Report on the Potential of Residual Oil Zones in the San Andres

2011 CO_2 Conference

David Vance, ARCADIS,
Bob Trentham, CEED/UTPB, and
Steve Melzer, Melzer Consulting

Thanks go the PB ROZ Team

- Our Corporate Partners
  - Chevron
  - Legado
- Martin Cassidy, University of Houston
- Phil Eager, Consultant
- Bob Kiker, PTTC and APTA
- Bill LeMay, Consultant
- Blake Wineinger, Consultant
- The ARCADIS Folks led by Steve Tischer and David Vance
- Trentham and Melzer

The Size of the Prize

Calibrating the Oil Recovery Models and EstimatingTechnically 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.

TZ/ROZ OOIP in these 56 fields is 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

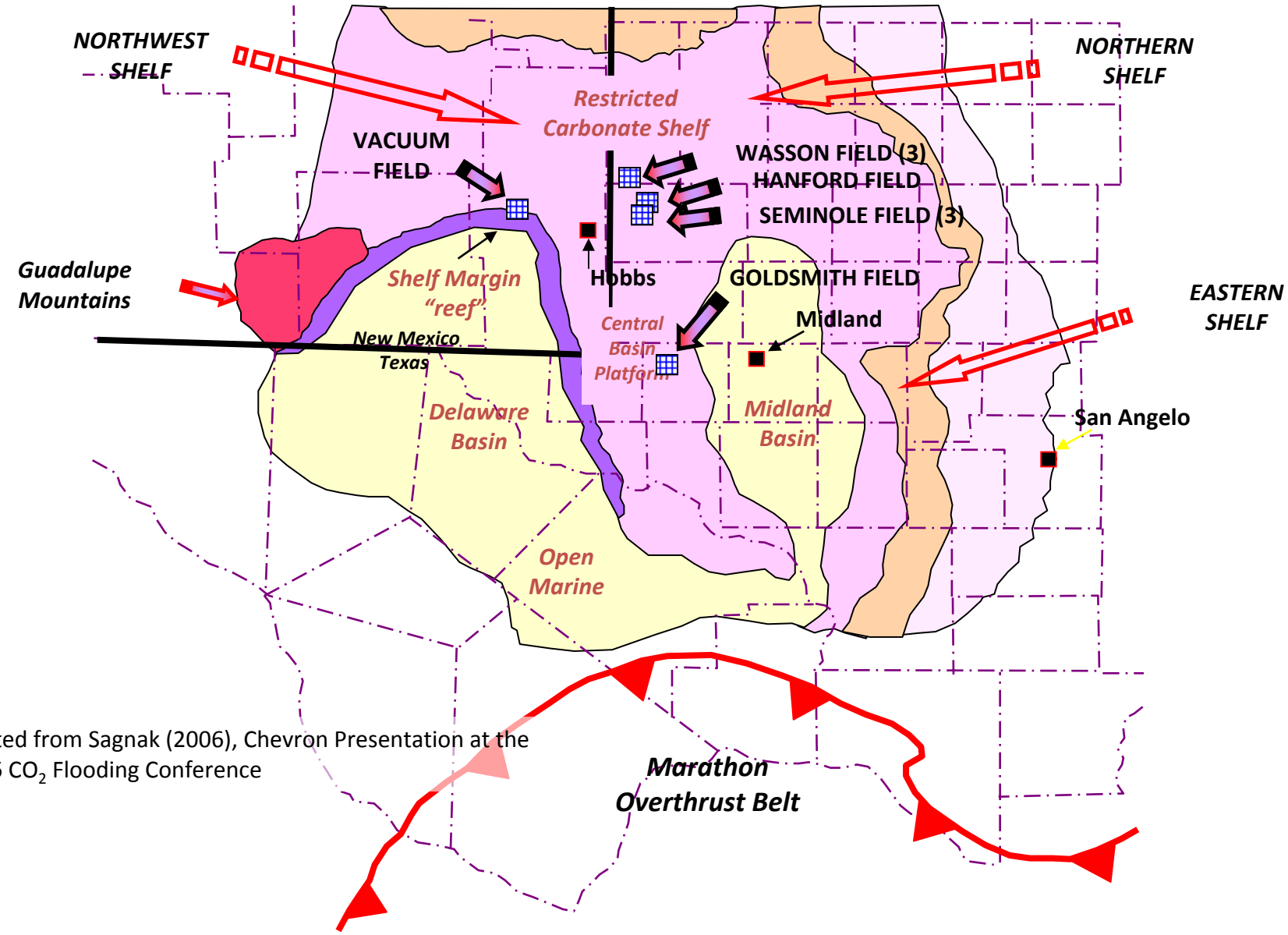
Based on reservoir modeling of applying CO_2-EOR to the TZ/ROZ resources, ARI estimates that

11.9 Billion BO is technically recoverable from the 30.7 Billion BO 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

MIDDLE SAN ANDRES PALEOGEOGRAPHY

with Location of Industry Documented ROZ Zones/Fields*



* Adapted from Sagnak (2006), Chevron Presentation at the 12/06 CO_2 Flooding Conference

The List of On-going ROZ Projects

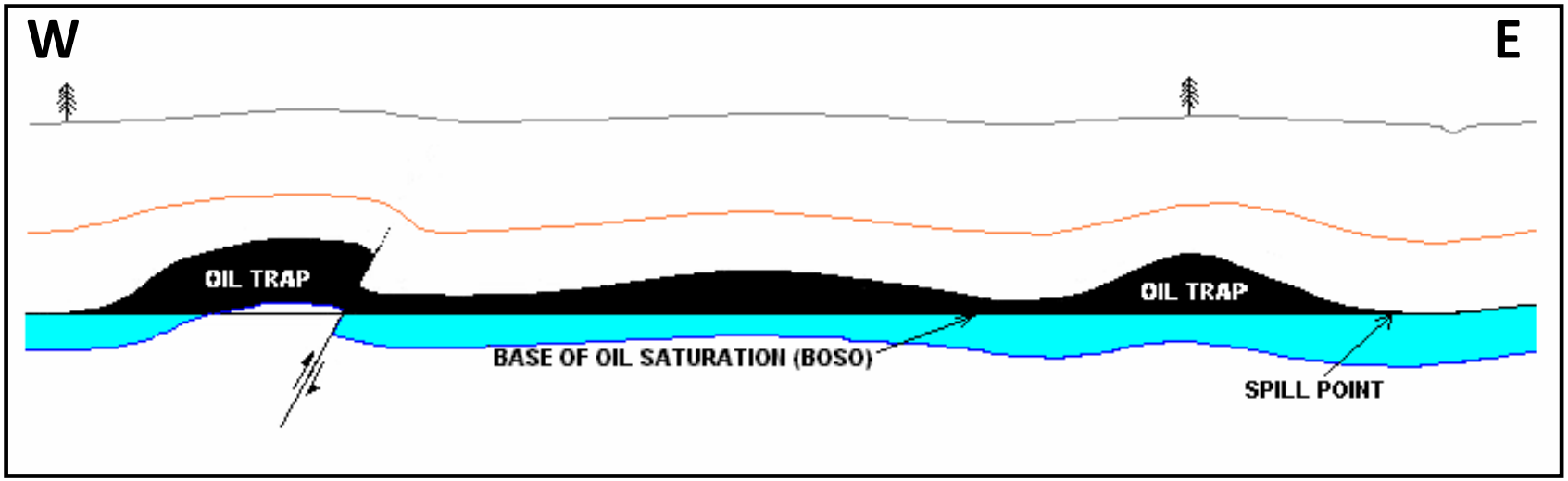
Type and operator	Field	State	County	Top MPZ Depth, ft	Pay zone
Active CO_2 miscible					
Chevron	Vacuum San Andres Grayburg Unit	NM	Lea Co.	4,550	San Andres/Grayburg
Fasken	Hanford	Tex.	Gaines	5,500	San Andres
Hess	Seminole Unit-ROZ Phase 1	Tex.	Gaines	5,500	San Andres
Hess	Seminole Unit-ROZ Phase 2	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

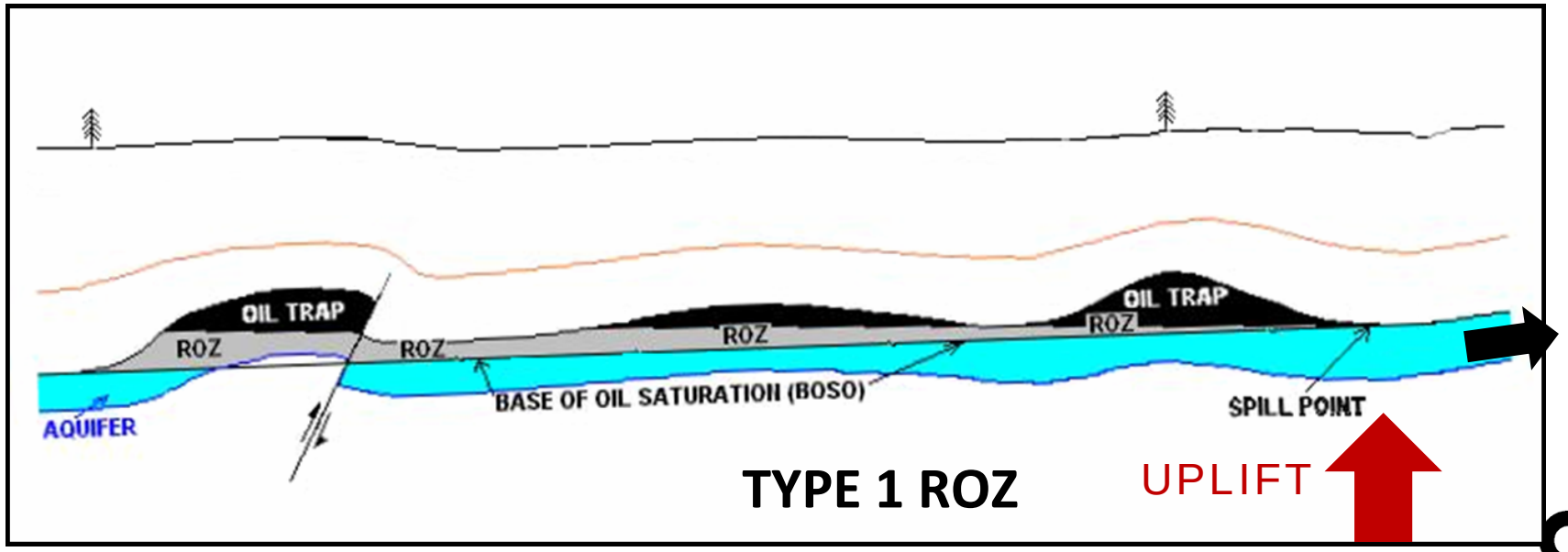
Announced Additions: Exxon at Means (2011)

Rumored Additions: Conoco at East Vacuum (2011)
Chevron at Central Vacuum (2012)
XTO at CA Goldsmith (2013?)
Tabula Rasa at E. Seminole and Lindoss (2013)

The Science of Residual Oil Zones

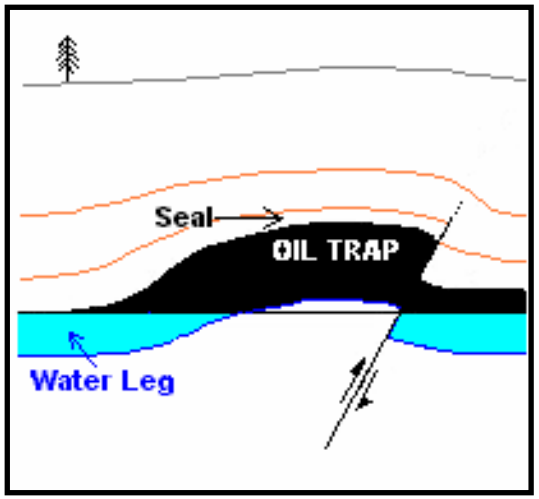
Original Oil Accumulation Under Static Aquifer Conditions (A Hypothetical Example)



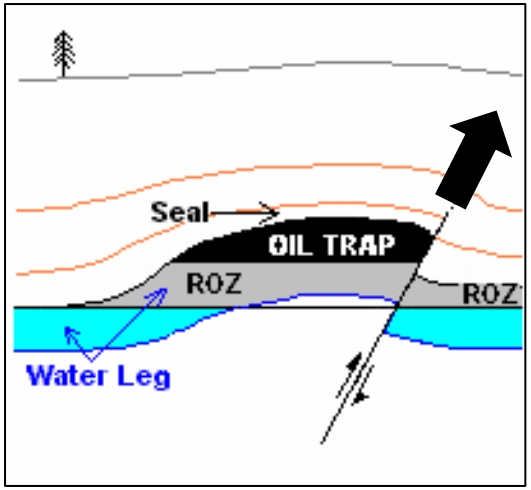


Original Accumulation with a Breached then Repaired Seal & Forming a ROZ

ORIGINAL

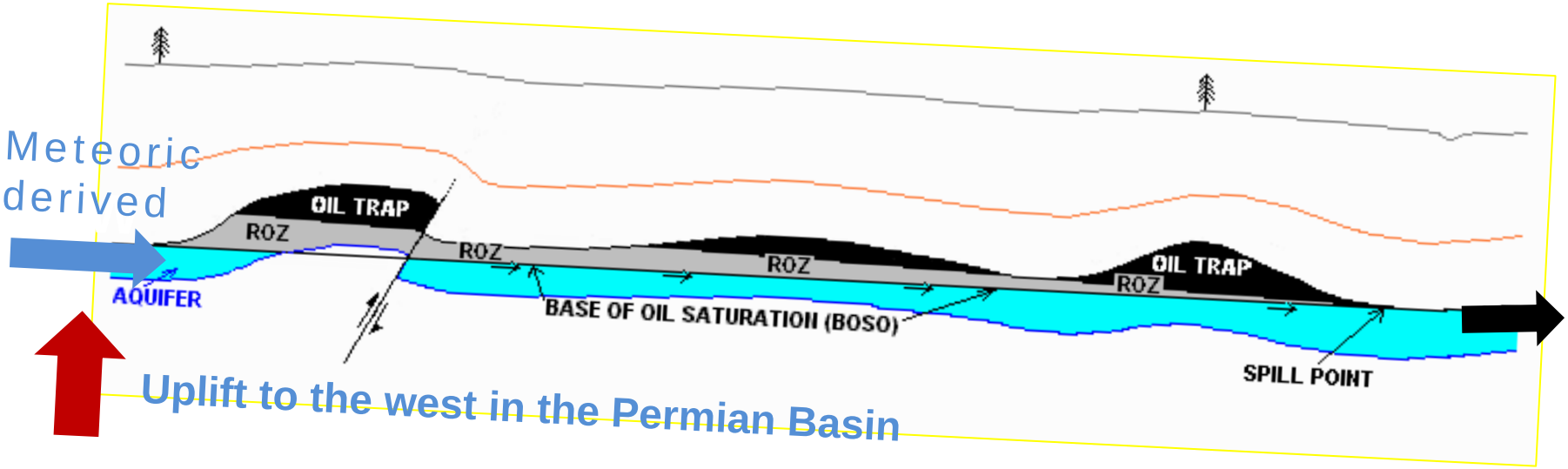


POST BREACH

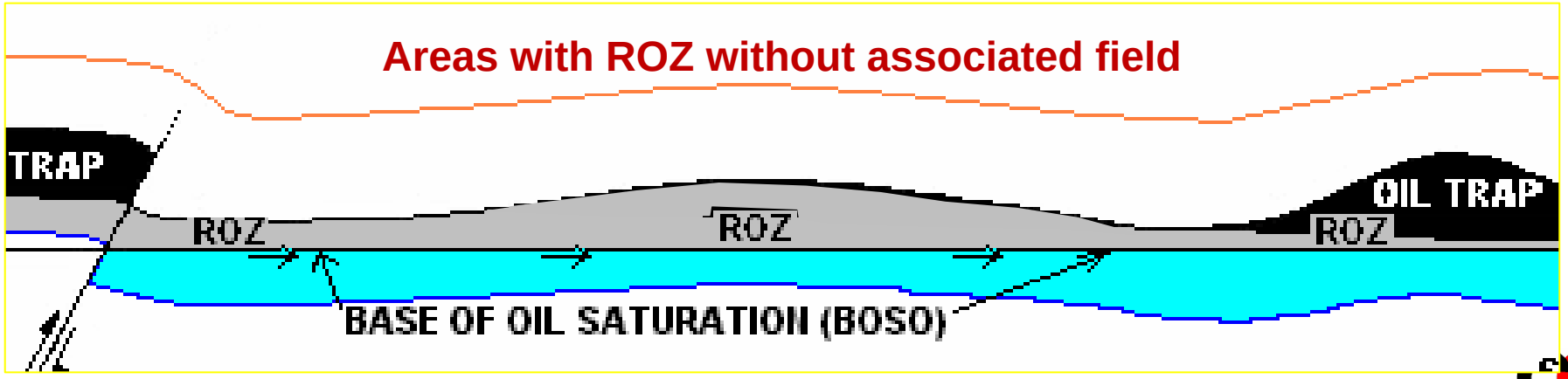


TYPE 2 ROZ

TYPE 3. Change in Hydrodynamic Conditions, Sweep of the lower part of the Oil Column and Development of a Residual Oil Zone.

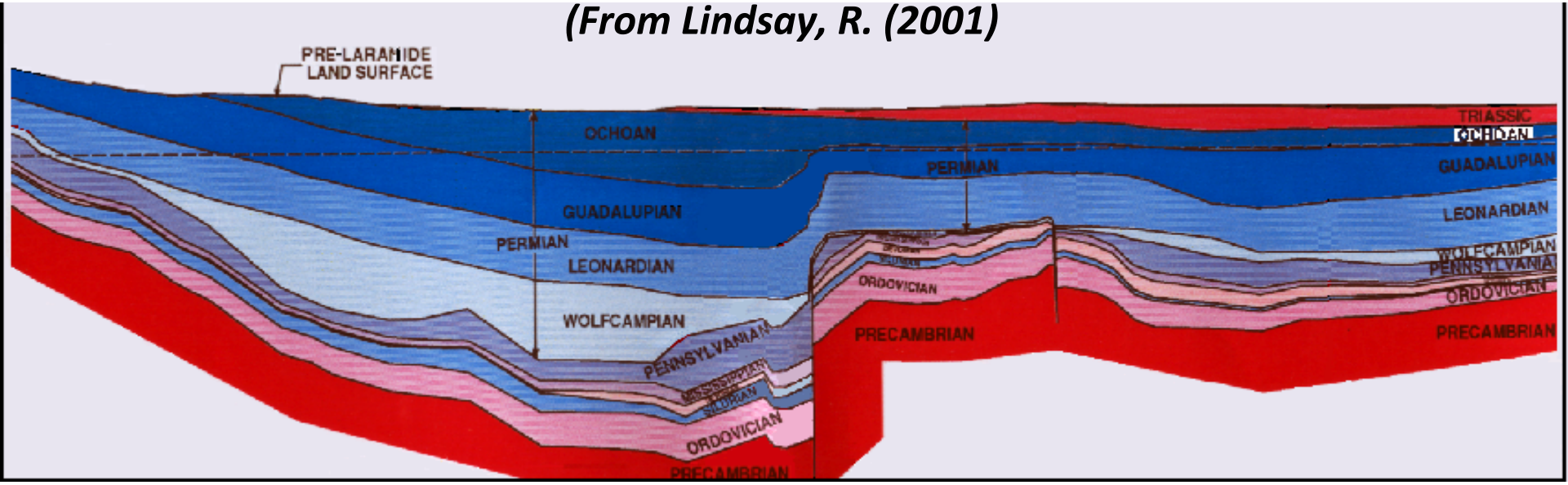


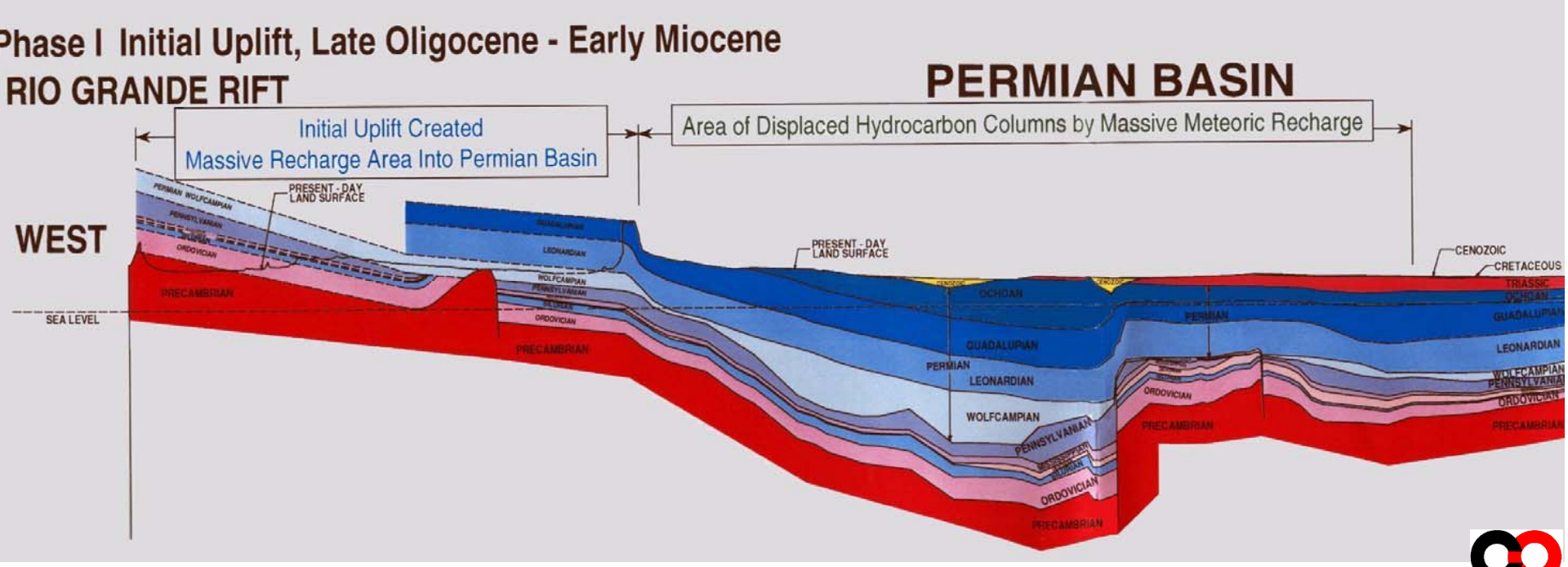
Dynamic System



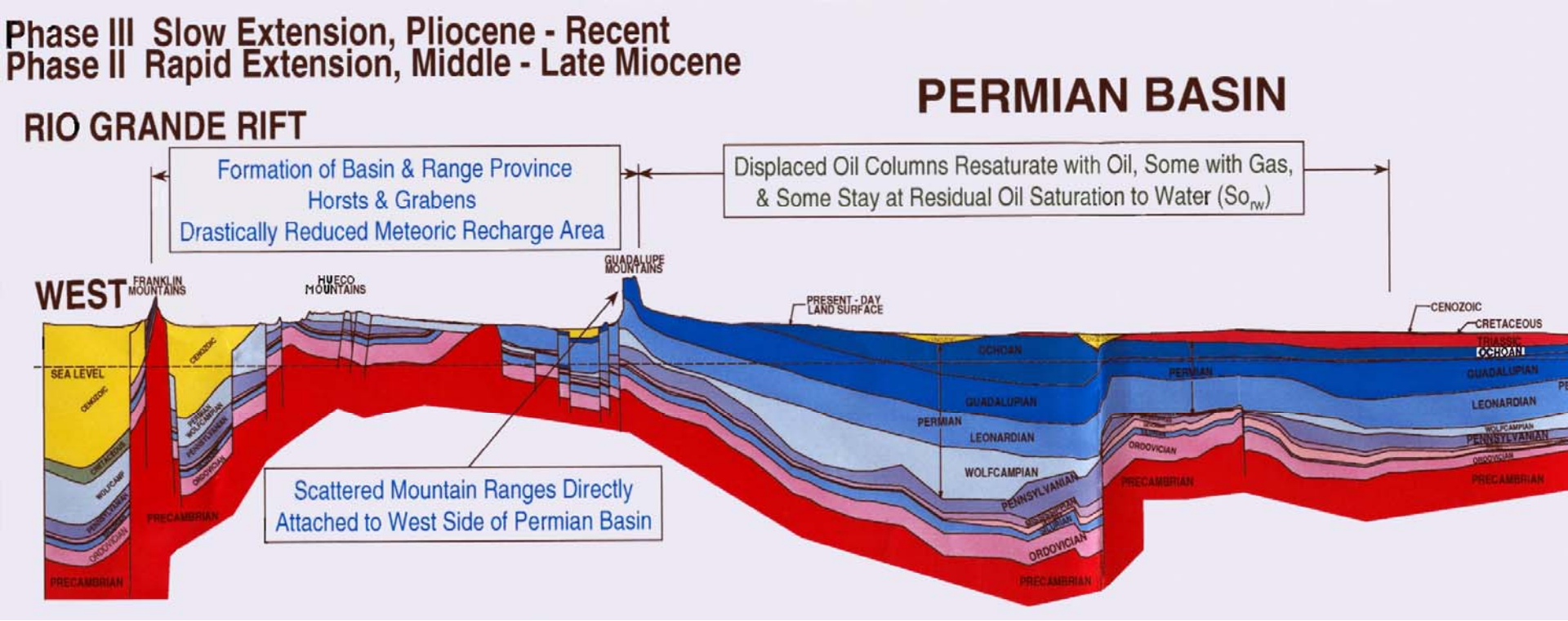
Post-Subsidence Phase of Permian Basin Development

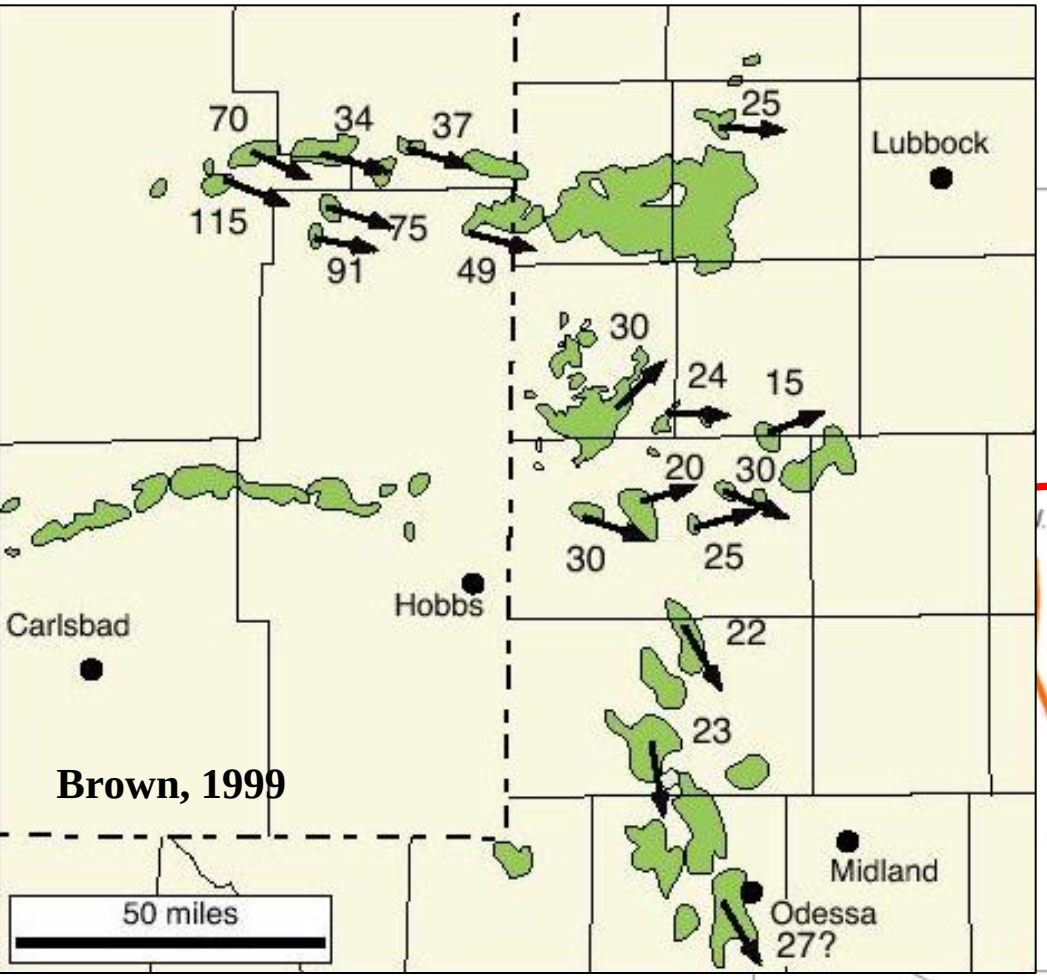
(From Lindsay, R. (2001)

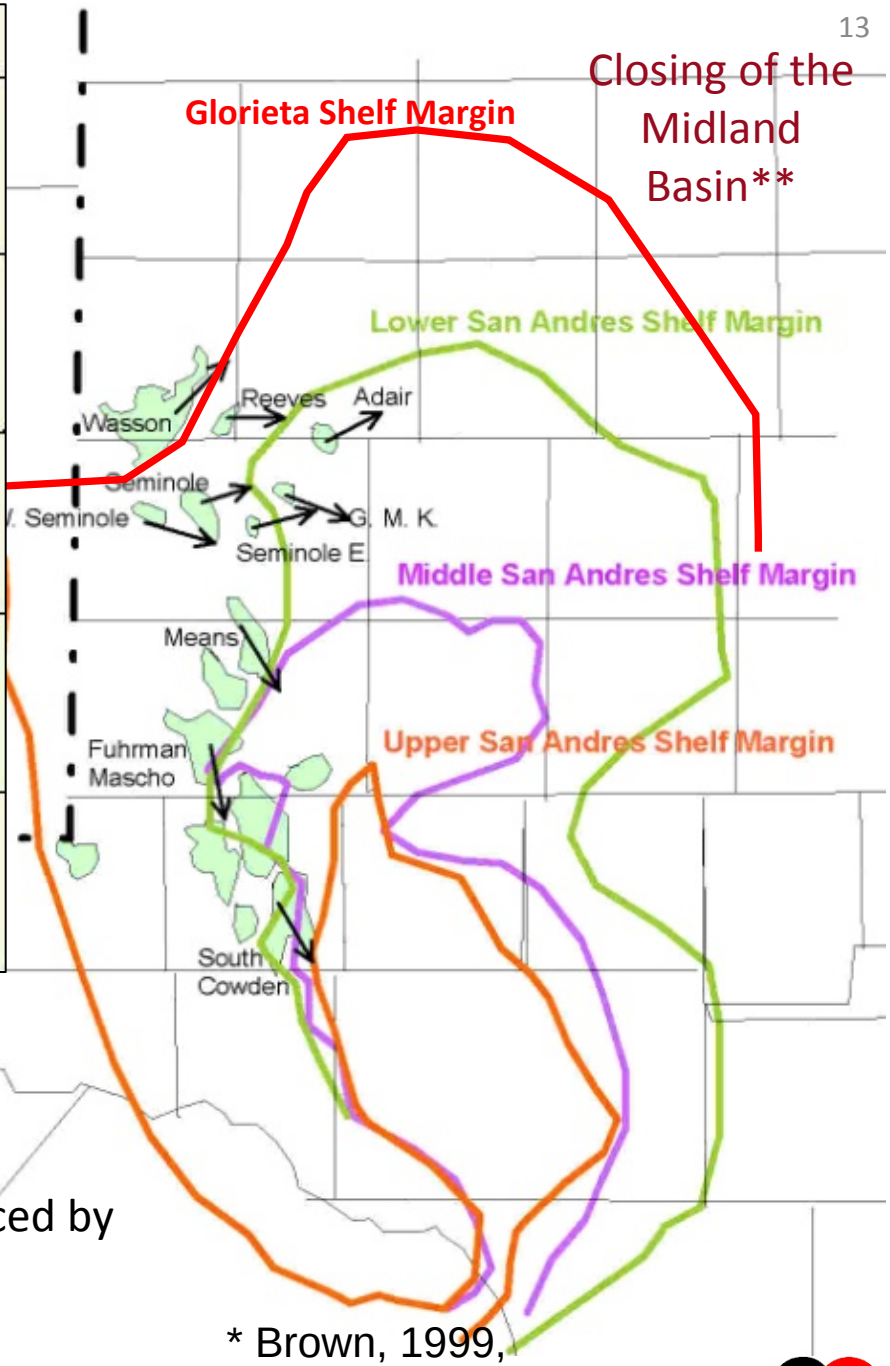




Extensional Phases and Reduction of Hydrodynamic Gradients in the Permian Basin *(From Lindsay, R. (2001)*



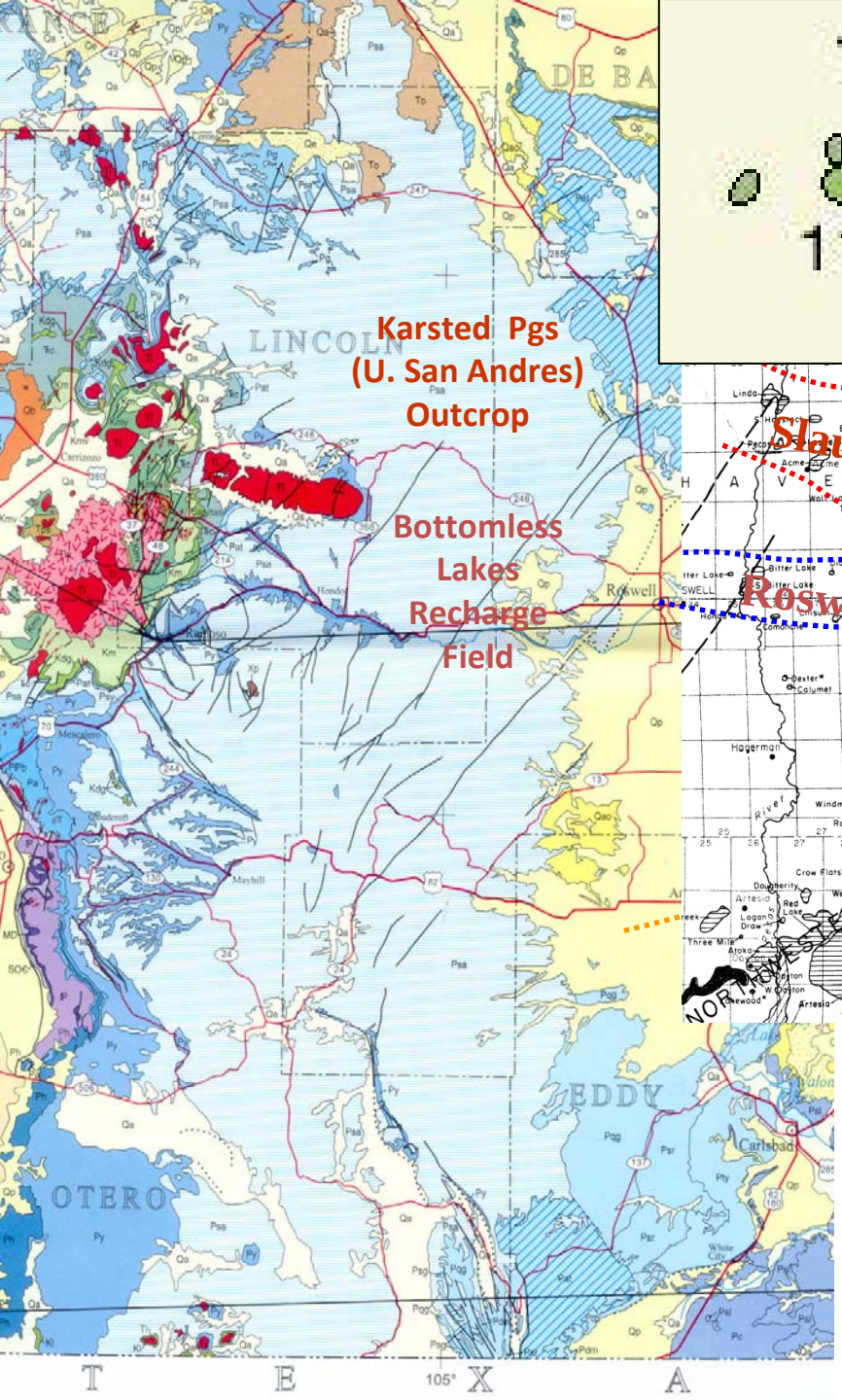


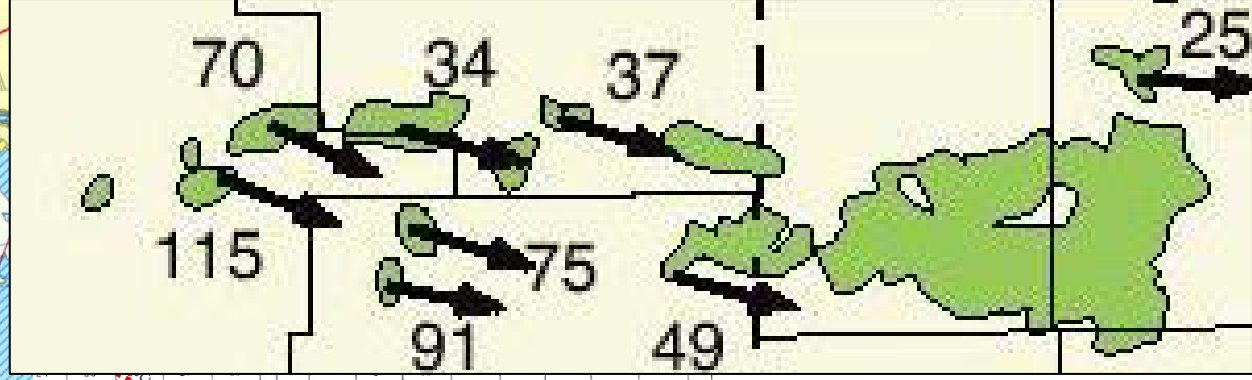


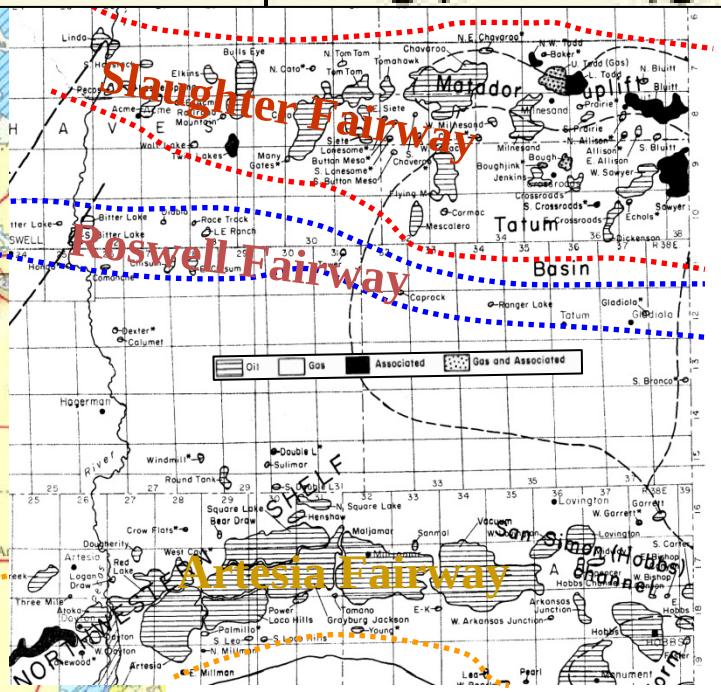
Distribution of Tilted Oil-Water Contacts in the Northern Shelf and Central Basin Platform Areas of the Permian Basin*

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



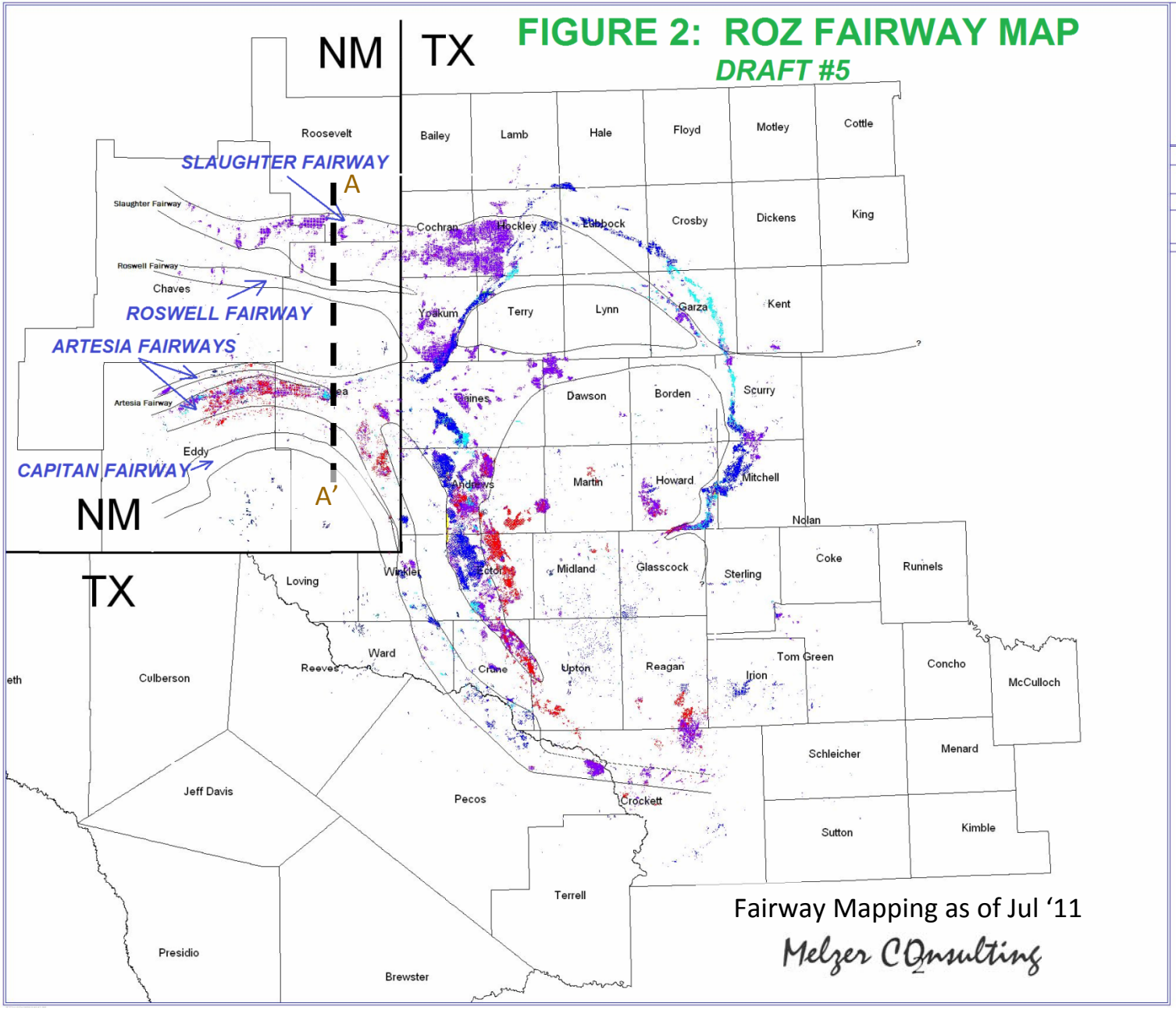




Relationship of San Andres outcrops and San Andres Fairways in New Mexico.

FIGURE 2: ROZ FAIRWAY MAP

DRAFT #5



Melzer COnsulting

Super Co2

Permian Basin

RPSEA

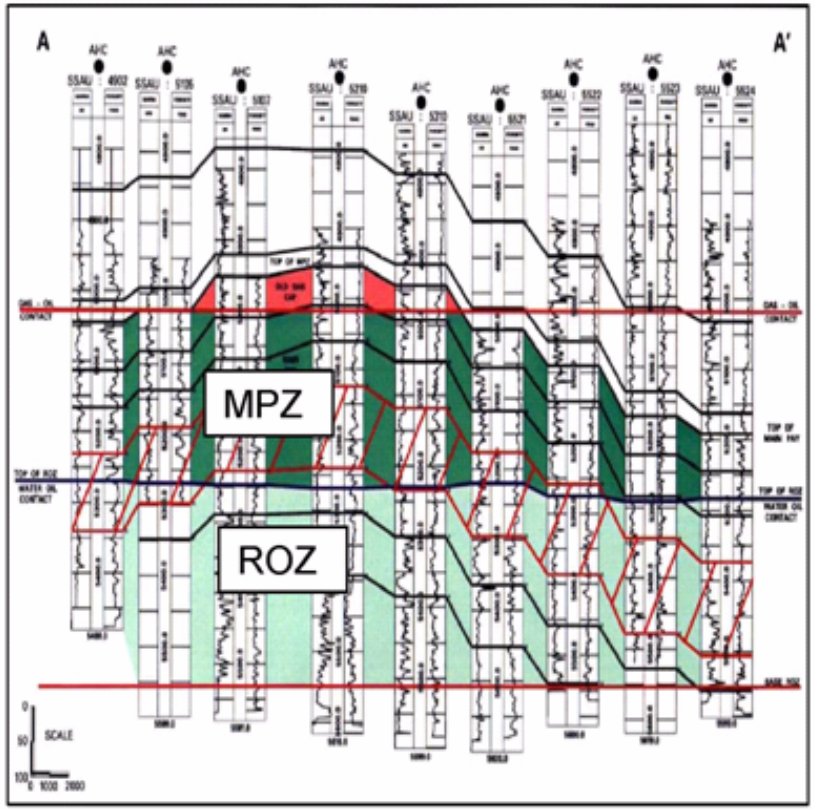
Research Partnership to Secure Energy for America

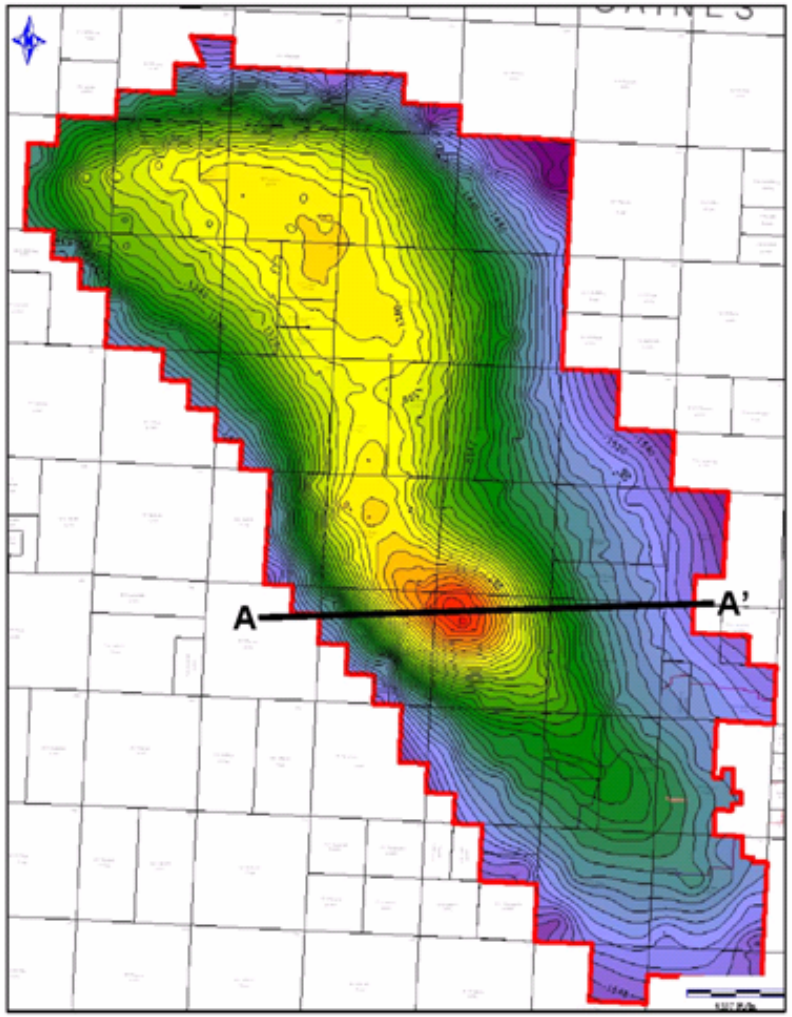
Seminole Field - The Gold Standard

Seminole San Andres Unit

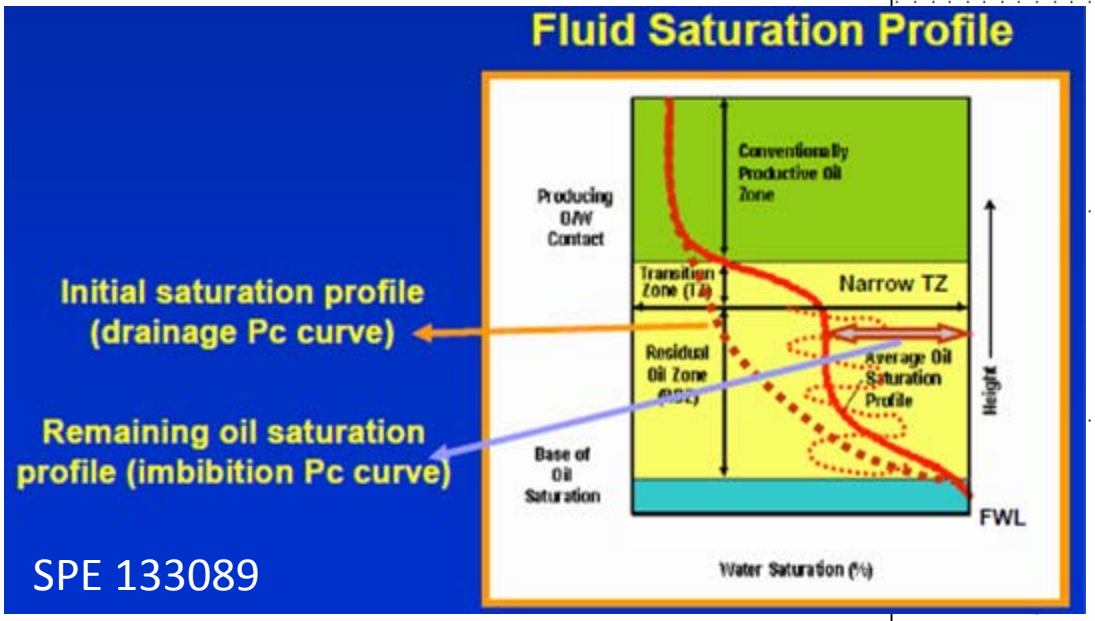
SSAU Structure Map & Cross Section

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

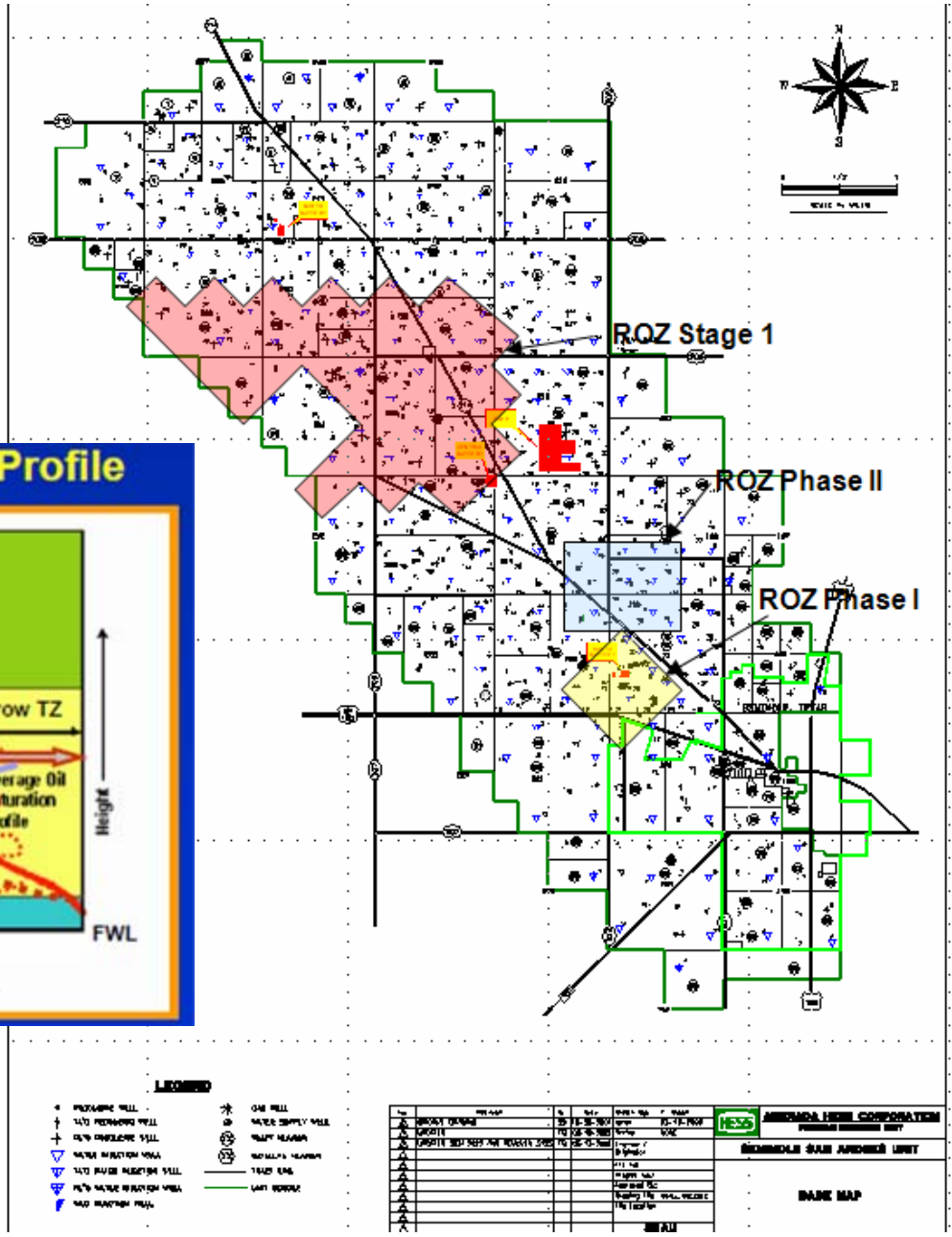




Seminole Field ROZ Projects

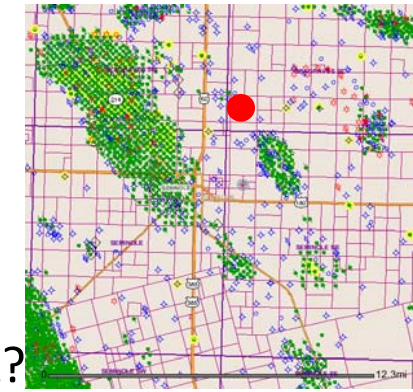


SPE 133089

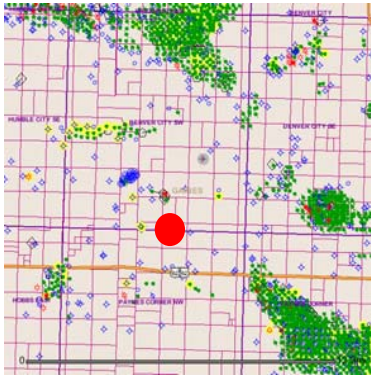


GREENFIELDS

Future Targets or goat pasture?

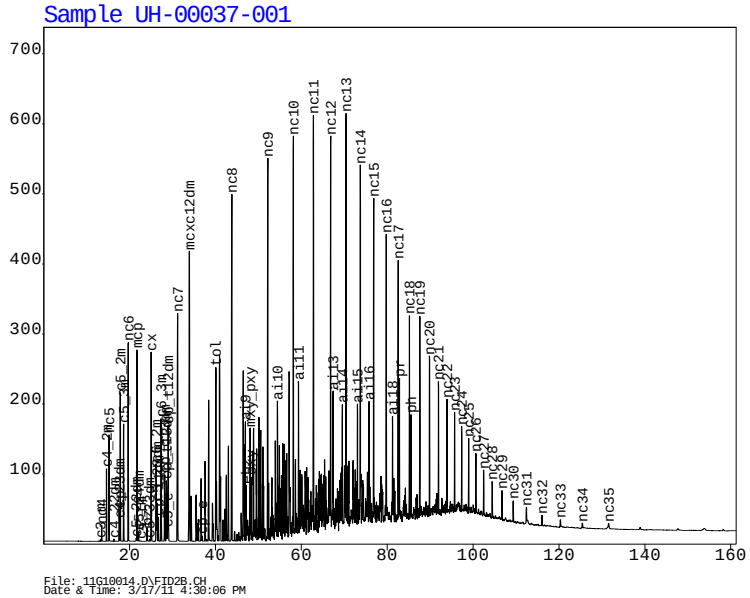


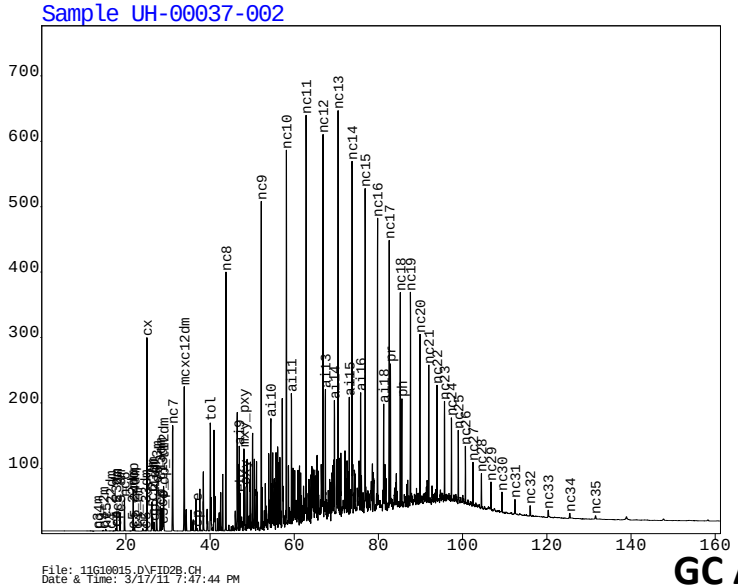
- A Clearfork test, the **IP #1 Campbell Heirs "158**" set pipe on "WET" San Andres test just south of Seminole.
- All wireline logs, drill time, gas curves and sampleshows said "slam dunk" oil production. Atlas log analyst said it should be a producer. 100% water test with barely a sniff of live oil. 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.



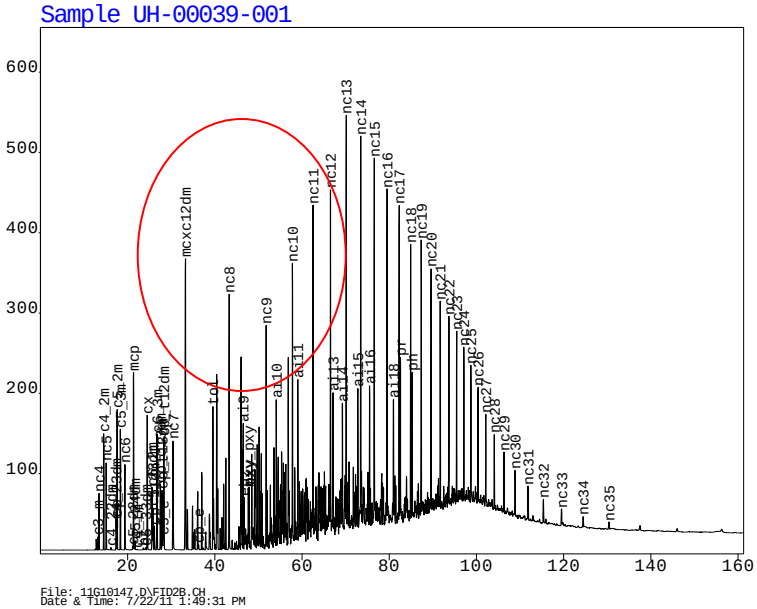
Permian Basin, San Andres Oil from Goldsmith Field

MPZ Reservoir Oil





From ROZ Interval

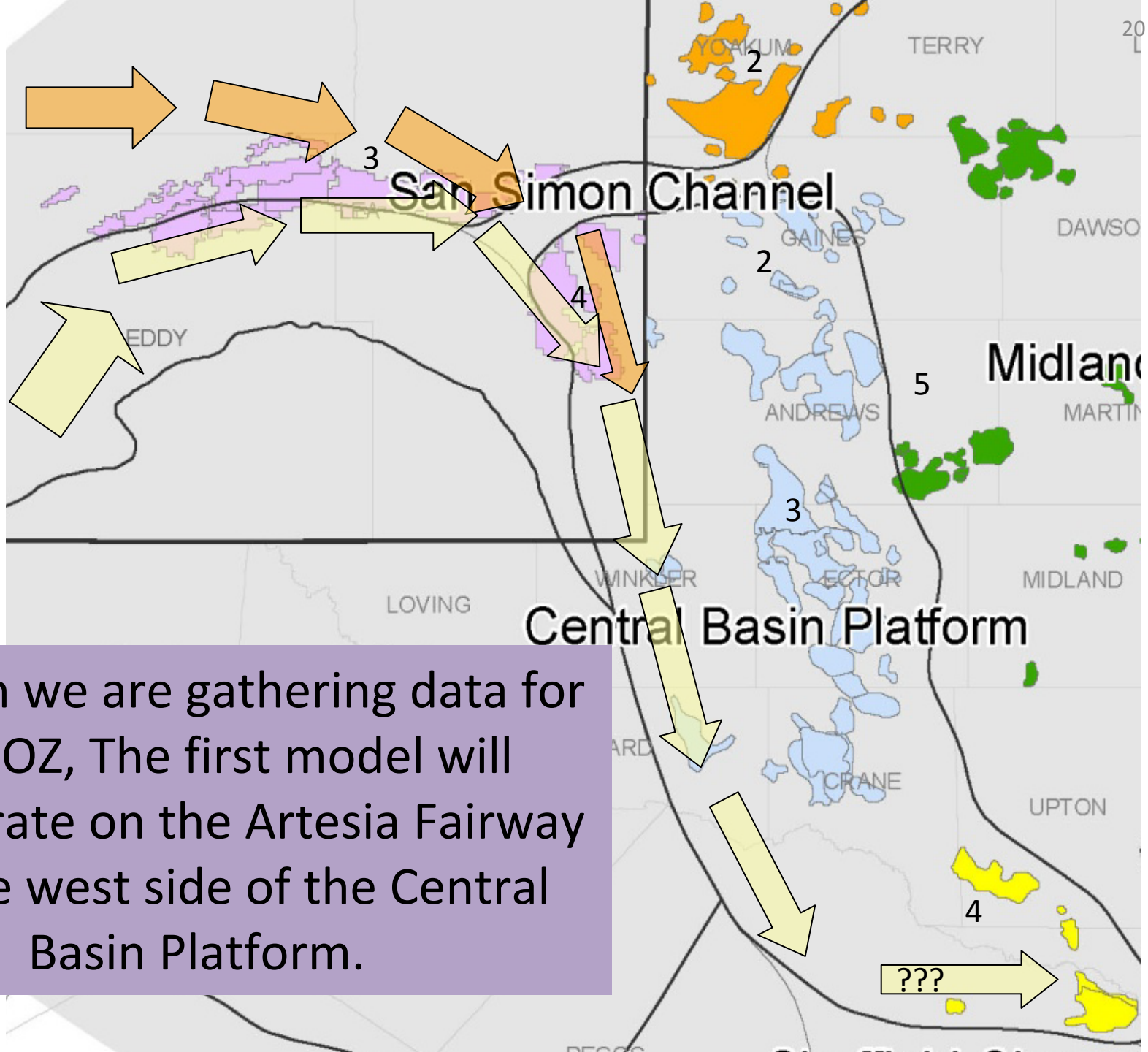


Acquired with corporate support from

LEGADO resources

….as per Martin Cassidy, UH

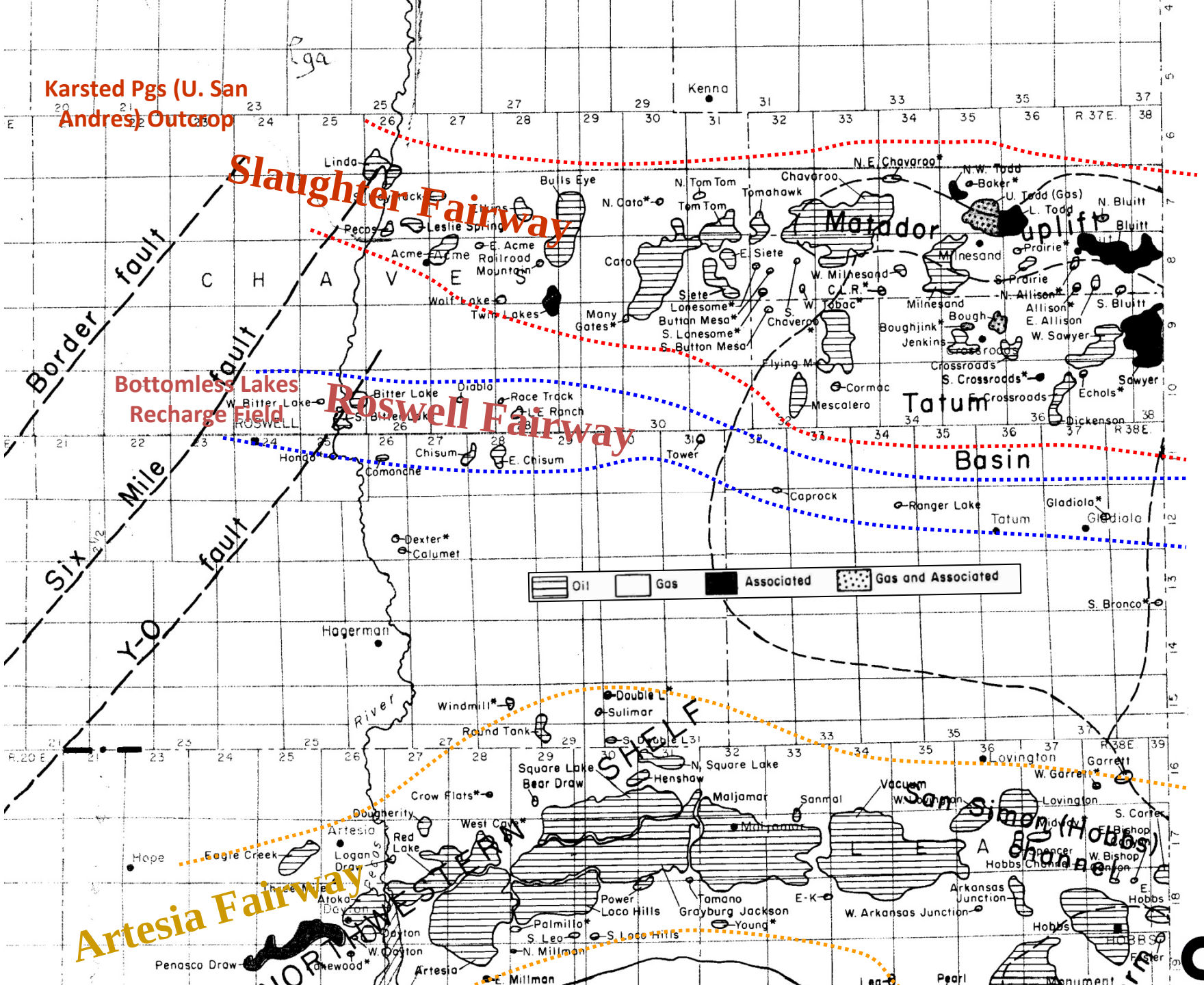
GC Analysis

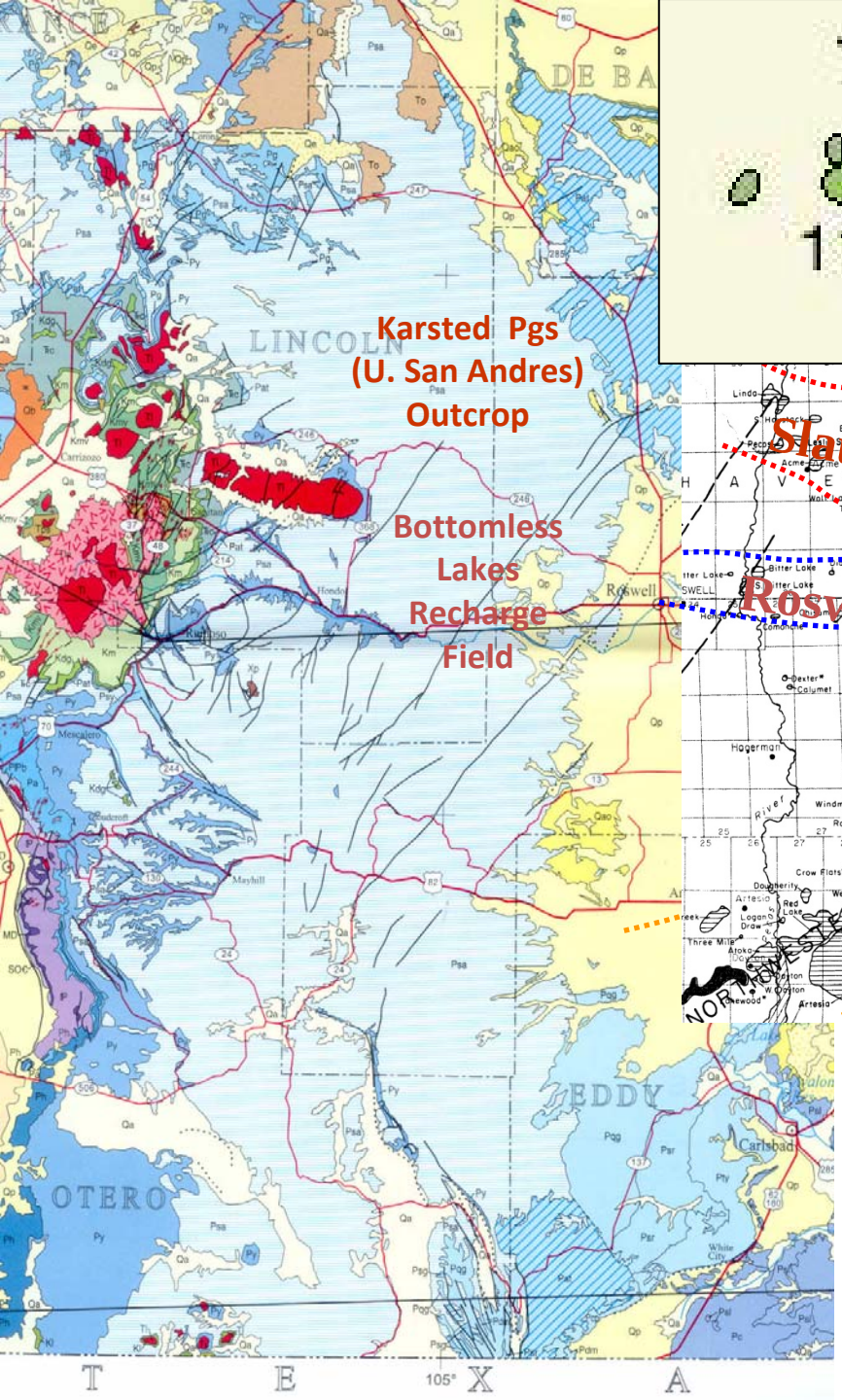


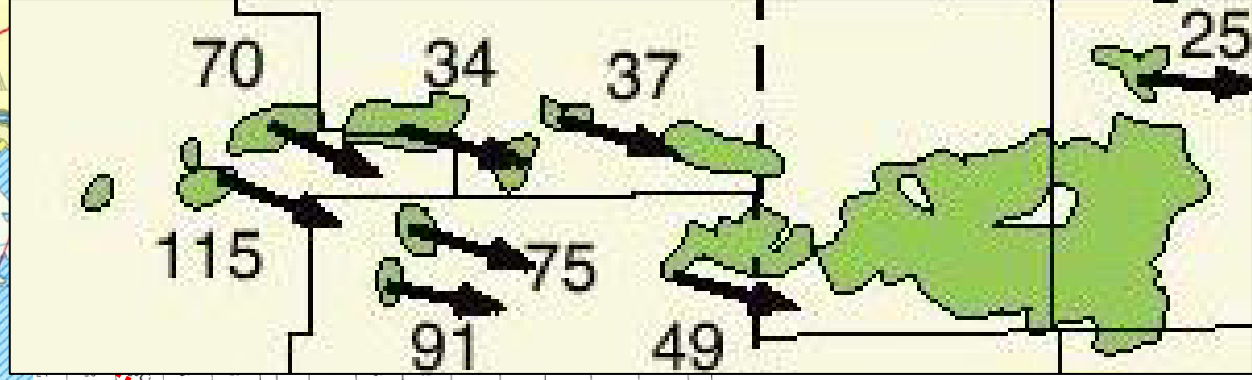
Although we are gathering data for any ROZ, The first model will concentrate on the Artesia Fairway and the west side of the Central Basin Platform.

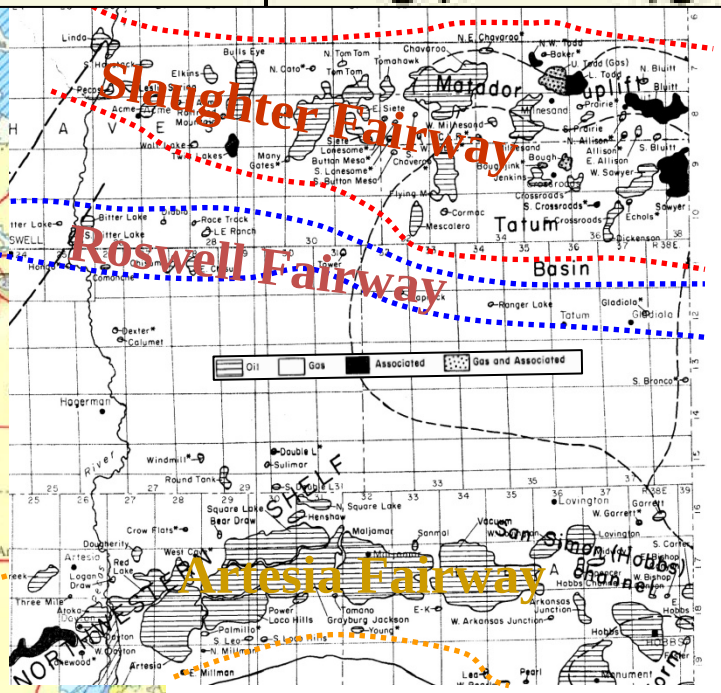
Modeling of the system that created "Mother Natures Waterflood".

- Focus on/Identify/Define the Artesia - West Central Basin Platform Trend
- Gather
  - Well data – location, tops, correlations (Cross Sections)
  - 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.

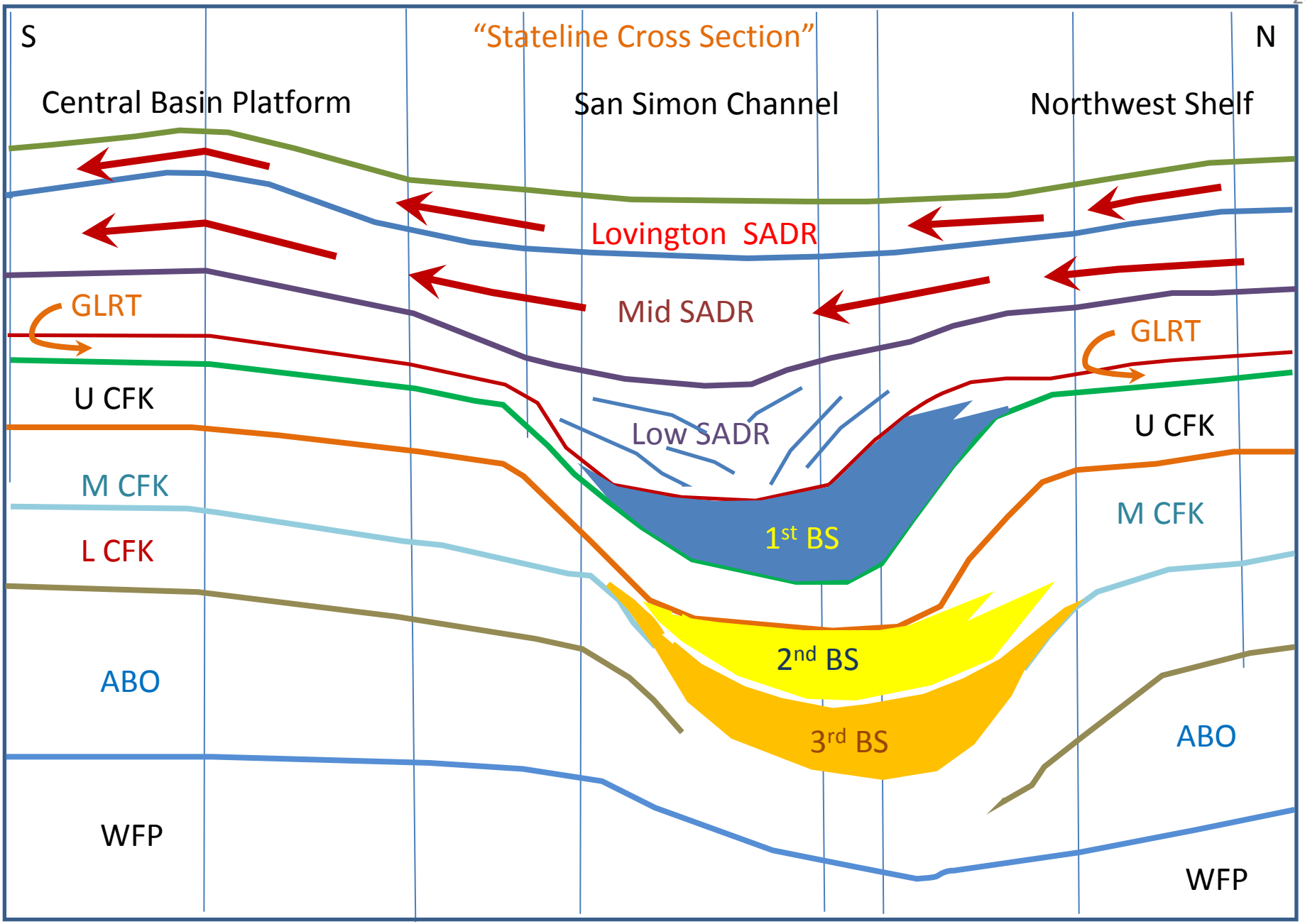

Karsted Pgs (U. San Andres) Outcrop
Slaughter Fairway
Bottomless Lakes Recharge Field
Roswell Fairway
Artesia Fairway
Border fault
Six Mile fault
Y-O fault
C H A V E S
Matador uplift
Tatum Basin
Oil
Gas
Associated
Gas and Associated
Kenna
Linda
Bulls Eye
N. Tom Tom
Tom Tom
Tomahawk
Chavaroo
N.E. Chavaroo
N.W. Todd
Baker
U. Todd (Gas)
L. Todd
N. Bluitt
Bluitt
S. Bluitt
Pecos
Leslie Spring
Acme
E. Acme
Railroad Mountain
N. Cato
Cato
E. Siete
Siete
Lonesome
Button Mesa
S. Lonesome
S. Button Mesa
Many Gates
Wolf Lake
Twin Lakes
W. Milnesand
C.L.R.
W. Tobac
S. Chavaroo
Milnesand
Prairie
S. Prairie
N. Allison
Allison
E. Allison
W. Sawyer
Boughjink
Bough
Jenkins
Crossroads
S. Crossroads
E. Crossroads
Flying M
Cormac
Mescalero
Echols
Sawyer
Dickenson
W. Bitter Lake
Bitter Lake
Diablo
Race Track
L.E. Ranch
ROSWELL
Hondo
Chisum
E. Chisum
Comanche
Tower
Caprock
Ranger Lake
Tatum
Gladiola
Dexter
Calumet
S. Bronco
Hagerman
Windmill
Double L
Sulimar
Round Tank
S. Double L
Square Lake
Bear Draw
N. Square Lake
Henshaw
Maljamar
Sanmal
Vacuum
W. Vacuum
Lovington
Garrett
W. Garrett
S. Carter
Crow Flats
Dougherty
Artesia
Red Lake
West Caw
Hope
Eagle Creek
Logan Draw
Atoka
Dayton
W. Dayton
Penasco Draw
Lakewood
Artesia
E. Millman
N. Millman
S. Millman
Palmillo
S. Leo
S. Loco Hills
Power
Loco Hills
Tamano
Grayburg Jackson
Young
E-K
Arkansas Junction
W. Arkansas Junction
Hobbs
E. Hobbs
Pearl
Monument
Lea
NORTHWESTERN SHELF
San Simon (Hobbs) channel
River







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

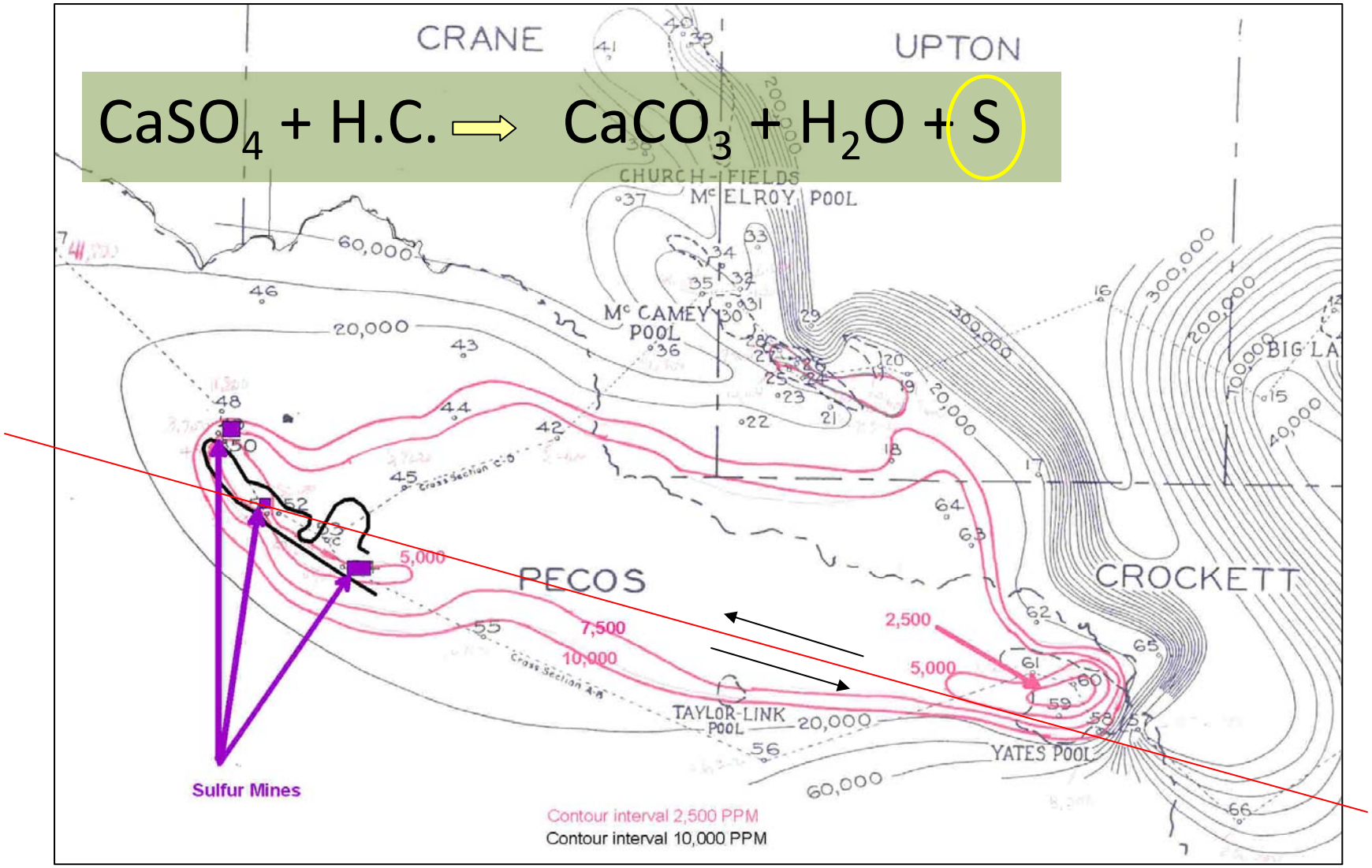


Pathway from NW Shelf to CBP

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 is also the location of Sulfur mines which document exit pathways for the system



San Andres Water Salinities and Sulfur Deposits

GATHERING THE "ANECDOTAL" EVIDENCE

Evidence from a growing number of exploration and production 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 explorationists and review and reinterpretation of research articles on Permian Basin fields, a set of common ROZ characteristics is developing

Oil Shows: DSTs, Cuttings, Cores

Water Salinities, Sulfur Water, Sour Oil

Corrosive Zones

Pervasive Zonal Dolomitization

Discharge Paths, Lineaments

Sulfur Deposits

Examples of Anecdotal Evidence

- :
  - The presence of sulfur crystals associated with gypsum/anhydrite in the swept carbonates,
  - Evaporites dissolved or altered in the lower part of the main pay.
  - Enhanced porosity and permeability developed as the result of meteoric dissolution of sulfates in the ROZ .
  - Transition from Dolomite in ROZ to Limestone beneath Paleo O/W contact
  - Sample shows of oil and/or gas of similar quality to Main Pay Zones
  - Sulfur water produced on DST's or attempted production tests
  - Cores with 20-40% oil saturation,
  - Log calculations that suggest producible hydrocarbons.
  - Pervasive "late" dolomitization which may indicate meteoric sweep.
  - Documentation of Sulfur Deposits, Pecos County.

Hydrogeologic Modeling

- Modeling Team -ARCADIS
  - Kuohui Suchecki – Midland, Texas
  - Scott Niekamp – Columbus, Ohio
  - Leone Gaston – Highlands Ranch, Colorado
  - David Vance – Midland, Texas

Hydrogeologic Modeling
The Approach

- Using Groundwater Vistas with Modflow
- Three vertical layers
- Nodes on half mile centers
- Total model has 374 rows and 160 columns
- Approximately 50,000 of the 59,840 nodes are active

Simulation of Geologic Past

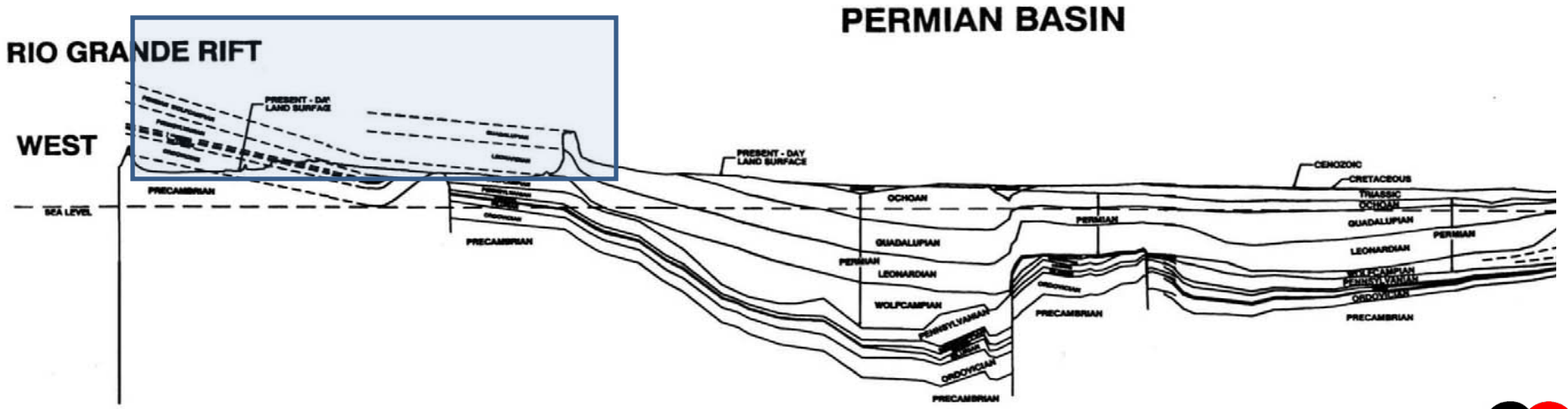
- Conceptualize Past Geologic Structure.
- Conceptualize Past Climatic Conditions.
- Conceptualize Flow Regime.

- Focus is on the Early Miocene.

Tectonics and Theorized Geologic Structure

(Early Miocene)

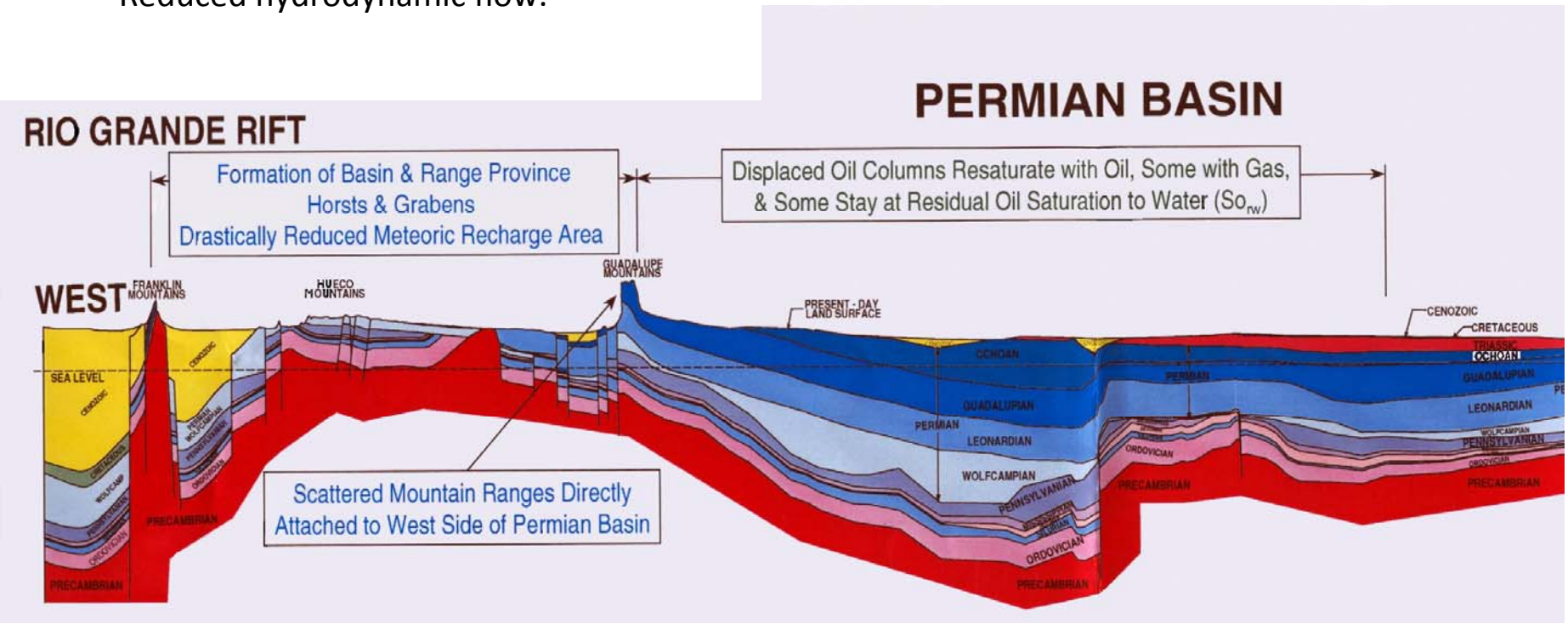
- Laramide orogeny begins in late Cretaceous/Early Cenezoic (~65 MYA)
- Second phase of hydrocarbon emplacement in Oligocene and Early Miocene in response to heating from tertiary intrusives and extrusives to the South (20-40 MYA).
- Extensional tectonics - broad structural arching and uplift centered on Rio Grande rift with minimal folding and faulting in Late Oligocene to Early Miocene (25-15 MYA).
- Eastward tilting of the Permian Basin resulted from uplift.
- Guadalupian system theorized to be unbroken to the west of current Guadalupe Mountains.
- Rocks extended upward to the center of the Rio Grande Rift (westward), perhaps as high as 12,000 feet as suggested by current elevation of Sierra Blanca Peak in Sacramento Mountains.
- Tilting of the geologic structure caused hydraulic gradients and hydrodynamic flow to occur.
- Enhanced conditions for meteoric recharge.
- Early Miocene flushing of hydrocarbons.



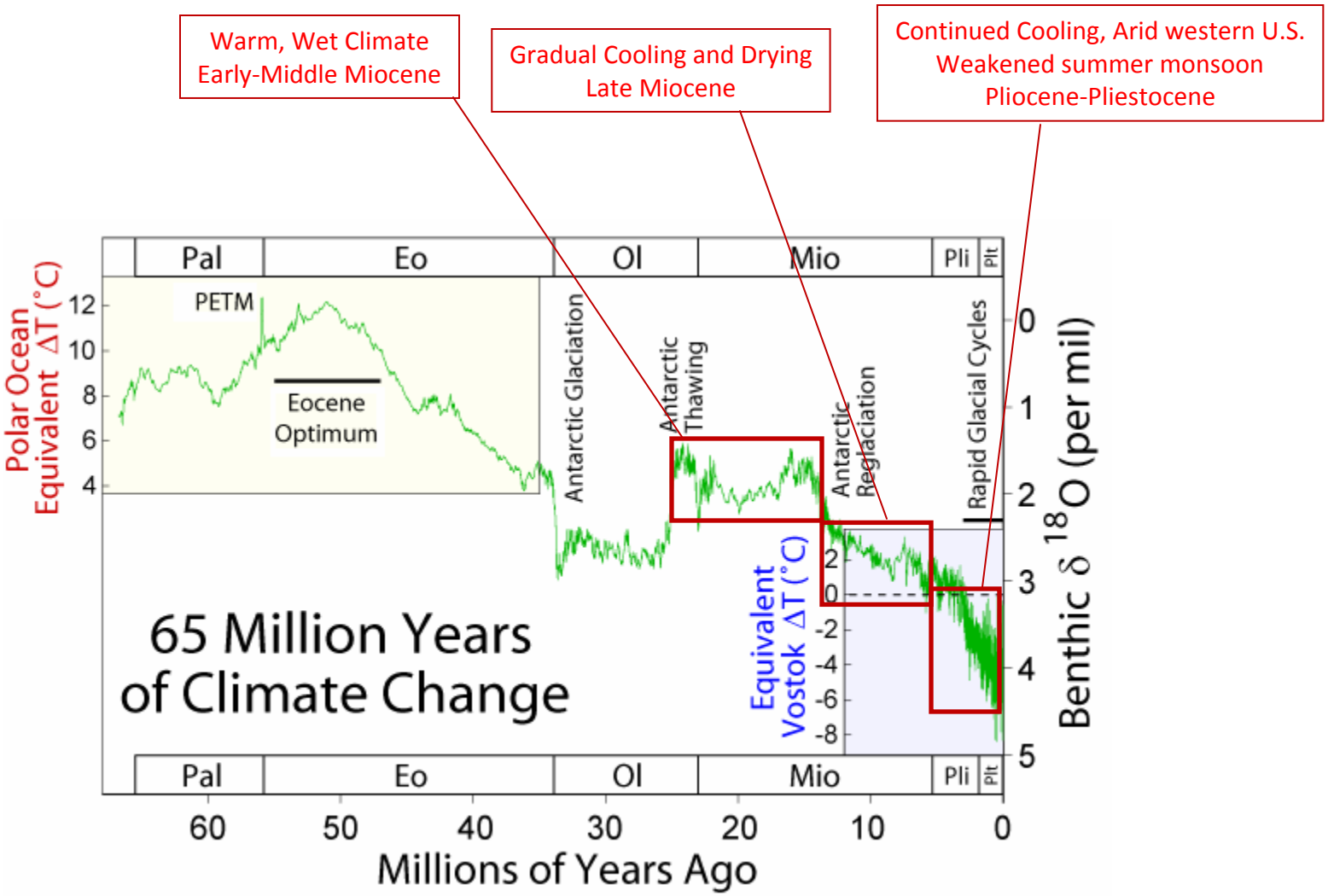
Geologic Structure

(middle Miocene to present)

- In middle Miocene (~15 MYA), rifting and block faulting disconnected the previously continuous Guadalupian system.
- Likely reduced meteoric recharge, which would reduce hydrodynamic flow in Permian Basin.
- Down-cutting of Pecos River formed a sink, which isolated portions of the fairway from recharge in the Guadalupe Mtns.
- Reduced hydrodynamic flow.

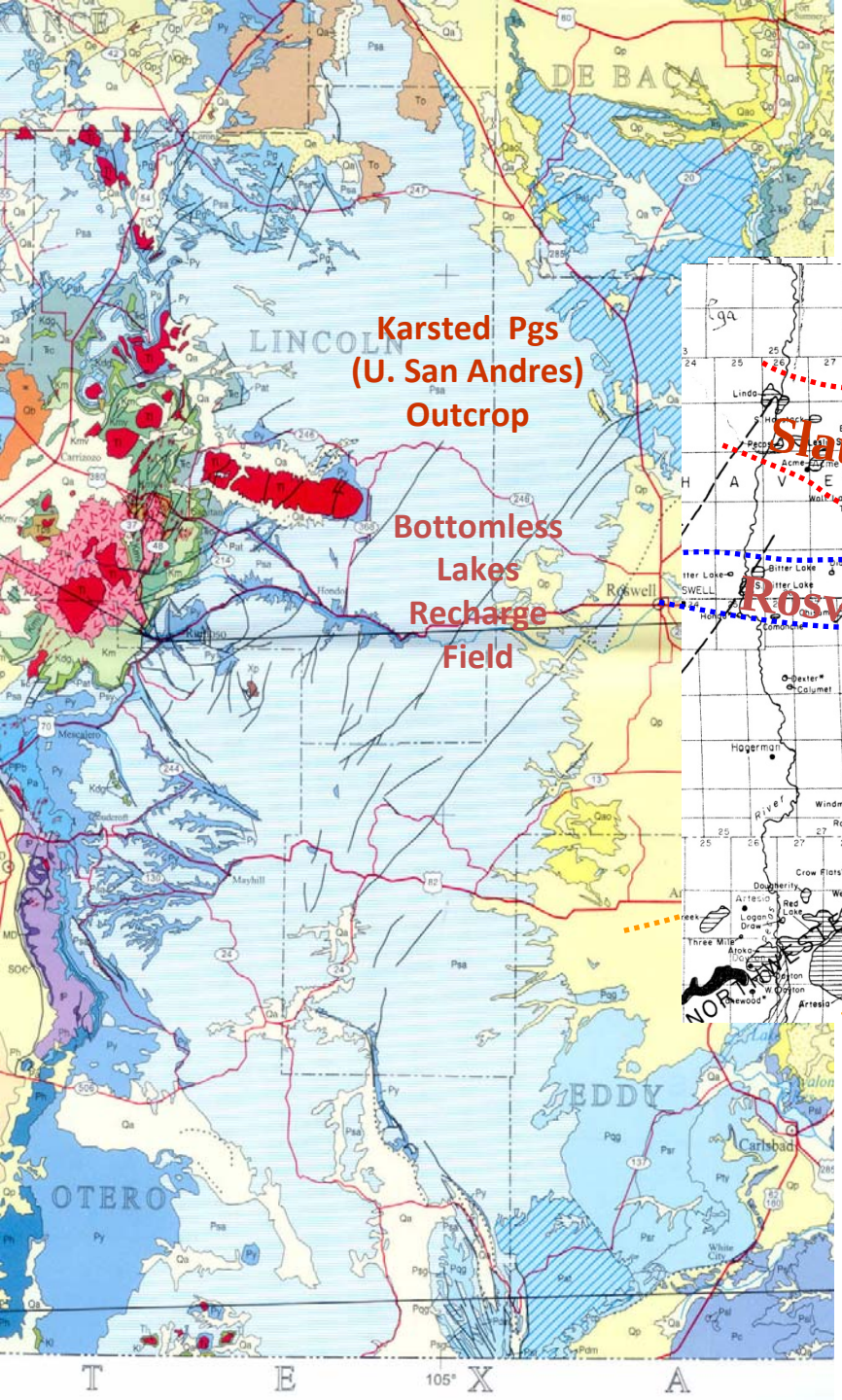


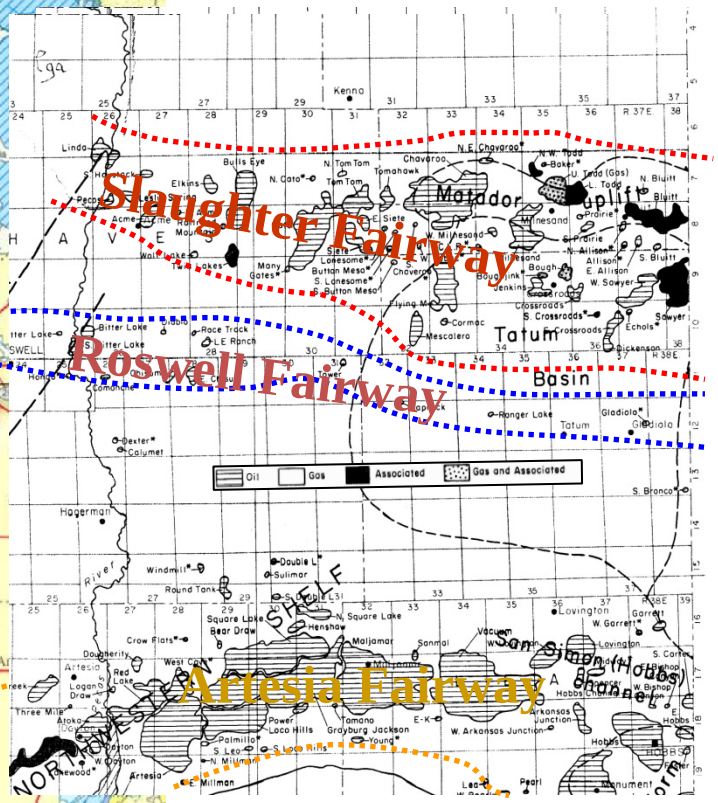
Climate Patterns Over Time



Climate (early-middle Miocene)

- Western U.S. covered with extensive mixed deciduous-conifer forests.
- Distributed to all altitudes (not just high altitude wet zones).
- Estimated that 400 mm (16 in.) of summer precipitation alone would be required to support this plant assemblage.
- 89-100 cm (35-39 in) total precipitation estimated in central Nevada.
- Probably around 30-35 inches total for eastern deciduous flora.
- Local climate less well understood.
- Gradual global cooling and drying of western U.S. begins following middle Miocene climate optimum (15 MYA).
- Arid conditions predominate by 5 MYA with change to arid flora except at high elevations
- Cause attributed to cooling of the pacific ocean and secondarily to rain shadows caused by uplift of mountain ranges to the west
- Greatly weakened summer monsoon.



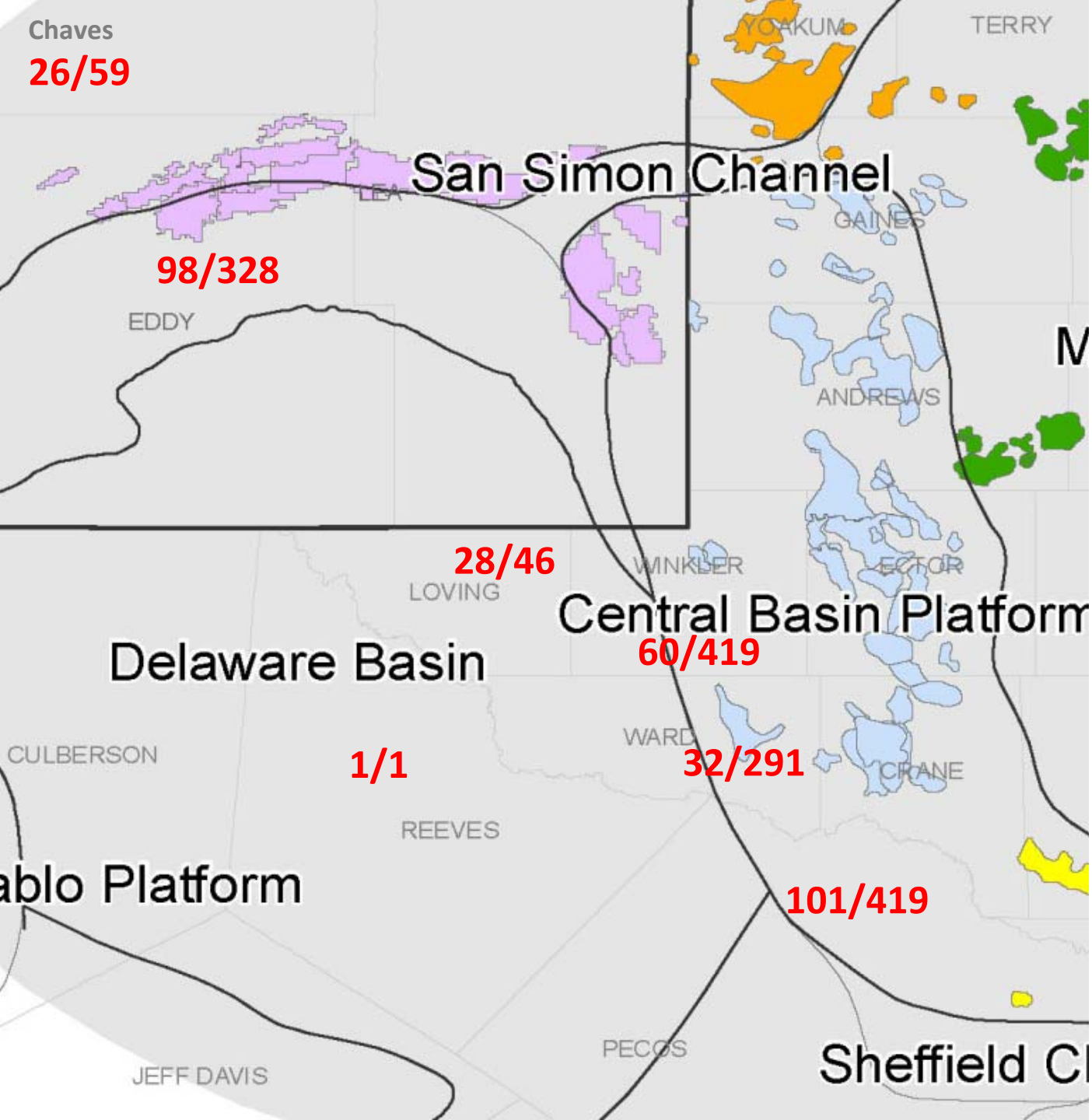


Relationship of San Andres outcrops and San Andres Fairways in New Mexico.

Data Gathering – Delimiting the Trends

- Focus on/Identify/Define the Artesia - West Central Basin Platform Trend
- Gathered
  - Well data – location, tops, correlations (Cross Sections)
  - Pressure Data - DST's, Well Test Data – 738 Wells
  - Permeability and Porosity Data (Core)
  - Water Chemistry – 3,315 wells

Modeling the Chosen Fairway



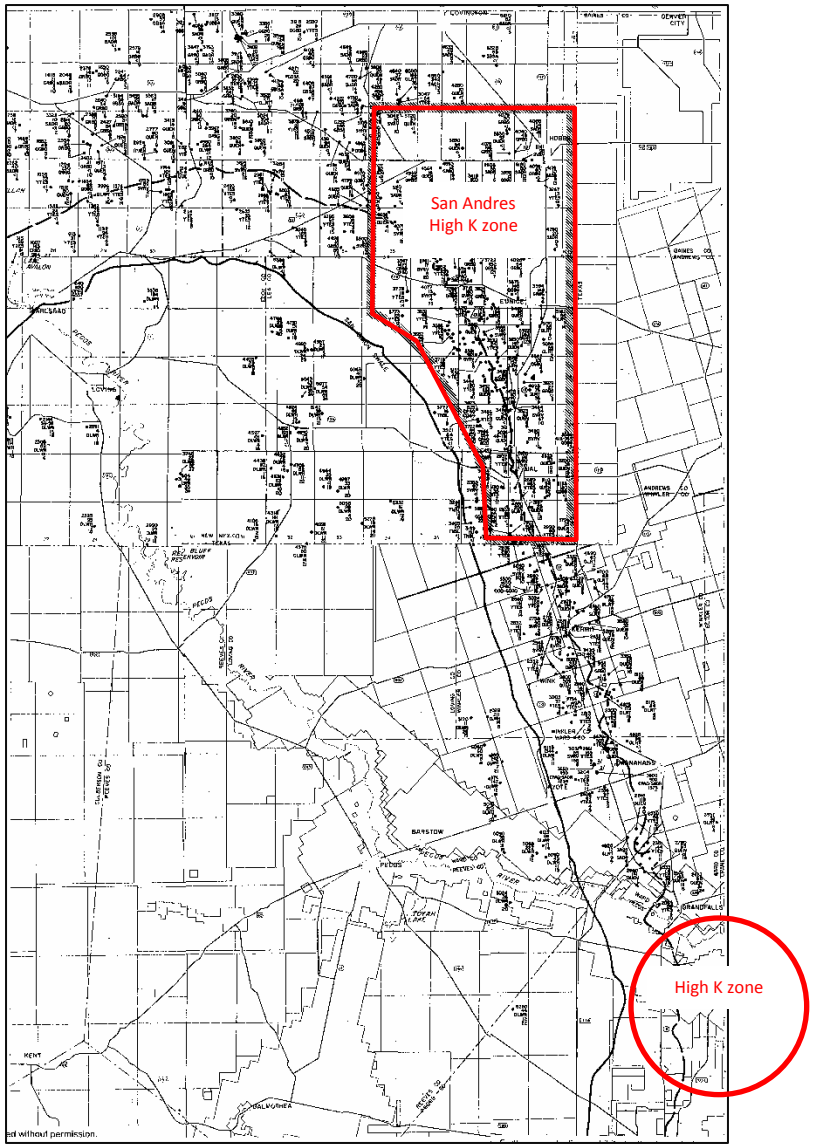
DST and Water Chemistry Data collected from various sources, by county

Wells by County

346/1563

DST / Water Chem

Permian Basin Plays, Dutton et al (2005)

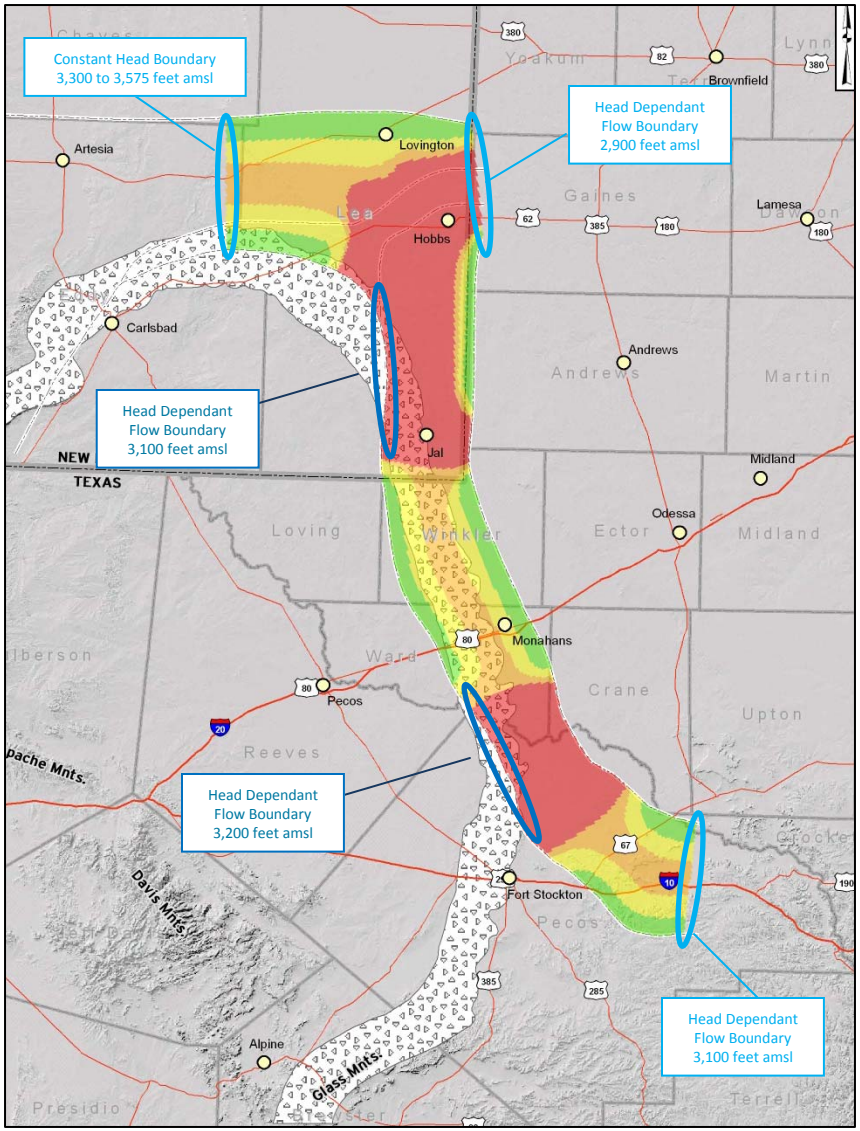


Regional Hydraulic Conductivities

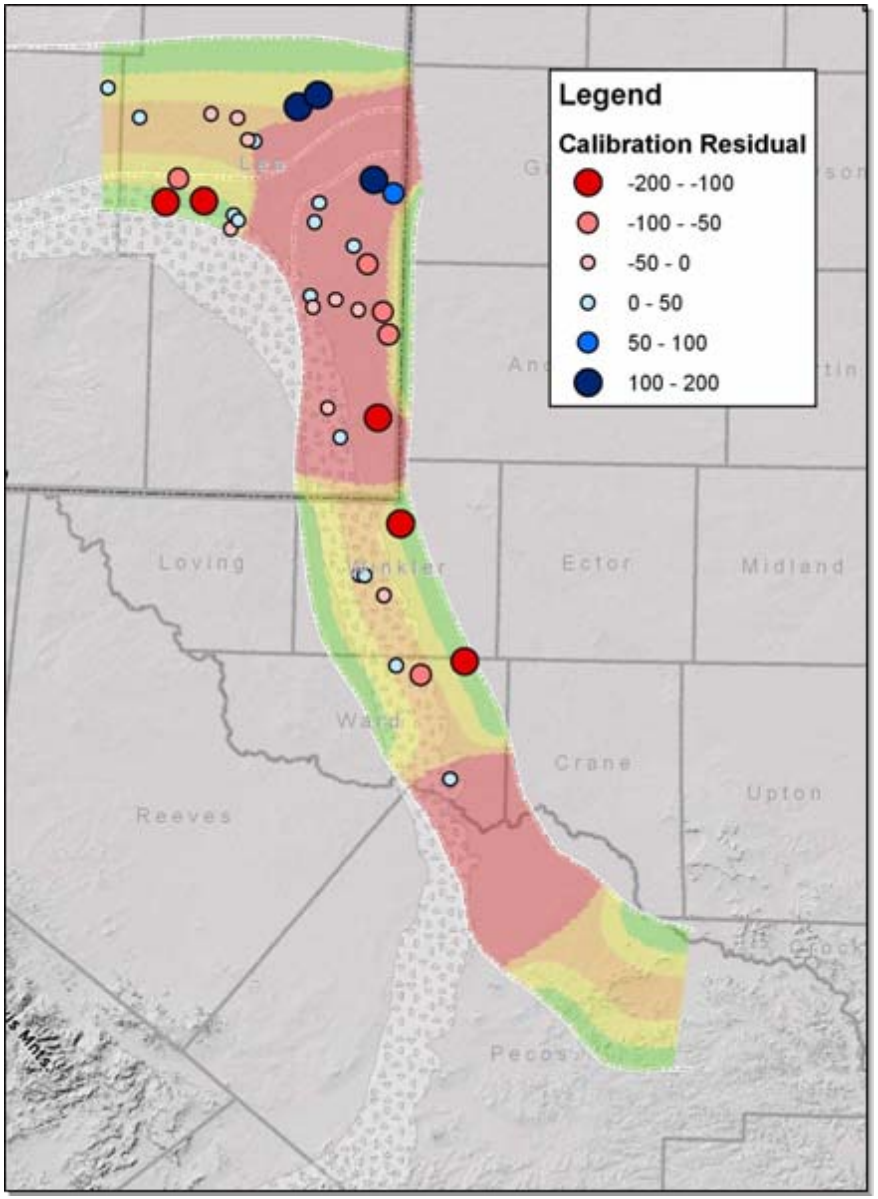
- Documented enhanced hydraulic conductivity zones in the San Andres Limestone in Lea County and Pecos County
- Lesser quantities of water likely discharge into the Artesia group since enhanced hydraulic conductivity is lacking.

Hydraulic Conductivity map Source: *Stratigraphy and Ground-water Hydrology of the Capitan Aquifer, Southeastern New Mexico and Western Texas.* (Hiss, 1975).

Conceptual Model
Model Boundaries



- Simulates flow into and out of the Artesian Fairway.
- Boundary heads assigned based on pre-development potentiometric surface map.
- Boundary conductance's assigned based on hydraulic conductivities of the formation.
- Northeast and southeast boundaries represent flow exiting (or entering) the Fairway in Gaines and Pecos Counties.
- Northwest boundary represents inflow from adjacent units that supports the groundwater flow divide.
- Western boundaries represent flow entering (or exiting) the Fairway in Lea and Pecos Counties.



Head Calibration

•Model is able to reproduce heads in the middle of the Fairway very well.

•Over-simulates heads at the edge of the fairway in eastern Lea, Winkler, and Ward Counties. Eastward component to the hydraulic gradient that can't be simulated.

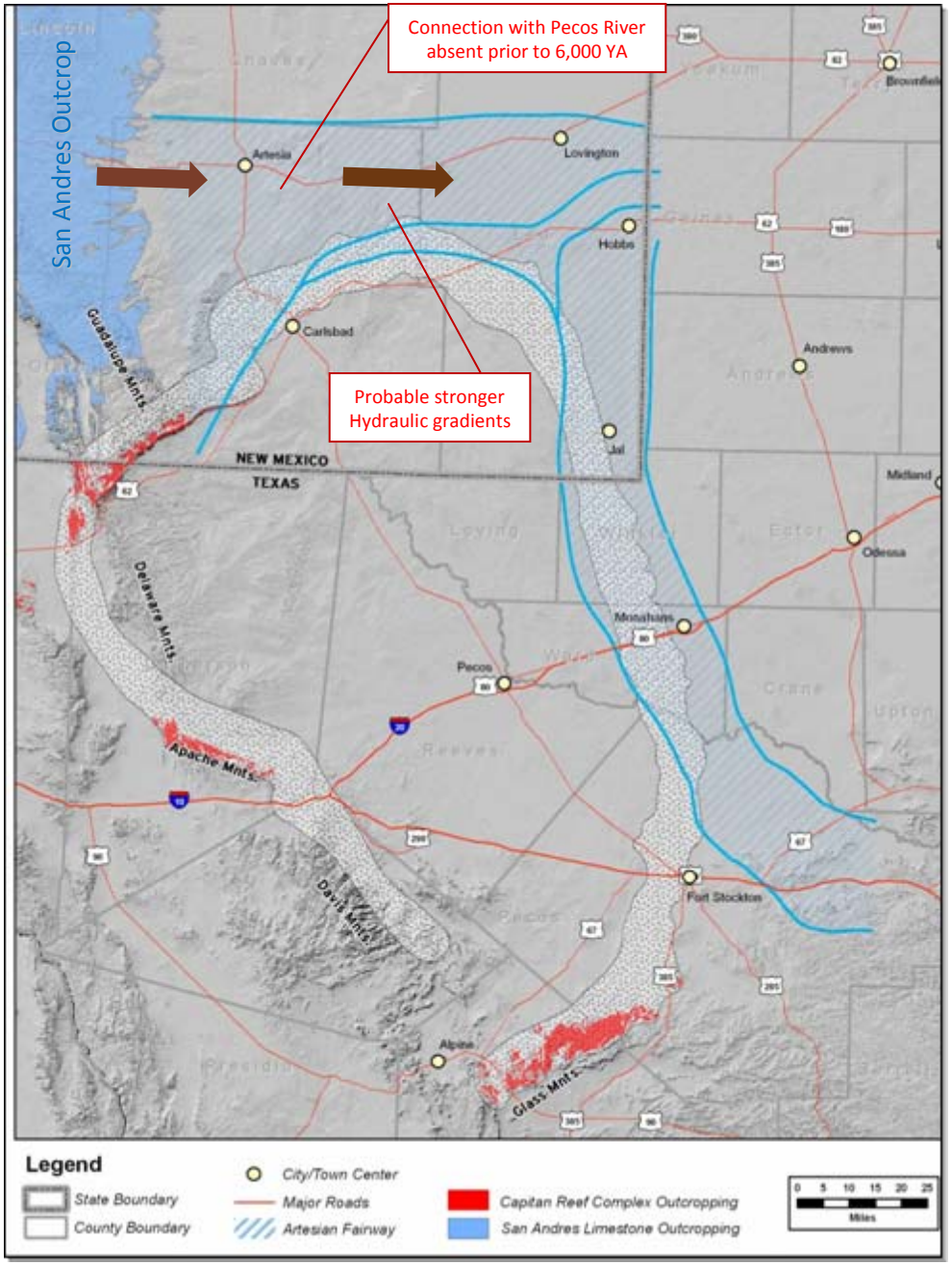
•Under-simulates heads in northeastern Lea County

•Compromise between reproducing flows and reproducing heads in this area.

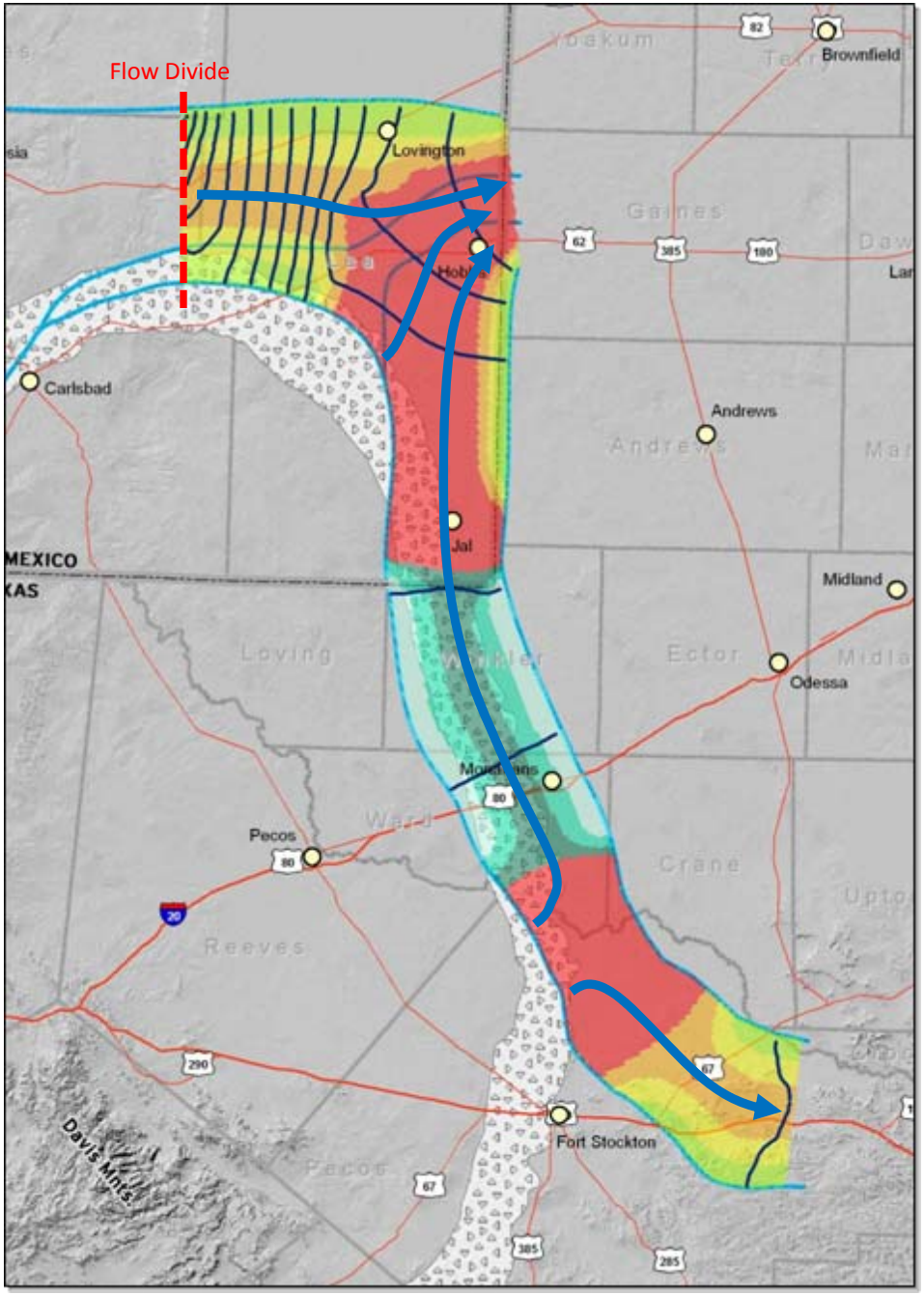
•Error = difference between simulated head and measured head

Error Type	Error Measurement
Mean Error	-17.8 feet
Absolute Mean Error	59.8 feet
RMSE/range in heads	14%

Artesia Fairway – Guadalupe Mountains (early Miocene)



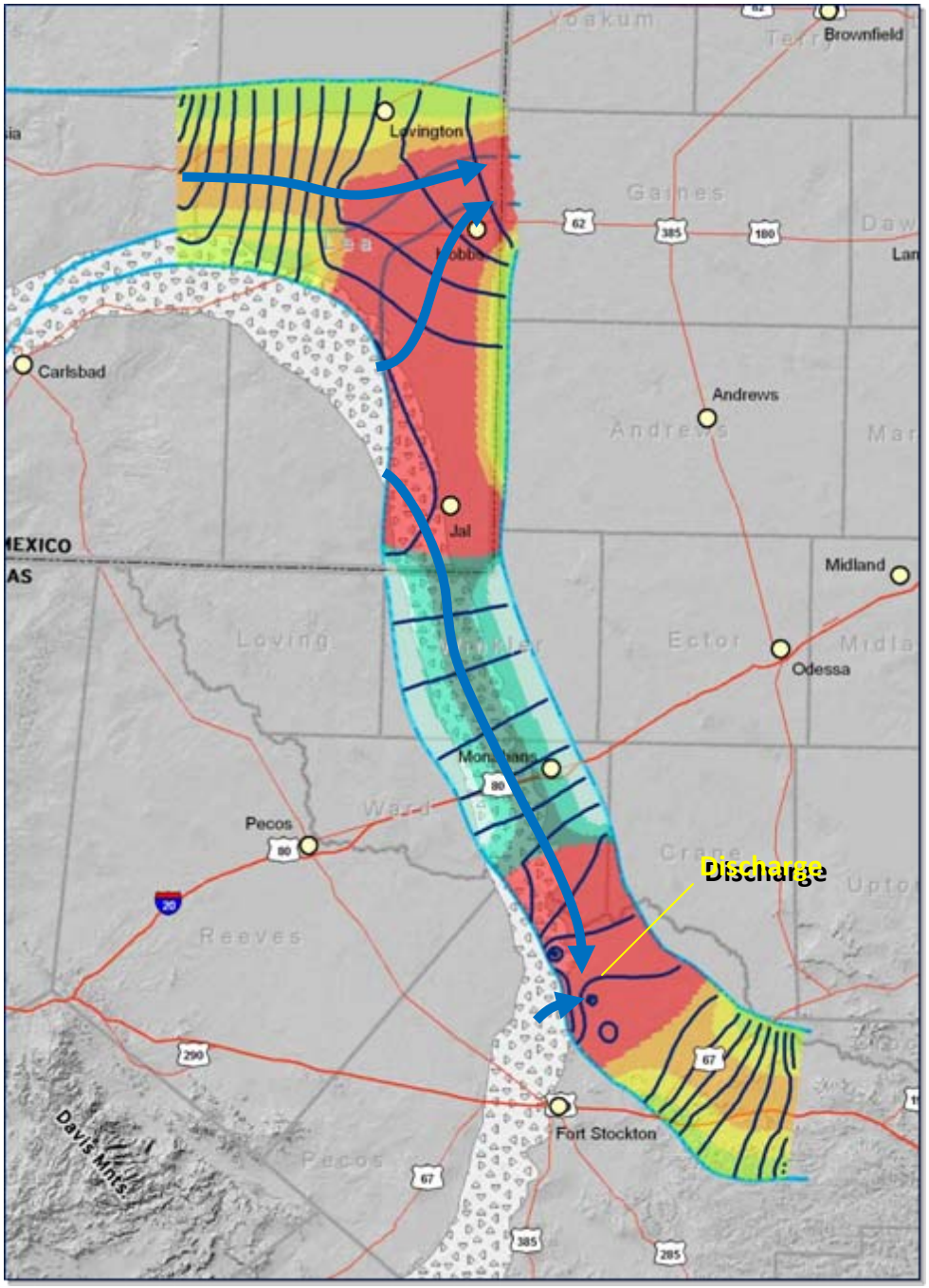
- The Pecos river is very young. Not present in early Miocene. Present groundwater divide absent.
- San Andres limestone likely extended westward, possible connected to the ridge over the Rio-Grande valley.
- Increased recharge and stronger hydraulic gradients
- Decreased karstic porosity?



Flow in the San Andres Modern Time, but Pre-Development

Legend

- Artesia Fairway
- Capitan Reef Complex
- Head Contour
- Flow through Artesia Fairway

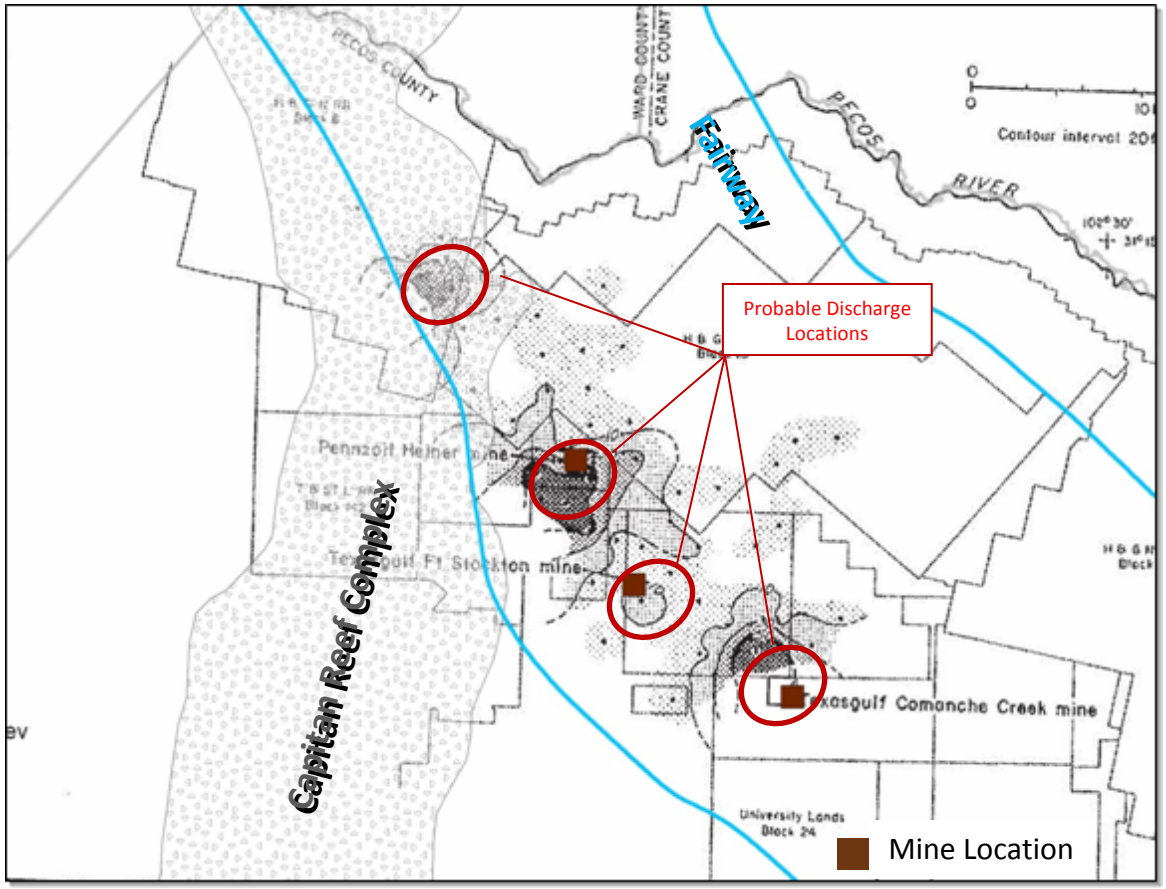


Flow in the San Andres in the Geologic Past

Legend

- Artesia Fairway
- Capitan Reef Complex
- Head Contour
- Flow through Artesia Fairway

Pecos County Discharge Points



Isopach of net thickness of sulfur.

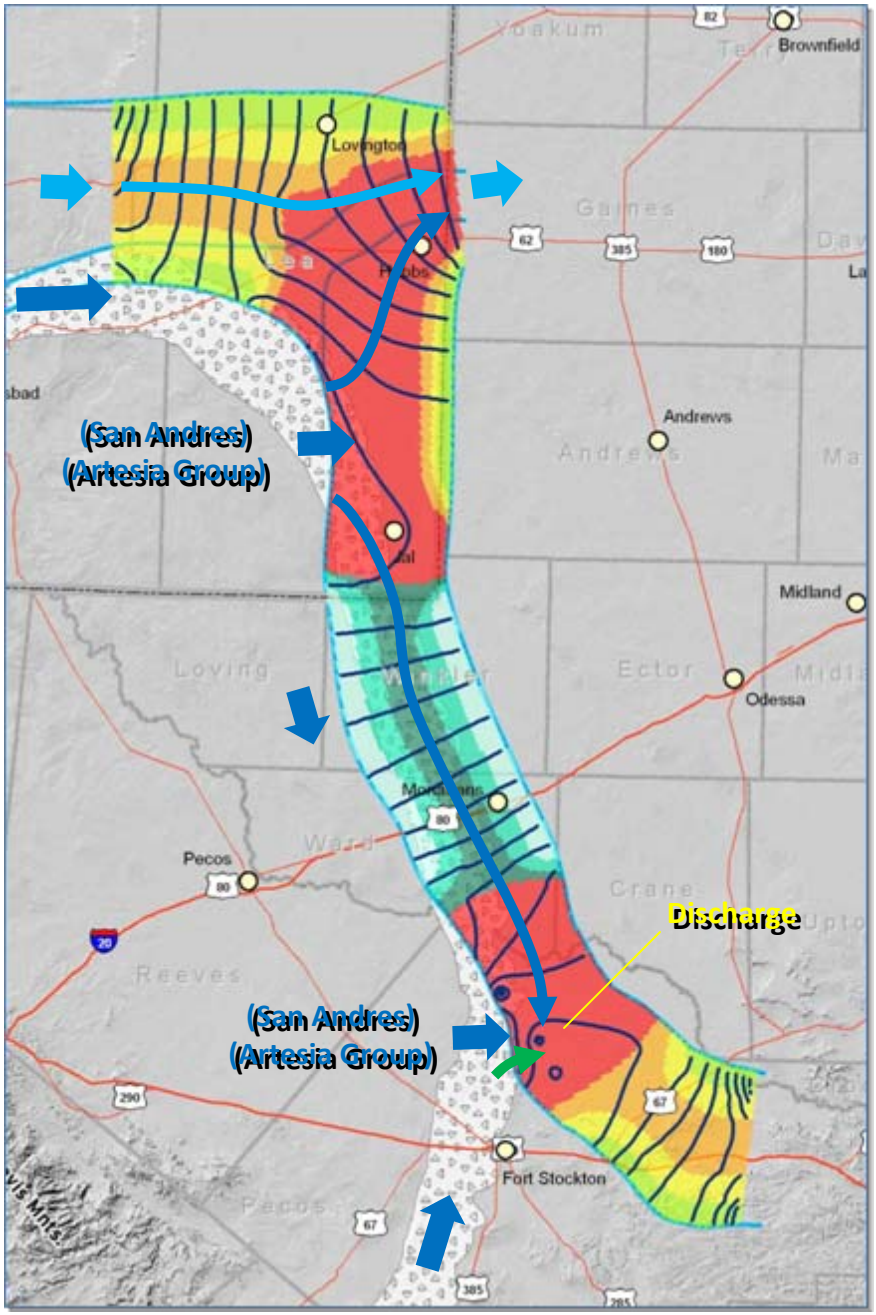
"Geologic Occurrence and Regional Assessment of Evaporite-Hosted Native Sulfur, Trans-Pecos Texas"
Hunt et al., 1989

- Thickness maps of Sulfur ore bodies suggests the presence of 4 discharge locations in geologic past.
- Sulfur mines were located at three of these locations
- Sulfur deposits theorized to have formed during episodes of hydrocarbon flushing, especially in late Oligocene –early Miocene.
- H_2S generated from microbial metabolism of flushed hydrocarbons along with reduction of sulfate from evaporites in chimney structures.
- H_2S oxidized to native sulfur
- Accumulated in structures defined by lineament chimney traps.
- Theorized discharge point for flow moving through the Artesia Fairway.

- Estimates of flow volumes required to produce sulfur deposits would be useful to refine water budget.

The Role of Sulfur Biogeochemistry

- The sulfur deposits in Pecos County were formed from the biogeochemical interactions of petroleum and calcium sulfate (gypsum/anhydrite)
- Similar reactions have taken place in the fairway flow path
- Sulfate biogeochemical processing effects:
  - Porosity driven by changes in carbonate mineral suites
  - Chemical composition of the petroleum
    - Hydrocarbons are consumed and graded by sulfate reducing microbes
    - That process generates hydrogen sulfide that inhibits microbial activity at concentrations over 100 to 200 mg/L – That prevents total hydrocarbon consumption
  - Mobility of the petroleum hydrocarbons
    - Sulfate reducing microbes generate biosurfactants that enhance the mobility of petroleum in the flow system



Preliminary Simulations General Observations

- Flow traveling down the Fairway in Eddy and Lea County discharges into Gaines County.
- Source of flow in Ward and Winkler County is the northern limb of the Capitan Reef Complex.
- Most of the recharge entering the Capitan Reef Complex from the Glass Mountains likely discharges in Pecos County.
- **Pore volume flushing ranges from 20 to 50 pore volumes over 15 million years (Late Oligocene through Middle Miocene)**

Legend

Flow outside model Area

- Flow through Capitan Reef Complex
- Flow through San Andres Artesia Fairway

Flow inside model Area (San Andres)

- Flow emanating from the Capitan Reef Complex
- Flow emanating from the Artesia Fairway

Questions to be Answered Future Work

Some we will do and some needed to be done by others

- a. Greenfield Fluid Sampling
- b. Water Salinity Impacts
- c. Permian Basin Wide Study
- d. Extrapolation to Other Basins (note ongoing Wyoming Work)
- e. ROZ vs. MPZ: Permeability Enhancements in the ROZ
- f. Size of the Oil Prize

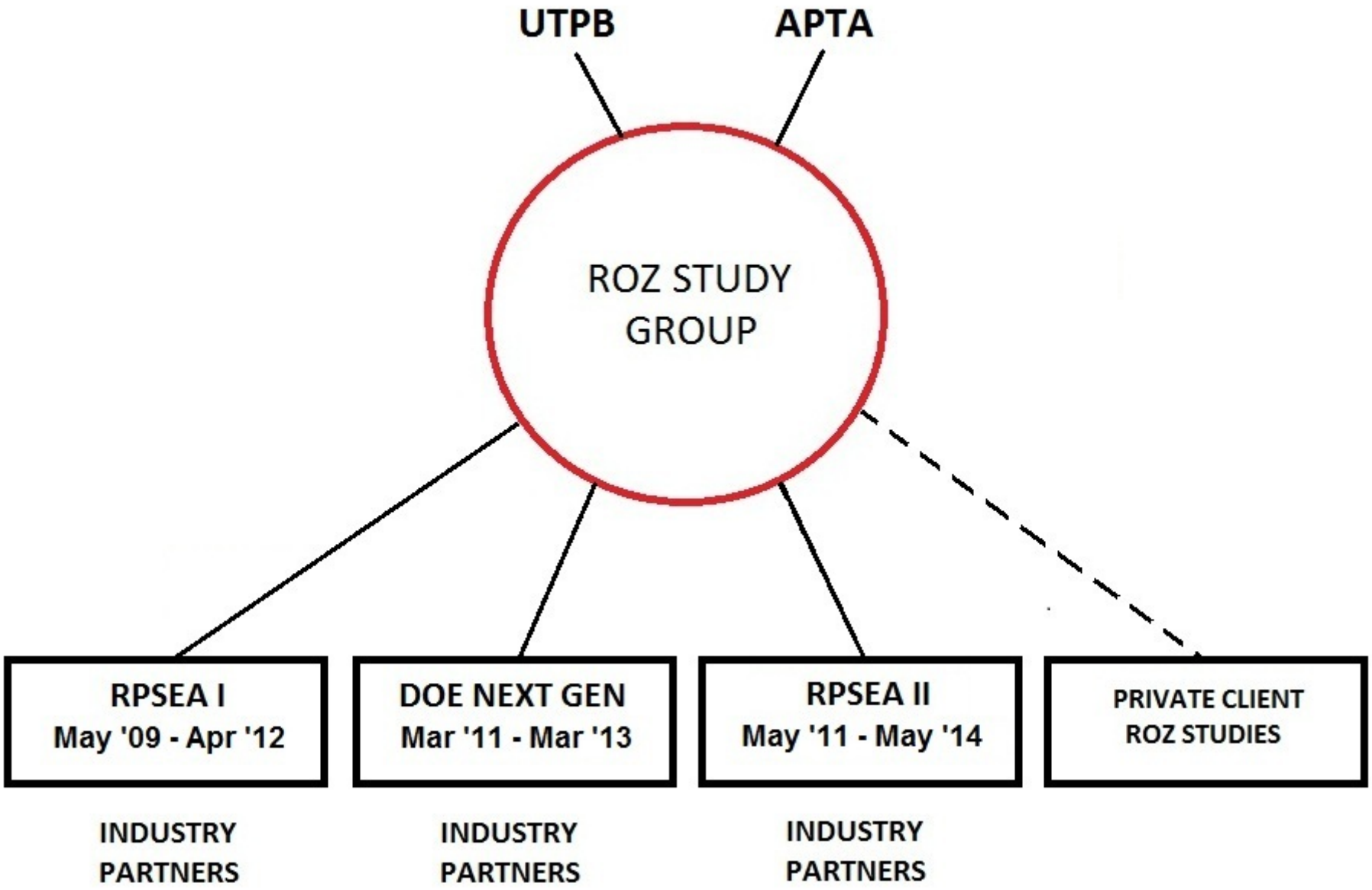
The PB ROZ Research Work

RPSEA I: Commercial Exploitation and The Origin of Residual Oil Zones: Developing a Case History in the Permian Basin of New Mexico and West Texas (Hydrodynamic Modeling: North and West Side of the Delaware Basin)

DOE Next Generation EOR: Commercial Exploitation and The Origin of Residual Oil Zones: Developing A Case History In The Permian Basin Of New Mexico And West Texas (Goldsmith-Landreth San Andres Unit)

RPSEA II: Identifying and Developing Technology for Enabling Small Producers to Pursue the Residual Oil Zone (ROZ) Fairways of the Permian Basin, San Andres: Regional PB Studies and Extrapolation to the Bighorn and Southern Williston Basins

Visit our website at: Residualoilzones.com


UTPB
APTA
ROZ STUDY GROUP
RPSEA I
May '09 - Apr '12
DOE NEXT GEN
Mar '11 - Mar '13
RPSEA II
May '11 - May '14
PRIVATE CLIENT ROZ STUDIES
INDUSTRY PARTNERS
INDUSTRY PARTNERS
INDUSTRY PARTNERS