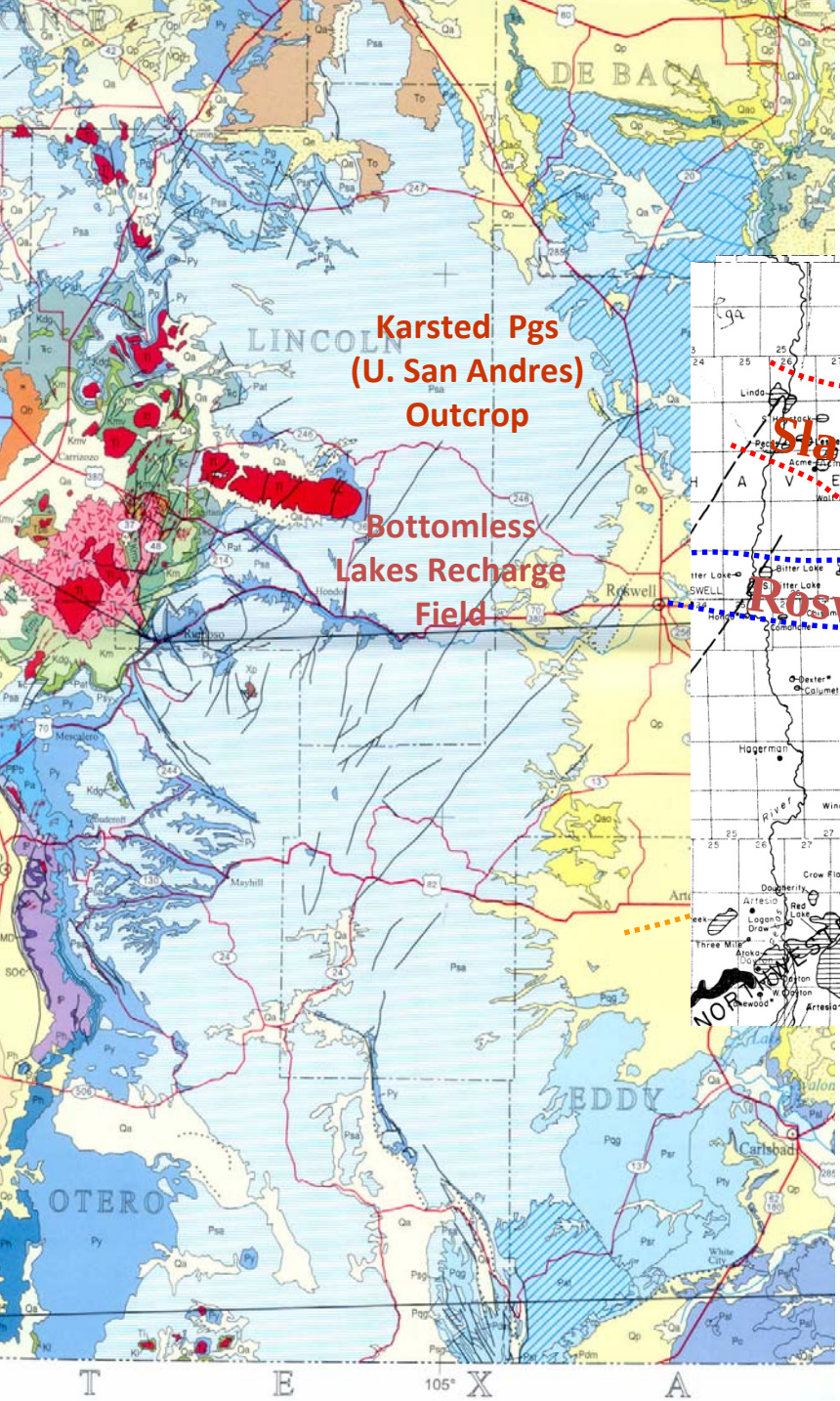
The direction of OWC tilt may be influenced by the age of the producing interval and it's relationship to the shelf margin

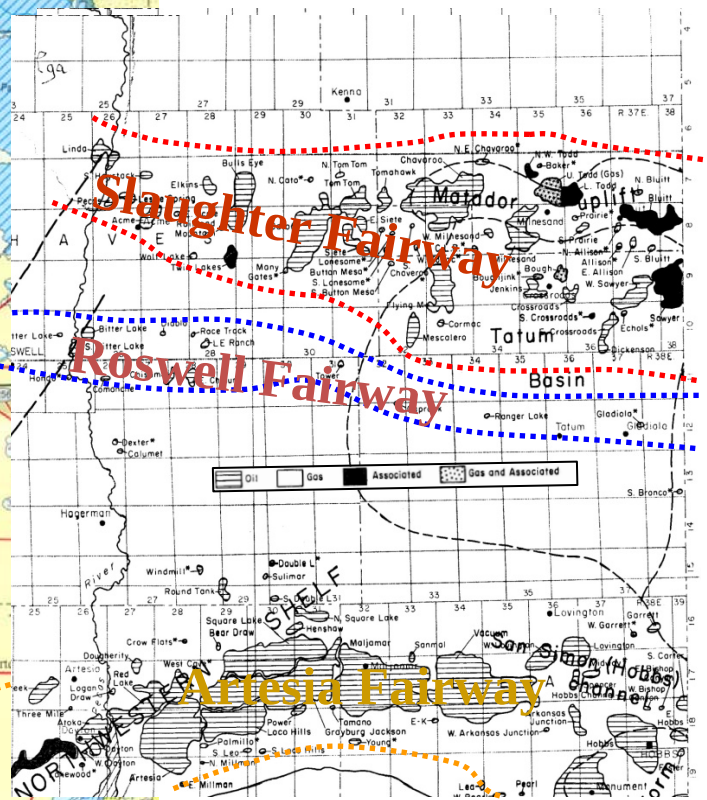
* Brown, 1999,
** Ward et al, 1986

Chevron

Melzer Consulting

LEGADO resources

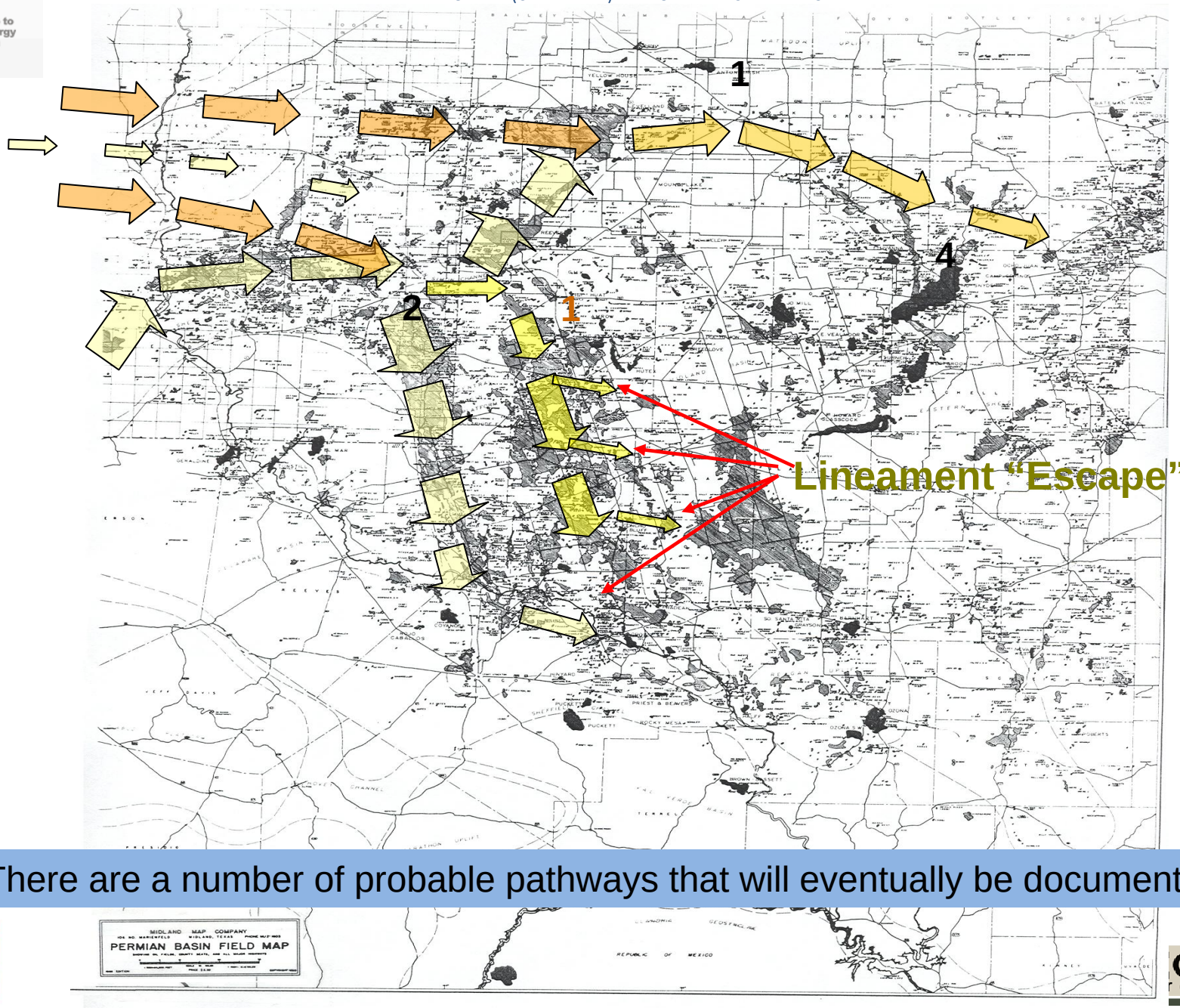




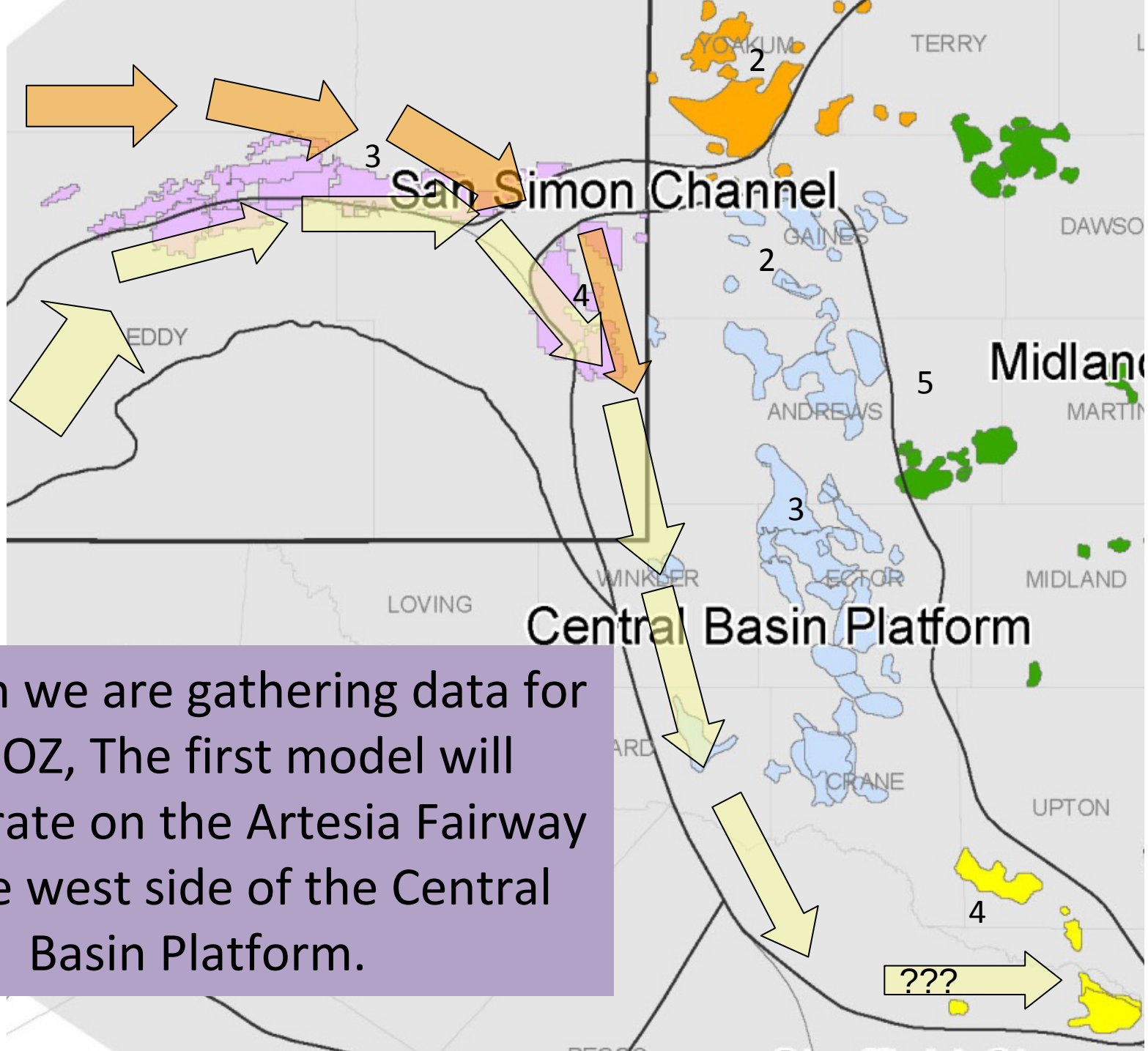
Relationship of San Andres outcrops and San Andres Fairways in New Mexico.

PERMIAN BASIN FIELD MAP

WITH THEORIZED (U. PERMIAN) HYDRODYNAMIC FAIRWAYS



There are a number of probable pathways that will eventually be documented



Although we are gathering data for any ROZ, The first model will concentrate on the Artesia Fairway and the west side of the Central Basin Platform.

Modeling the system that created "Mother Nature's Waterflood"

- Focus on/identify/define the Artesia - West Central Basin Platform Trend
- Gather
  - Well data – location, tops, correlations
  - Pressure data - DST's, well test data
  - Permeability and porosity data (core)
  - Water chemistry
- Arcadis will use ModFlow, a U.S.G.S. developed, finite ground water modeling program with regional capabilities.

DISCHARGE PATH CONCEPTS (Hose Nozzle)

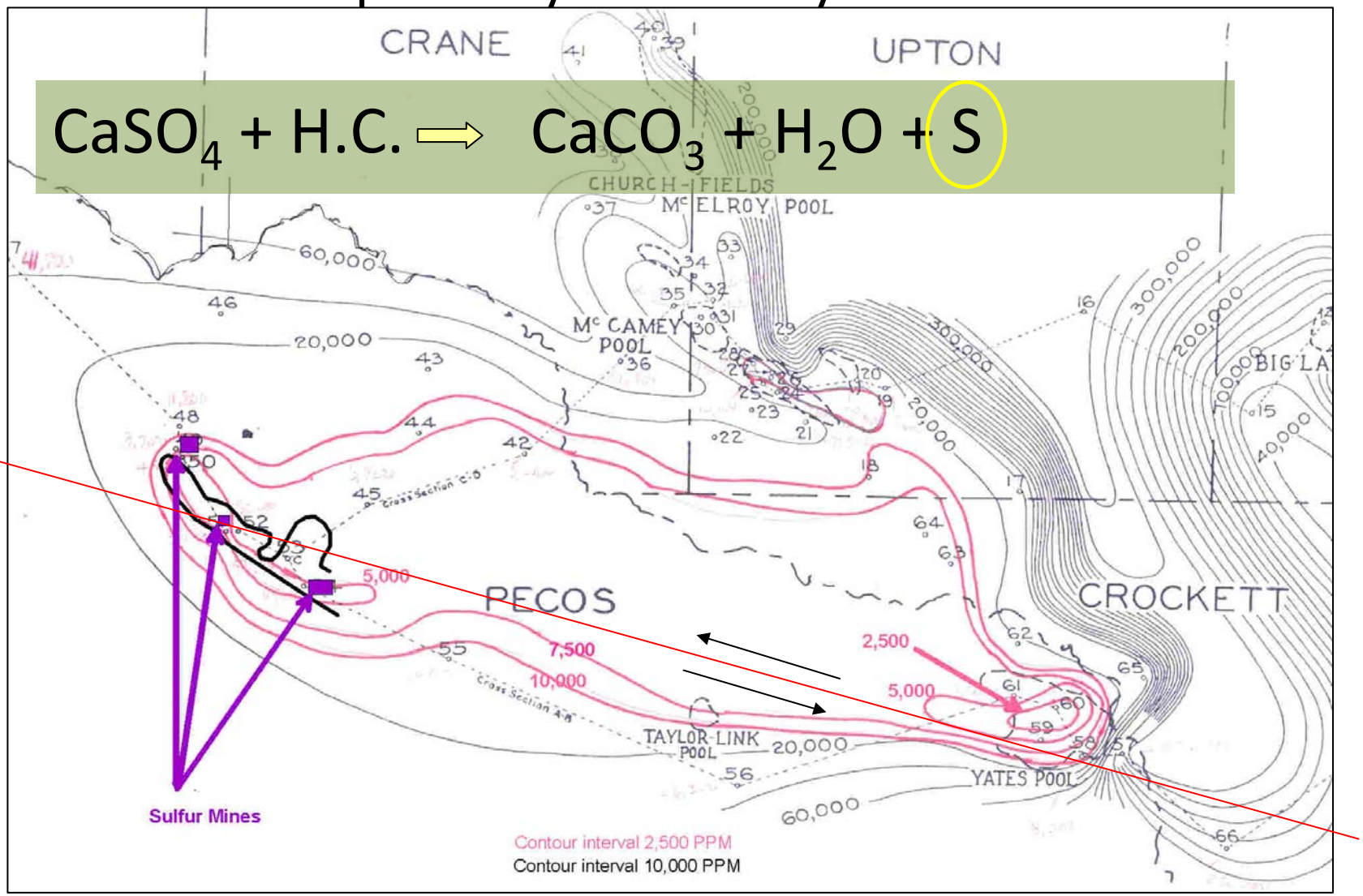
- We have a source of the water, we also need discharge points in order to have movement of the meteoric water.
- Direction of OWC tilt is evidence of both movement and direction.
- Do we have other pathway clues?

Sulfur

- The large sulfur deposits in northern Pecos County are believed to represent one exit point on the CBP for the flushed oil and meteoric waters.
- Other potential sulfur deposit exit points on the E. Shelf.
- 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 dissolution of evaporites
    - Source of H_2S (and sour oil)
- The sulfur deposits (product-of-reaction, residue)
  - Are proof of oil 'passing by'
  - Fairways of oil movement
  - Proof of oil 'consumption'

The ‘Heel of the Boot’ of the CBP is also the location of sulfur mines which document exit pathways for the system

$$CaSO_4 + H.C. \rightarrow CaCO_3 + H_2O + S$$

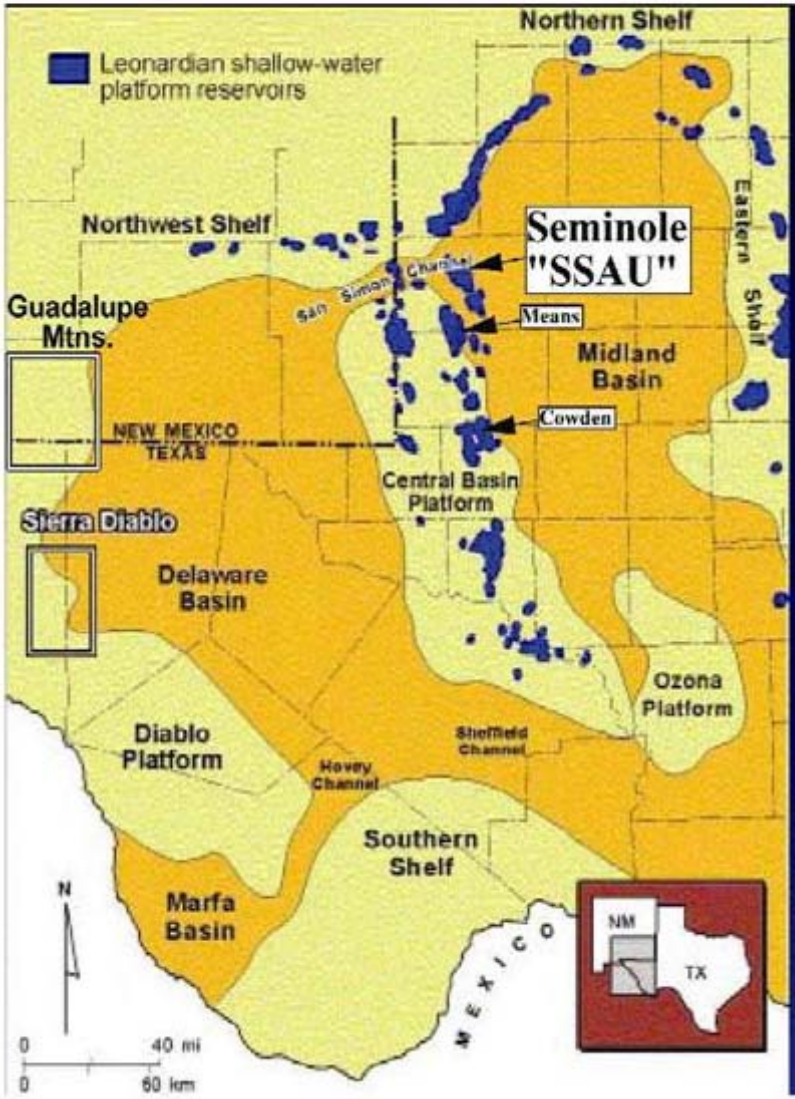


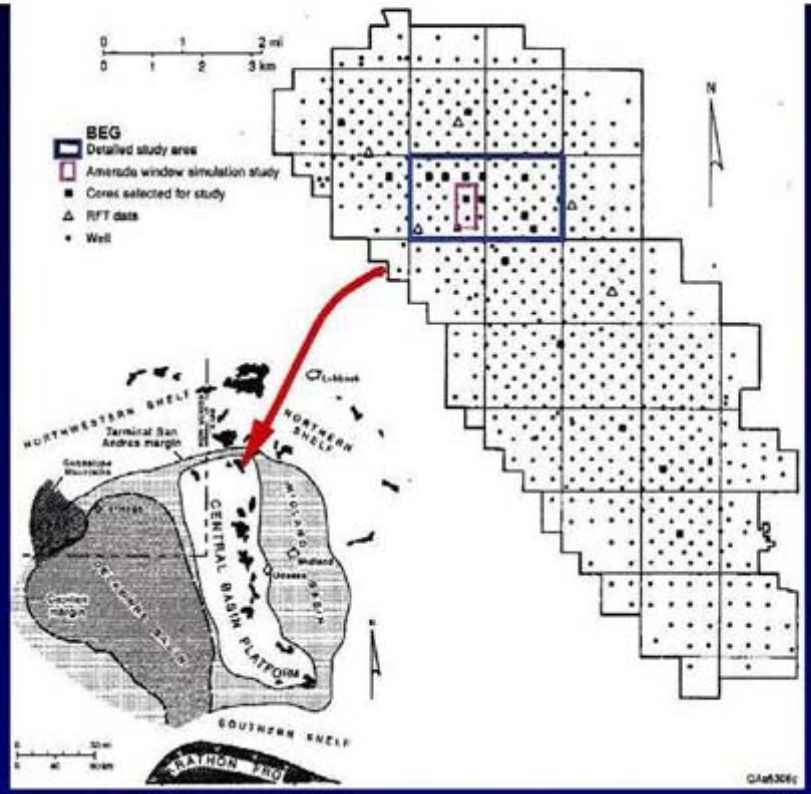
San Andres Water Salinities and Sulfur Deposits

Producing ROZ's

Seminole San Andres Unit

SSAU Geologic Setting

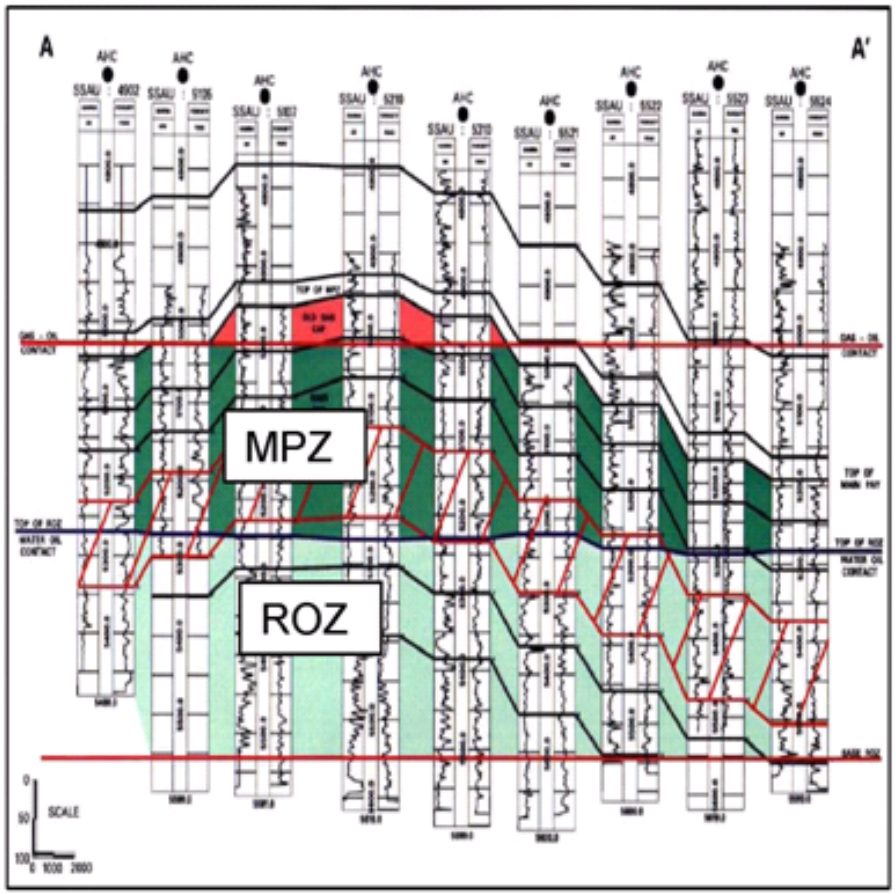


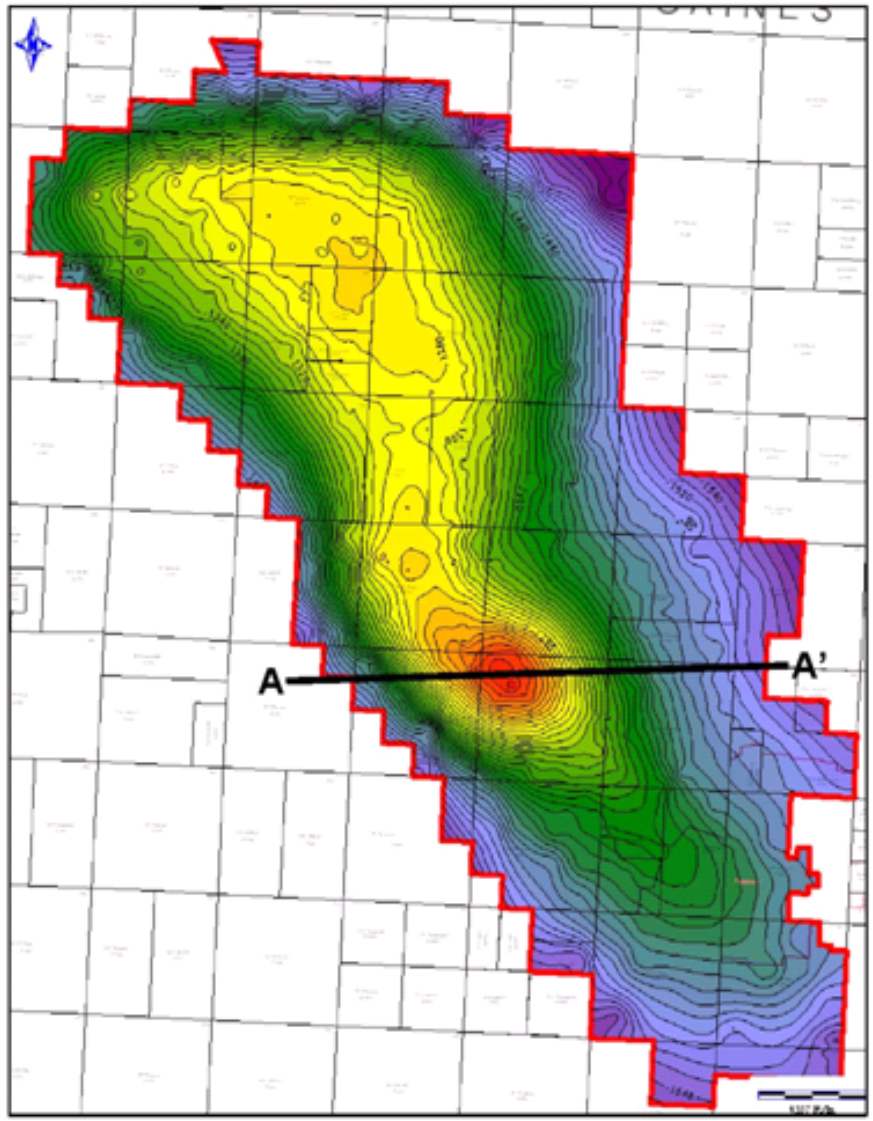


- In the lower San Andres (late Leonardian), Seminole was an aggradational buildup isolated from the Central Basin Platform (left).
- By late San Andres time (above) this low and the San Simon Channel were annealed by carbonate progradation.
- Later differential compaction re-accentuated these paleo-structures, forming present day producing structures.

SSAU Structure Map & Cross Section

	Net Thickness	Average Permeability	Initial Oil Saturation
Main Pay Zone (MPZ):	126'	9 md	84%
Residual Oil Zone (ROZ):	213'	12 md	32%

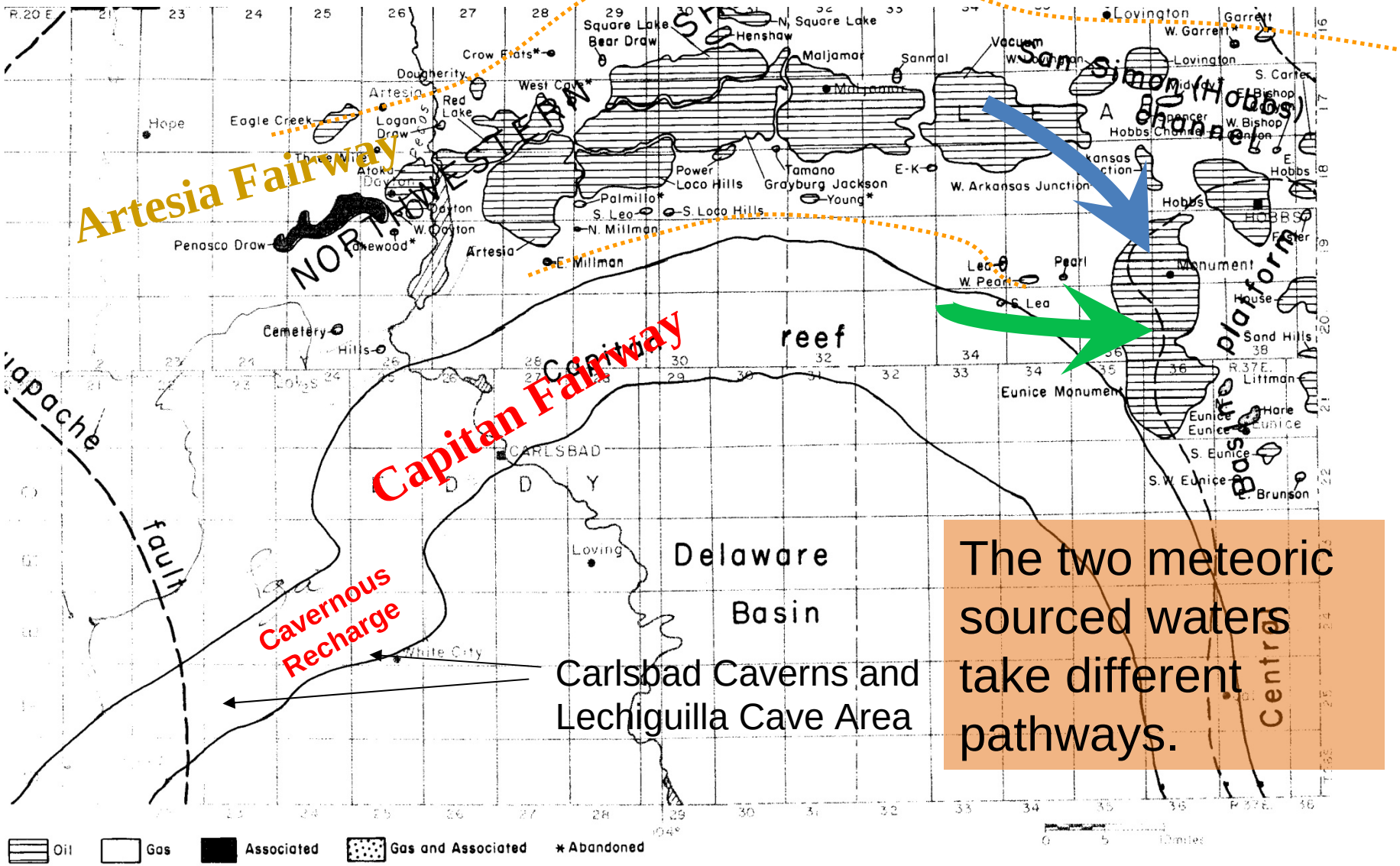




Eunice Monument

- Grayburg productive with NaCl rich connate water
- San Andres mostly wet with sulfate rich connate water
- Two different sources for the connate waters
- **Eunice Monument South Unit** is 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 at Eunice Monument

SE NM Grayburg & Upper San Andres Dolomitization Trend



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

Anecdotal Evidence

Anecdotal evidence documents examples of what can be interpreted as ROZ's where well tests were unsuccessful. From discussions, reviews and reinterpretation of research articles on Permian Basin fields, a set of common ROZ characteristics is developing:

- Presence of S crystals associated with gypsum in swept carbonates
- Evaporites may be dissolved or altered in the lower part of the MPZ
- Enhanced porosity and permeability 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 production tests not salt water
- Core with 20-40% oil saturation
- Log calculations suggest producible hydrocarbons
- Porosities and permeabilities can be higher in the ROZ than in the main pay zone as a result of the meteoric dissolution
- Pervasive "late" dolomitization may indicate meteoric sweep

Oil Saturations

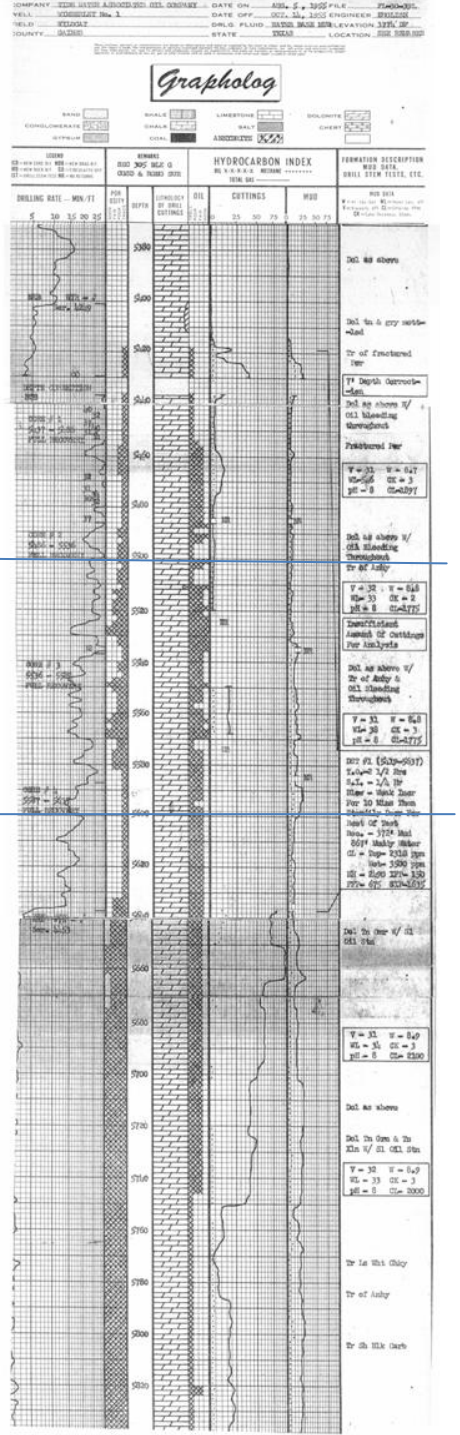
Higher Oil Saturations

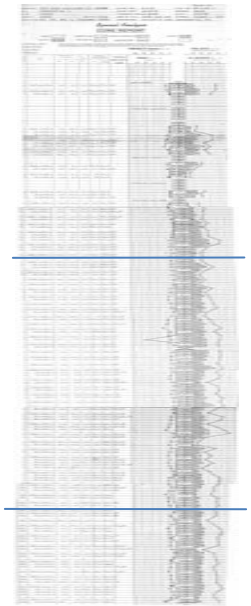
- Laterally driven, pervasive dolomitization by Mg rich high salinity waters
- Lateral flushing of oil entrapments with high salinity water displacing oil
- Oil wetting of new dolomitic rock surfaces
- This establishes a 30-40% Sor *(good EOR target)*

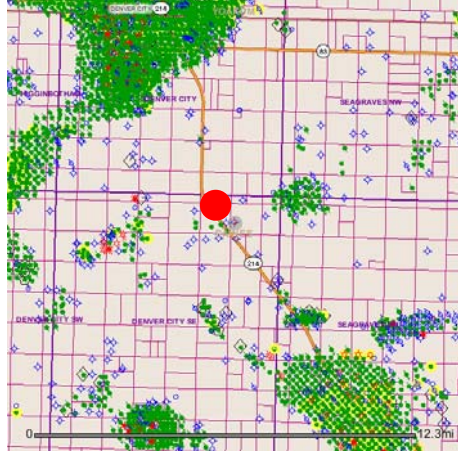
Lower Oil Saturations

- Initial or progressive lateral flushing of MPZ or ROZ oil entrapments with low salinity water
- Reversing of oil wetting of formerly oil wet dolomitic rock surfaces and (partially?) replacing ('de-sorbing')* oil in wetting phase
- Establishes a 10-20% Sor*(poorer EOR target)*

ROZ's have been tested for 50 years.



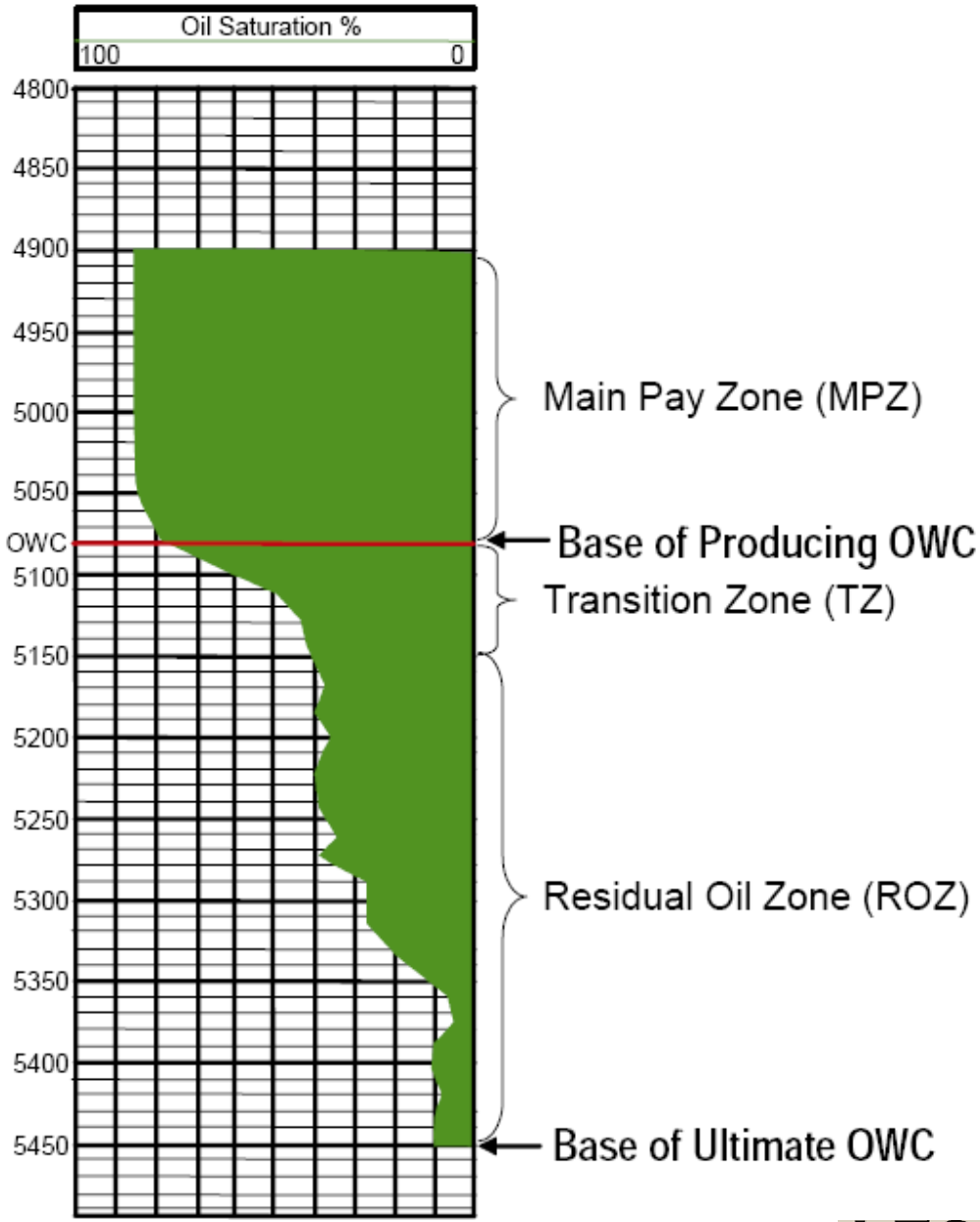




At **Bale East**, Gaines Co., **Tidewater #1 Wimberley**, sec 305, Blk G CC&RGNGRR.
Is on the east flank of a structure.
Drilled in **1955**. Cored interval, 5437-5637, had bleeding oil & gas throughout, has 20 to 30% oil saturation throughout the length.
DST'd 5419-5637, rec 372' mud, 867' MCSW.
Mudlog 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?).

When the entire oil column is swept by Mother Nature, you are left with a tertiary recovery target.



Summary

- A number of presentations have been/or will be made and can be found on our RPSEA supported website: **Residualoilzones.com**.
- 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 being compiled.
- Phase 2 – testing models in the field.

Thanks go to….

- Robert Trentham, UTPB/CEED
- Steve Melzer, Melzer CO2 Consulting
- Arcadis - David Vance, Steve Tischer
- Phil Eager, Edith Stanton, Saswati Chakraborty
- Chevron
- Legado Resources
- George Koperna, Advanced Resources International
- All those who have battled with ROZ's in the past.