ROZs: Science and Fairways - An Update*

Robert Trentham[1]

Search and Discovery Article #70353 (2018)**
Posted August 6, 2018

*Adapted from oral presentation given at AAPG 2018 Southwest Section Annual Convention, El Paso, Texas, April 7-10, 2018
See similar articles by author Search and Discovery Article #40787 (2011) Search and Discovery Article #10648 (2014) Search and Discovery Article #51259 (2016) Search and Discovery Article #51400 (2017)

[1]University of Texas of the Permian Basin, Odessa, TX (trentham_r@utpb.edu)

Abstract

Residual Oil Zones (ROZ's) have been exploited in the Permian Basin since the late 1990's. However, it was only in the last decade that the science of ROZ's has been understood and documented. Beginning in 2006, a series of DOE- and RPSEA-sponsored projects has resulted in a basic understanding, modeling, case histories, a cookbook for identification, and regional evaluation of ROZ's in the San Andres. These projects, and others, have generated a more complete understanding, which in turn, has led to advancing production from the ROZ's.

Regional flow modeling has demonstrated that meteoric derived flushing (Mother Nature's Waterflood, MNW) follows a number of pathways and that each pathway has a unique set of parameters and is unique in the distribution of lithofacies, traps, seals, and fluid flow. The San Andres is more complex than any one simple model of MNW can encompass, and therefore there are two regional "flow models" and a number of "rules of thumb" that can be applied to ROZ's. The flow modeling utilized Basin and Range uplift, and applied a modern day Bahama's platform model. The study of the Slaughter-Levelland Trend and eastern Central Basin Platform has utilized an Arabian Gulf model.

The "Rules of Thumb" center on trend geometries and the location of ROZ's and their relationship to Main Pays (MP's) within the San Andres. These rules apply:

- most ROZ's are found below the Pi Marker (top Guad 4);
- to date all exploited ROZ's are above the San Andres Maximum Flood (McKnight/Guad 1 – Guad 2);
- fields along the Northwest Shelf shelf margins have MP's above the Pi Marker, and associated ROZ's below the Pi Marker;
- the continuity of ROZ reservoirs in the lower San Andres (Guad 1 - Guad 4) follows the Bahamas Model;
- the Slaughter-Levelland Trend fields have updip traps/seal fitting the Persian Gulf Model where the Main Pay is trapped by tidal flats and sabkha deposits.
- beneath the Slaughter – Levelland trend, the ROZ follows the Bahama's model with an up-dip trap found as far north as the Tucumcari Basin;
- the Horizontal San Andres Play in Yoakum and on the northern Central Basin Platform is composed of "shingles" with multiple thin subtidal reservoirs shallowing to tidal flats, while the ROZ portion of the play is composed of open marine facies reminiscent of the open marine in the Bahama's model.

References Cited

Brown, A., 2001, Effects of Hydrodynamics on Cenozoic Oil Migration, Wasson Field Area, Northwestern Shelf of the Permian Basin, *in* J.J. Viveiros and S.M. Ingram (eds.), The Permian Basin: Microns to Satellites, Looking for Oil and Gas at All Scales: West Texas Geological Society Fall Symposium, Pub 01-110, p. 133-142.

Dutton, S.P., E.M. Kim, R.F. Broadhead, C.L. Breton, W.D. Raatz, S.C. Ruppel, and C. Kerans, 2005, Play Analysis and Digital Portfolio of Major Oil Reservoirs in the Permian Basin: The University of Texas at Austin, Bureau of Economic Geology Report of Investigations No. 271, 287 p., CD-ROM.

Dutton, S.P., E.M. Kim, R.F. Broadhead, C.L. Breton, W.D. Raatz, S.C. Ruppel, and C. Kerans, 2004, Play Analysis and Digital Portfolio of Major Oil Reservoirs in the Permian Basin: Application and Transfer of Advanced Geological and Engineering Technologies for Incremental Production Opportunities: Final Report Prepared for the U.S. Department of Energy, DE-FC26-02NT15131, 408 p.

Google Maps, 2018.

Harris P.M., S.J. Purkis, J. Ellis, P.K. Swart, and J.J.E. Reijmer, 2015, Mapping Bathymetry and Depositional Facies on Great Bahama Bank: Sedimentology, v. 62, p. 566-589.

Hill, C.A., 1996, Geology of the Delaware Basin: Guadalupe, Apache, and Glass Mountains New Mexico and West Texas: Society of Economic Paleontologists and Mineralogists, Permian Basin Section, Publication No. 96-39, 480 p.

Kerans, C., 2006, San Andres Formation: Outcrop to Subsurface Stratigraphic Framework. Bureau of Economic Geology: PGGSP Annual Meeting, Austin, TX.

Lindsay R.F., 1998, Meteoric Recharge, Displacement of Oil Columns and the Development of Residual Oil Intervals in the Permian Basin, *in* The Search Continues into the 21st Century, Stratigraphy and Sedimentology: West Texas Geological Society Publication No. 98-105, p. 271-274.

Matchus, E.J., and T.S. Jones, (Co-Chairman), 1984, East-West Cross Section through Permian Basin of West Texas: Prepared by Stratigraphic Problems Committee of the West Texas Geological Society, 1 sheet.

Ward, R.F., C.G. St. C. Kendall, and R.M. Harris, 1986, Upper Permian (Guadalupian) Facies and their Association with Hydrocarbons - Permian Basin, West Texas and New Mexico: American Association of Petroleum Geologists Bulletin, v. 70/3, p. 239-262.

Ward, R. F., 1988 and 1989 personal communication.

ROZs: Science and Fairways - An Update

Southwest AAPG

El Paso

April 9, 2018

Dr. Bob Trentham

University of Texas of the Permian Basin

The relationship between the San Andres regional setting and Residual Oil Zones (ROZs) in the Permian Basin.

Residual Oil Zones (ROZs) in the San Andres have gone from a “one off” a decade ago to established, economically producible reservoirs today. The science of ROZs have been documented over the past decade with DOE and RPSEA supported projects. There are now a variety of different methodologies used to produce oil from ROZs: co-mingled and separate “brownfield” ROZ and Main Pay CO_2 floods, CO_2 EOR ROZ floods peripheral to existing fields, “greenfield” CO_2 EOR ROZ floods without an associated main pay. Recently, horizontal depressuring (DUROZ) projects where horizontal wells target uneconomic classic vertical pay zones and ROZs together, have been developed on the Northwest Shelf and northern Central Basin Platform.

Despite the fact that there is now a decade of research into ROZs, and close to 20 projects producing oil for the ROZ, we need to step back and evaluate the relationship between ROZ targets and the complex depositional and diagenetic history of the San Andres to avoid the pitfalls associated with developing any new play. Assuming that the environment of deposition and diagenetic overprint are the same will lead you down that same garden path. Ditto for the fluid’s properties in the ROZ.

An understanding of the regional is essential. The Bureau of Economic Geology (2005) *Play Analysis and Digital Portfolio of Major Oil Reservoirs in the Permian Basin* identified 7 plays or trends in the San Andres and/or San Andres and Grayburg. A closer look at the regional context of the Main Pays and ROZs requires further refinement of these trends and leads to a better understanding of the ROZ potential of the San Andres in the Permian Basin. A regional review of the relationship between sea level fluctuations and reservoir distribution during the San Andres, and the impact of last stage tectonics and associated diagenetic overprint on the Northwest Shelf of New Mexico and Texas, leads to conclusions about ROZ distribution across the Permian Basin.

Outline

- Brief Background and Available Resources
- Mother Nature's Waterflood/Meteoric Flushing
- Modern Analogs – Bahamas and Arabian Gulf
- "Rules of Thumb" for ROZ's in the San Andres
- The importance of the Pi Marker/Brushy Canyon Bypass Surface.

Residual Oil Zone Studies and Technical Reports

Overview

- Assessing Technical and Economic Recovery of Oil Resources in Residual Oil Zones. ARI, Melzer, DOE Report, 2006. www.fossil.energy.gov.

Modeling

- Commercial Exploitation and the Origin of Residual Oil Zones: Developing a Case History in the Permian Basin of New Mexico and West Texas. Trentham, Melzer, Arcadis. RPSEA 08123-19 final report, June 2012. NETL Website.

Case Study

- Case Studies of the ROZ CO2 Flood and the Combined ROZ/MPZ CO2 Flood at the Goldsmith Landreth Unit, Ector County, Texas. Using "Next Generation" CO2 EOR Technologies to Optimize the Residual Oil Zone CO2 Flood. Trentham, Melzer, ARI. DOE DE-FE0005889, Sept 2015. NETL Website.

Regional Reserves

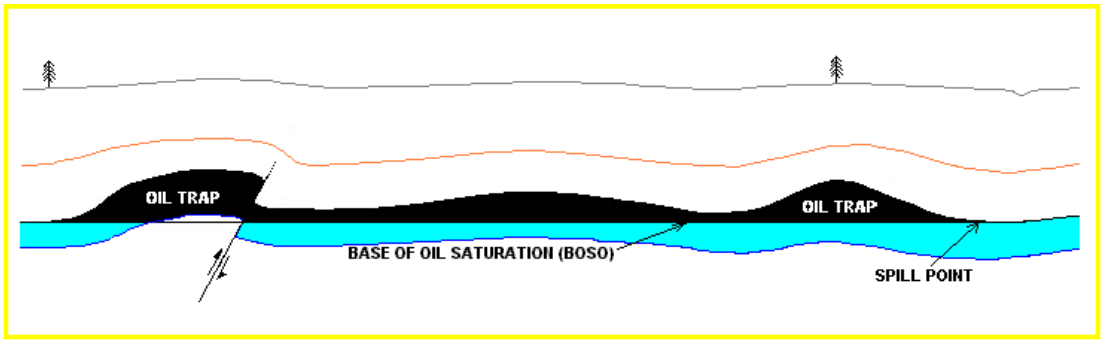
- Identifying and Developing Technology for Enabling Small Producers to Pursue the Residual Oil Zone (ROZ) Fairways in the Permian Basin San Andres. Trentham, Melzer, Arcadis, ARI. RPSEA 10123.17 Final Report, Dec 2015. NETL Website.

Residual Oil Zones (ROZ's) have been exploited in the Permian Basin since the late 1990's. However, it was only in the last decade that the science of ROZ's has been understood and documented. Beginning in 2006, a series of DOE- and RPSEA-sponsored projects has resulted in a basic understanding, modeling, case histories, a cookbook for identification, and regional evaluation of ROZ's in the San Andres. These projects, and others, have generated a more complete understanding, which in turn, has led to advancing production from the ROZ's.

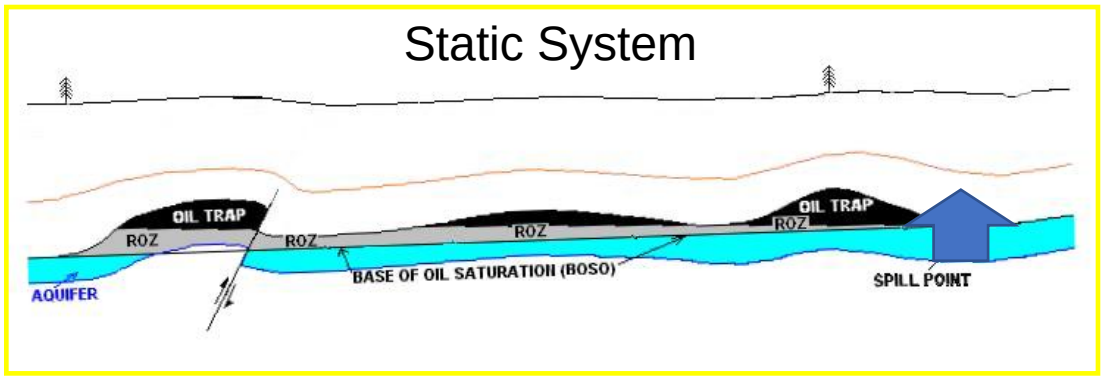
Looking for more geologic background? Search and Discovery:

- R. C. Trentham, 2011, Residual Oil Zones: The Long Term Future of Enhanced Oil Recovery in the Permian Basin and Elsewhere. #40787
- R. C. Trentham 2014, Goldsmith Landreth San Andres Unit (GLSAU) # 203R – A CO2 Oil Bank Caught in the Act. #10648
- R. C. Trentham, L. Stephen Melzer, 2016, A Cookbook Approach to Exploring for, and Evaluating, Residual Oil Zones in the San Andres Formation of the Permian Basin. #51259.
- R. C. Trentham, 2017, San Andres on the Northwest Shelf: Things You May Not Know, #51400.
- Also an extended version presented to engineers at the CO_2/ROZ Seminar at the 23rd Annual CO_2/ROZ Conference, Dec 2017, in Midland.

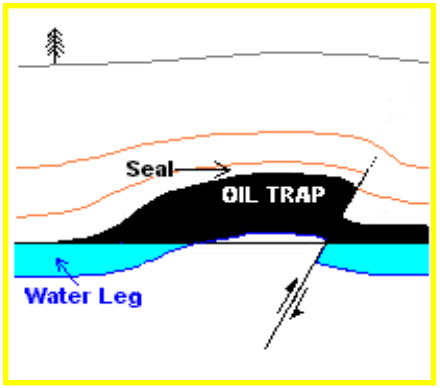
Quick Background Review

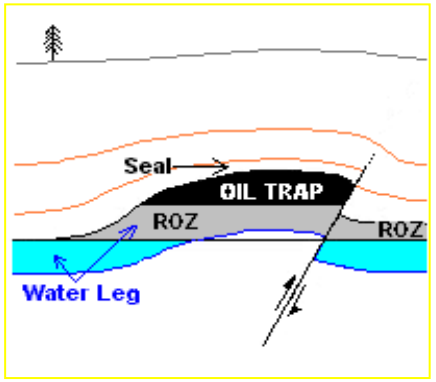


Original Oil Accumulation Under Static Aquifer Conditions
(A Hypothetical Example)



TYPE 1. Original Accumulation Subject to a Eastward Regional Tilt & Forming a ROZ.
The new O/W contact is horizontal
The base of the ROZ is tilted
Oil would have migrated out of the basin.

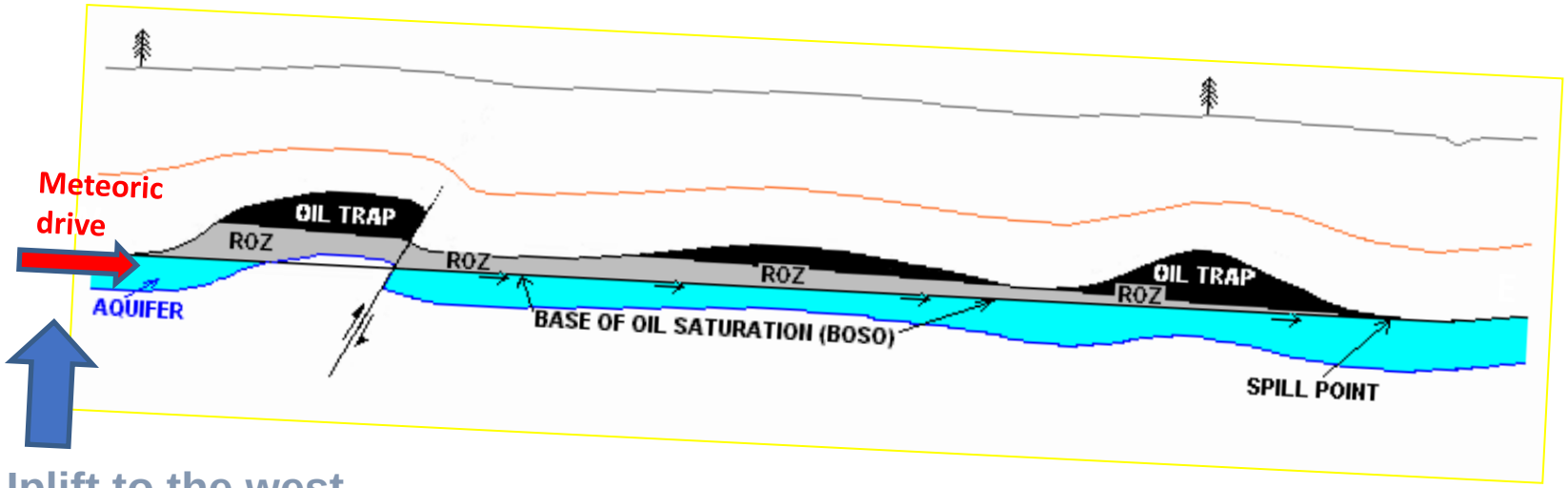




TYPE 2. Original Accumulation with a Breached, then Repaired, Seal, forming a ROZ/TZ.
A horizontal O/W contact on the main pay and the ROZ.
May also “de-gas” the reservoir.
Present in the Permian Basin.

TYPE 3. ROZ's - Mother Nature's Waterflood (MNW)

Changes 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 can be almost flat, regionally tilted.

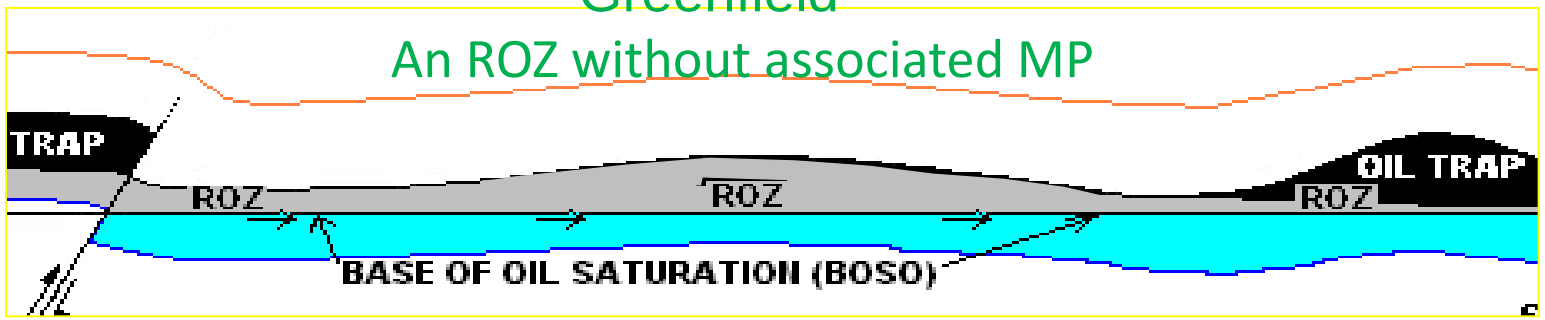


Uplift to the west of the Permian Basin

Dynamic System

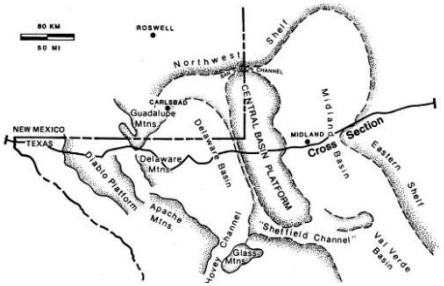
Greenfield

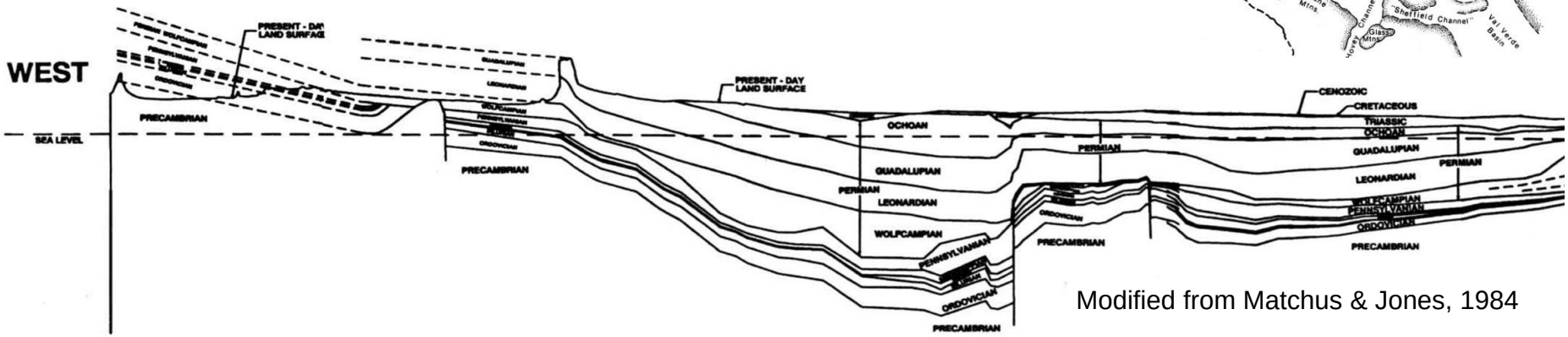
An ROZ without associated MP



The Evidence suggests Type 3 are common in the Permian Basin

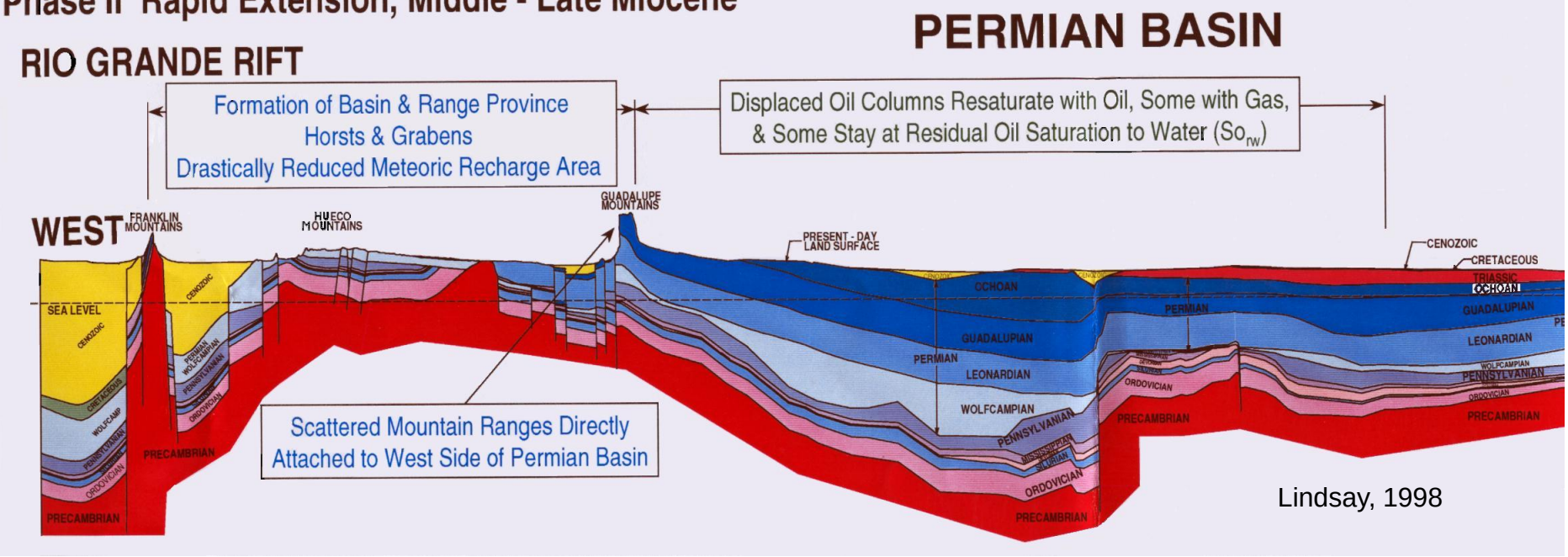
Rio Grande Uplift Phase



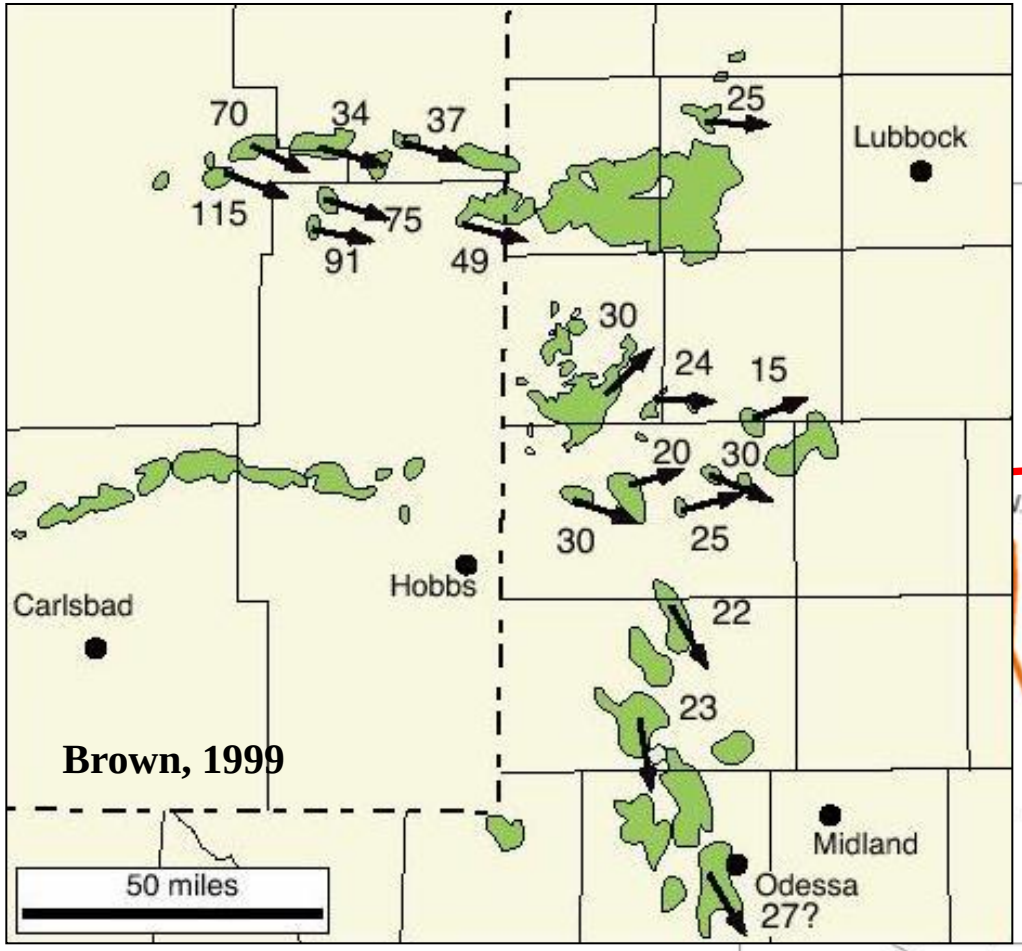


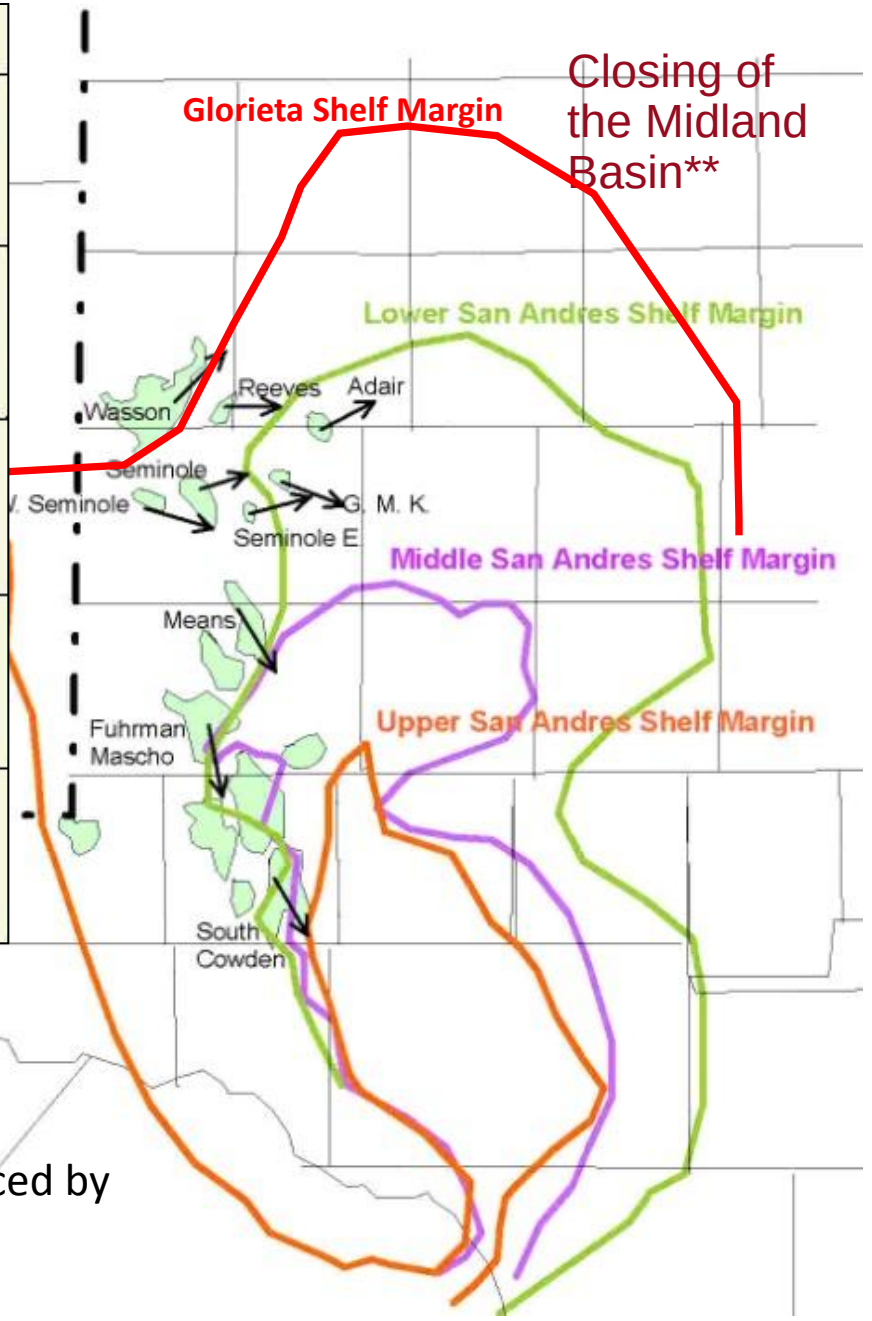
Modified from Matchus & Jones, 1984

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



Lindsay, 1998



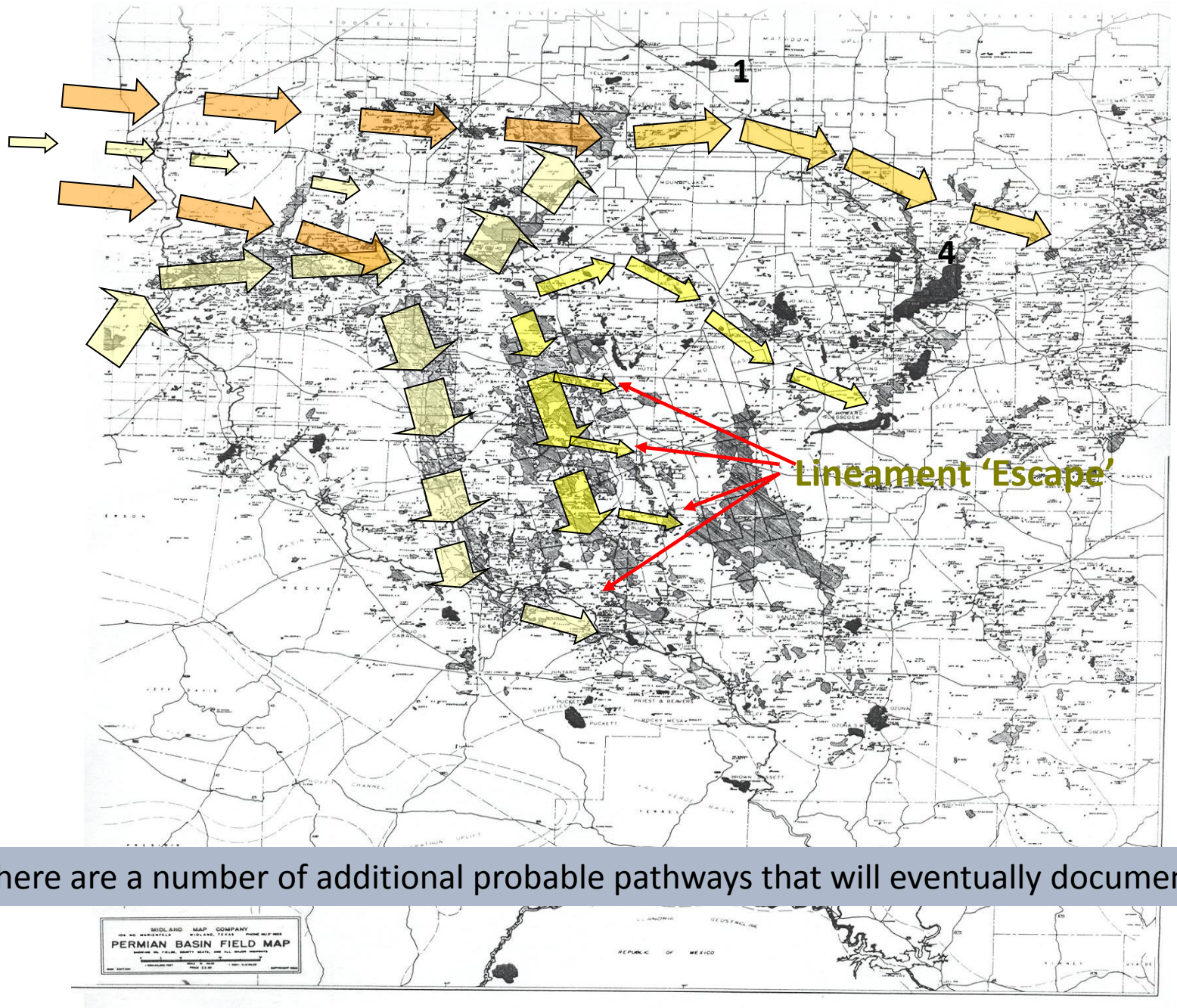


Distribution of Tilted Oil-Water Contacts in the Northern Shelf and Central Basin Platform Areas of the Permian Basin*

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

Brown, 2001* Ward et al, 1986 **

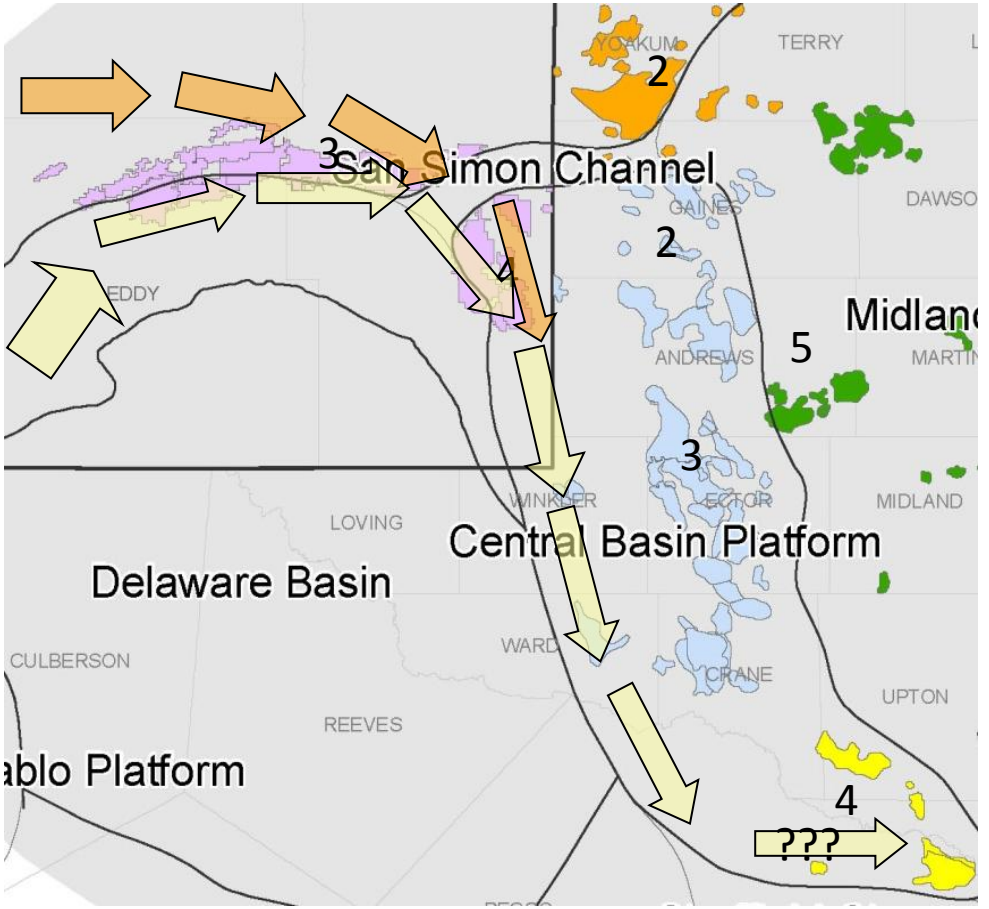
THEORIZED (U. PERMIAN) HYDRODYNAMIC FAIRWAYS



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

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



Base modified from Dutton, et.al., 2004

Arcadis will use ModFlow, a U. S. G. S. developed, finite ground water modeling program with regional capabilities.

Timing of Post Permian Tectonic Overprint and Meteoric Flushing

Quat	Pliocene - Pleistocene - Holocene	-5 Ma to Present	Base level downcutting of ancestral Pecos River. At ~600 Ka Capitan Aquifer hydrologically connects with Pecos River at Carlsbad. Possible draining of lower Carlsbad and Lechuguilla Caverns. Rio Grande Rifting.
	Late Miocene	-12 to -5 Ma	H2S ascends into Guadalupe Mtns from basin. Sulfuric acid caves develop from Se to NE, enlarge and cut across older thermal caves. Rio Grande Rifting.
Cenozoic	Early Miocene	-25 to -12 Ma	Rio Grande Uplift accelerating. Maximum uplift of Guadalupe Mtns block begins (~20Ma). Delaware Basin geothermal gradient reaches 40-50°C/km. "Second" maturation and migration of hydrocarbons. H2S produced where hydrocarbons react with evaporites. Thermal caves developing. Dewatering Calcite spar fills basin and range fault zones.
	Oligocene	-40 to -25 Ma	Trans-Pecos Magmatic Province: Tertiary intrusives and extrusives to SW, dikes in Delaware Basin.. Transition from volcanic to Basin and Range in Delaware Basin Delaware Basin tilts eastward and heats up. "Second" maturation and migration of hydrocarbons. H2S produced where hydrocarbons react with Castile anhydrite. Begin Rio Grande Uplift in late Oligocene.
	Paleocene	-65 to -58 Ma	Laramide uplift continues into Early Tertiary. Older caves get enlarged and connected.
Mesozoic	Cretaceous-Gulfian	-95 to -65 Ma	Late Cretaceous Laramide Orogeny begins. Guadalupe and Apache Mtns. Lifted 1000's of feet above sea level.
	Early & Mid Cretaceous Jurassic Triassic	145-95 199-145 2510199	A time of relative quiescence in the Permian Basin Some section added.
Paleo	Ochoan Guadalupian	-255 to -251 Ma	Castile and Salado Seven Rives Yates and Tansill backreef, Capitan Reef, Delaware Mountain Group Deposition. Early dolomitization in Apache and Glass Mountains.

The top of San Andres was uplifted over 7000' by the tectonism. A gradient of ~80' mile exists today between the Guadalupe Mountains (+6000') and the Central Basin Platform (-1000')

Modified from Hill, 1996

Horizontal Fluid Movement per 1000 years

Conductivity Zone	Velocity (ft/1,000 years). Porosity = 6%	Velocity (ft/1,000 years) Porosity =10%	Velocity (ft/1,000 years) Porosity = 16%
Layer One	1.9	1.1	0.7
Layer Two – Center Zone	**738**	**446**	**278**
Layer Two – Intermediate Zone	72	44	27
Layer Two – Edge Zone	7.2	4.3	2.7
Layer Three	1.9	1.1	0.7

Between one quarter (¼) and three quarters (¾)of a foot a year.

Time Period and Pore Volumes

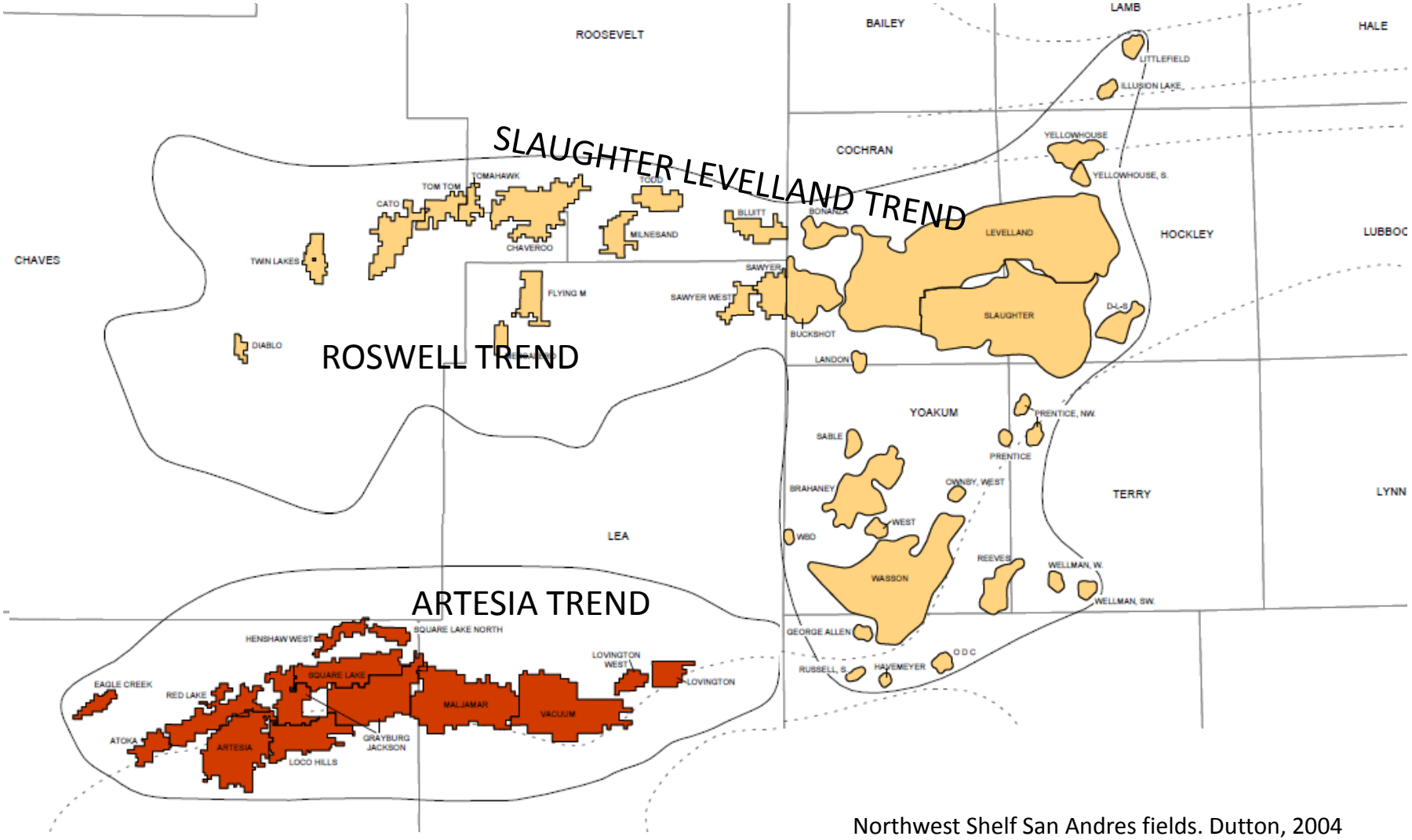
I	Porosity = 6%	Porosity = 10%	Porosity = 16%
Total Pore Volume (ft^3)	1.22×10^{11}	2.04×10^{11}	3.26×10^{11}
Flow Rate (ft^3/day)	1,030		
Time Period (Million Years)	15		
Total Flow (cubic feet)	5.64×10^{12}		
Number of Pore Flushes	46.0	27.7	17.3

Mother Nature is VERY patient "Engineer":
1 to 3 pore flushes per million years

Modern Analogs

- **The flow modeling utilized Basin and Range uplift, and applied a modern day Bahama's and Arabian Gulf platform model for defining the pathway of migration of the flushing fluids.**
- **The study of the Slaughter-Levelland Trend and eastern Central Basin Platform has utilized an Arabian Gulf model.**
- **Although the Main Pays are Arabian Gulf/Sabkha related, the ROZ's are more akin to the Bahamas Model.**

Northwest Shelf San Andres production, with the Slaughter-Levelland, Roswell, and Artesia Trends



Northwest Shelf San Andres fields. Dutton, 2004

50 miles

Modern Analog for Northwest Shelf ROZ

North Palmetto Point

Nassau

The Bahamas

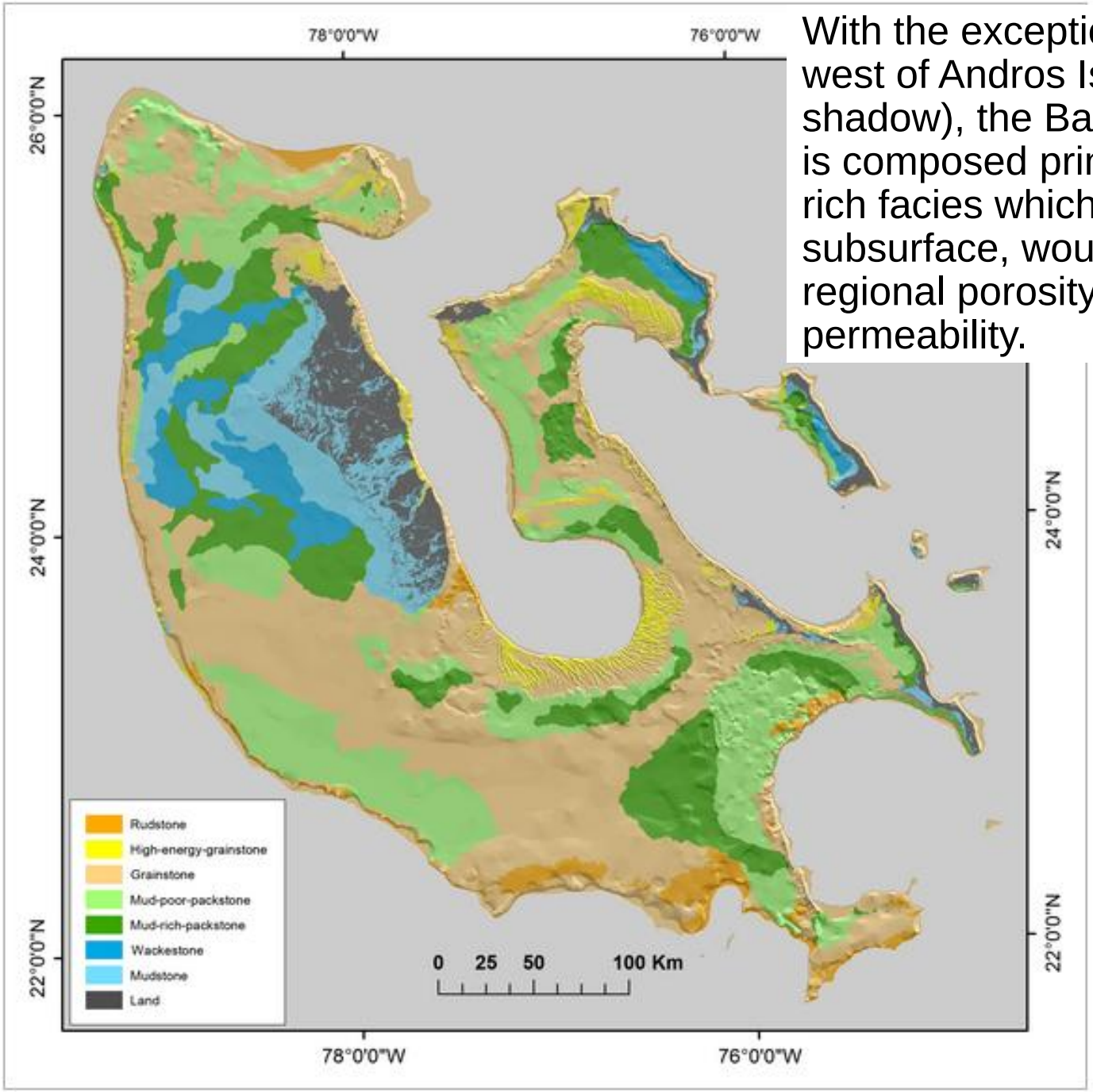
West Side National Park

Arthur's Town

50 Miles

The Bahamas Platform is located east of Florida and northeast of Cuba. A tectonically quiet, shallow marine carbonate platform with similarities to the **Northwest Shelf**.

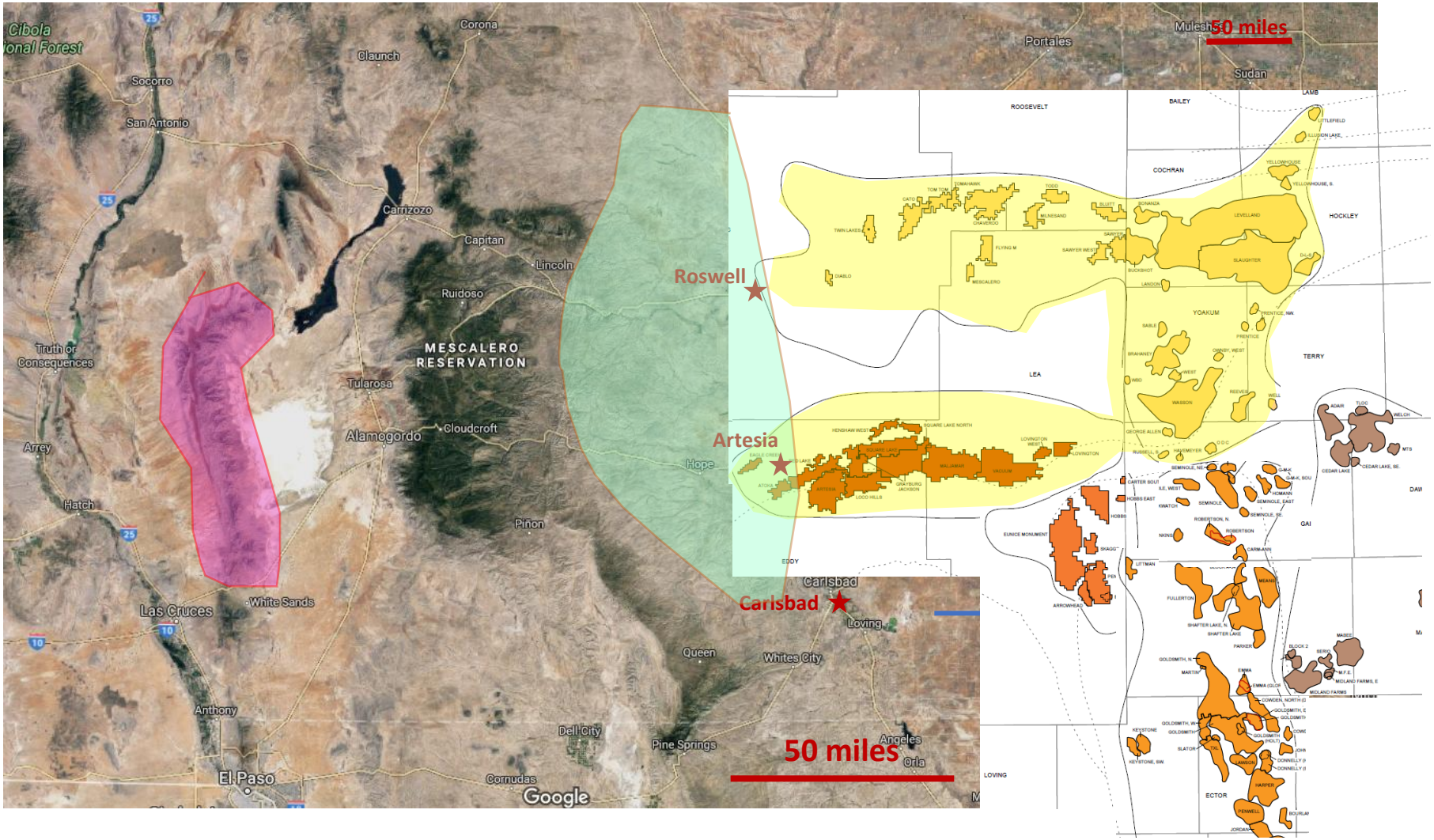
Google Maps, 2018



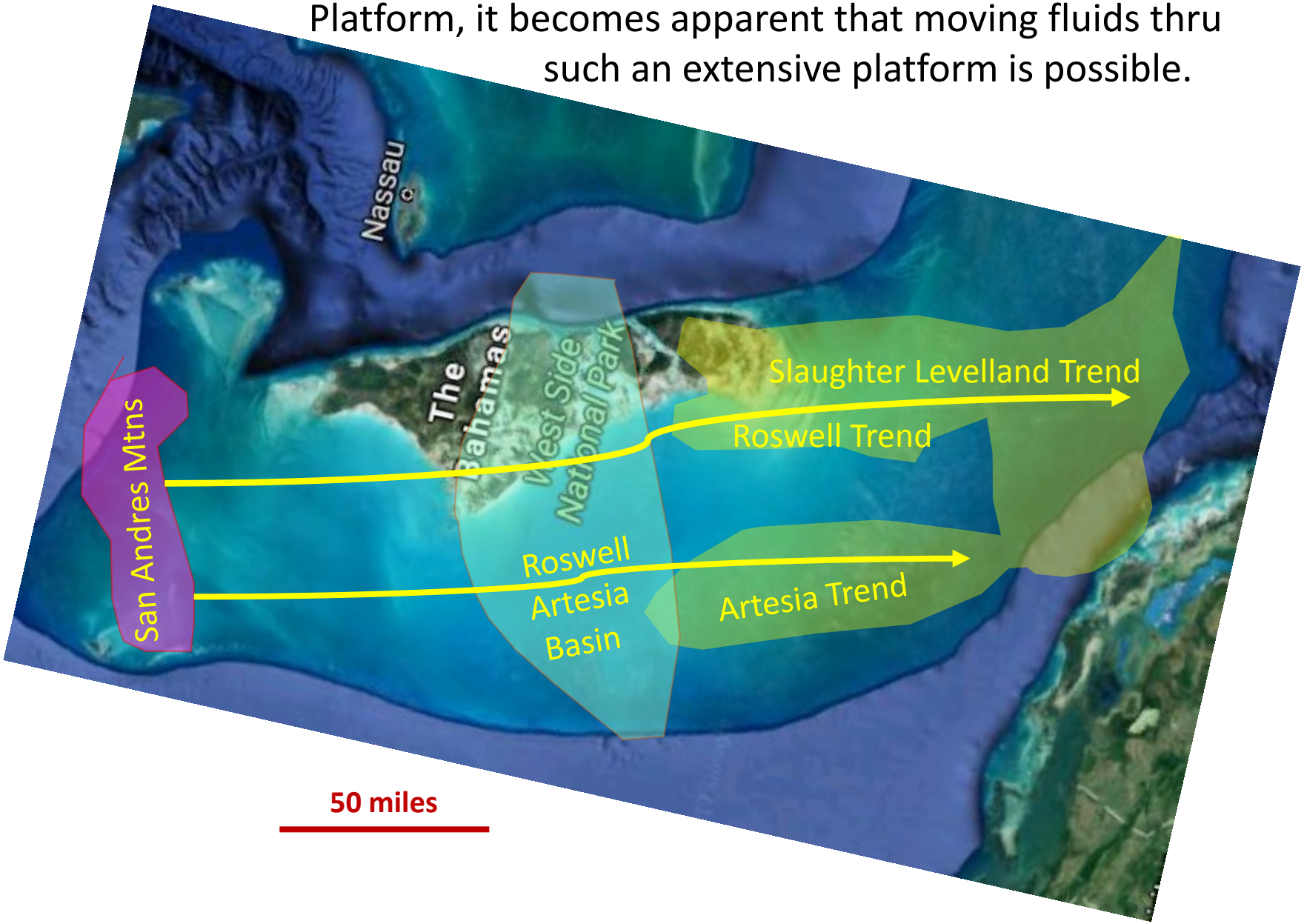
With the exception of the area west of Andros Island (an energy shadow), the Bahamas Platform is composed primarily of grain rich facies which, in the subsurface, would have better regional porosity and permeability.

Harris, et.al, 2015

The San Andres age platform extended to the San Andres Mountains (RED) and Rio Grande during Rio Grande Uplift and Mother Nature's Waterflood. The present day Roswell-Artesia Basin (GREEN) is the source of continued, but reduced, meteoric recharge into the San Andres.



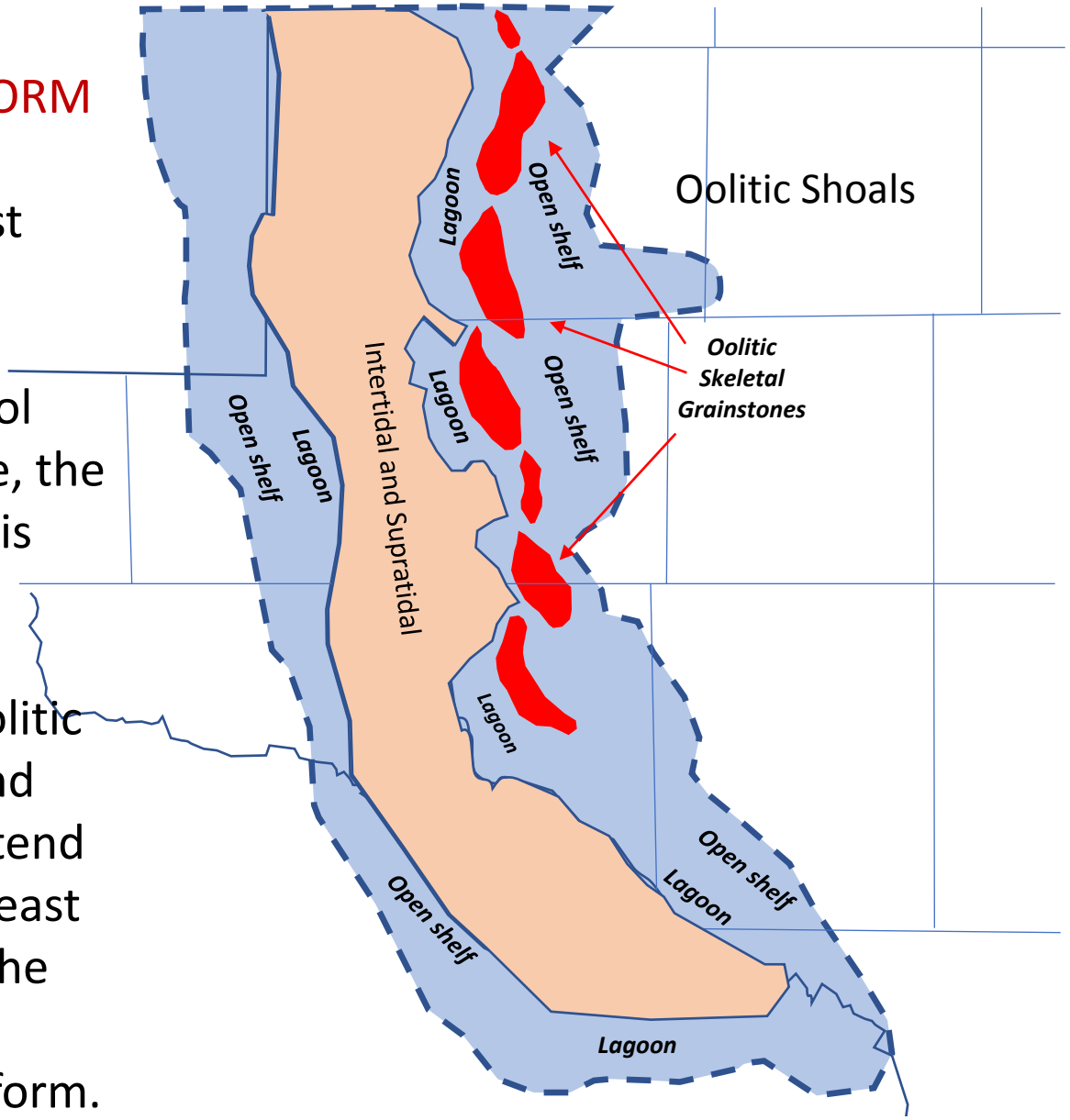
By placing the Northwest Shelf San Andres trends, Roswell Artesia Basin, and San Andres Mountains on the western portion of the Bahamas Platform, it becomes apparent that moving fluids thru such an extensive platform is possible.



CENTRAL BASIN PLATFORM

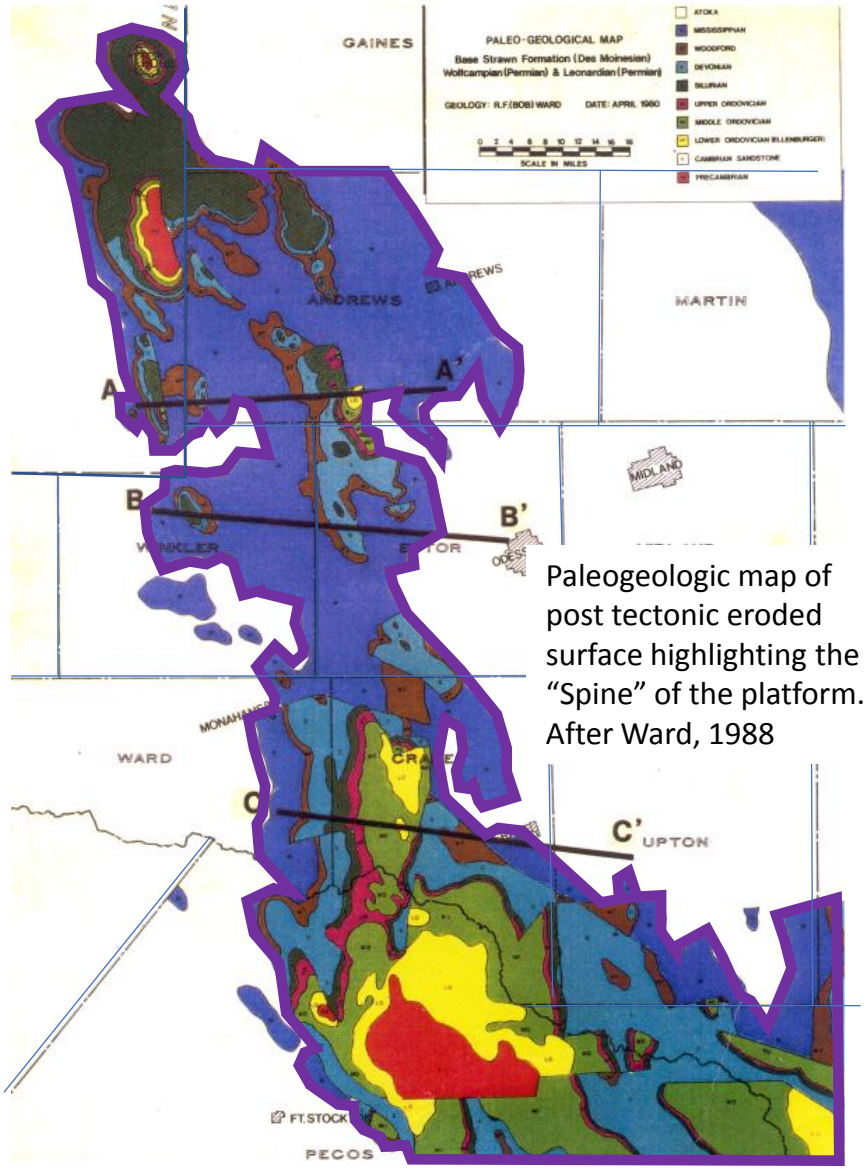
Whereas the Northwest Shelf is a broad, open marine platform with minimal tectonic control during San Andres time, the Central Basin Platform is narrower and more complex.

However, a trend of Oolitic Skeletal Grainstones and Open Marine facies extend north-south along the east and west side (where the flow modeling was conducted) of the platform.

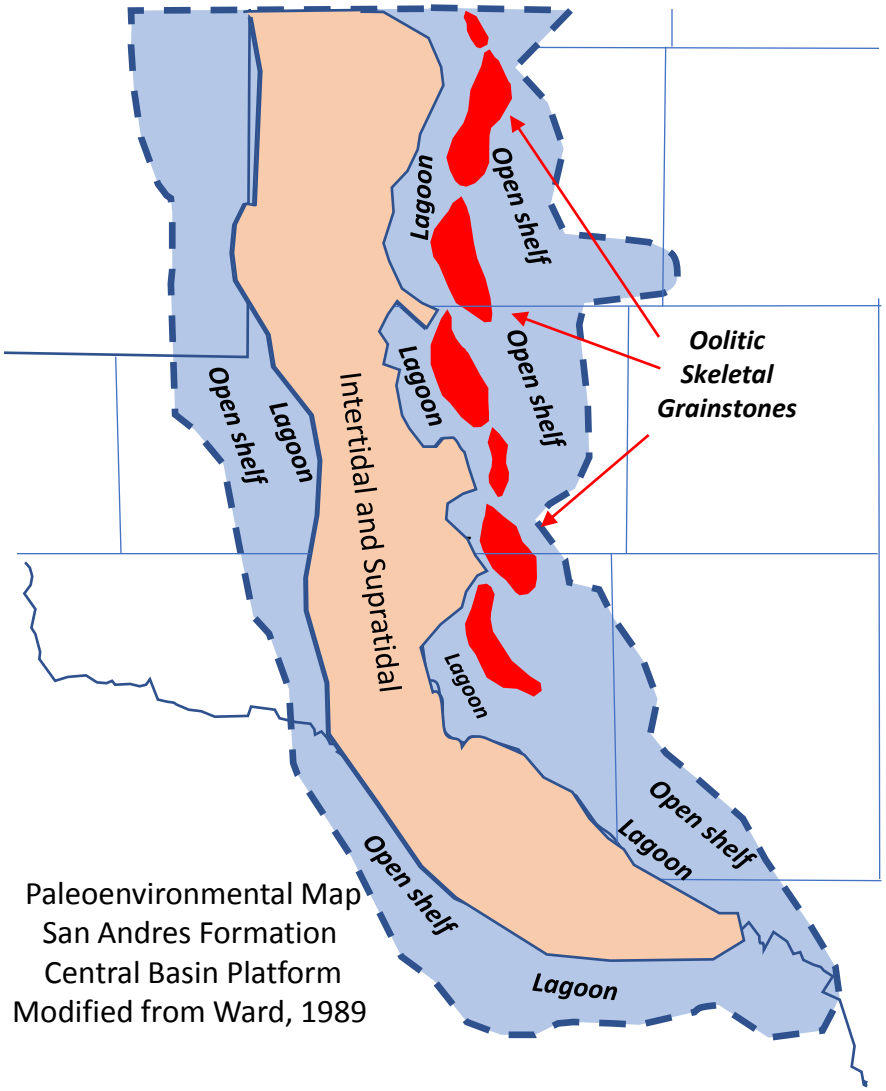


Paleoenvironmental Map
San Andres Formation
Central Basin Platform
Modified from Ward, 1989

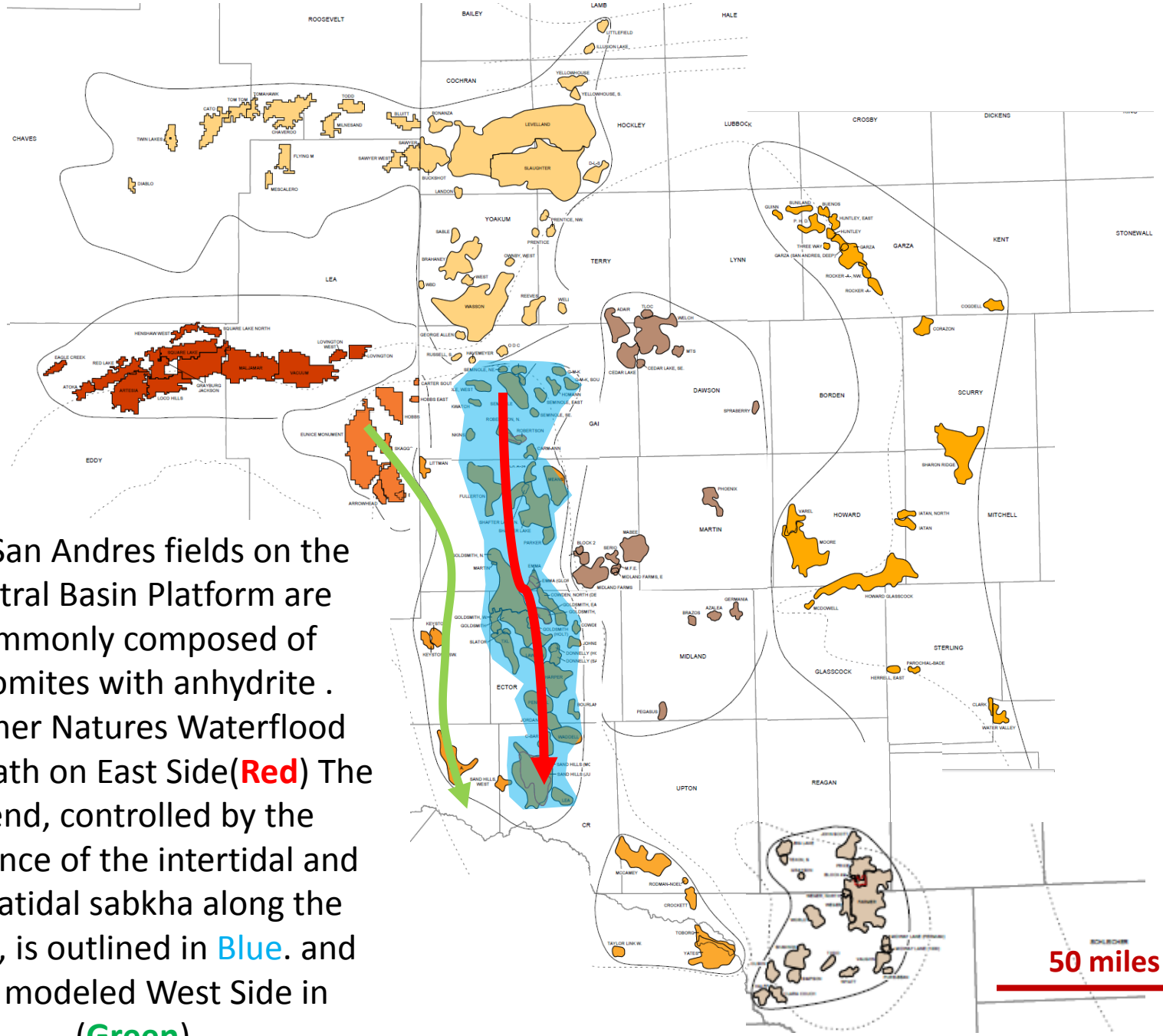
The “tectonism” which controlled the depositional environments of the San Andres on the platform was related to the major uplift of blocks along the “Spine” of the Central Basin Platform. There was continued periodic uplift throughout the Permian which impacted reservoir distribution.



Paleogeologic map of post tectonic eroded surface highlighting the “Spine” of the platform. After Ward, 1988



Paleoenvironmental Map
San Andres Formation
Central Basin Platform
Modified from Ward, 1989

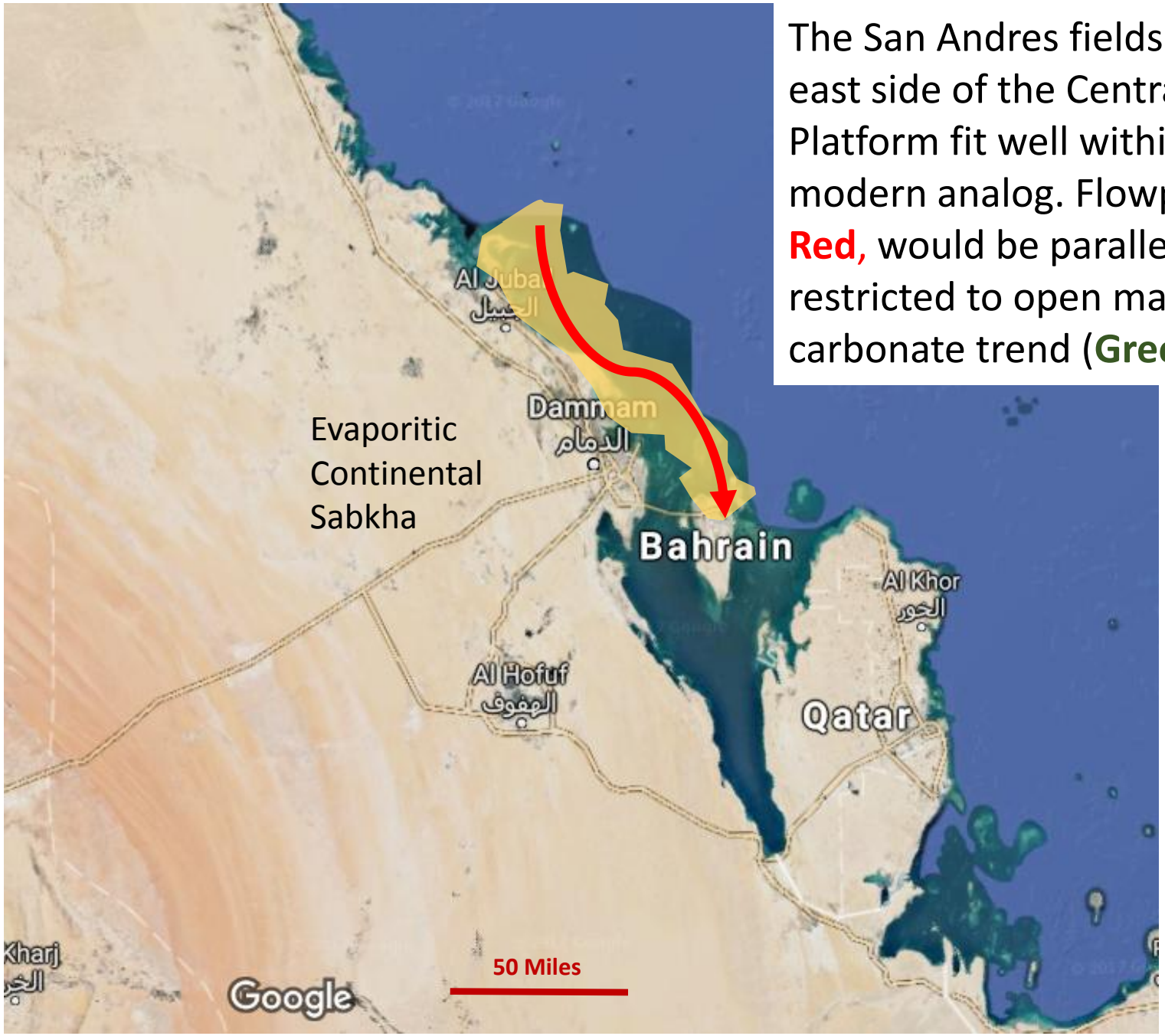


The San Andres fields on the Central Basin Platform are commonly composed of dolomites with anhydrite . Mother Natures Waterflood Flowpath on East Side(**Red**) The trend, controlled by the presence of the intertidal and supratidal sabkha along the spine, is outlined in Blue. and the modeled West Side in (**Green**).

San Andres fields base modified from. Dutton, et.al.2004

The Central Basin Platform, being more complex and narrow compared to the Northwest Shelf, requires a different modern analog. The Arabian Gulf, with a narrow open marine to lagoonal to sabkha transition is a widely used modern analog for the Central Basin Platform.

Google Maps, 2018



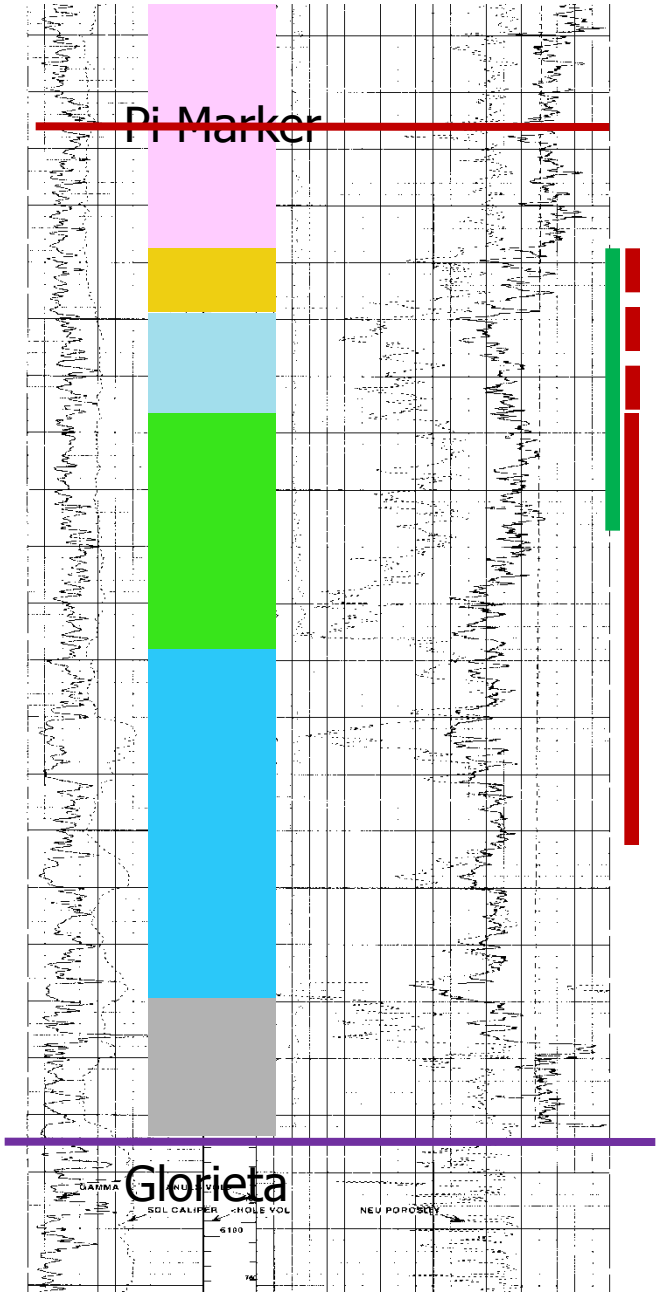
The San Andres fields on the east side of the Central Basin Platform fit well within the modern analog. Flowpath, in **Red**, would be parallel to the restricted to open marine carbonate trend (**Green**).

Google Maps, 2018

The "**Rules of Thumb**" center on trend geometries, the location of ROZ's, and their relationship to Main Pays (MP's) within the San Andres. These rules apply:

- Most ROZ's are found below the BCBPS/Pi Marker (top Guad 4);
- To date all exploited ROZ's are above the San Andres Maximum Flood (McKnight/Guad 1 – Guad 2);
- Fields along the Northwest Shelf shelf margins have MP's above the BCBPS/Pi Marker, and associated ROZ's below the BCBPS/Pi Marker;
- The continuity of ROZ reservoirs in the lower San Andres (Guad 1 - Guad 4) follows the Bahamas Model;
- The Slaughter-Levelland Trend fields have updip traps/seal fitting the Arabian Gulf Model where the Main Pay is trapped by tidal flats and sabkha deposits.
- Below Slaughter – Levelland trend, the Bahama's model fits the ROZ with up dip trap as far north as the northern edge of the Tucumcari Basin.
- The Horizontal San Andres Play in Yoakum and on the northern Central Basin Platform is composed of "shingles" with multiple thin subtidal reservoirs shallowing to tidal flats, while the ROZ portion of the play is composed of open marine facies reminiscent of the open marine in the Bahama's model.
- The Tall Cotton Field, a true GREENFIELD, is open marine probably below the BCBPS.
- ROZ's on the west side of the CBP are believed to be in the SADR below the BCBPS.

Huntington 2 Walden
501 34599



"Lower San Andres"

Lower San Andres facies tracts on Northwest Shelf (Yoakum), is an overall shallowing upward sequence

Anhydrite and anhydritic dolostone

Restricted marine peloidal wk-pk & peritidal

High-energy ramp-crest grainstones

Outer ramp fusulinid-dominated facies

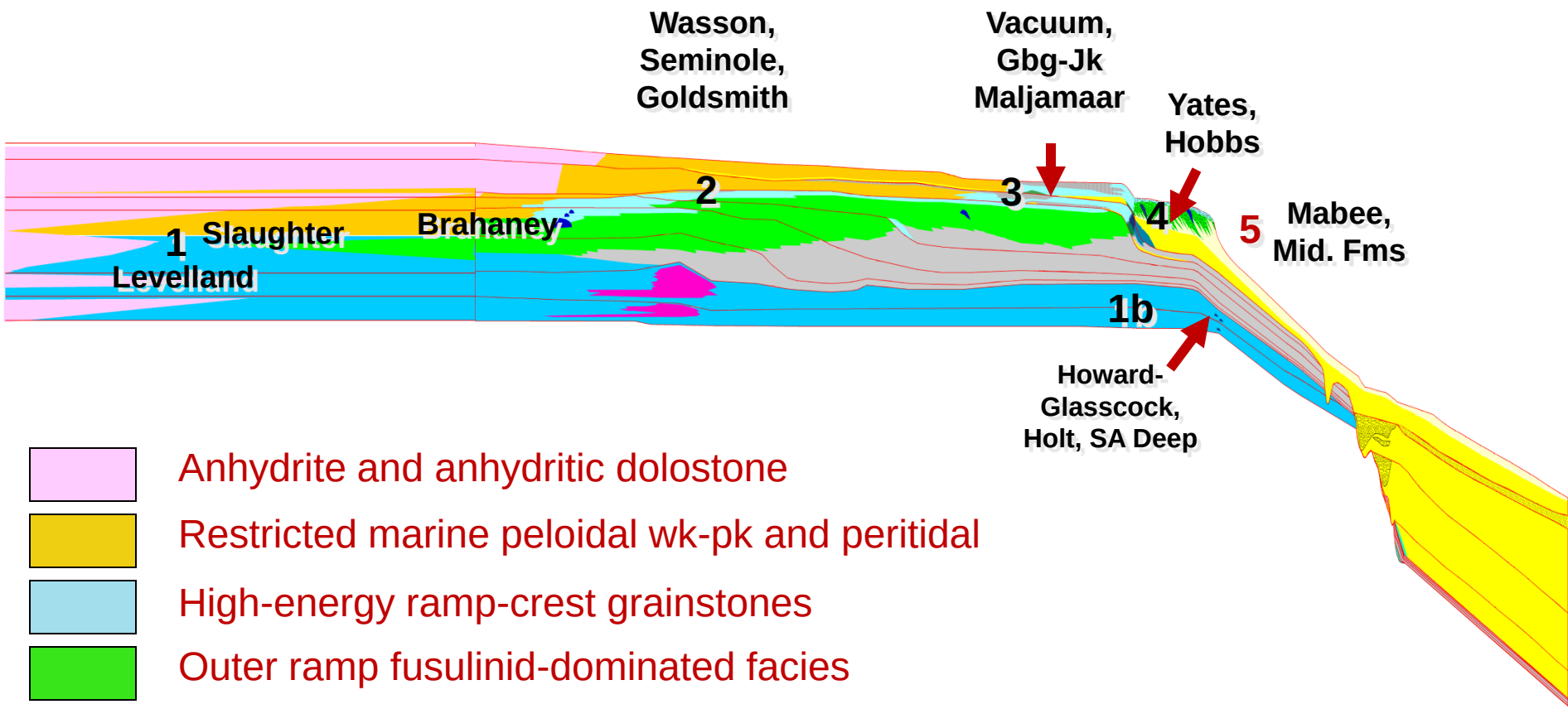
Open marine limestones & dolostones ,

Deeper-water mudstones

MAIN PAY

ROZ

Main Pays can be found in Restricted Marine, High Energy Ramp Crest, Outer Ramps, or Open Marine



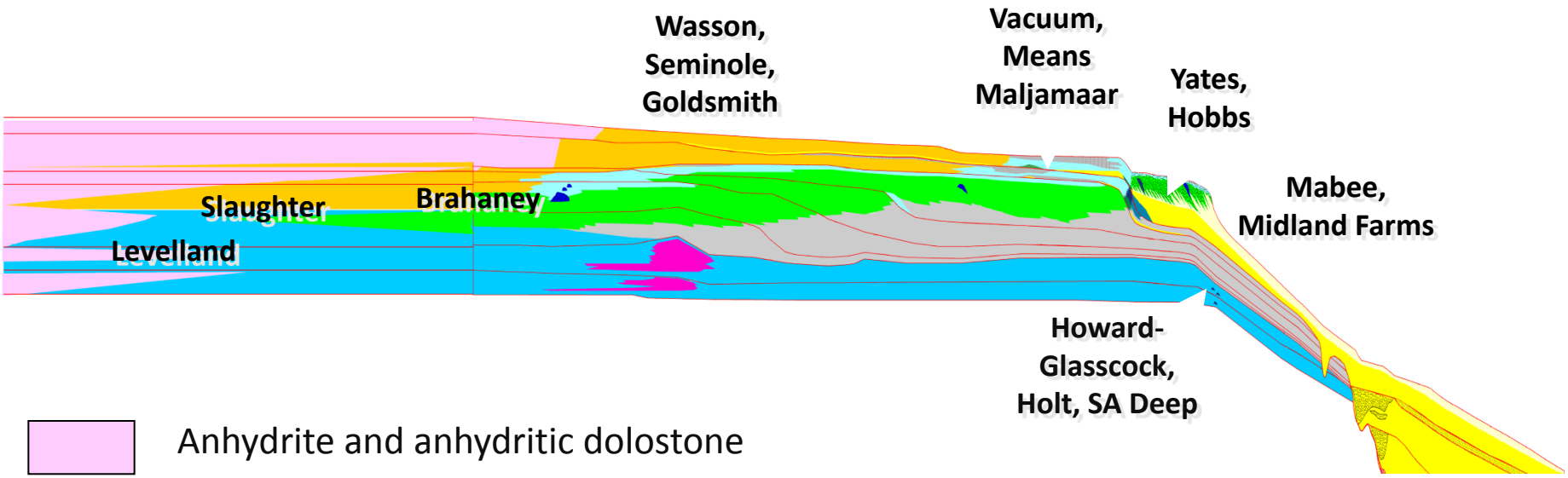
- Anhydrite and anhydritic dolostone
- Restricted marine peloidal wk-pk and peritidal
- High-energy ramp-crest grainstones
- Outer ramp fusulinid-dominated facies
- Open marine limestones and dolostones,
- Deeper-water mudstones (Cutoff)

Kerans, 2006

Where are the ROZs?

All these Fields have ROZs.

As shown, all the settings are different, BUT…..



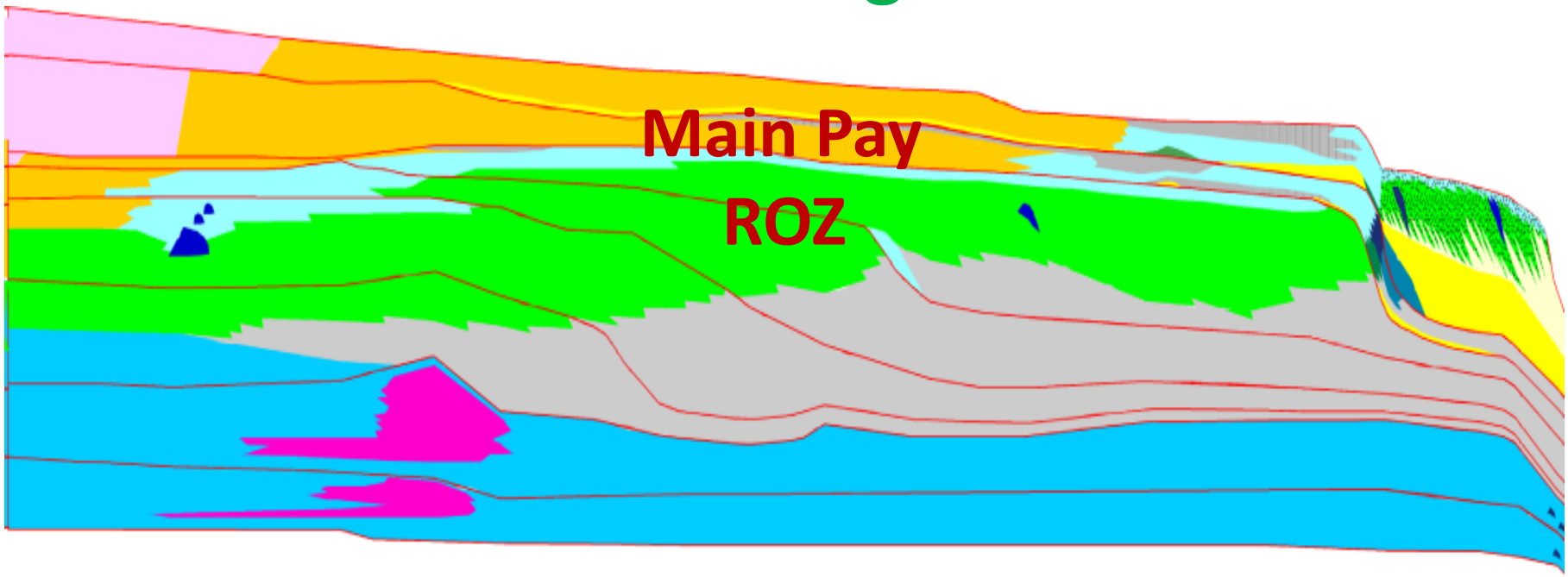
- Anhydrite and anhydritic dolostone
- Restricted marine peloidal wk-pk and peritidal
- High-energy ramp-crest grainstones
- Outer ramp fusulinid-dominated facies
- Open marine limestones and dolostones, L7-8
- Deeper-water mudstones (Cutoff)

Industry ROZ & Main Pay CO2 Floods

- **Seminole San Andres (HESS)**
- **Denver Unit –Wasson (OXY)**
- **Vacuum (Chevron)**
- **Goldsmith Field (Legado)**
- **Means (XOM)**

Kerans,2006

In each case, the ROZ is located in a more outer ramp to open marine setting.



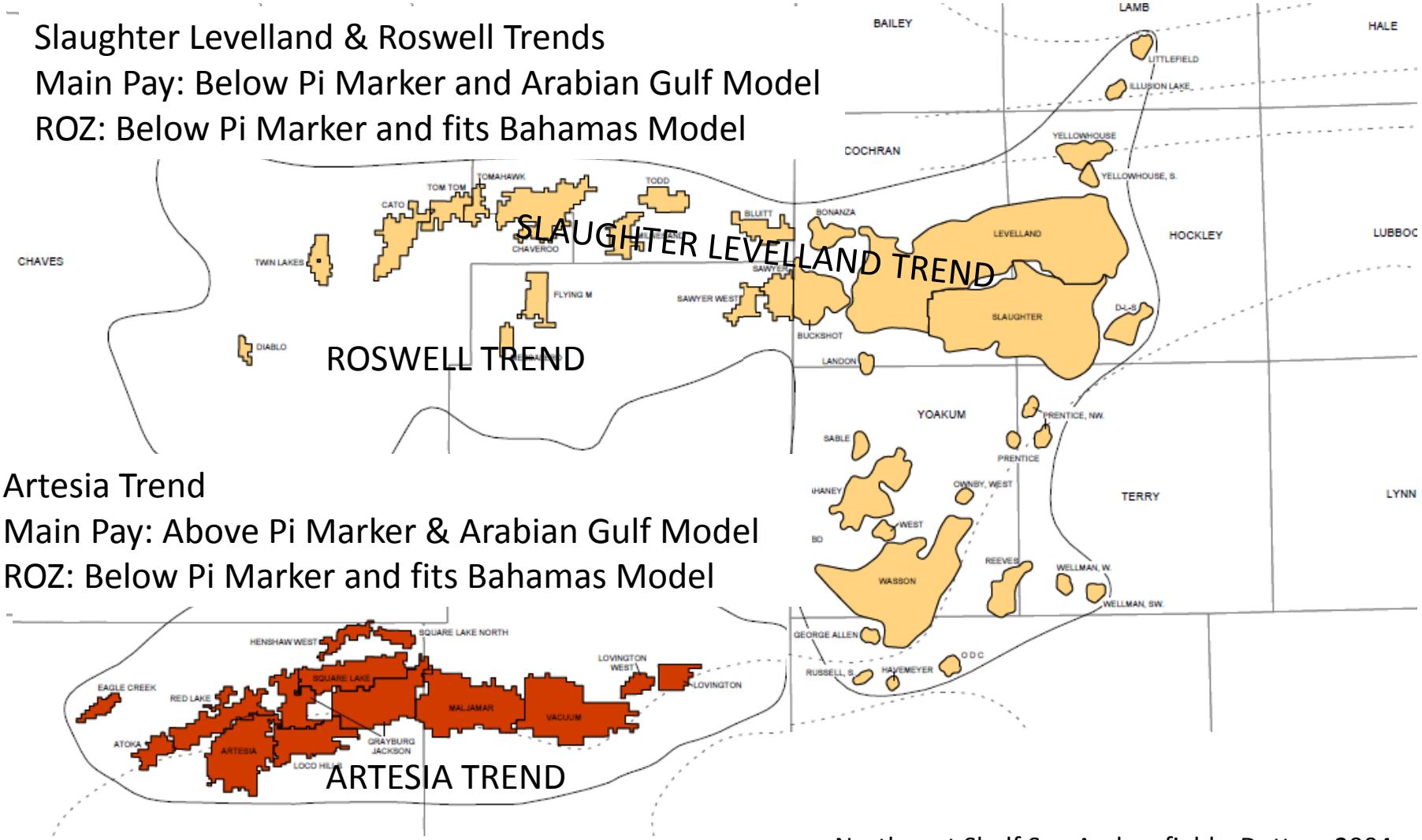
- Anhydrite and anhydritic dolostone
- Restricted marine peloidal wk-pk and peritidal
- High-energy ramp-crest grainstones
- Outer ramp fusulinid-dominated facies
- Open marine limestones and dolostones,

modified from Kerans,2006

Northwest Shelf San Andres - Slaughter-Levelland, Roswell, and Artesia Trends are a complex mix of models

Slaughter Levelland & Roswell Trends
Main Pay: Below Pi Marker and Arabian Gulf Model
ROZ: Below Pi Marker and fits Bahamas Model

Artesia Trend
Main Pay: Above Pi Marker & Arabian Gulf Model
ROZ: Below Pi Marker and fits Bahamas Model



Northwest Shelf San Andres fields. Dutton, 2004

Summary

- ROZ's are well established in the literature
- Mother Nature's Waterflood/Meteoric Flushing has been modeled and "proven" to exist.
- Modern Analogs for San Andres ROZ's includes both Bahamas and Arabian Gulf facies models.
- "Rules of Thumb" for ROZ's in the San Andres capture the relationship between open marine facies and ROZs.
- Identification of the Pi Marker/Brushy Canyon Bypass Surface in important in understanding the relationship of Main Pays to Residual Oil Zones .

Thanks Go To:

- Research Partners:
  - Steve Melzer, Melzer Exploration
  - David Vance, Arcadis
  - George Koperna, Vello Kuuskraa, Robin Petrusak, Advanced Resources International (ARI)
  - Phil Eager
  - Steve Robichaud
- Funding Support:
  - Department of Energy (DOE)
  - Research Partnership to Secure energy for America (RPSEA)
- Industry In-kind Partners:
  - Legado
  - Kinder Morgan
  - Chevron
- And the many others who have fought the ROZ battle for decades.

Thank You