

# Hybrid Model of Dolomitization, Permian Basin\*

Robert F. Lindsay<sup>1</sup>

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## Abstract

A hybrid model of dolomitization is responsible for dolomitization of Permian carbonate strata via: 1) reflux-mechanical compaction dolomitization during the Permian; and 2) tectonic and topographic driven dolomitization during the Late Eocene to Early Miocene.

### Reflux-Compaction Model:

Study of >3000 thin sections and >150 cores revealed that dolomitization of Permian strata was during initial burial as strata experienced mechanical compaction. Dolomitizing brine was sourced from a distant, broad, inner ramp lagoon-intertidal environment. During burial, Mg<sup>2+</sup> rich brine was expelled by mechanical compaction to dolomitize down-dip carbonate strata. Proof was mechanical compaction of grains and mud prior to lithification by dolomitization and is herein called the reflux-mechanical compaction model of dolomitization. Dolomitization formed cloudy, inclusion-rich, E-planar, highly etched dolomite. Porosity was preserved in grain-rich strata, with additional porosity created as the brine became depleted with Ca<sup>2+</sup> and CO<sub>3</sub><sup>2-</sup>, with partial dissolution of carbonate grains during dolomitization. Relative sea level fluctuations during late-highstand–early-lowstand restricted the inner ramp to form Mg<sup>2+</sup> rich brine favored density-driven circulation of brines. Inner ramp strata are 1.25-3+ times wider than down-dip carbonate strata. A problem is the speed with which brine could move from up-dip to down-dip.

### Tectonic and Topographic Driven Models:

During the Late Eocene-Early Miocene, uplift formed the Southern Rocky Mountain Epeirogen (SRME) and Rio Grande Rift (RGR) via crustal heating as intrusive plutons and extrusive volcanism formed the Trans-Pecos magmatic province and larger North American Cordilleran alkali igneous belt. By 38-35 Ma, an erosional surface extended across New Mexico to form an immense recharge area into the Permian Basin. Meteoric water heated to 113°-224° C by contact with plutons. During recharge, undersaturated meteoric water partially dissolved Permian dolomite and precipitated clear, inclusion-poor, E-planar, limpid dolomite cement. Area of meteoric recharge was 130 miles (209 km) wide and partially to completely swept Permian Basin oil fields of primary and secondary recovery oil to residual oil saturation to waterflood (Srow),

forming residual oil zones (ROZ's). Extension of RGR, during Middle-Late Miocene, destroyed the massive recharge area and allowed oil columns to partially to completely resaturate with oil or gas.

### **Selected References**

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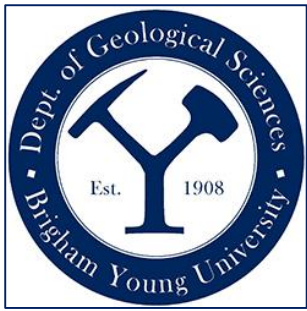
Eaton, G.P., 2008, Epeirogeny in the southern Rocky Mountains region: evidence and origin: Geosphere, v. 4, p. 764-784, doi:10.1130/GES00149.1.

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Lawton, T.F., and N.J. McMillan, 1999, Arc abandonment as a cause for passive rifting: comparison of the Jurassic Mexican borderland rift and the Cenozoic Rio Grande rift: Geology, v. 27, p. 779-782.

Meissner, F.F., 1972, Cyclic sedimentation in middle Permian strata of the Permian basin, west Texas and New Mexico: in J.G. Elam and S. Chuber (eds.), Cyclic sedimentation in the Permian basin: West Texas Geological Society, p. 203-232.

Ward, R.F., C. Kendall, and P.M. Harris, 1986, Upper Permian (Guadalupian) facies and their association with hydrocarbons - Permian basin, west Texas and New Mexico: AAPG Bulletin, v. 70/3, p. 239-262.



# Hybrid Dolomitization Permian Basin

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Midland, Texas & Provo, Utah**

# *“Tight West Texas Dolomites Waterflood Well”*

Ganesh Thakur

Past President SPE

Primary Recovery = 15-20% OOIP

Secondary Recovery = 15-20% OOIP

Tertiary Recovery = 10+% OOIP

Permian Basin Dolostone Reservoir:

Ave Porosity = 9%, Range = <2-31%

Ave Perm = 6 mD, Range = 0.001-2000 mD

## Outline:

- Data base
- Permian – Reflux-mechanical compaction dolomitization
- Late Eocene-Early Miocene – Tectonic-topographic driven-hydrothermal dolomitization
- Enhanced porosity-permeability, connectivity & productivity of strata & formed residual oil zones (ROZ's)
- Conclusions

## Data base (Permian):

- 131 outcrop measured sections
- 150+ core descriptions
- 3000+ thin section petrography
- Scanning electron micrographs (SEM)
- High pressure mercury injection capillary pressure (MICP)
- Cathodoluminescence data
- Fluid inclusion data
- Geochemistry (oil-water)
- Engineering data
- Production data

# Dolomitization Models

Machel (2004)

## Penecontemporaneous to Shallow Burial

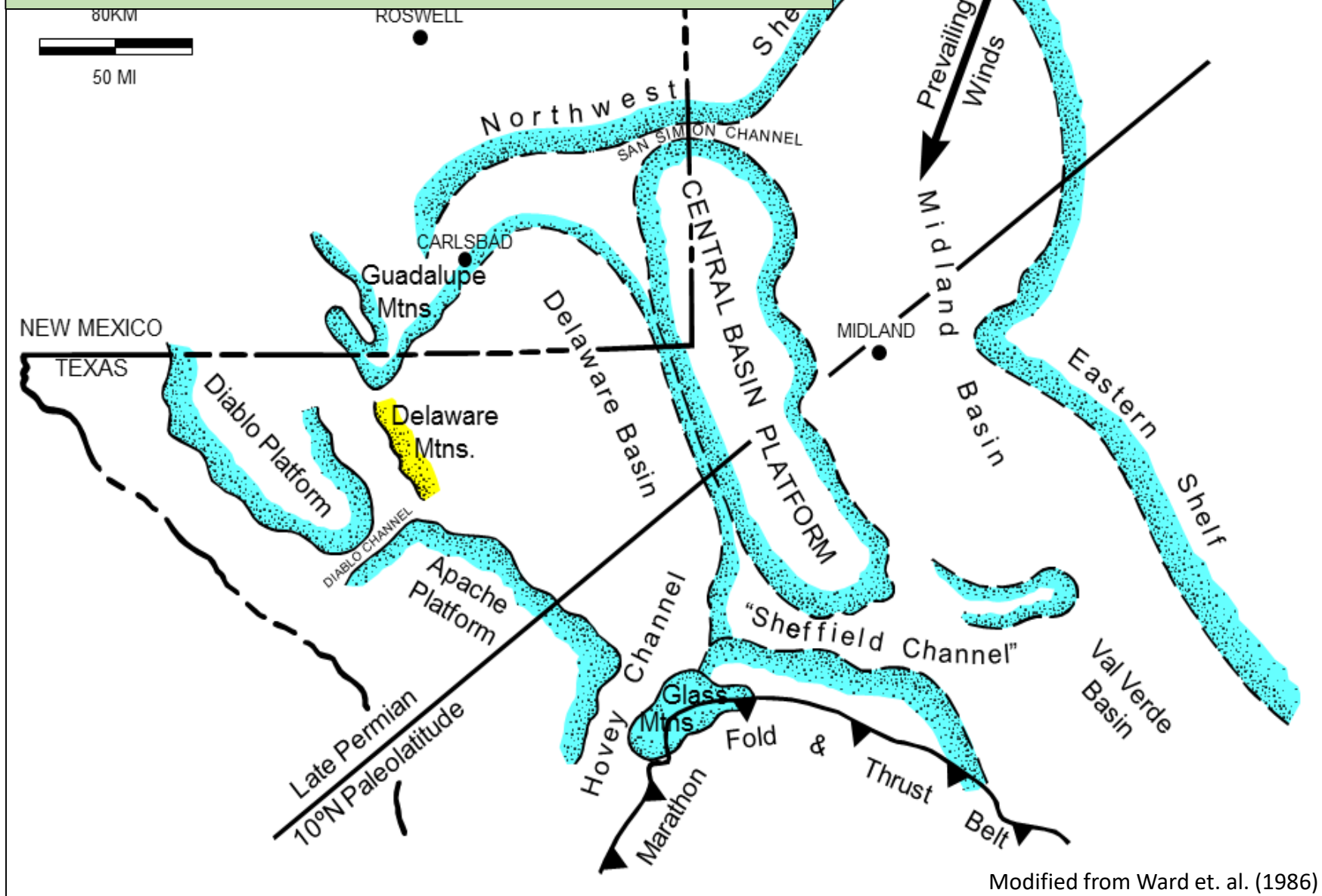
- Penecontemporaneous-Microbial/Organogenic
- Mixing Zone
- **Reflux** } **Permian**
- Sabkha
- Seawater Dolomitization

## Intermediate to Deep Burial

- Compaction
  - Thermal Convection
  - **Tectonic**
  - **Topographic Driven**
  - **Hydrothermal**
- } **Late Eocene – Early Miocene**

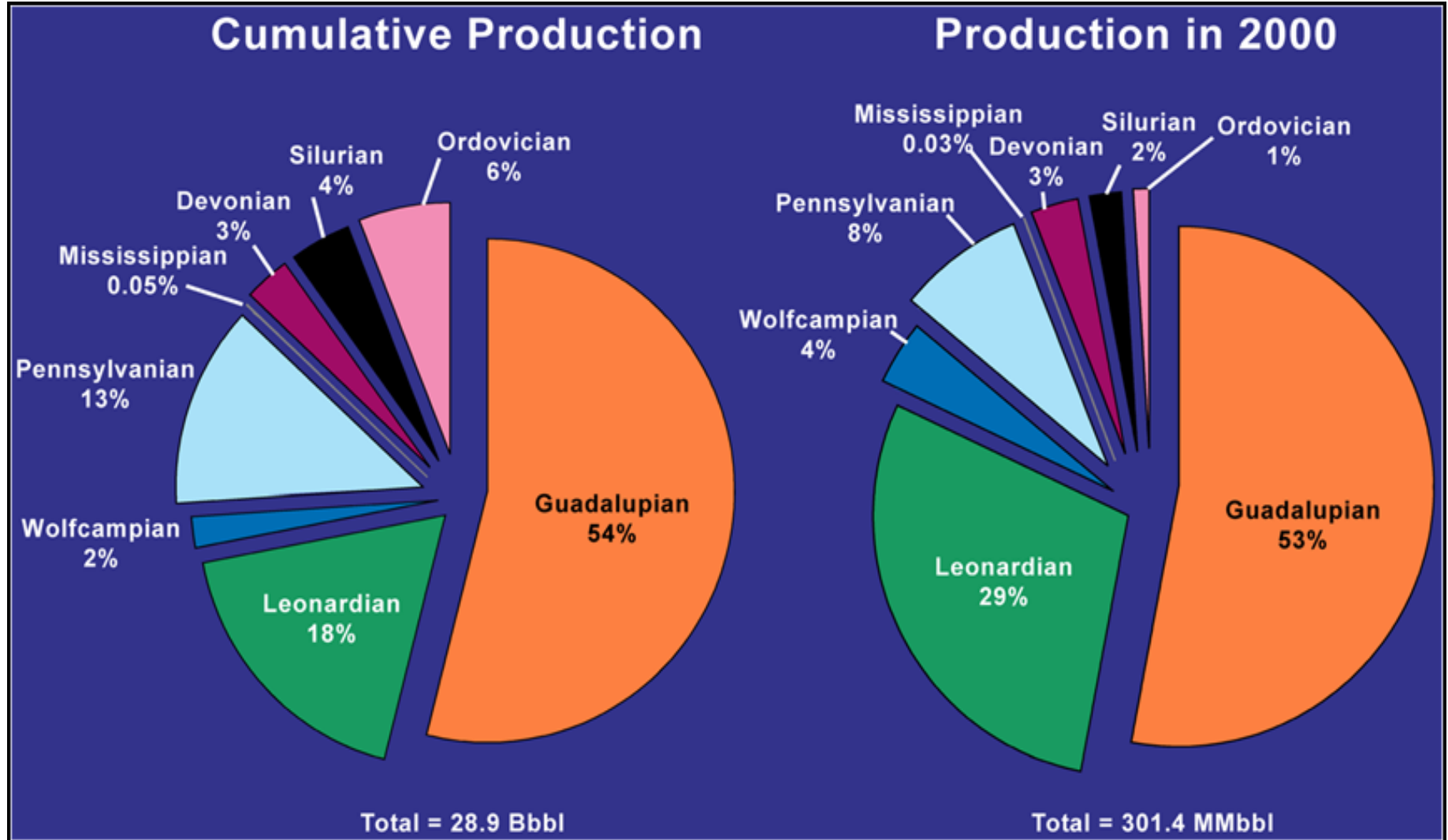
# Permian Basin

## Home of Reflux Model of Dolomitization



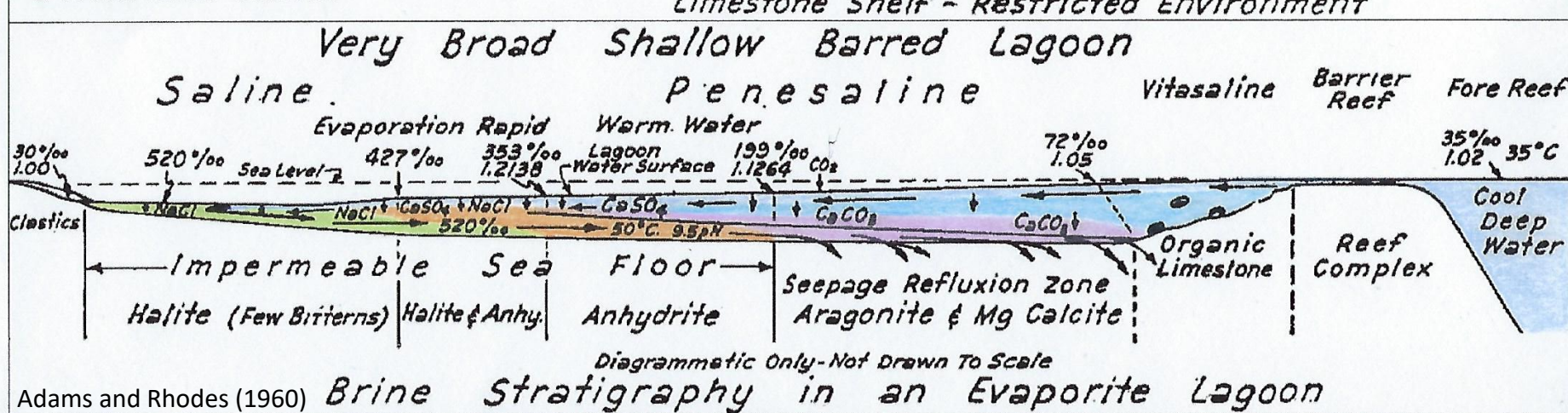
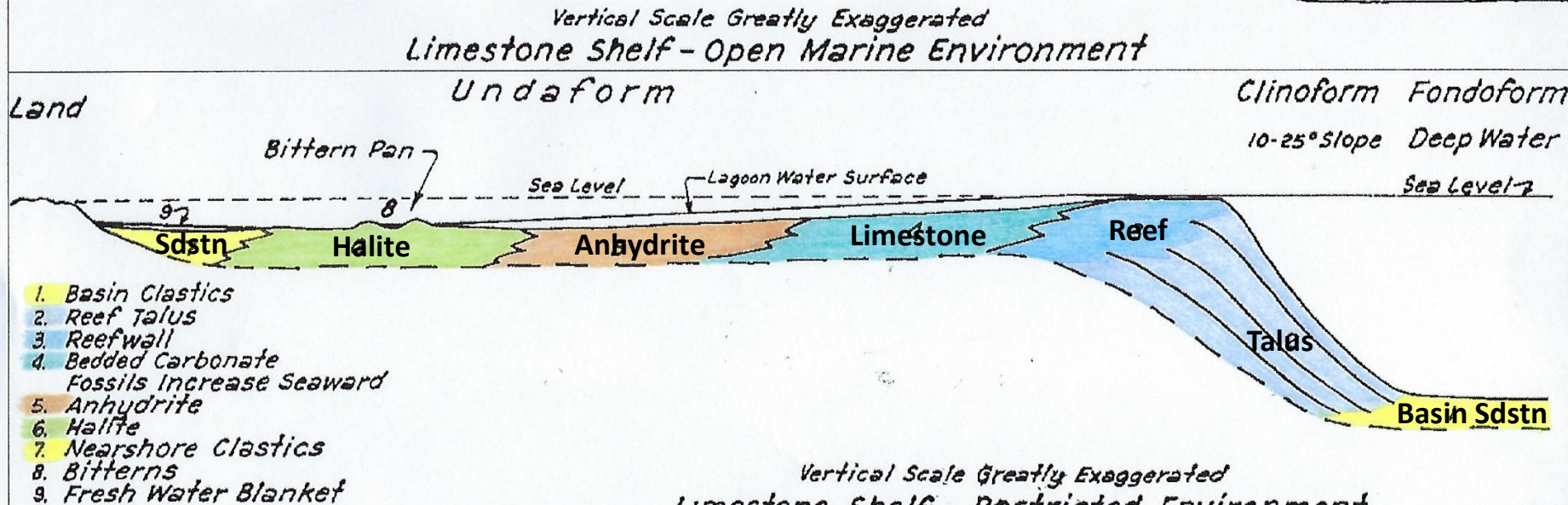
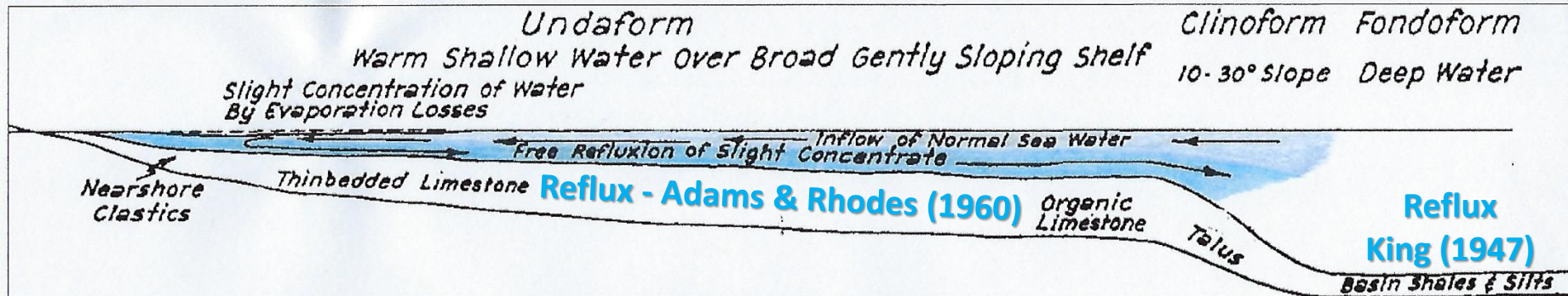
Modified from Ward et. al. (1986)

# Permian Dolomitization

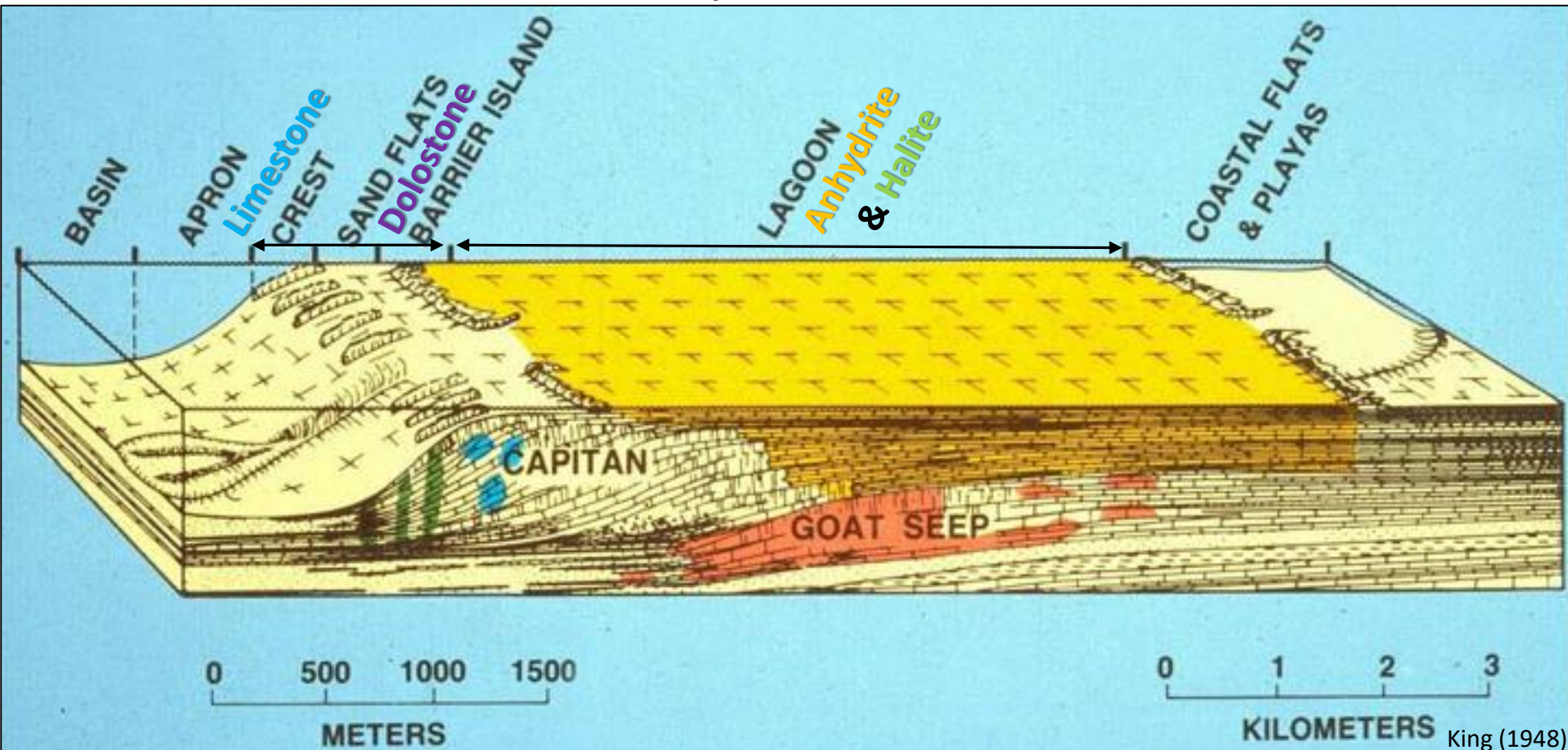


Conventional Reservoirs

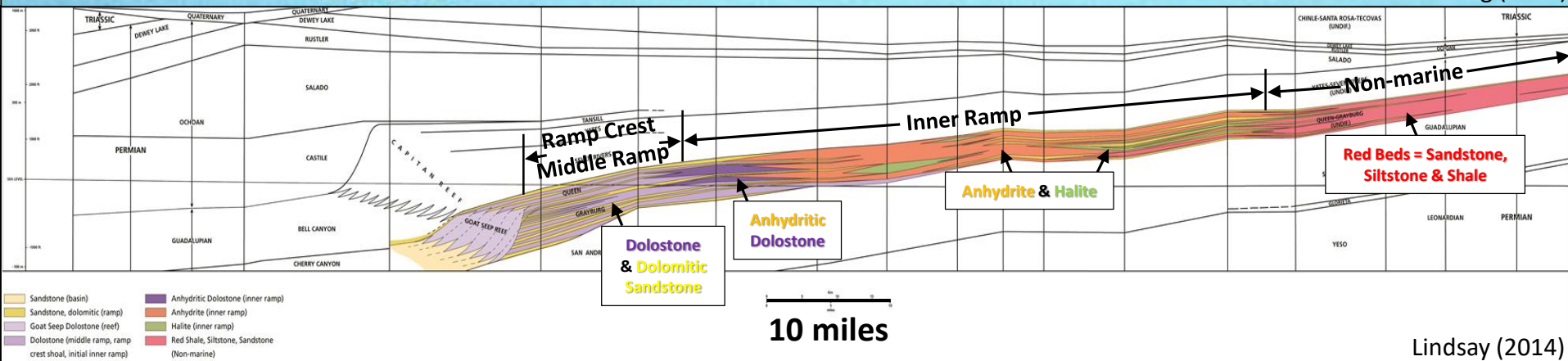
Dutton et al. (2004)



# Permian Depositional Models

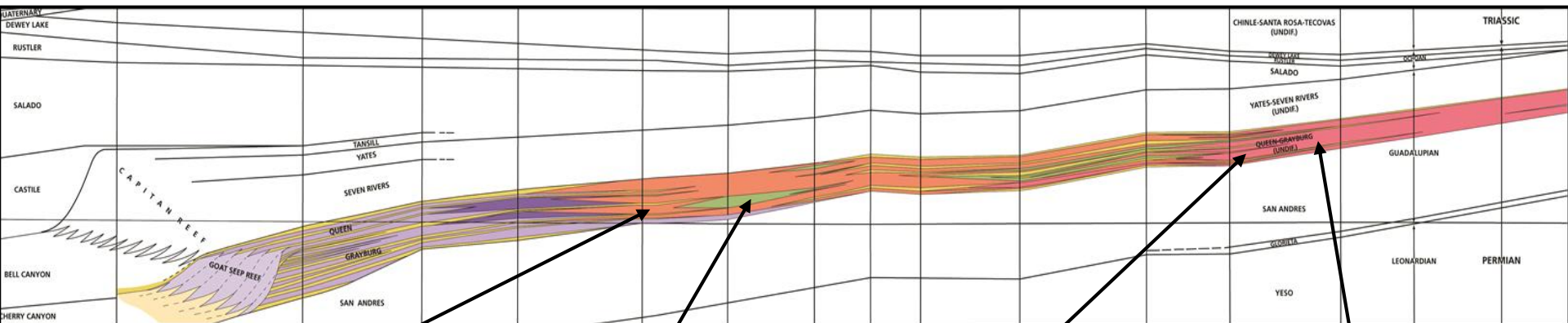


King (1948)



Lindsay (2014)

# Inner Ramp & Non-marine Red Bed Lithofacies



**Anhydrite**



**Halite**



**Red Shale**



**Red Sandstone**



Core courtesy of BEG

# Mechanical Compaction

## Grayburg Formation

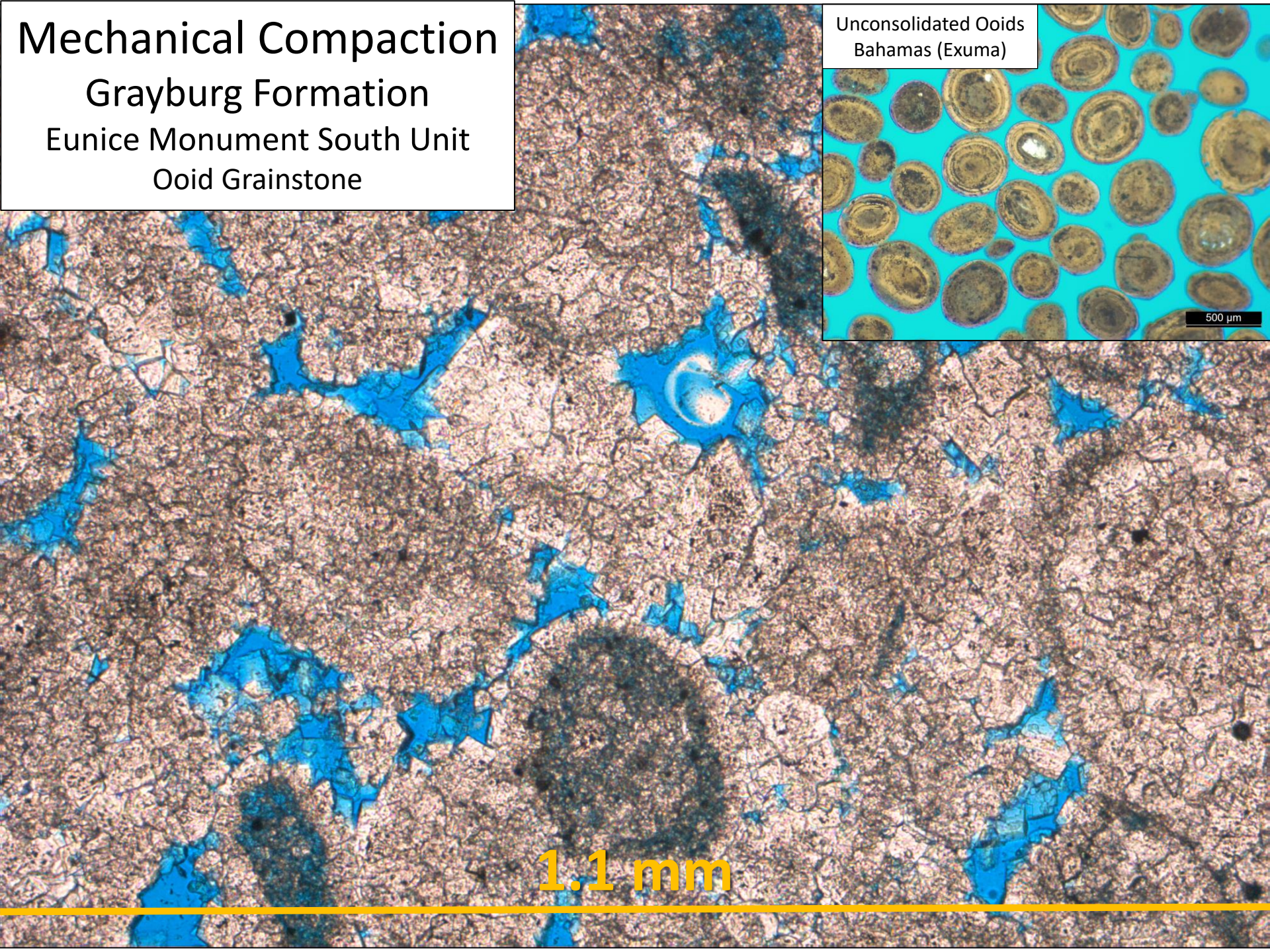
Eunice Monument South Unit

Ooid Grainstone

Unconsolidated Ooids  
Bahamas (Exuma)

500  $\mu\text{m}$

1.1 mm



GRAYBURG



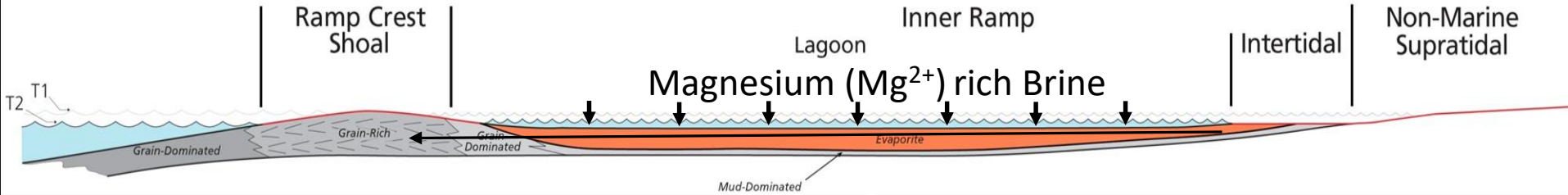
Modified from R.F. Ward et al. (1986) and R.F. Ward (1999)

# Permian Basin

## Ramp Profile Time T2

Subtidal-Intertidal Evaporite Factory

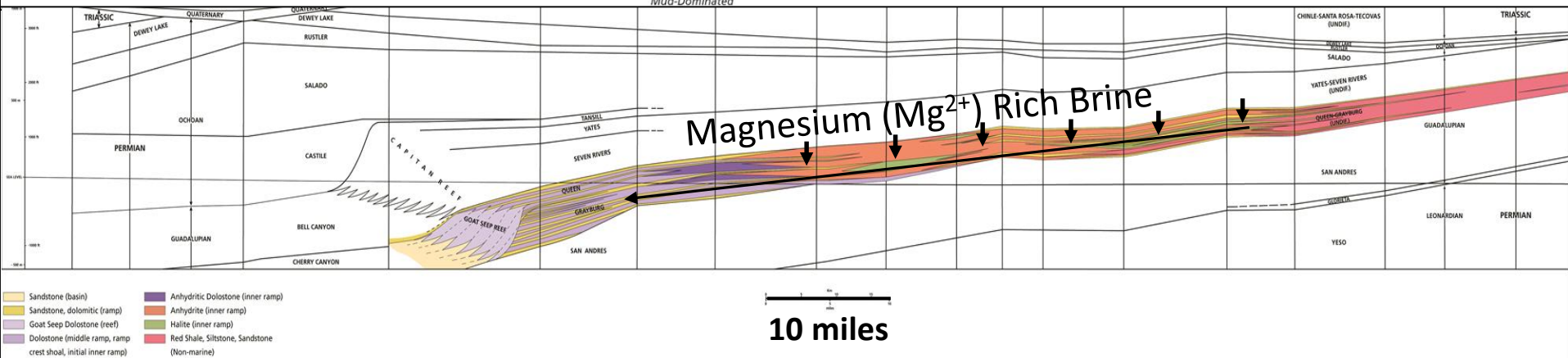
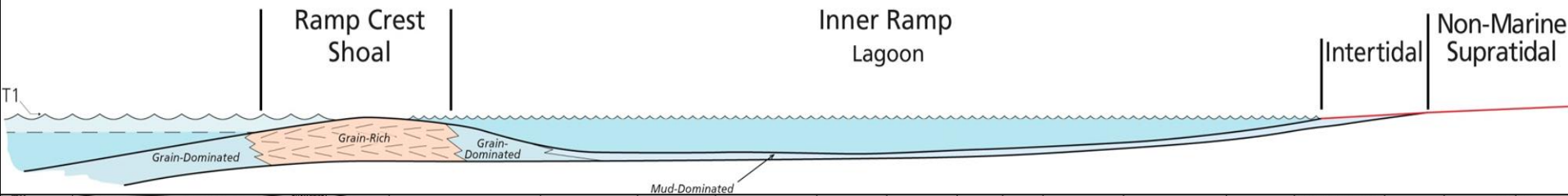
### Highstand Systems Tract

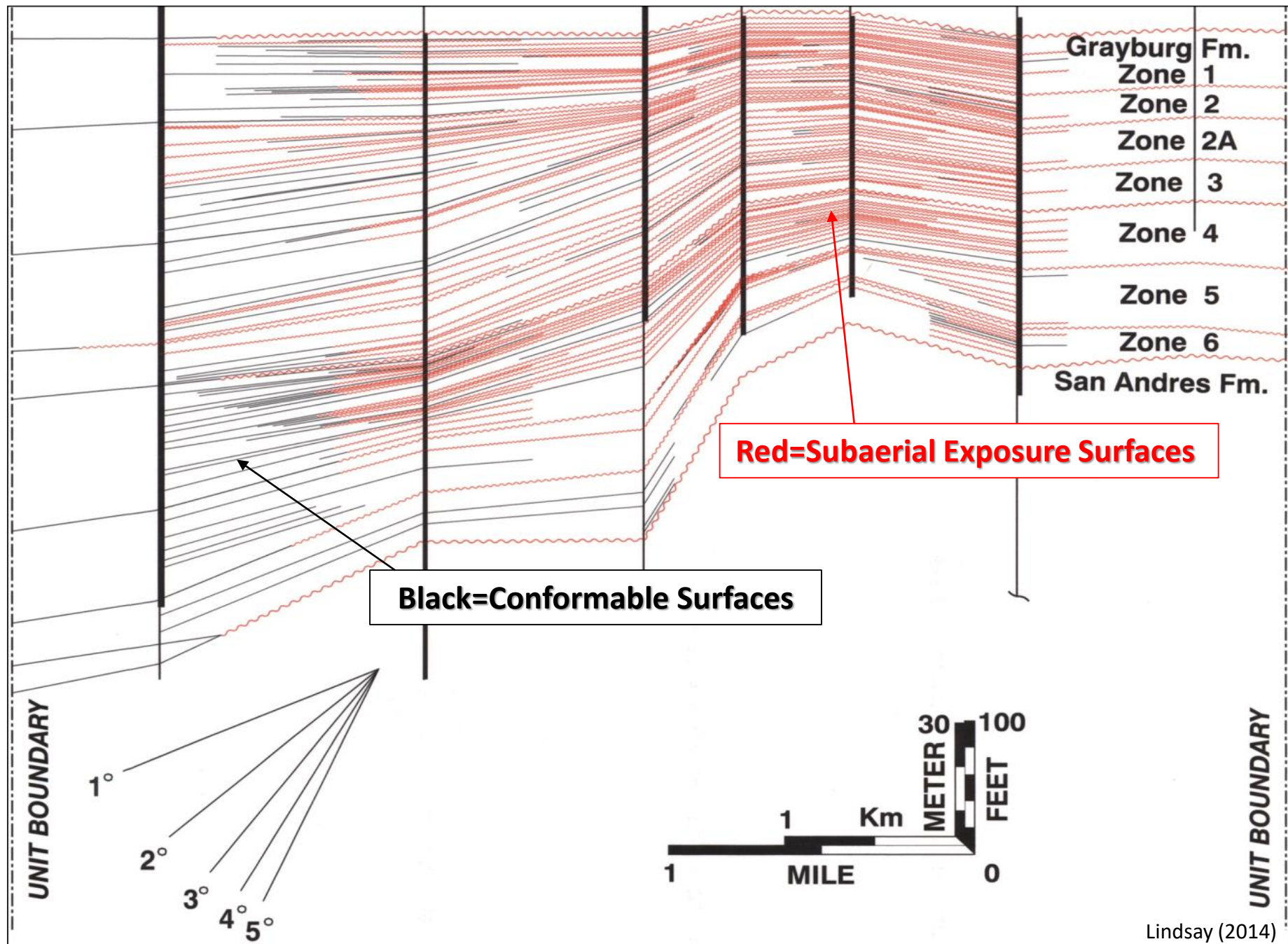


## Ramp Profile Time T1

Subtidal Carbonate Nursery

### Transgressive Systems Tract





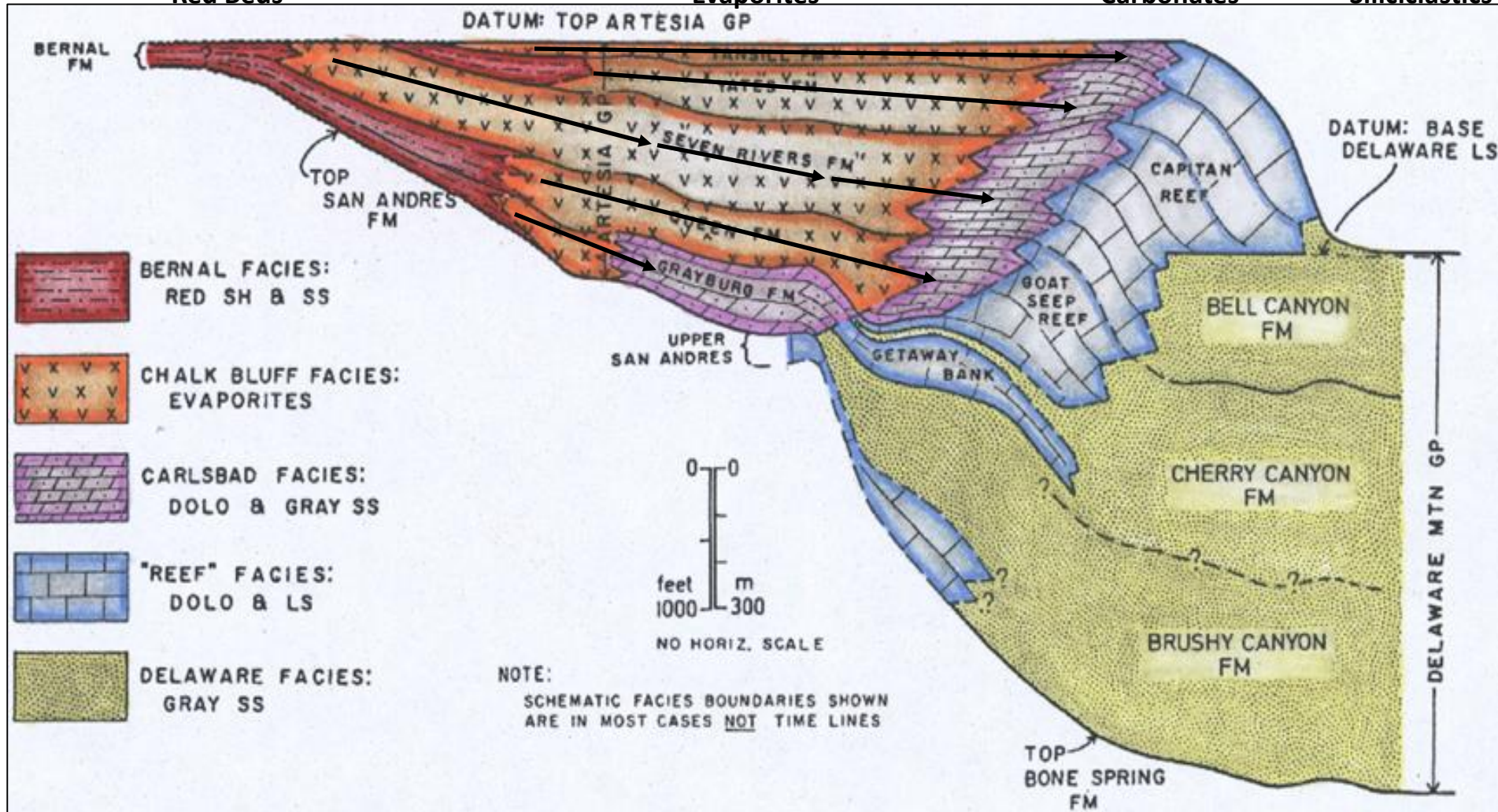
# Long Distance Transport of Magnesium ( $Mg^{2+}$ ) Rich Brine

Non-marine  
Red Beds

Inner Ramp/Shelf  
Evaporites

Ramp/Shelf Margin  
Carbonates

Basin  
Siliciclastics



## Reflux-Mechanical Compaction Dolomitization

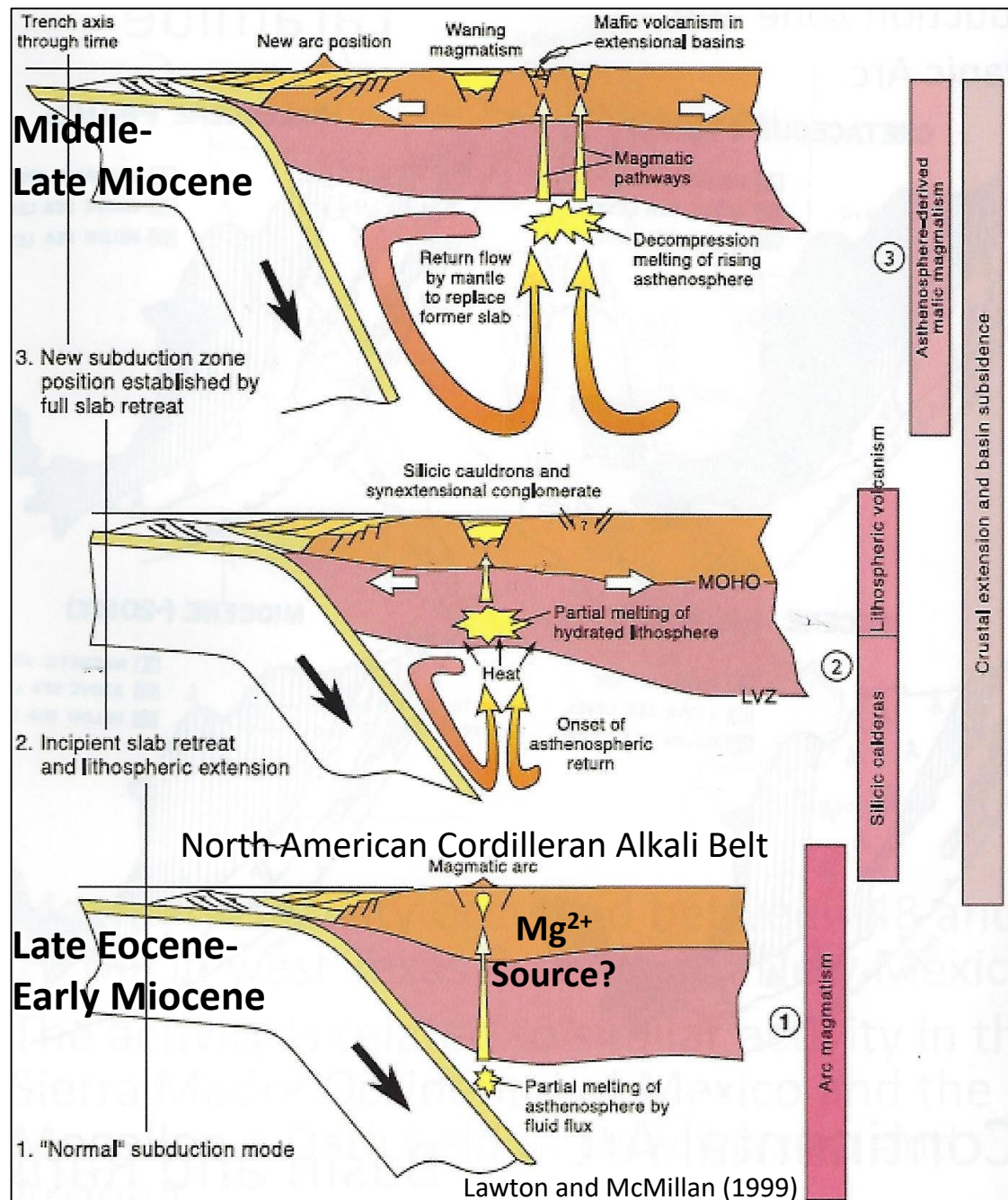
Finely crystalline, E-planar dolomite

Preserved original rock fabric & porosity-permeability

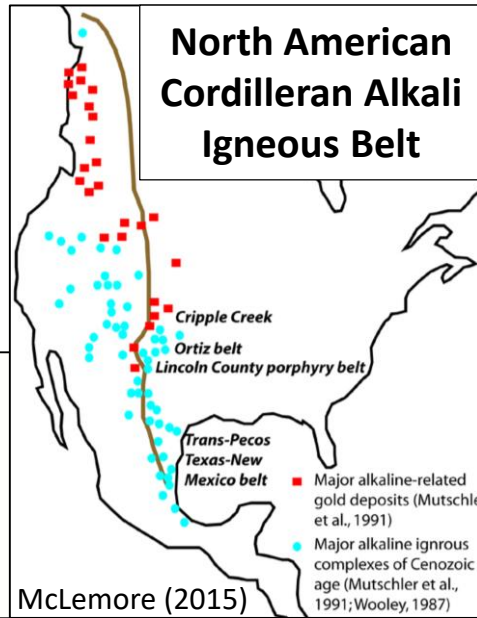
# Late Eocene-Early Miocene

## Subduction & Magmatic Arc

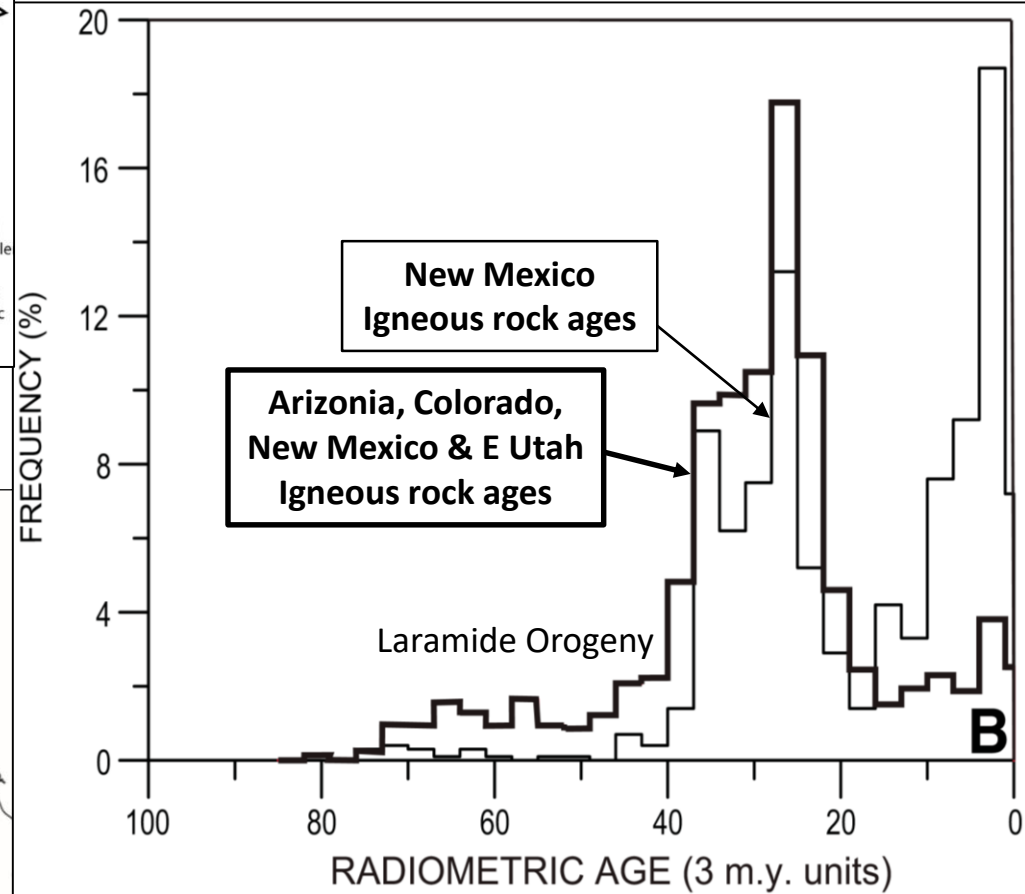
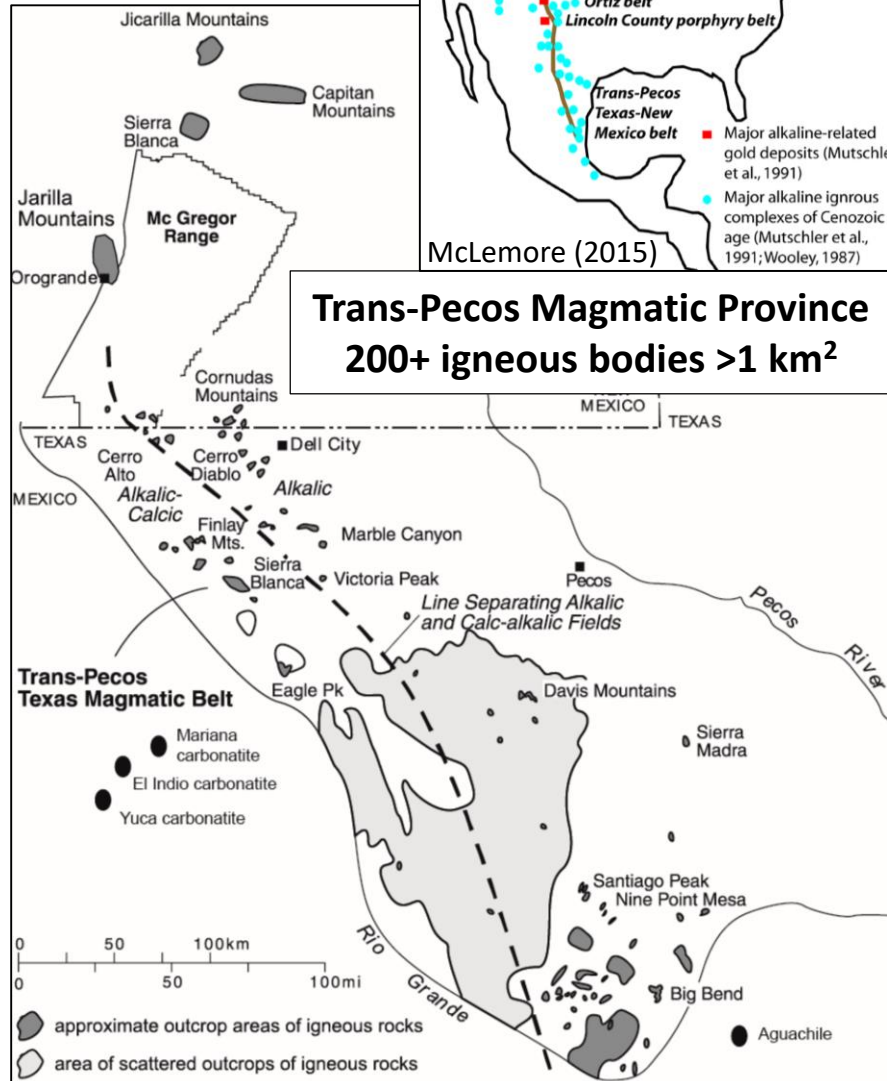
Created North American  
Cordilleran Alkali Belt  
Tectonic-Topographic  
Driven-Hydrothermal  
Dolomitization



# North American Cordilleran Alkali Igneous Belt



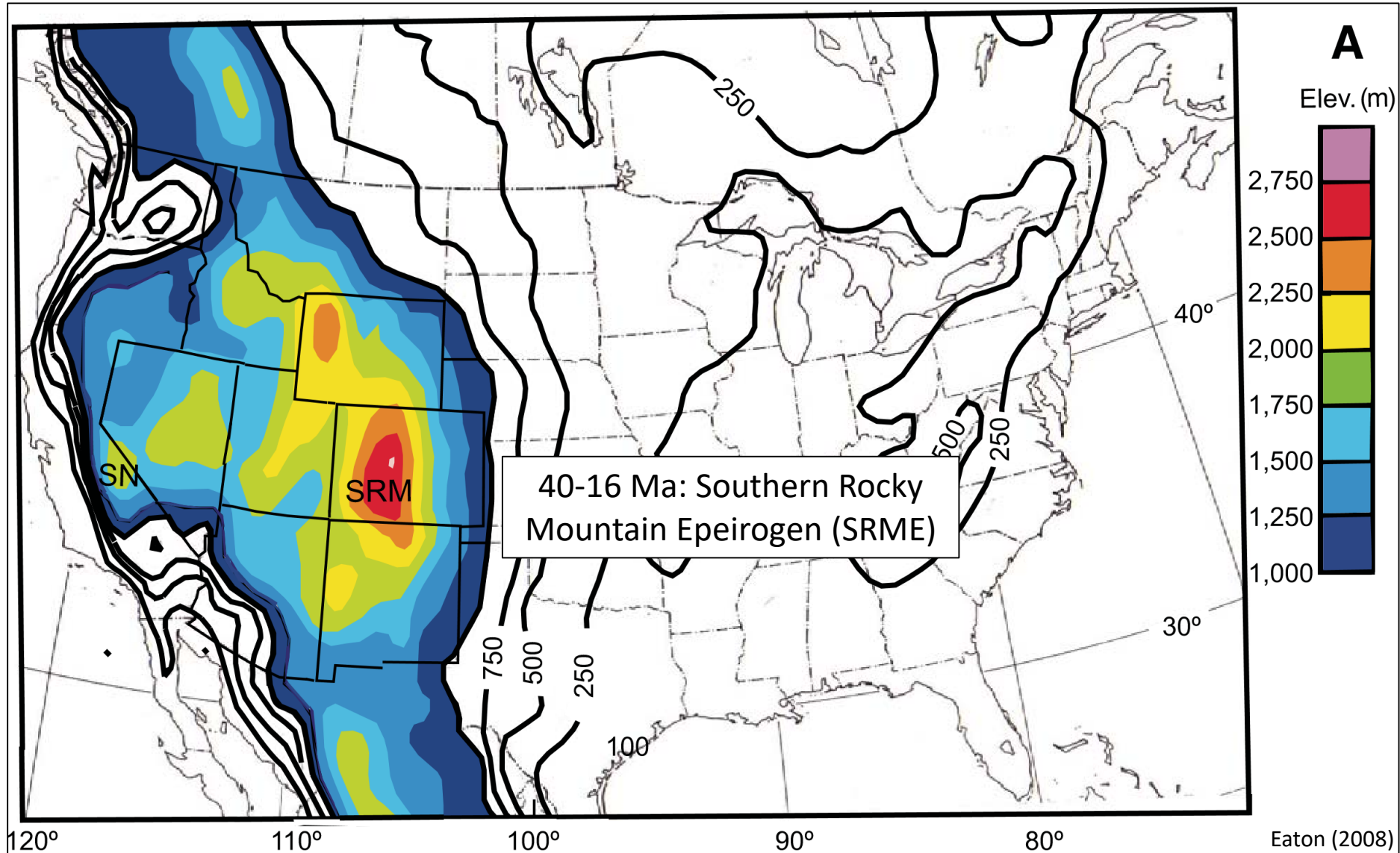
## Trans-Pecos Magmatic Province 200+ igneous bodies >1 km<sup>2</sup>



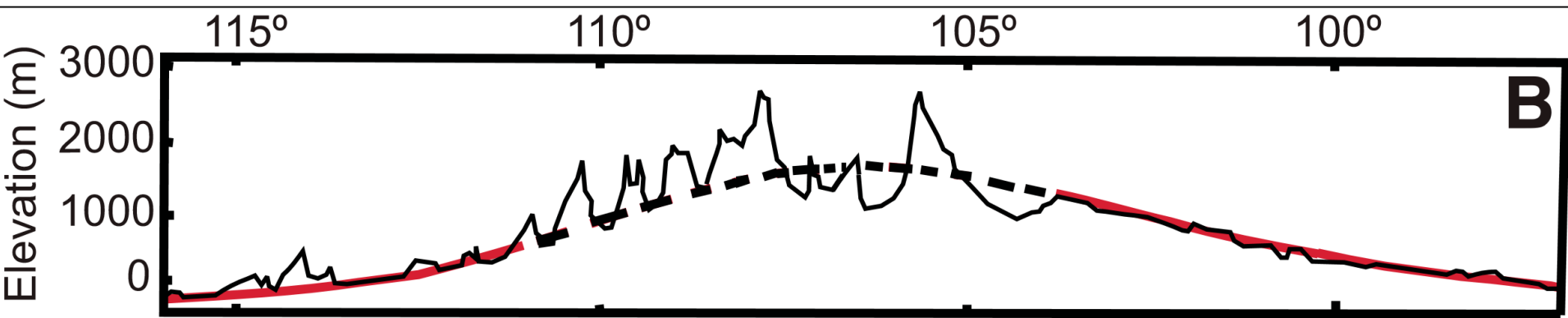
Chaplin et al. (2004), Luedke (1993a; 1993b),  
Luedke & Smith (1978a; 1978b), & Eaton (2008)

Barker (1977) & Others

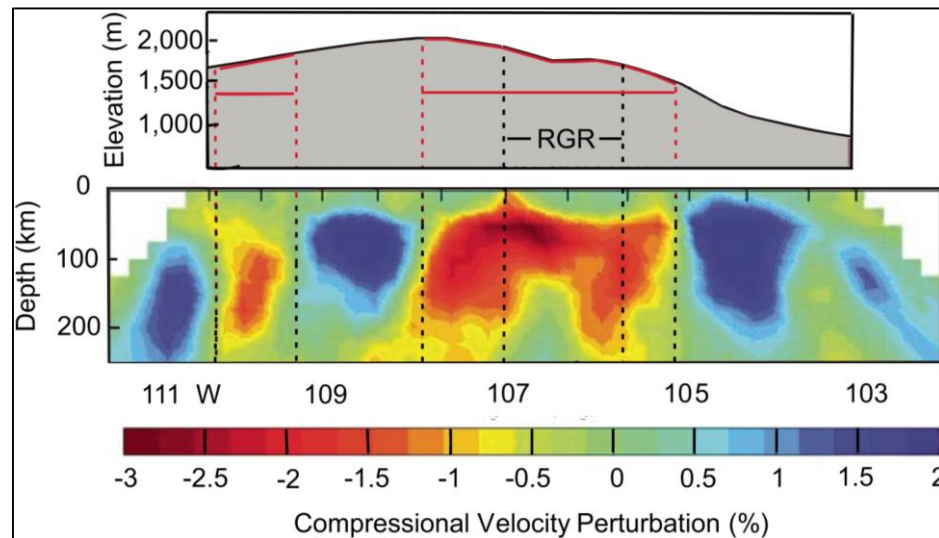
# Southern Rocky Mountain Epeirogen



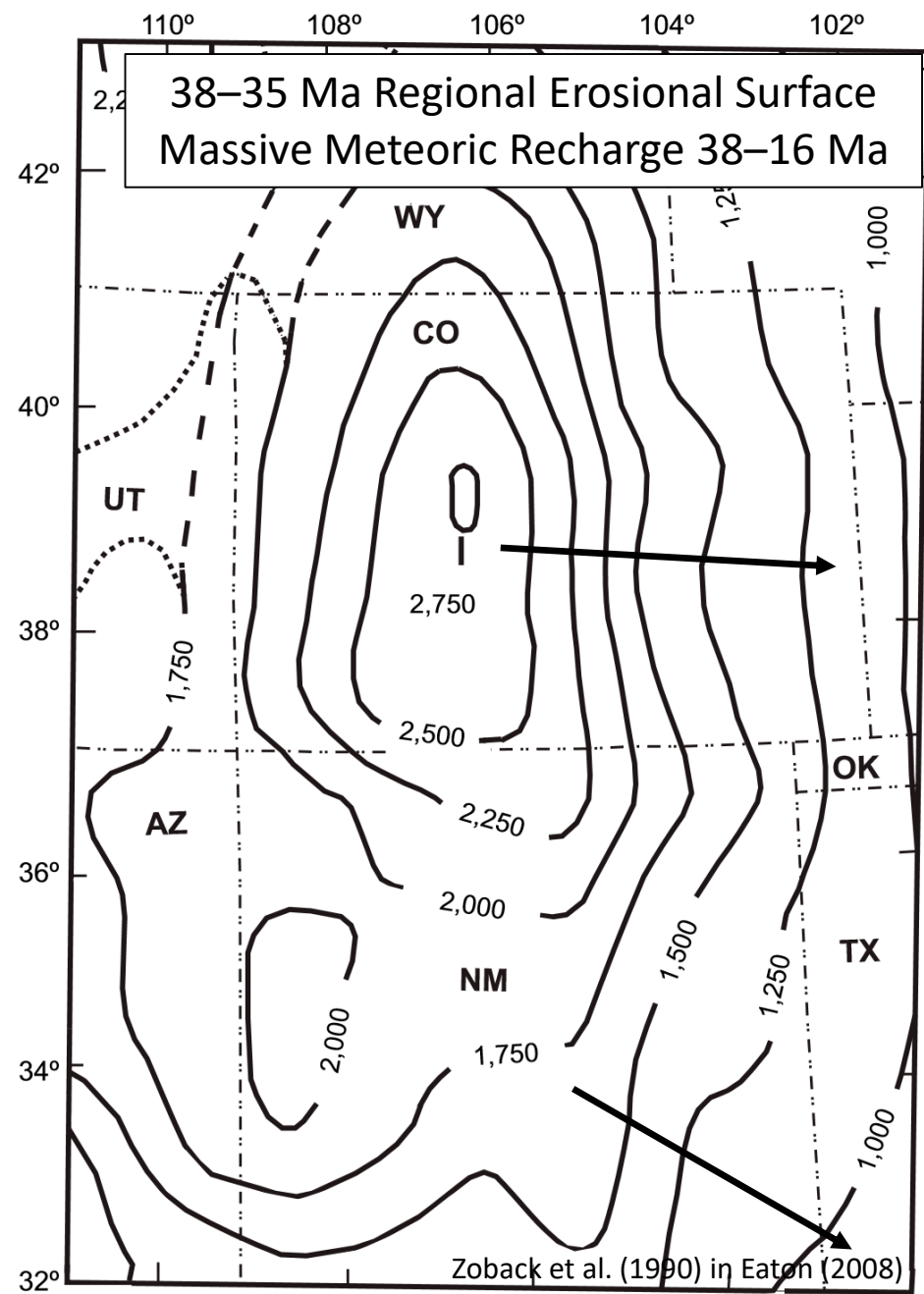
Uplift provided by: North American Cordilleran Alkali Igneous Belt



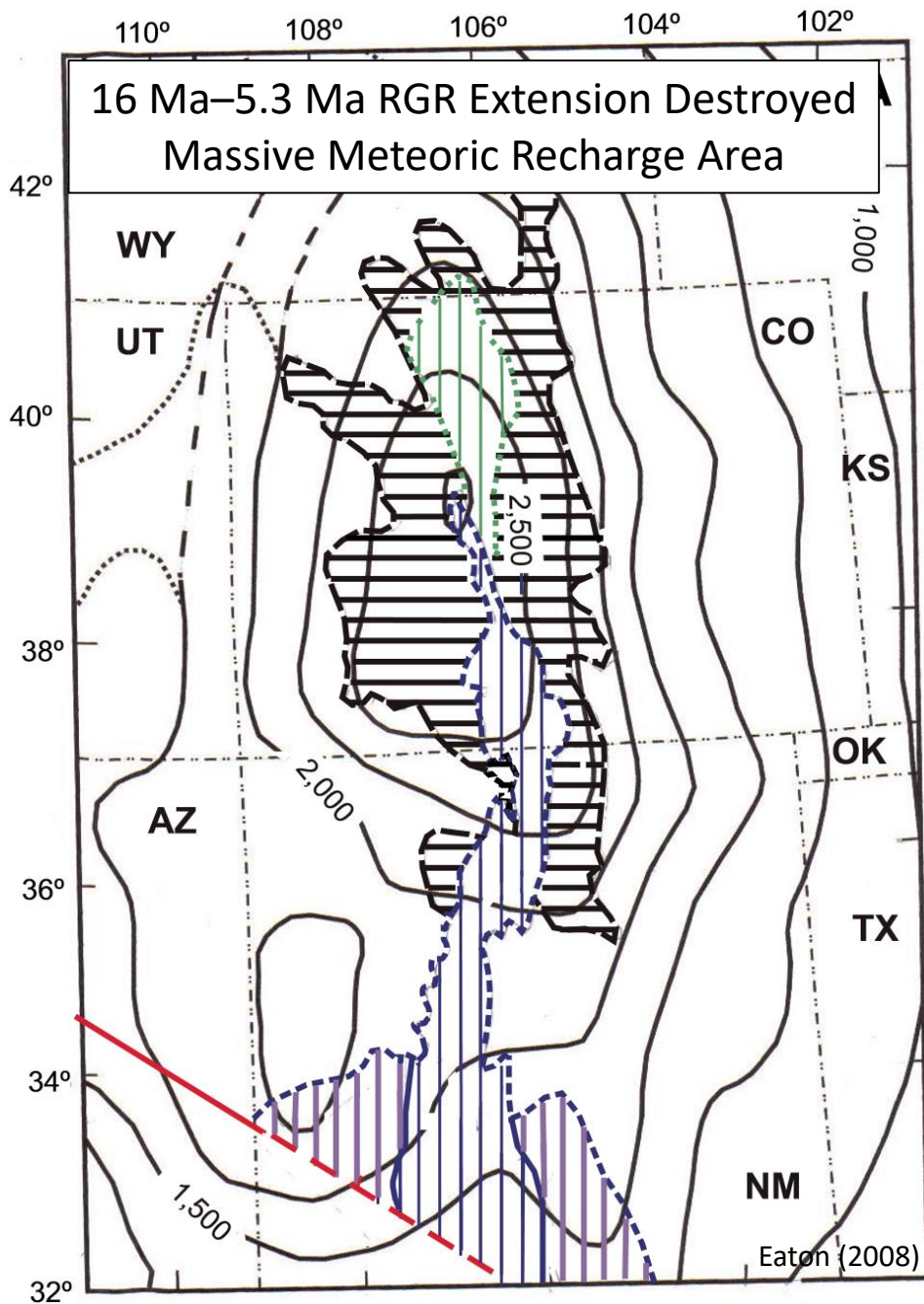
West to east topography and smoothed topography of Southern Rocky Mountain Epeirogen (SRME) at latitude 33°N. From Eaton (2008).



SRME smoothed topography and P velocities to 250 km, red = low P velocity. RGR = Rio Grande Rift. From Eaton (2008).



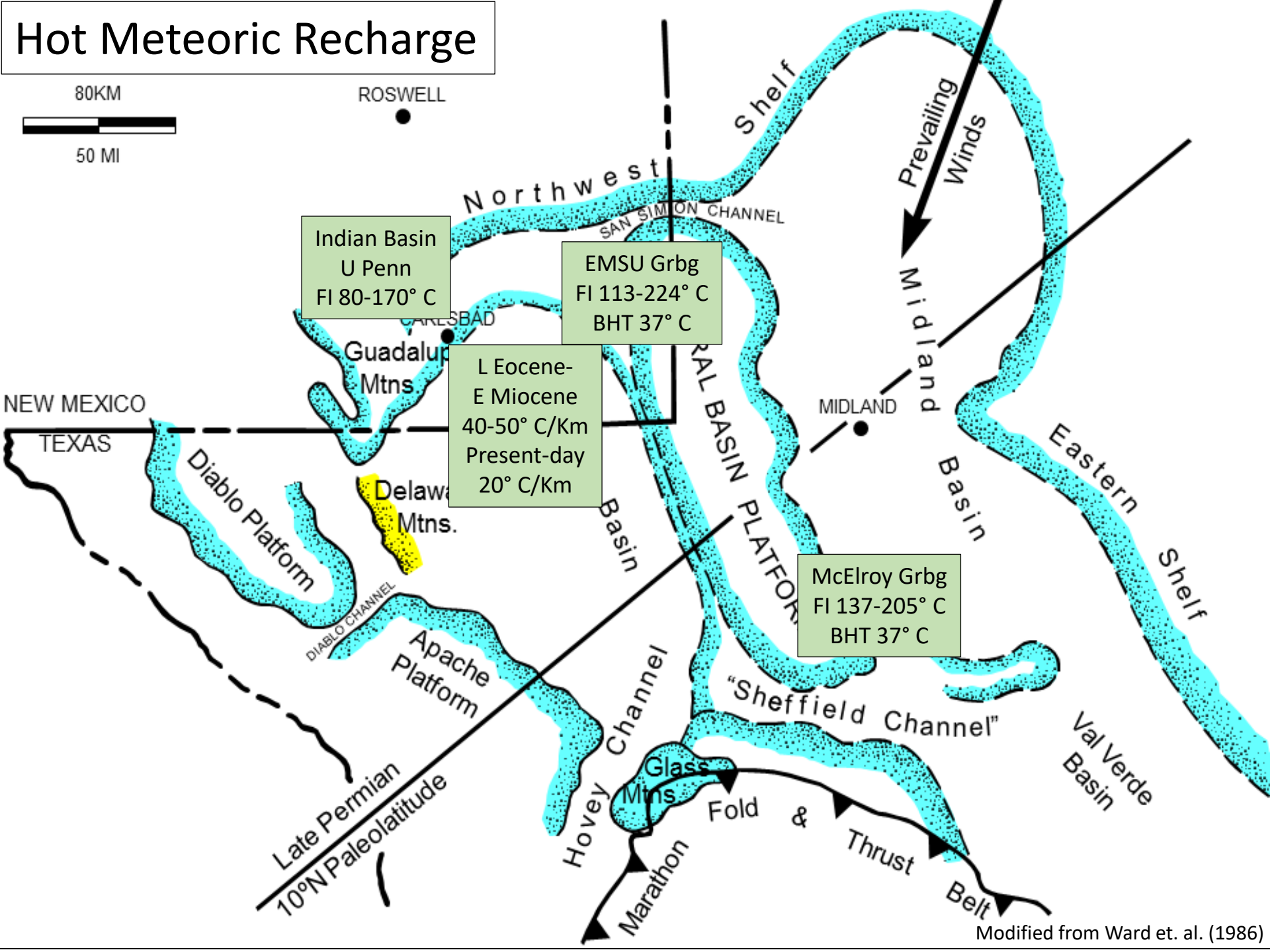
Southern Rocky Mountain Epeirogen (SRME)

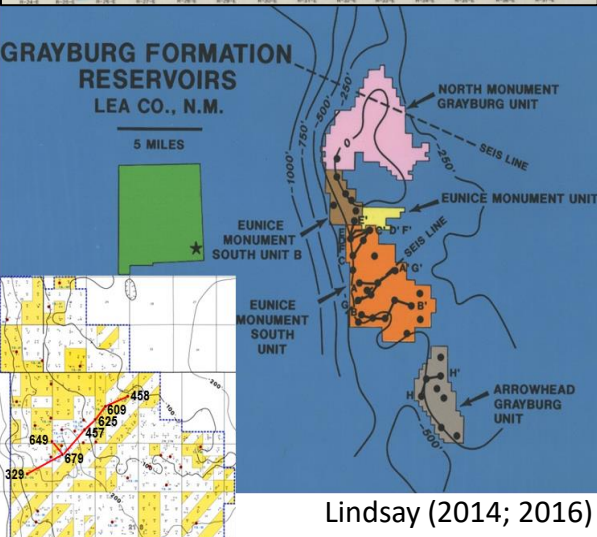


SRME w/Rio Grande Rift Extension



# Hot Meteoric Recharge





Lindsay (2014; 2016)

★ = EMSU 458

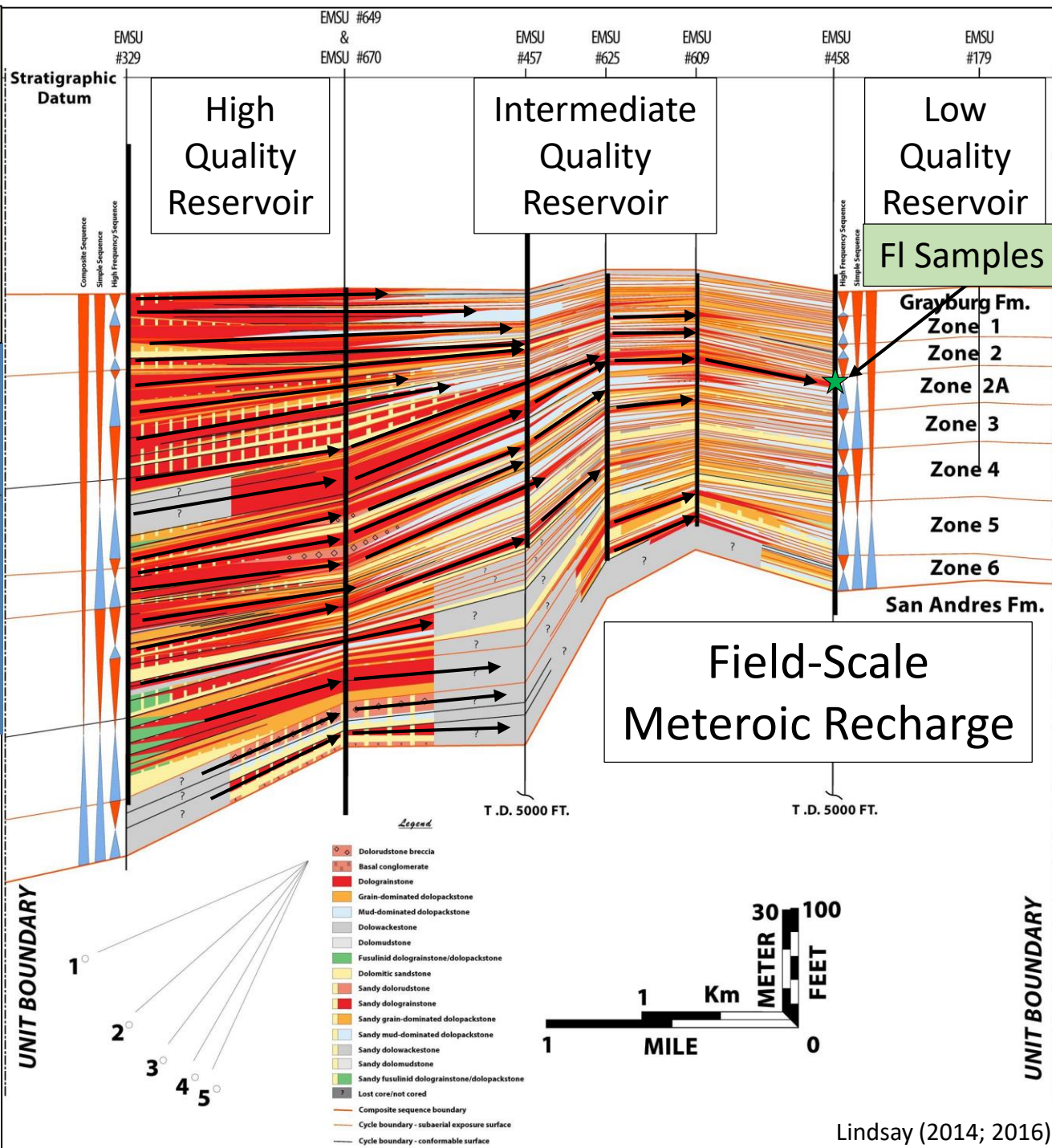
3720 Ft

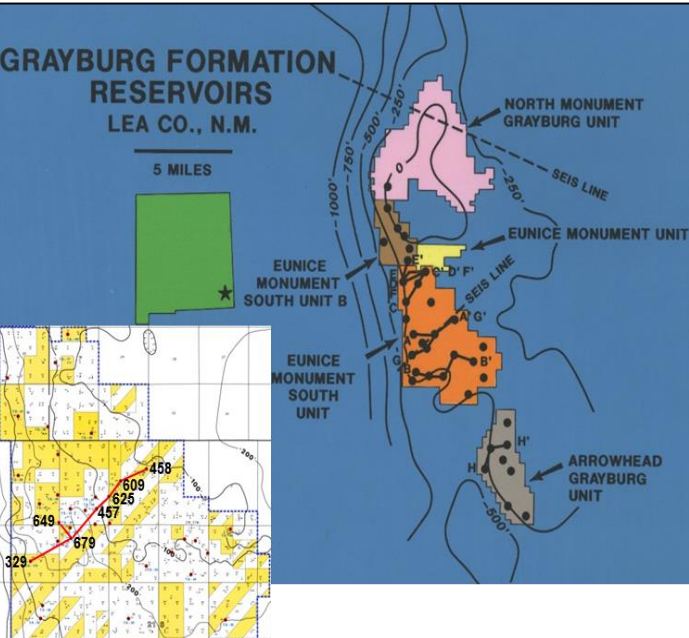
Fluid Inclusions

Homogenization

Temperatures =

113°-224°C



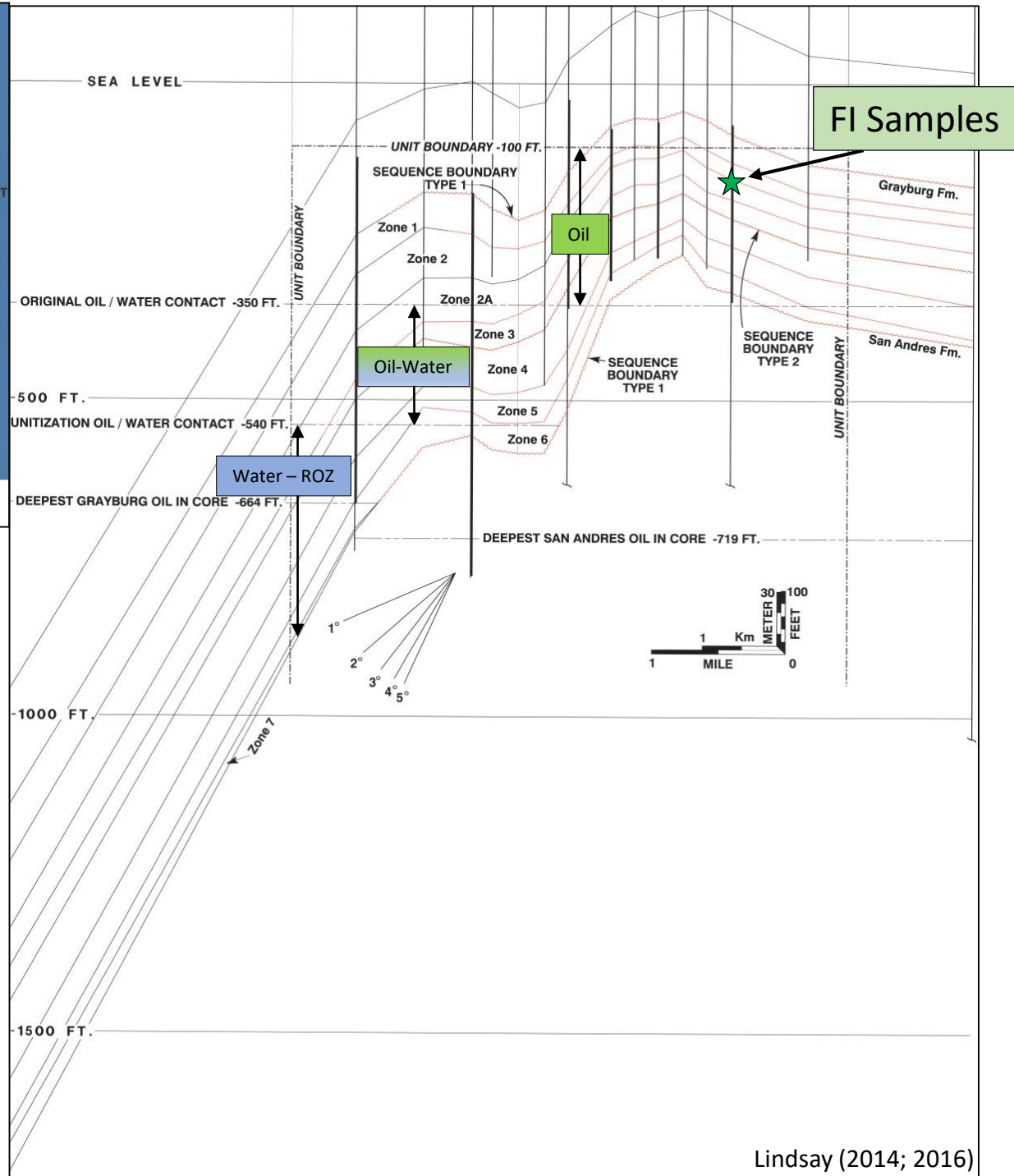


## EMSU: Present-day Oil & Water Production & ROZ

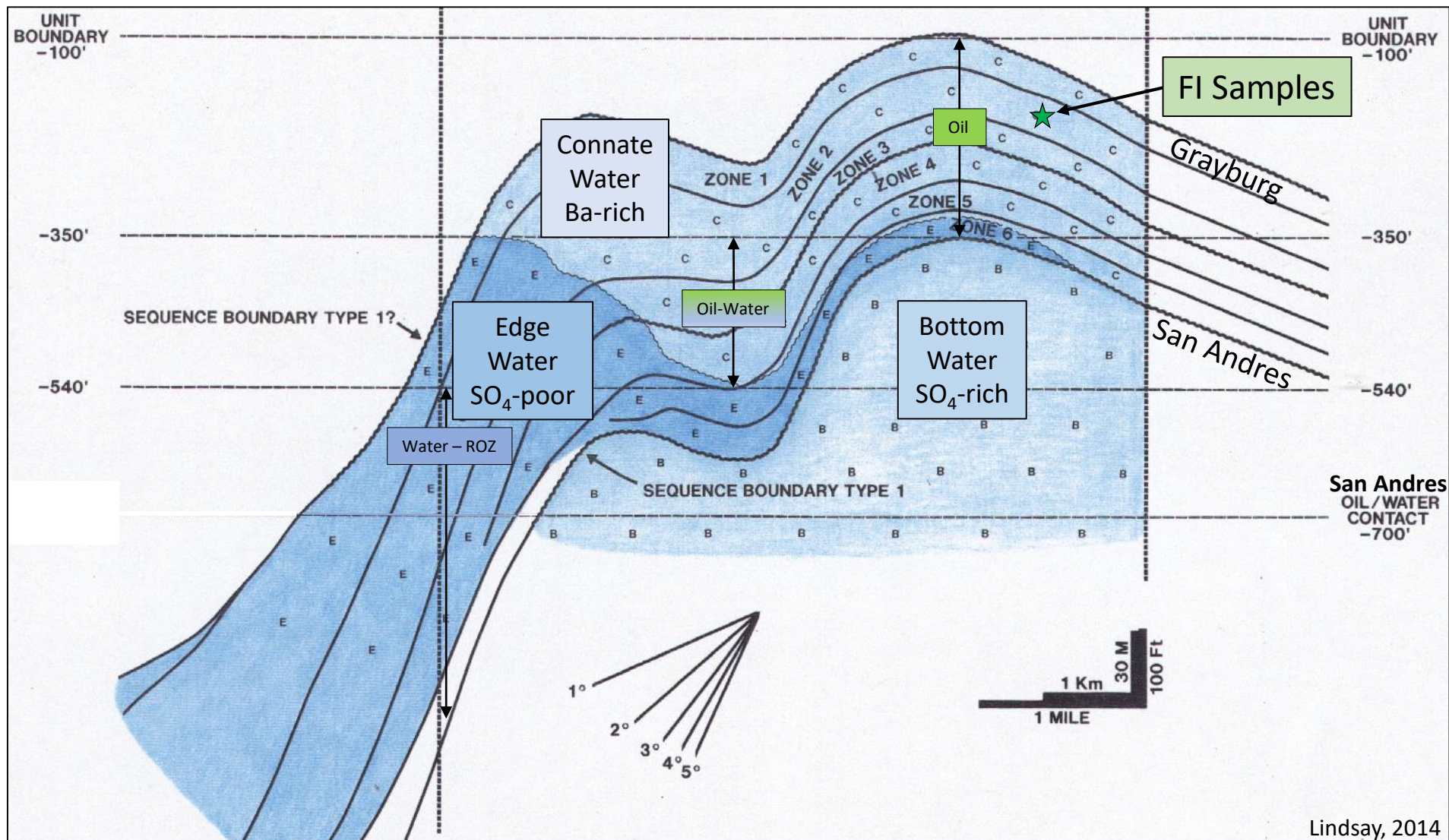
★ = EMSU 458

3720 Ft

Fluid Inclusions  
Homogenization  
Temperatures =  
113°-224°C



# EMSU



Lindsay, 2014

Present-day Edge Water Entry  
Via pressure drop within reservoir

# Eunice Monument South Unit (EMSU)

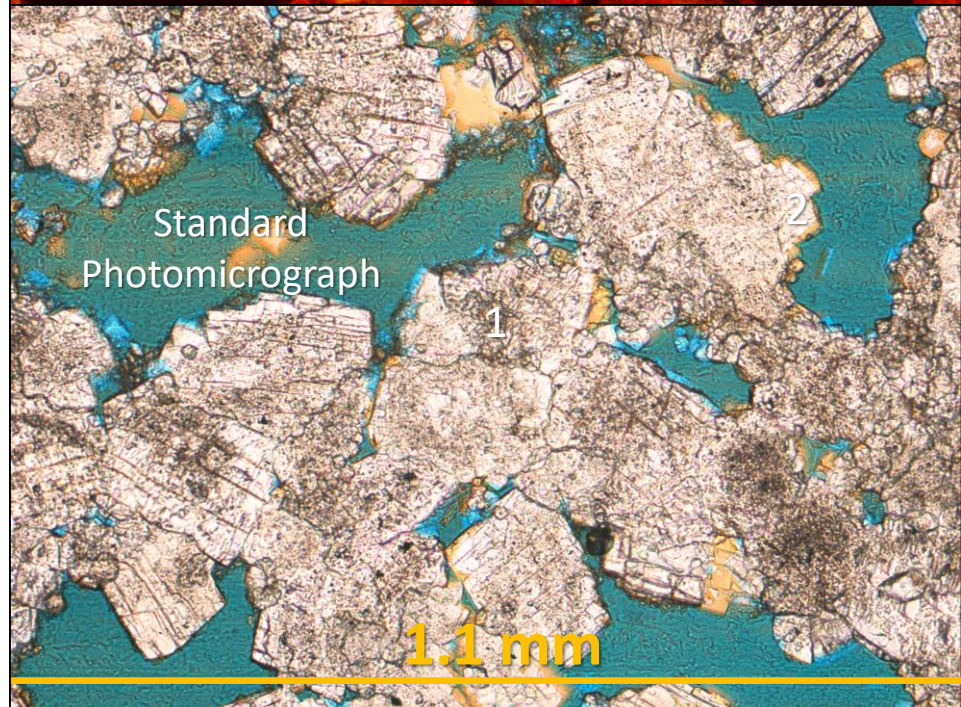
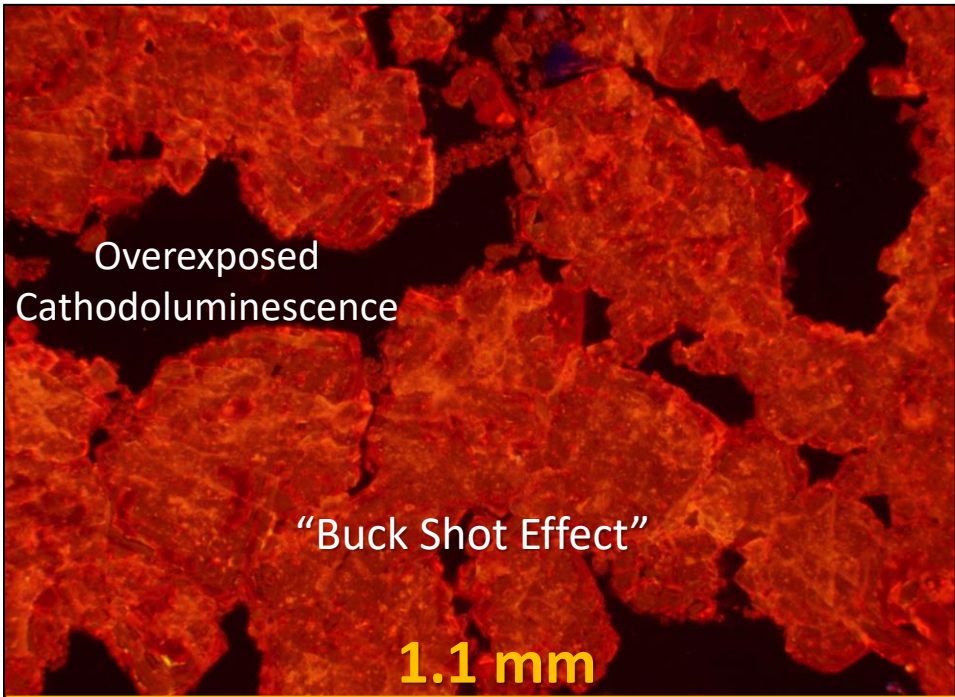
Grayburg Formation

EMSU-458 3720 ft

Homogenization Temps =  
113°–224° C

Dolomite Crystals

1. Inclusion-rich = Oil Column
2. Inclusion-poor = ROZ



FI Sample  
Eunice Monument  
South Unit (EMSU)

Grayburg Formation

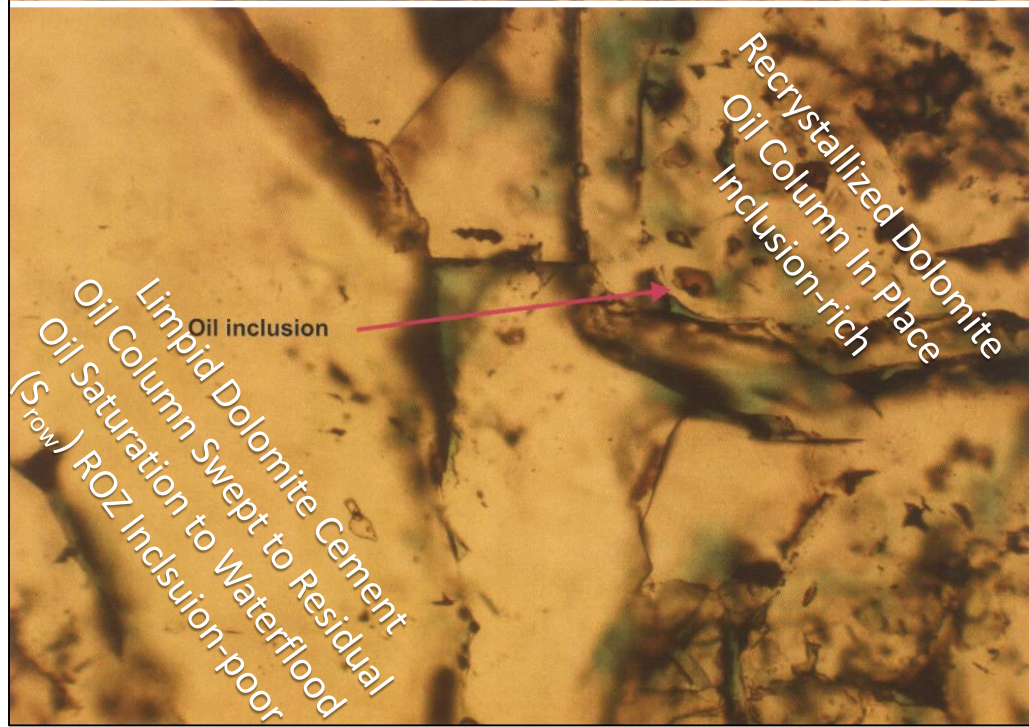
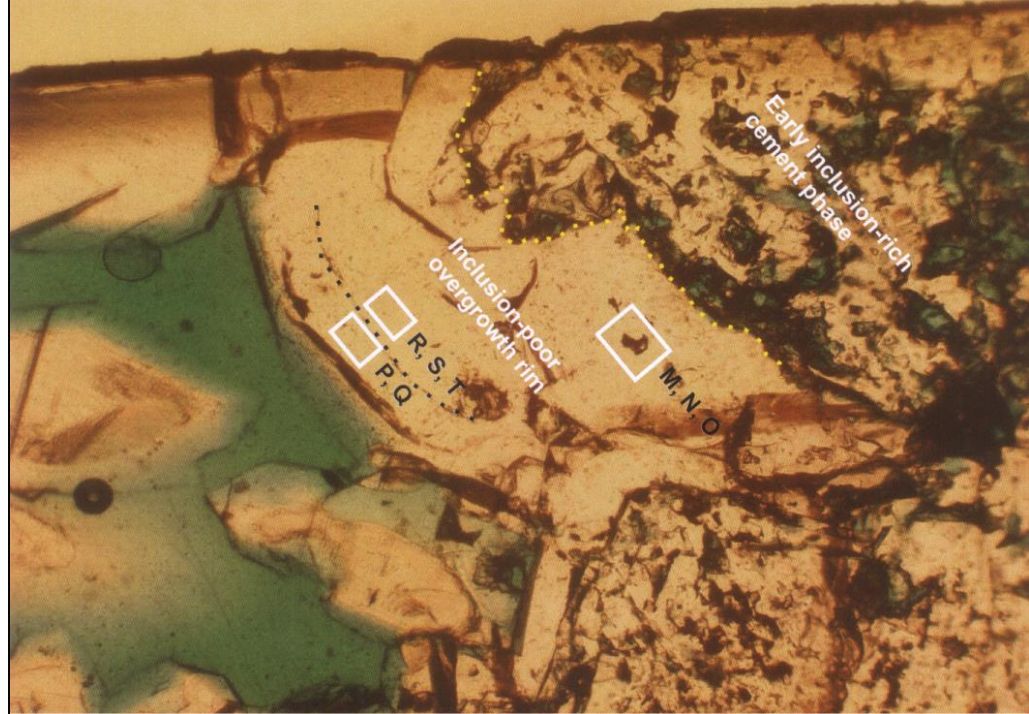
EMSU-458 3720 ft

Homogenization Temps =

113°–224° C

Dolomite Crystals

1. Inclusion-rich = Oil Column
2. Inclusion-poor = ROZ



EMSU

Grayburg Fm

EMSU-458 3720 ft

Highly Altered Rock Fabric  
Multiple Partial Dissolution  
& Precipitation (Recrystallization) Events

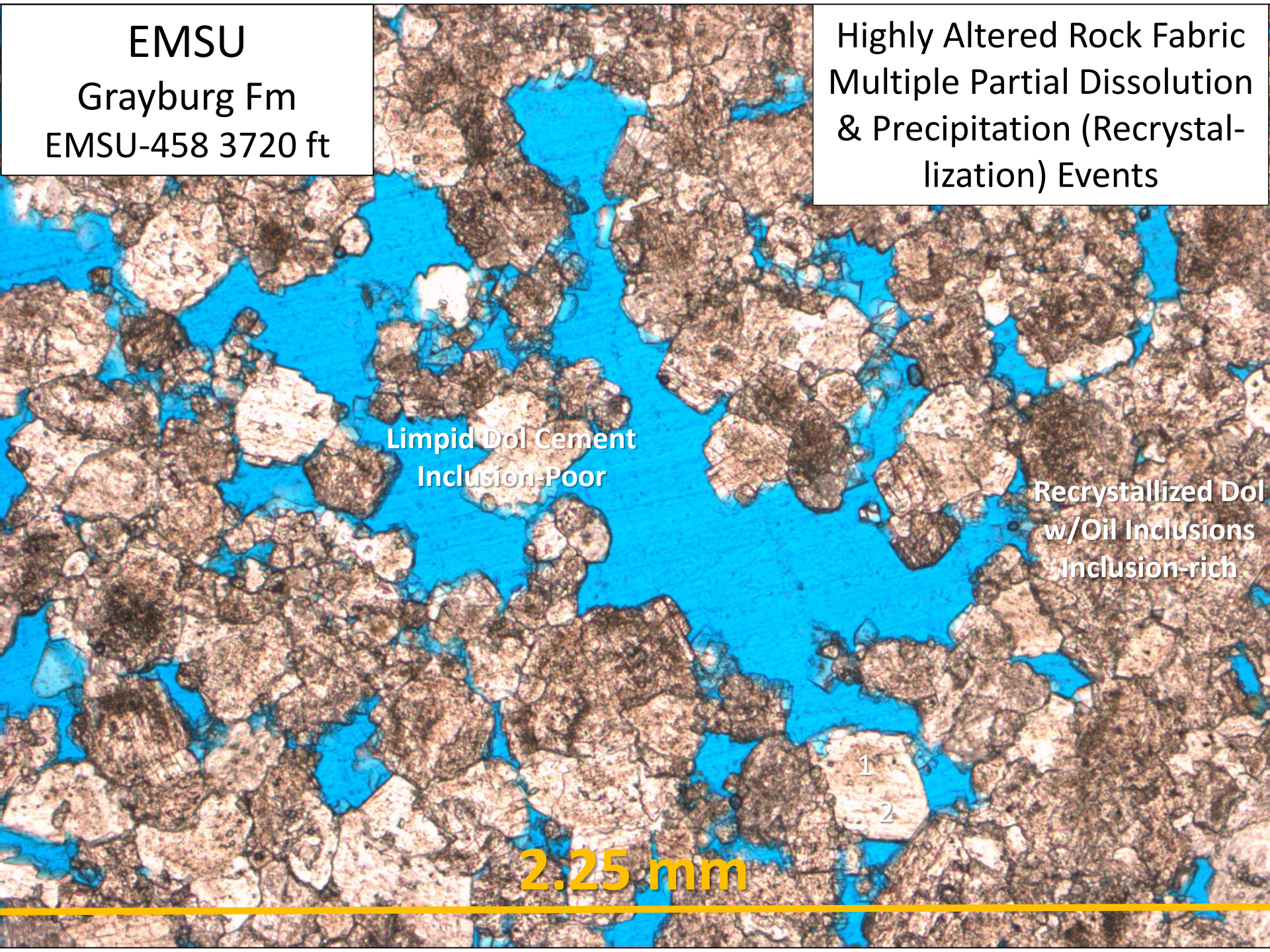
Limpid Dol Cement  
Inclusion-Poor

Recrystallized Dol  
w/Oil Inclusions  
Inclusion-rich

2.25 mm

1

2



EMSU

Grayburg Fm

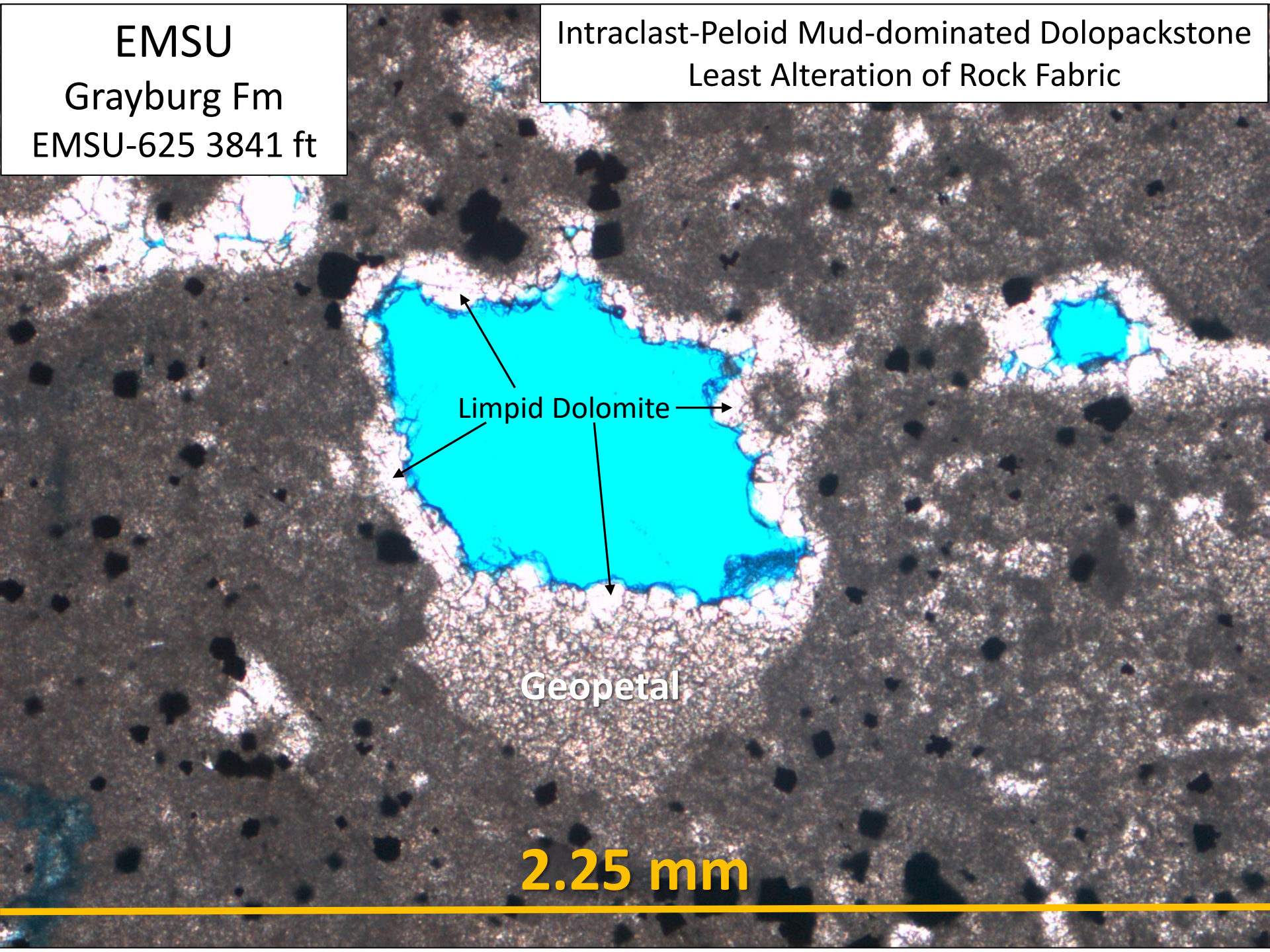
EMSU-625 3841 ft

Intraclast-Peloid Mud-dominated Dolopackstone  
Least Alteration of Rock Fabric

Limpid Dolomite

Geopetal

2.25 mm

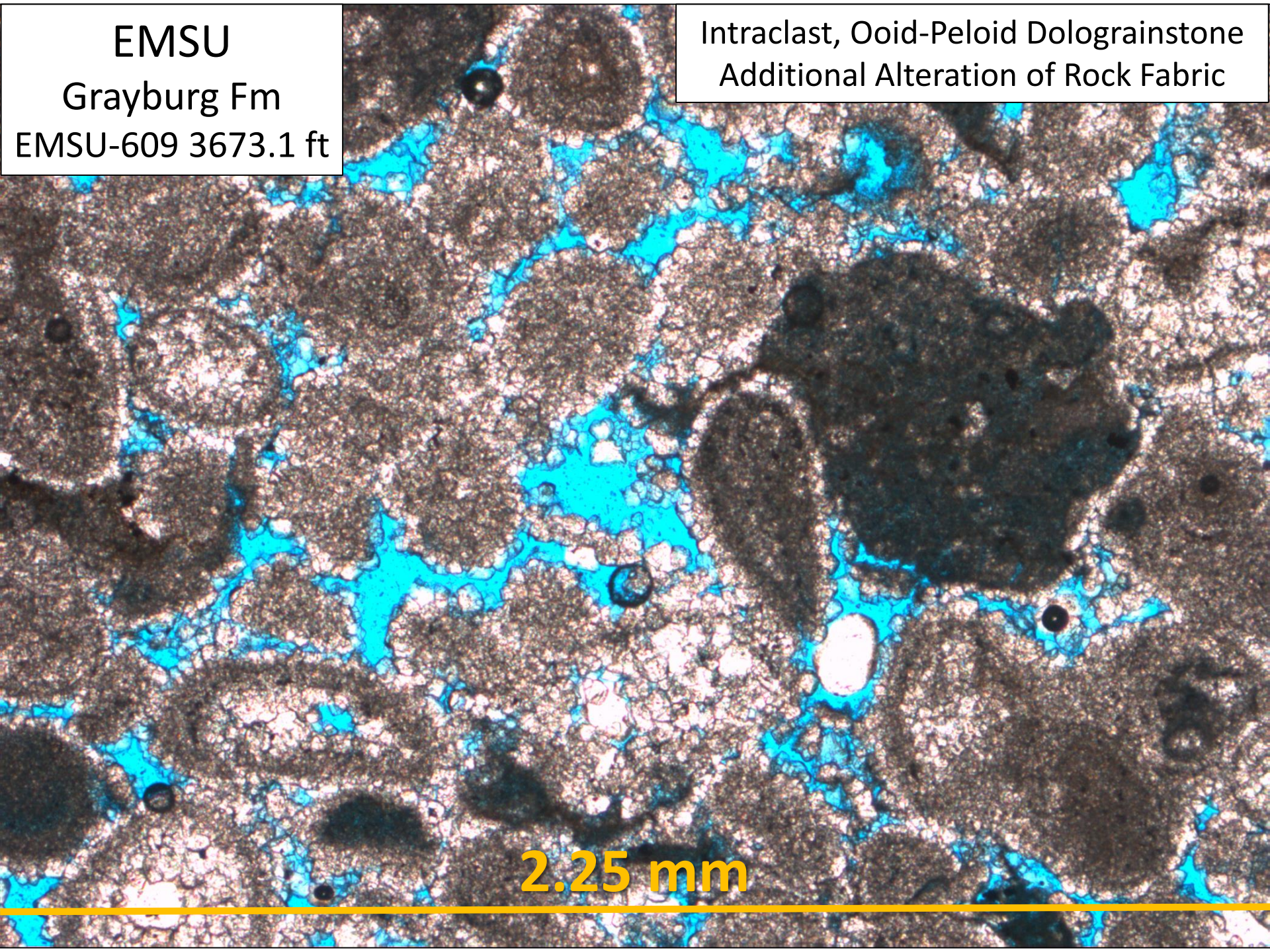


EMSU

Grayburg Fm

EMSU-609 3673.1 ft

Intraclast, Ooid-Peloid Dolograinstone  
Additional Alteration of Rock Fabric



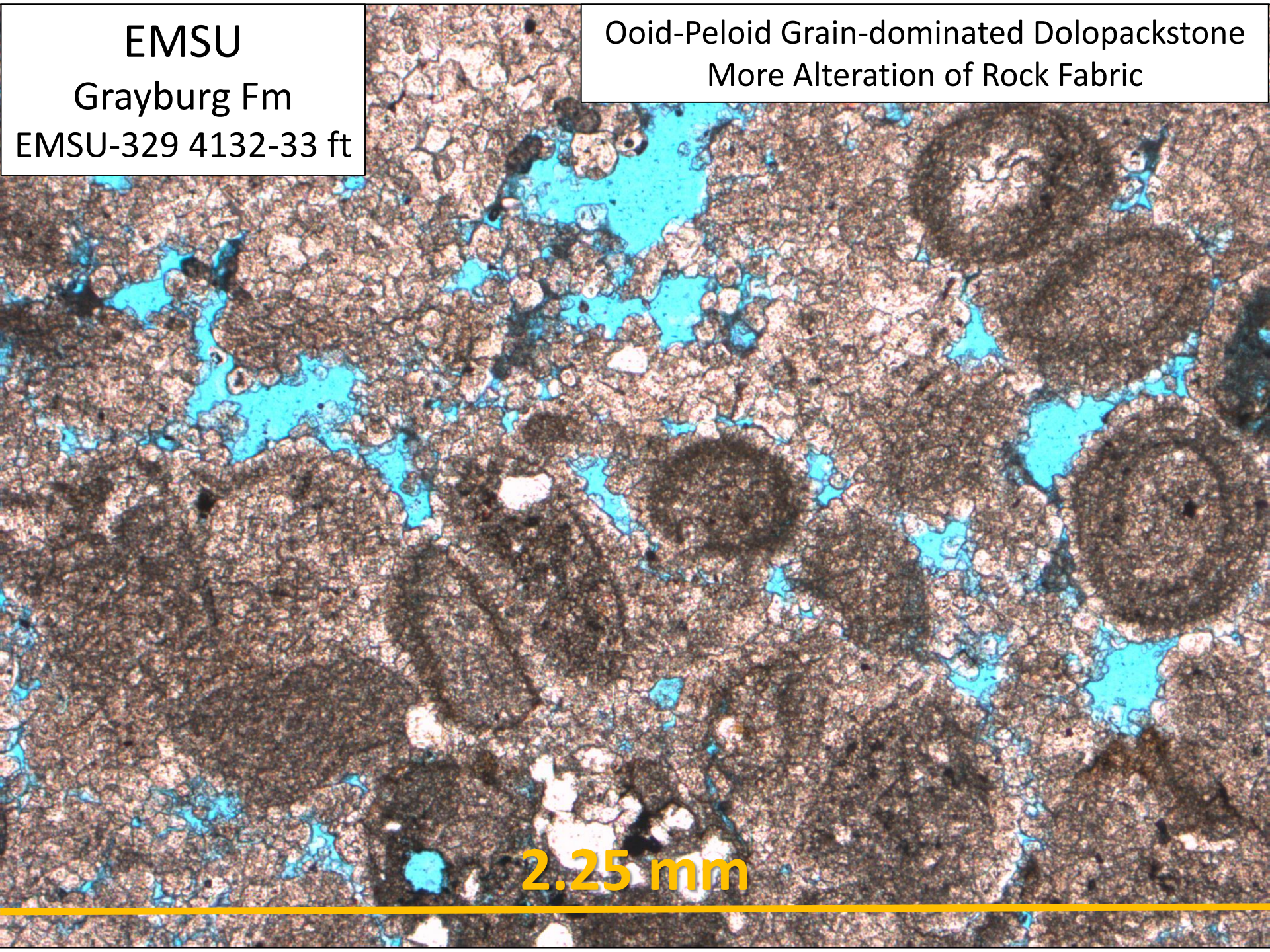
2.25 mm

EMSU

Grayburg Fm

EMSU-329 4132-33 ft

Ooid-Peloid Grain-dominated Dolopackstone  
More Alteration of Rock Fabric



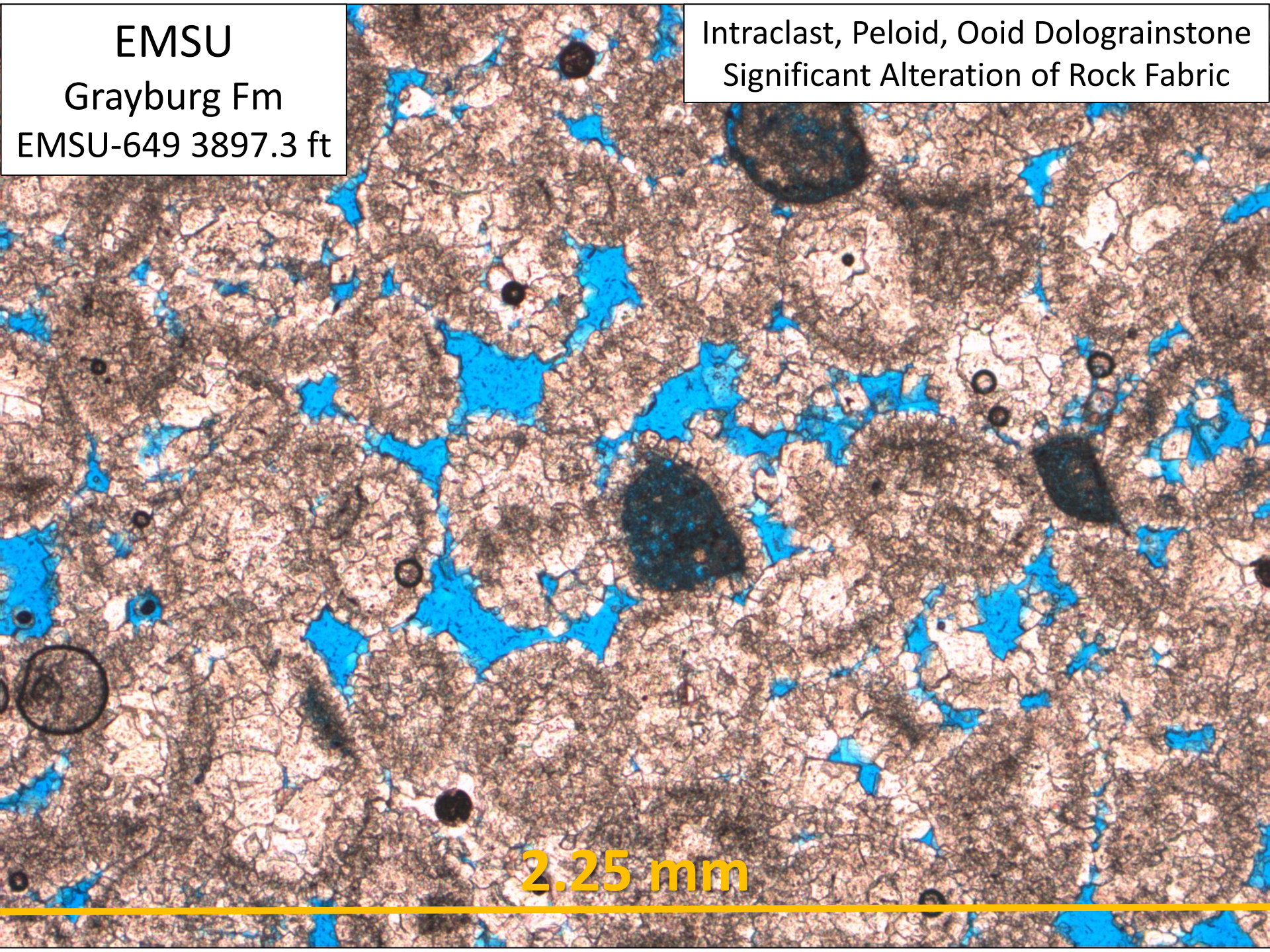
2.25 mm

EMSU

Grayburg Fm

EMSU-649 3897.3 ft

Intraclast, Peloid, Ooid Dolograinstone  
Significant Alteration of Rock Fabric



2.25 mm

EMSU

Grayburg Fm

EMSU-609 3708.6 ft

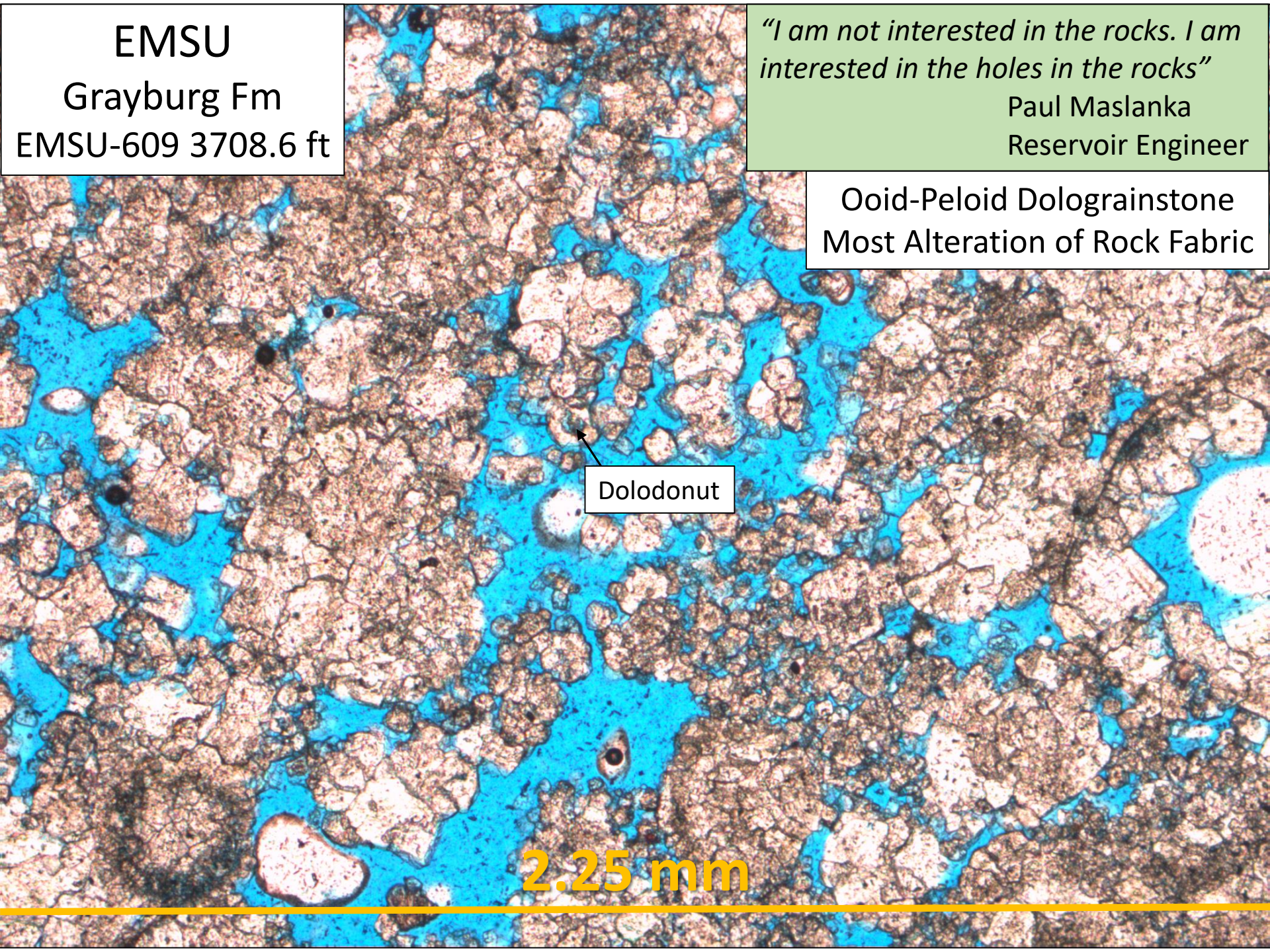
*"I am not interested in the rocks. I am interested in the holes in the rocks"*

Paul Maslanka  
Reservoir Engineer

Ooid-Peloid Dolograinstone  
Most Alteration of Rock Fabric

Dolodonorut

2.25 mm

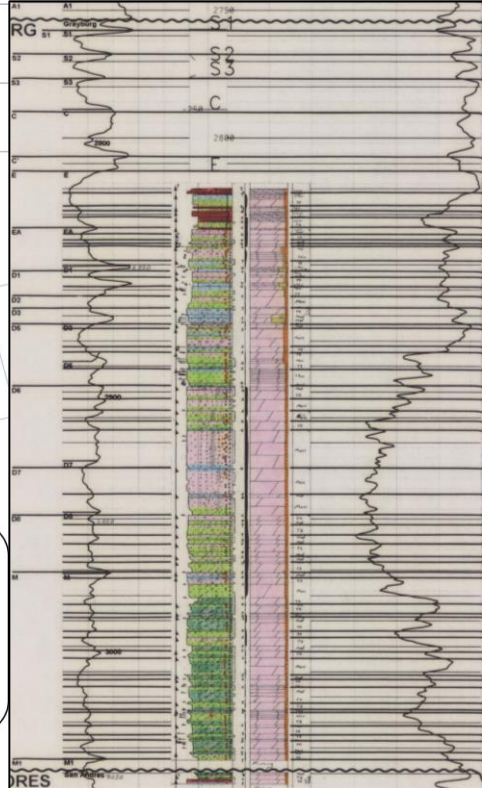
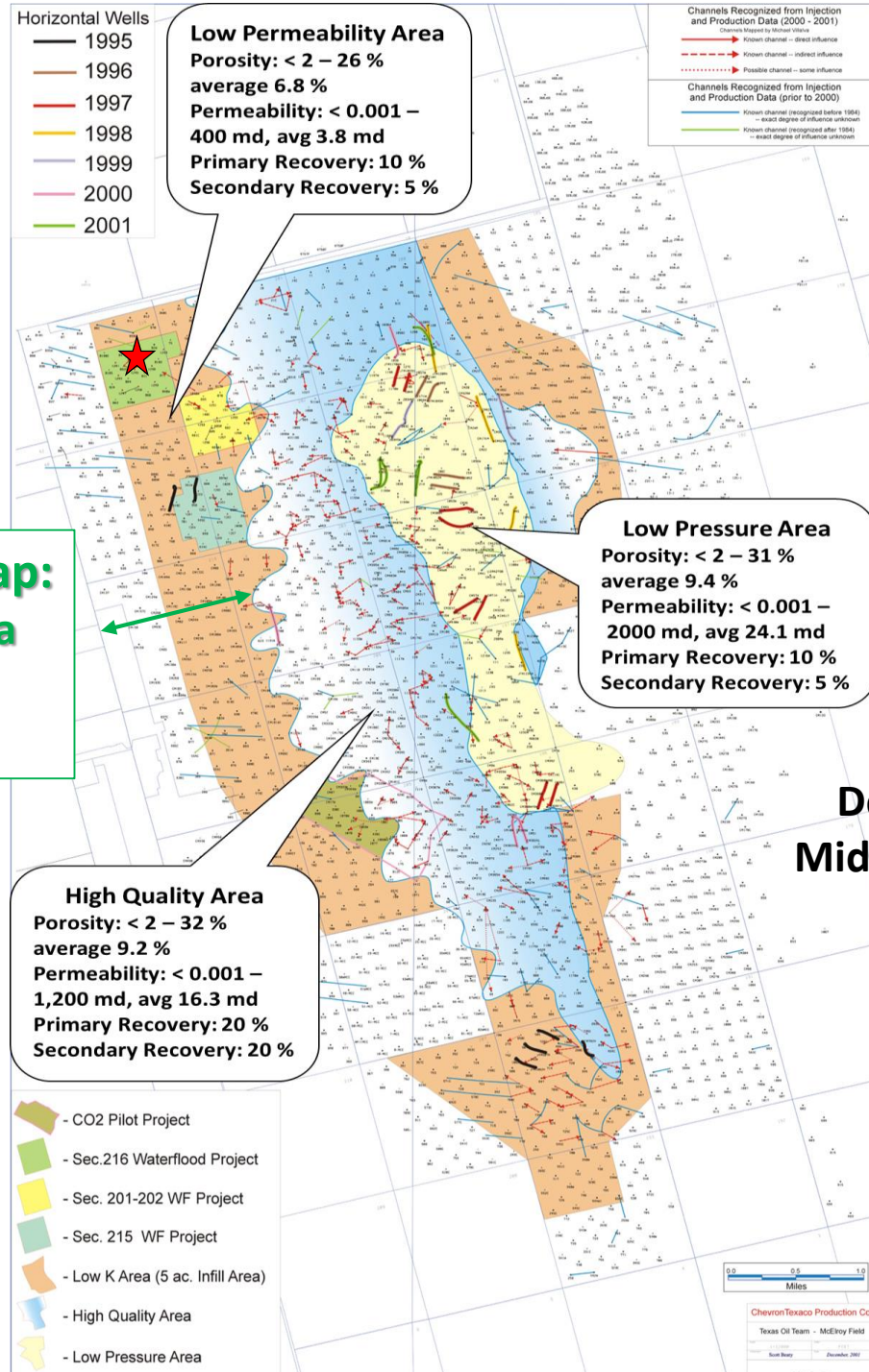


# McElroy Field Grayburg Formation

**Lateral Stratigraphic Trap:  
Moved 1 Mile Up-dip via  
Dolomite & Evaporite  
Cement Dissolution**

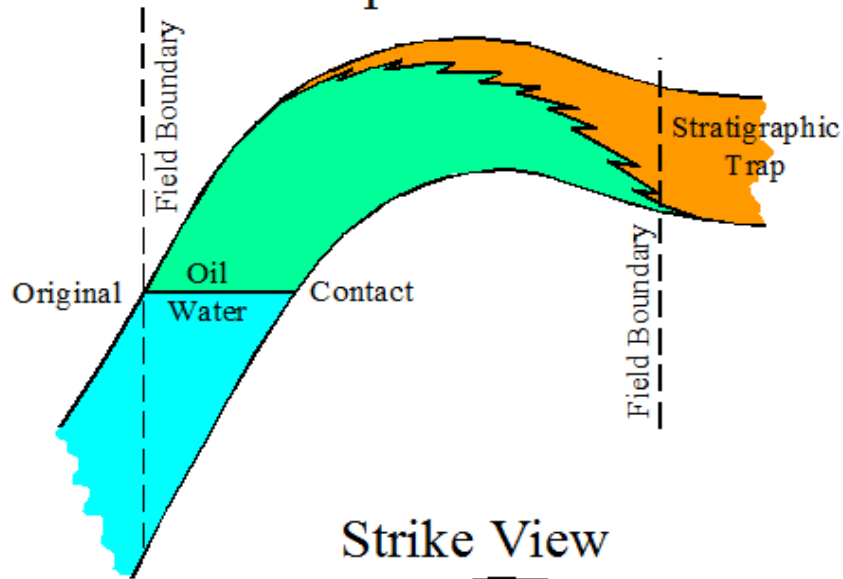
**Up-dip  
Central Basin Platform**

**Down-dip  
Midland Basin**

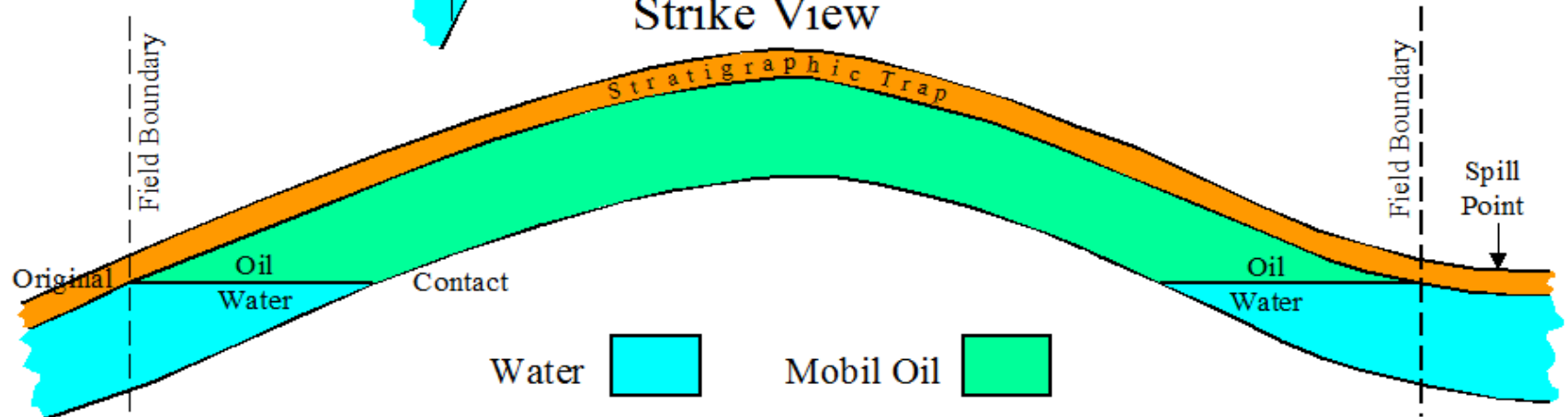


# Pre-Late Eocene Original Oil Column

Dip View



Strike View

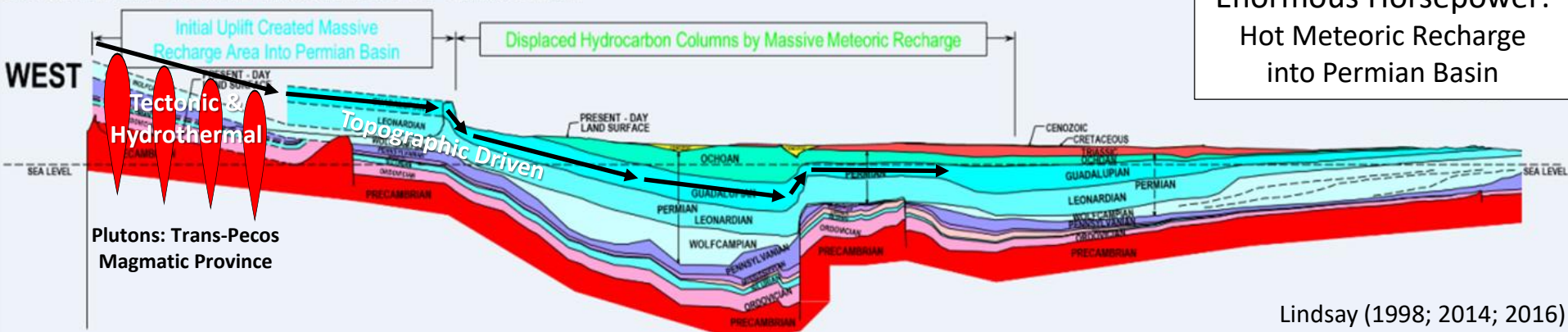


**Structural Closure Created by Laramide Tectonism**

# Permian Basin

## West-East Cross Section

### SOUTHERN ROCKY MOUNTAIN EPIIROGENE



Massive Recharge Area  
Half Width of Permian Basin

*"All you need is horsepower"*

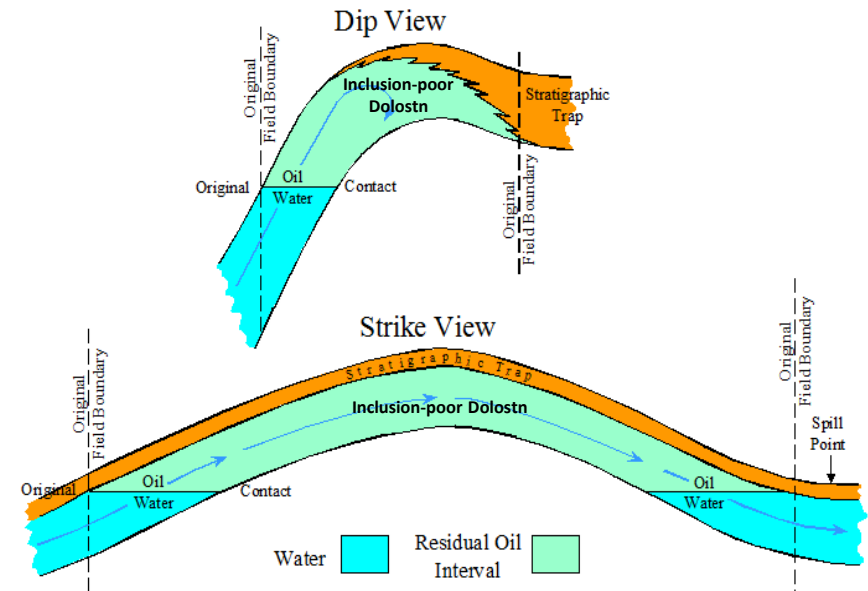
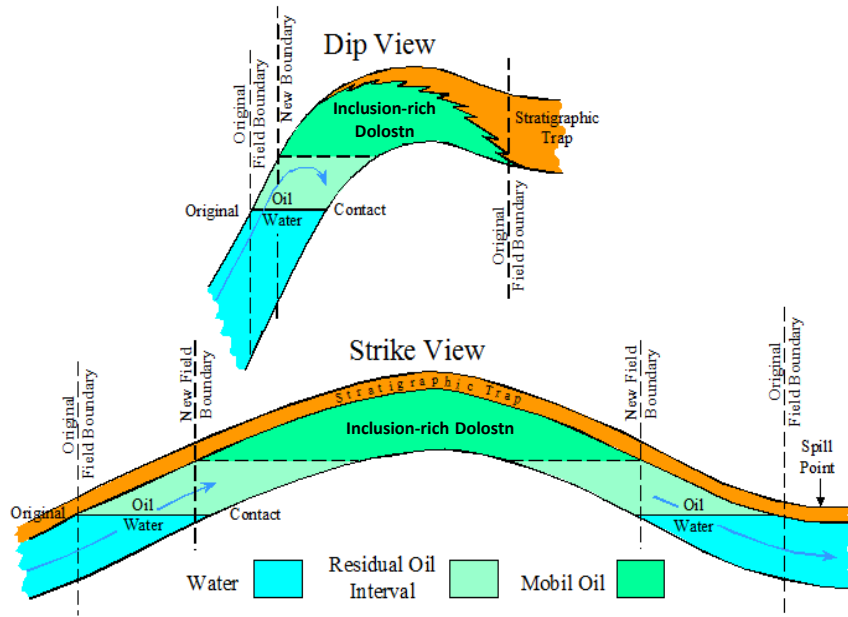
Ganesh Thakur

Past President SPE

Late Eocene – Early Miocene

Partially Swept Oil Column

Completely Swept Oil Column



Massive Recharge of Meteoric Water  
Partially to Completely Sweeps Oil Columns to Residual Oil Saturation ( $So_{rw}$ )

Hot Meteoric Recharge into Permian Basin

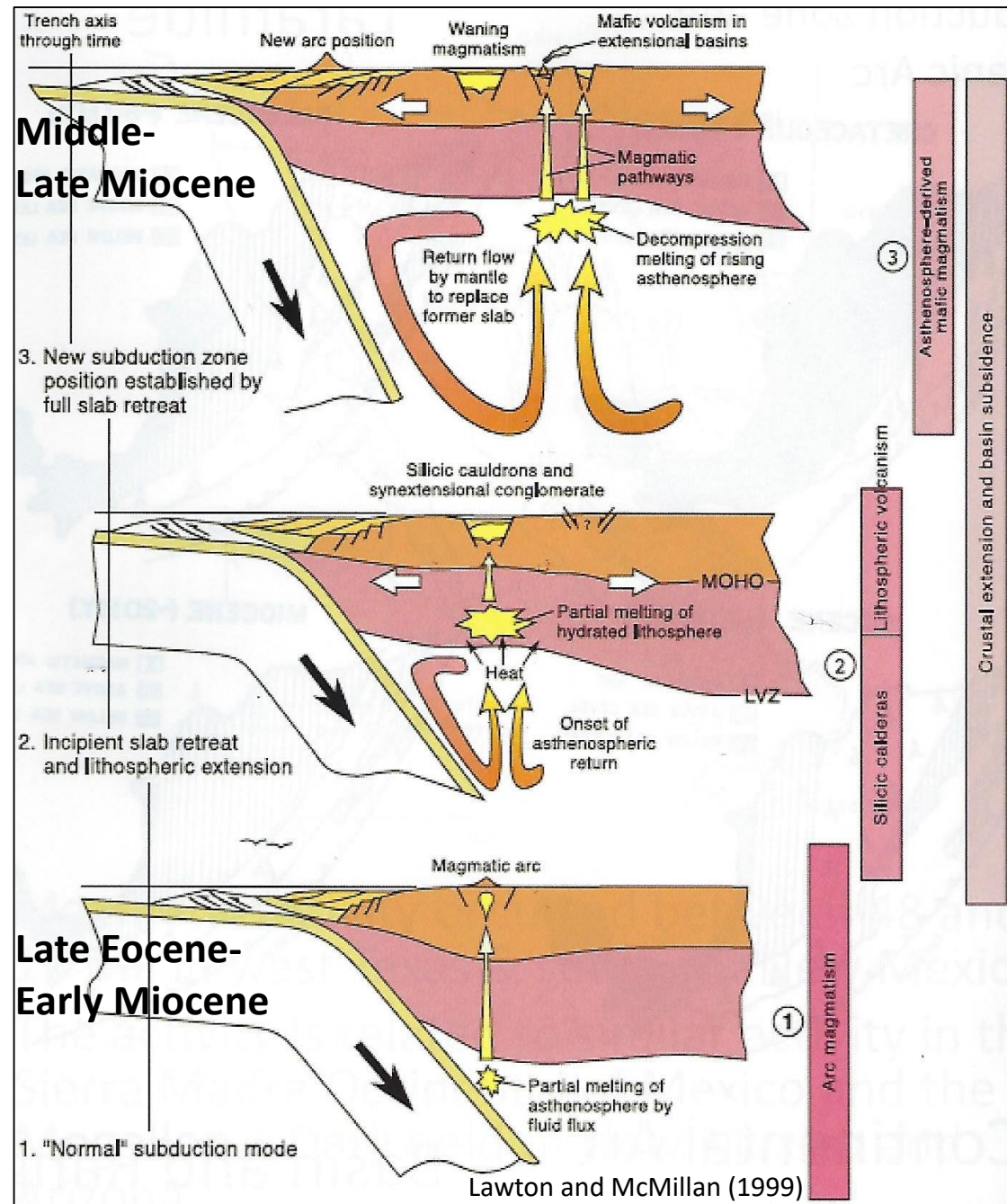
# Middle-Late Miocene

Rio Grande Rift

## Rio Grande Rift Extension

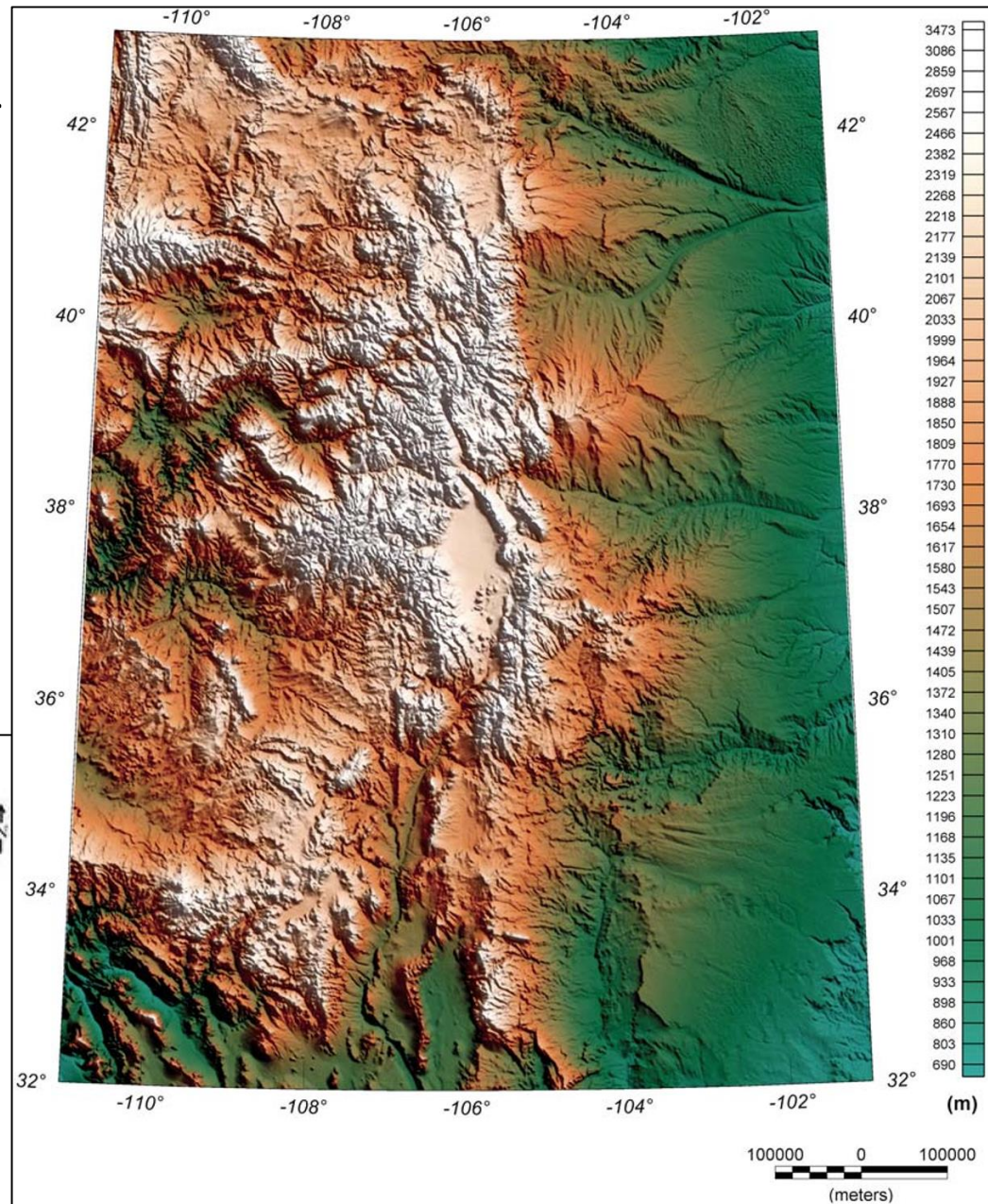
Destruction of Massive  
Meteoric Recharge Area

Fault Development  
of Horsts & Grabens



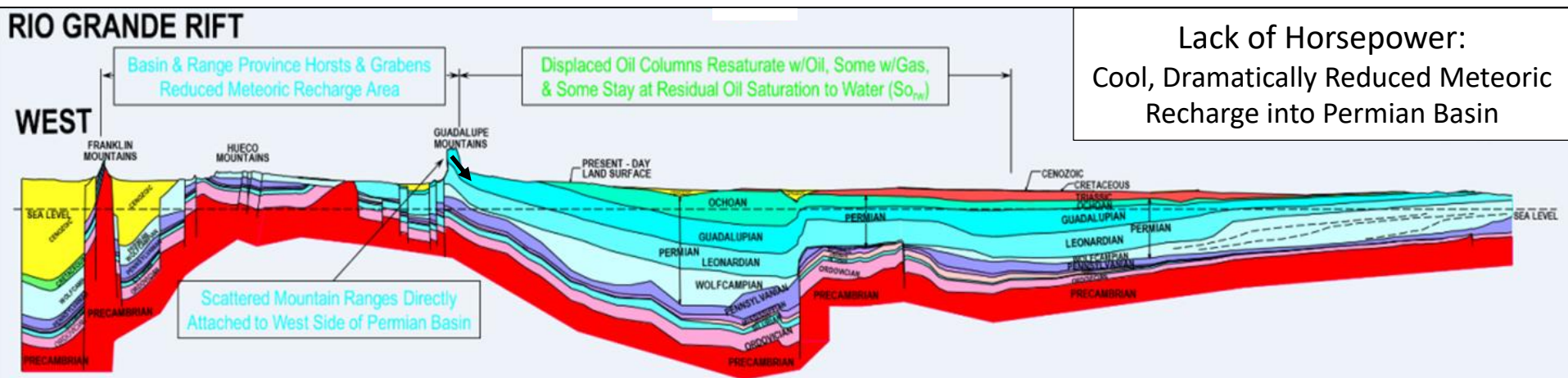
# Rio Grande Rift

- 1<sup>st</sup> Phase: Initial Uplift & Tilting (28.4 to 16 Ma, Late Oligocene-Early Miocene)
- 2<sup>nd</sup> Phase: Rapid Extension-  
Transtension formed Horsts & Grabens (16 to 5.33 Ma, Middle-Late Miocene)
- 3<sup>rd</sup> Phase: Quiescennce, Erosion, Stream Entrenchment & Piracy (5.33 Ma to Present, Pliocene-Recent)



# Permian Basin

## West-East Cross Section

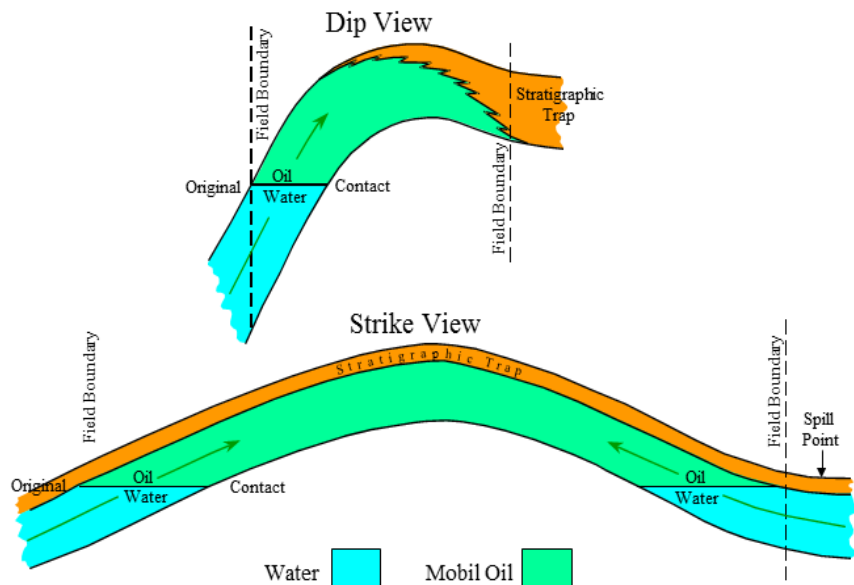


Lindsay (1998; 2014; 2016)

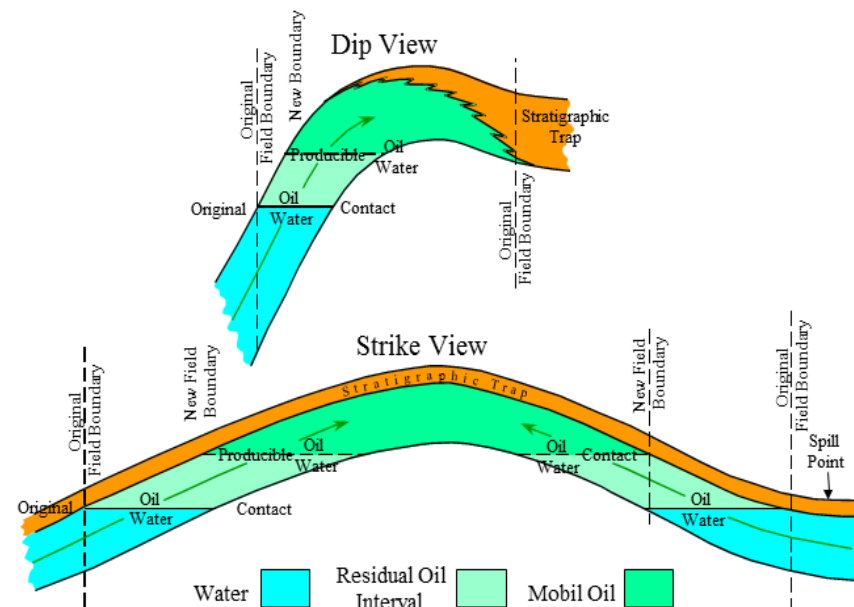
Sacramento, Guadalupe, Sierra Diablo, Delaware, Apache & Glass Mtns  
Attached to Permian Basin

## Middle Miocene - Present

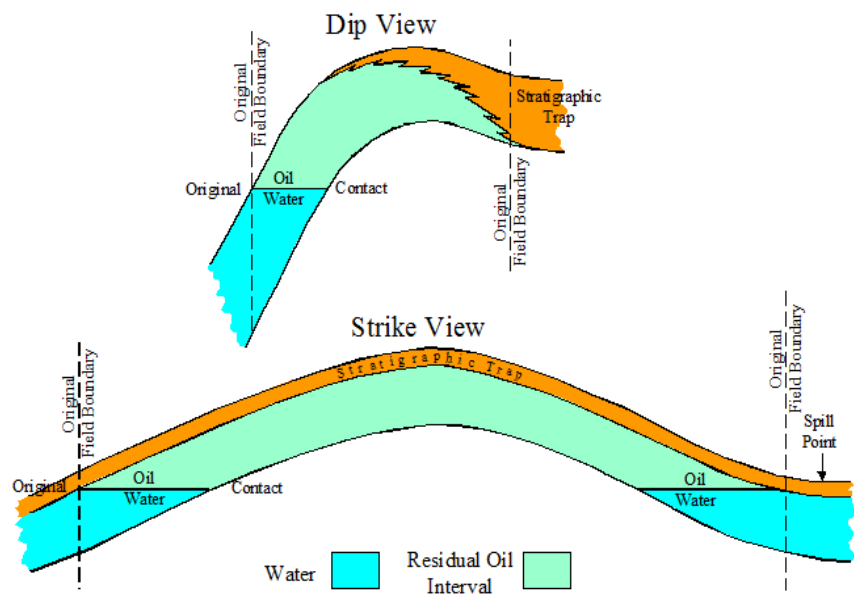
### Reservoir Resaturated w/Mobile Oil



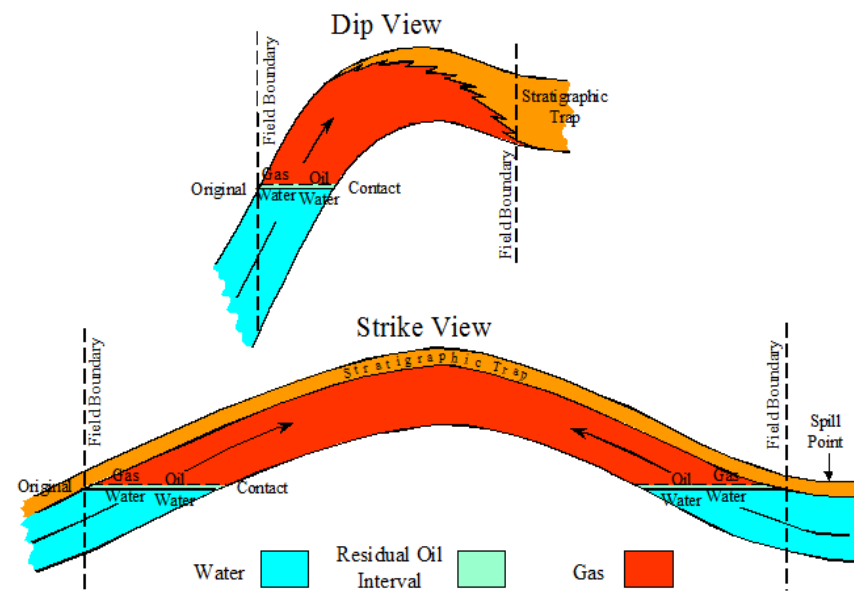
### Reservoir Partially Resaturated w/Mobile Oil



### Reservoir Does Not Resaturate



### Reservoir Resaturated w/Gas



# *“Tight West Texas Dolomites Waterflood Well”*

Ganesh Thakur

Past President SPE

Primary Recovery = 15-20% OOIP

Secondary Recovery = 15-20% OOIP

Tertiary Recovery = 10+% OOIP

Permian Basin Dolostone Reservoir:

Ave Porosity = 9%, Range = <2-31%

Ave Perm = 6 mD, Range = 0.001-2000 mD

# Conclusions:

- Hybrid dolomitization of Permian Basin strata
- 1<sup>st</sup> Permian – Reflux-mechanical compaction dolomitization
- Preserved rock fabric & porosity-permeability
- 2<sup>nd</sup> Late Eocene-Early Miocene – Tectonic-topographic driven-hydrothermal dolomitization
- Multiple pore volumes - Hot meteoric recharge into Permian Basin
- Partially dissolved Permian dolomite ( $\text{Mg}^{2+}$  source): Precipitated inclusion-rich dolomite (aqueous & hydrocarbon inclusions)
- Once oil columns were swept to residual oil saturation to waterflood ( $\text{So}_{\text{row}}$ ): Precipitated inclusion-poor limpid dolomite
- Dissolution - Altered rock fabric, enhanced porosity-permeability, connectivity of strata, producibility of reservoirs & formed ROZ's
- Rio Grande Rift extension – Destroyed meteoric recharge area
- Oil columns resaturated w/oil or gas, or did not resaturate & created ROZ's

Thank You