

# **Controls on Hydrothermal Dolomites and Their Reservoir Properties\***

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## **Abstract**

Hydrothermal dolomites occur in Precambrian to Cenozoic strata, with many models for hydrothermal dolomite emphasizing proximity to faults. Although some hydrothermal dolomites occur adjacent to significant faults, many do not. In this presentation, hydrothermal dolomite is described in three intervals and locations – Wabamun Group (Upper Devonian) in western Canada, Swan Hills Formation (Middle Devonian) in western Canada, and the upper Pennsylvanian at Reinecke Field in west Texas. In all three areas, petrographic and stable isotope data indicate dolomitization at high temperatures after moderate to deep burial.

Porous dolomites are surrounded by impermeable Wabamun limestones creating stratigraphic traps that are scattered across the southern Peace River Arch in western Alberta. Many hydrothermal dolomites in the Wabamun follow depositional facies and early dolomitization. Some oil fields are adjacent to mappable faults, but many are not. Many of the Wabamun fields were discovered by 3D seismic data targeting anomalies away from faults.

Porous hydrothermal dolomites in and around Rosevear Field in western Alberta occur in grainstones and grain-rich stromatoporoid boundstones. Adjacent micrite-rich facies are generally not dolomitized and not porous, creating the stratigraphic traps at Rosevear Field. Hydrothermal brines apparently moved up into platform-margin grainstones and then moved long distances along the permeable platform margin and connected embayments.

At Reinecke Field in west Texas, hydrothermal dolomites occur in an upper Pennsylvanian limestone buildup. The hydrothermal dolomites created high-permeability horizontal and vertical “raceways” within the largely limestone reservoir. Those “raceways” fundamentally affected oil production during primary, secondary, and CO<sub>2</sub> recovery at Reinecke Field.

Hydrothermal dolomites are important hydrocarbon reservoirs in many parts of the world. They have excellent reservoir characteristic because of their large crystal sizes, vugs, and fractures. Many factors other than faults can control their distribution, including depositional facies, early

dolomite, highly saline brines in the basin, and convective flow. Careful petrography, collection of stable isotope data, and a good understanding of the basin history can help predict these types of reservoirs in the subsurface.

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# Controls on hydrothermal dolomites and their reservoir properties

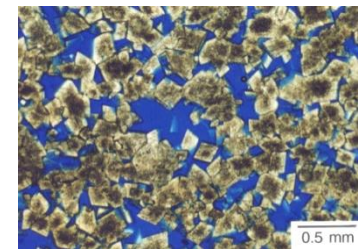
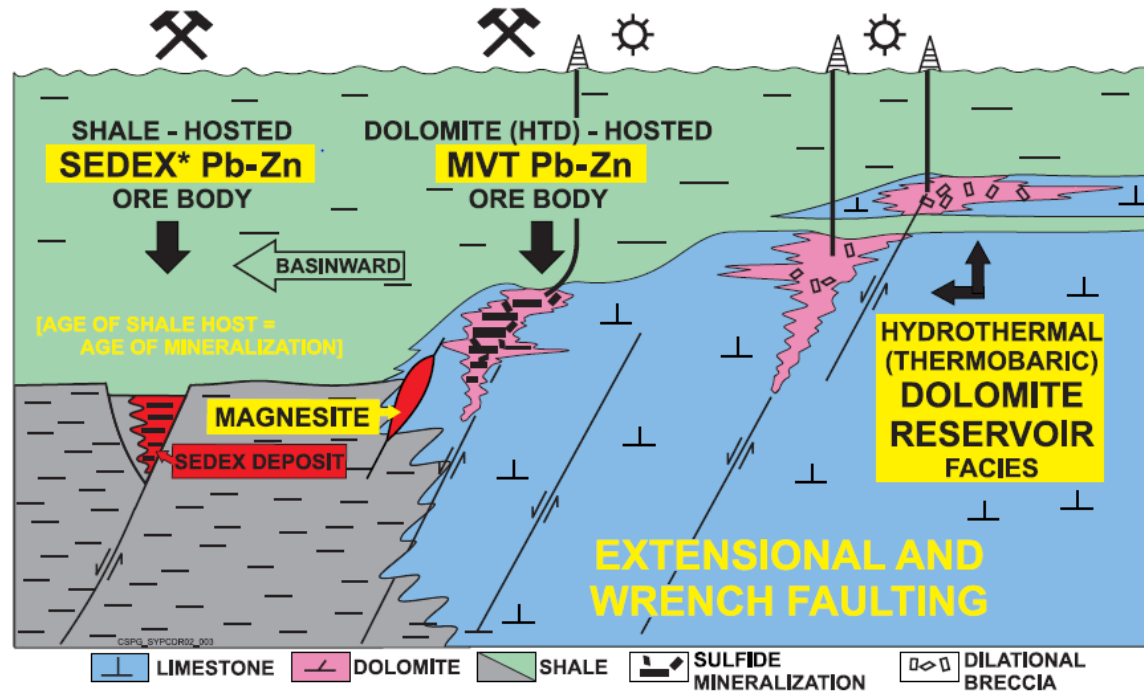


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Although a volumetrically minor part of the rock record, hydrothermal dolomites are important oil reservoirs & associated with many ore deposits



Although some hydrothermal dolomites occur adjacent to faults, many do not.

Understanding the controls on hydrothermal dolomite is important for predicting their distribution.

# HYDROTHERMAL DOLOMITES

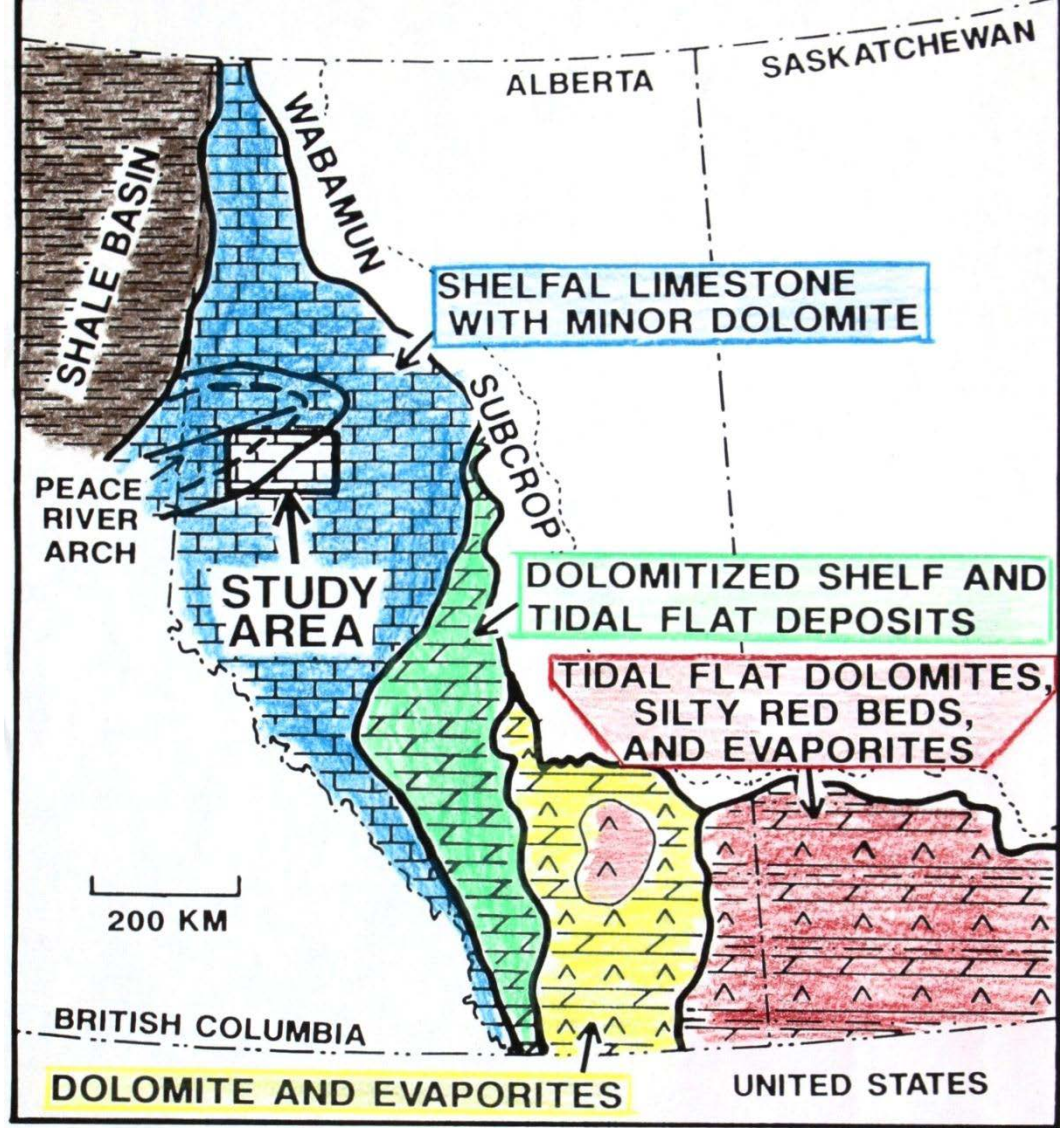
- Introduction
- Wabamun, subsurface Canada
- Swan Hills – Rosevear Field, Canada
- Reinecke Field, west Texas
- Summary & Models (facies and early diagenesis are commonly critical)



# Wabamun Dolomites, south Peace River Arch

- Porous reservoir dolomites are surrounded by non-porous limestone creating stratigraphic traps
- 2 generations of dolomite,
  - Early replacive
    - Dull green fluorescence
    - Petrographically early (before fracturing)
    - High  $\delta^{18}\text{O}$  (low temperature)
  - Late, hydrothermal replacive & pore-lining cement
    - Black & yellow fluorescence
    - Petrographically late (before and after fracturing)
    - Low  $\delta^{18}\text{O}$  (high temperature)
  - Most samples are a mixture
- Hydrothermal dolomite occurs with early dolomite and mud mounds
- Substantial dissolution was associated with hydrothermal dolomite causing vugs, fractures, collapse, and geopetal structures
- Some hydrothermal dolomite bodies are near faults, many are not
- Can be found using 3D seismic-
  - differential compaction sometimes created highs at top Wabamun,
  - collapse created lows at top Wabamun
  - irregular dissolution caused disrupted seismic in the middle

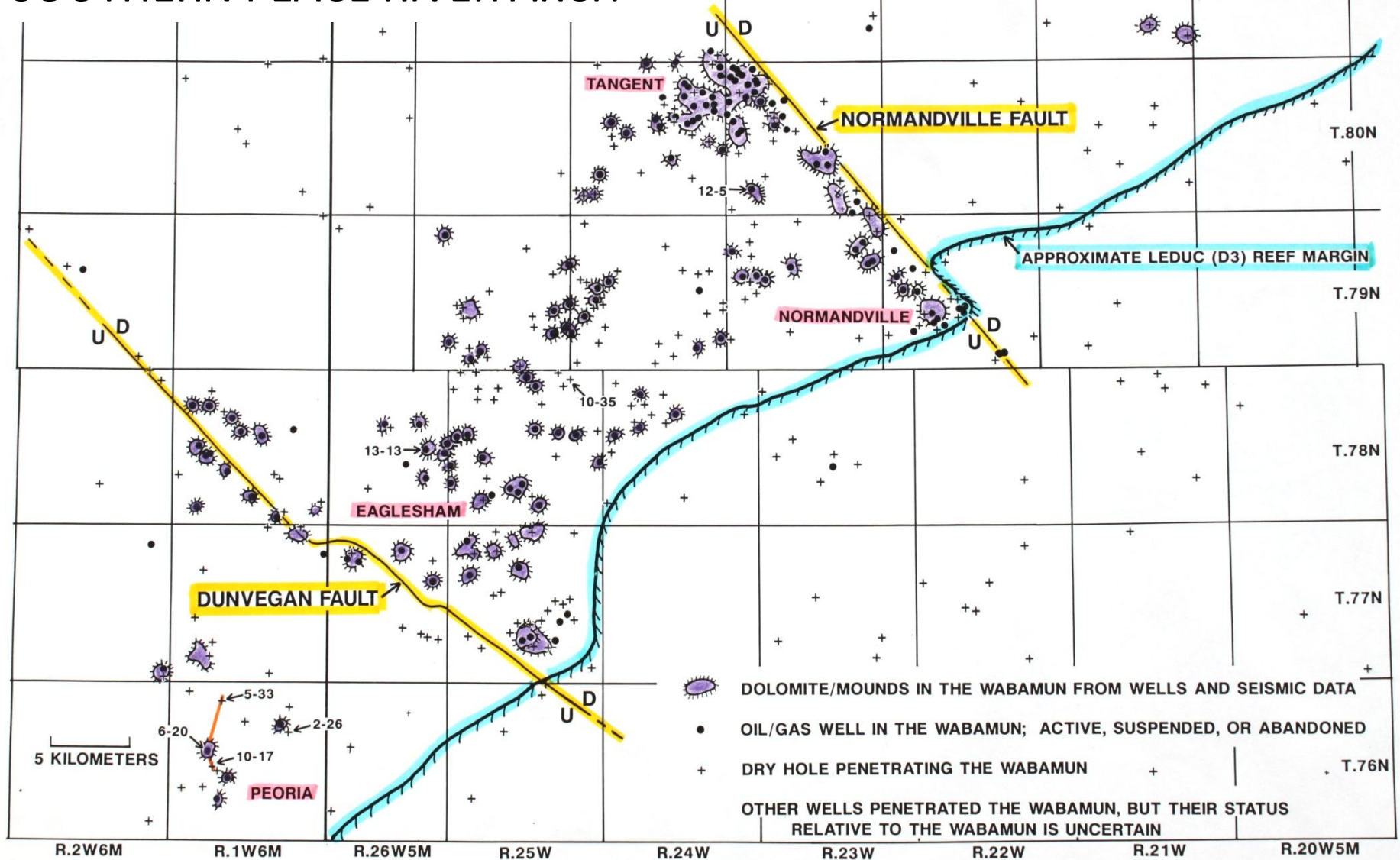
MISSISSIPPIAN	BANFF	
	EXSHAW	
UPPER DEVONIAN	WABAMUN GROUP	BIG VALLEY
		CARDINAL LAKE
		NORMANDVILLE
		WHITE LAKE
		DIXONVILLE
	WINTERBURN GROUP (Graminia, Blueridge, Calmar, Cynthia, Nisku)	



## MAP OF WABAMUN DEPOSITIONAL FACIES

Material in this segment is from  
 Saller, A.H., and K. Yaremko, 1994, Dolomitization  
 and porosity development in the middle and upper  
 Wabamun group, southeast Peace River Arch,  
 Alberta, Canada: *AAPG Bulletin*, v. 78, p. 1406-1430.

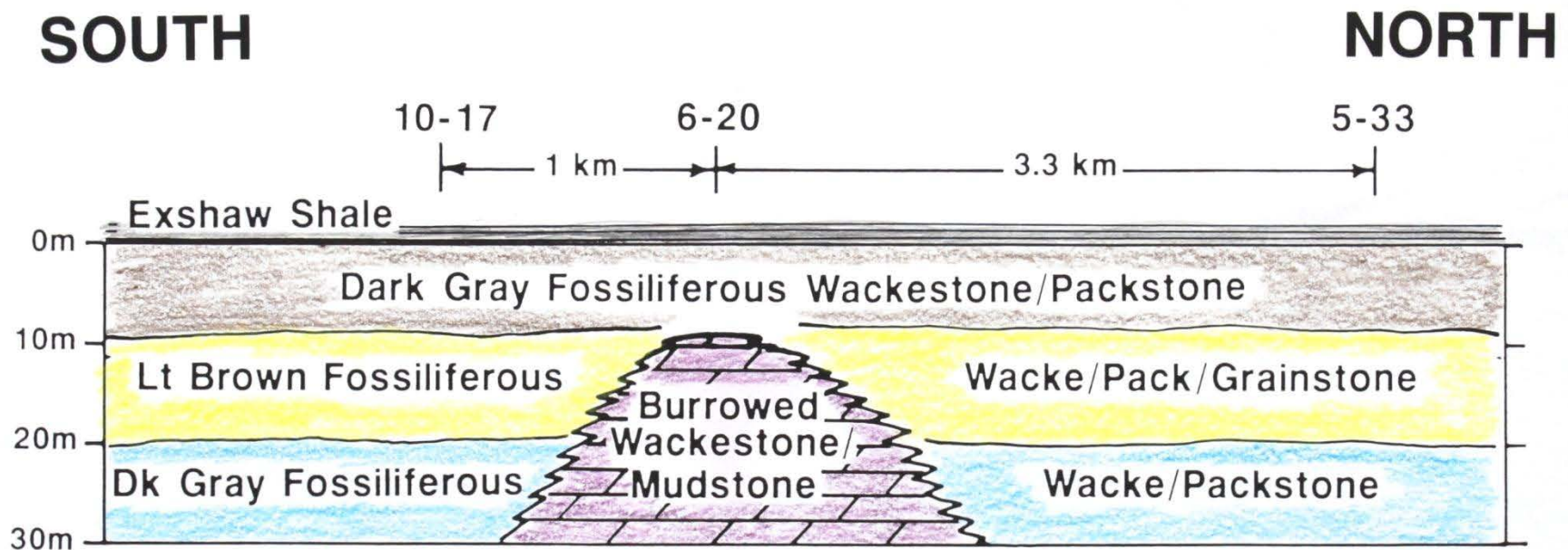
# DISTRIBUTION OF DOLOMITE IN THE WABAMUN SOUTHERN PEACE RIVER ARCH



Dolomite occurs as isolated patches within Wabamun limestone.  
Some dolomites are adjacent to faults. Most are not.

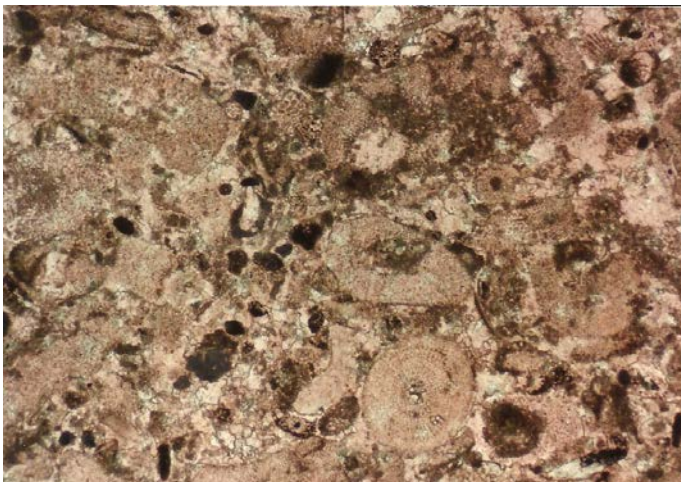
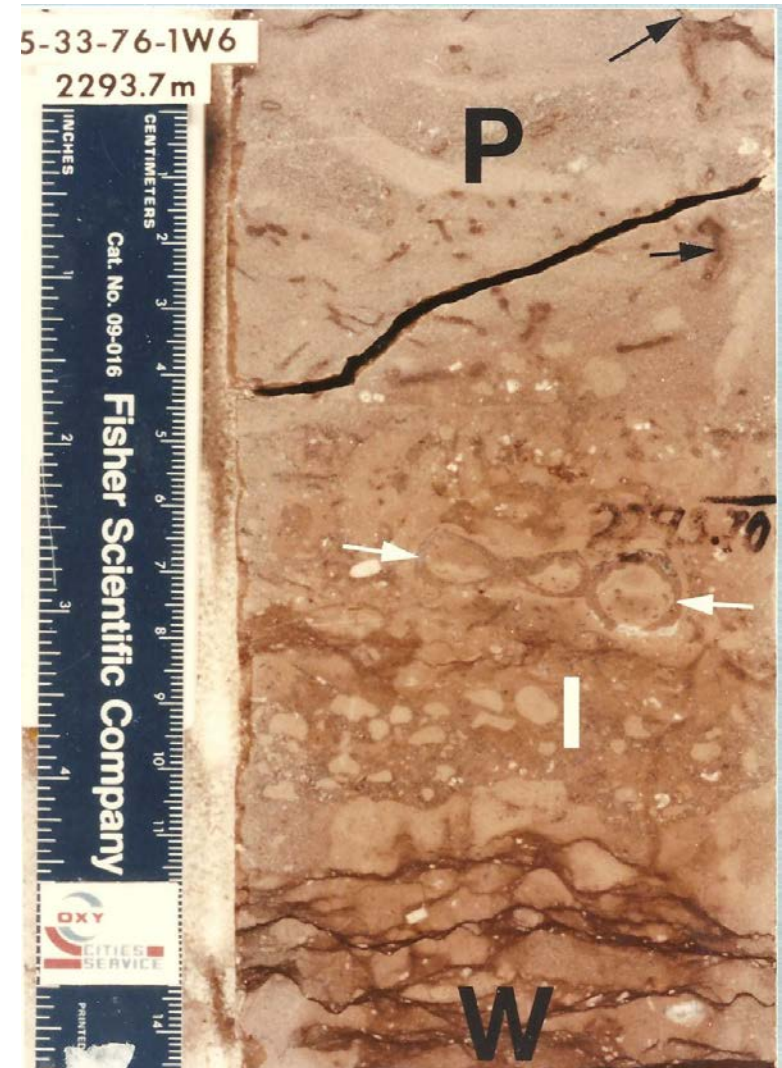
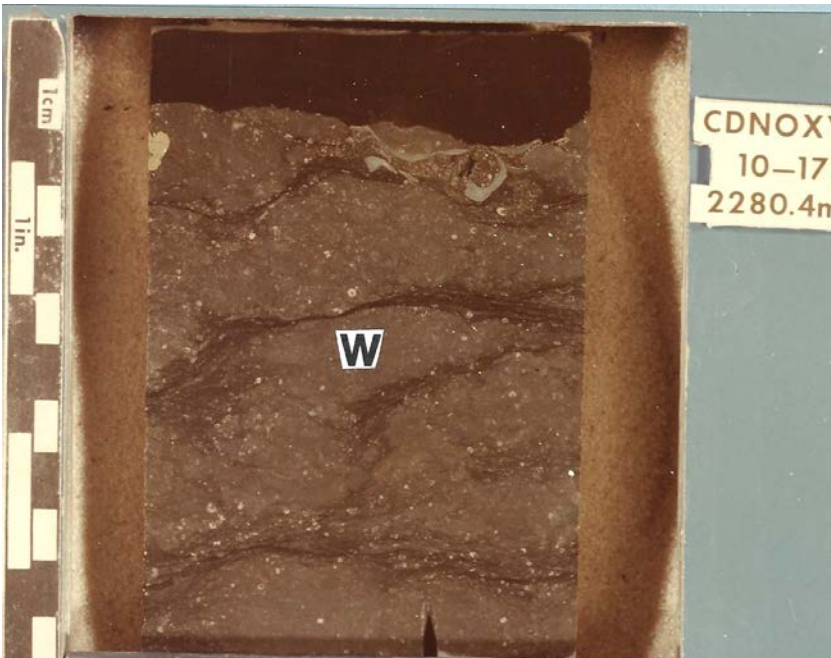
Understanding where hydrothermal dolomite isn't, is critical to predicting where it is.

We need to Understand Depositional Facies & Structural Setting



Certain facies are preferentially dolomitized & others remain limestone

Wabamun Limestones are commonly fossiliferous wackestone & packstone, & intraclastic packst-grainstone



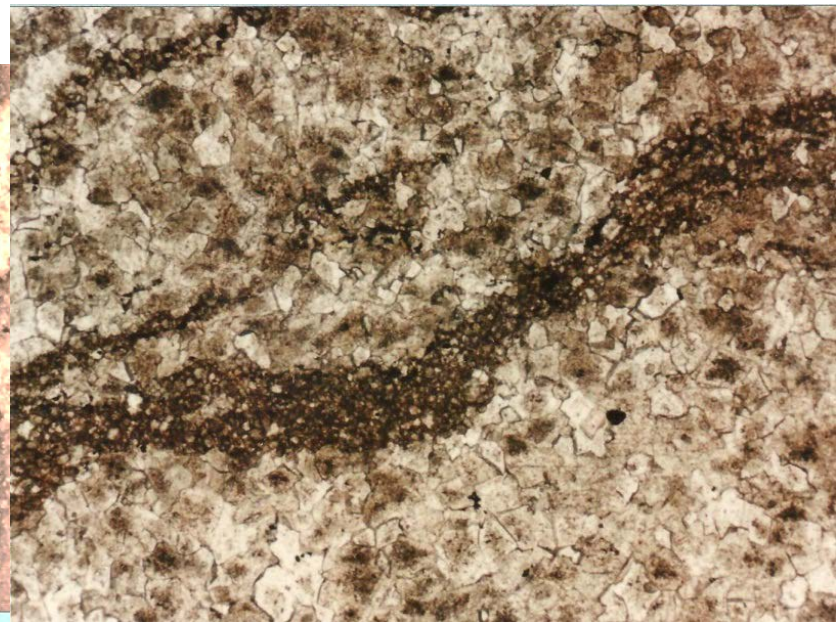
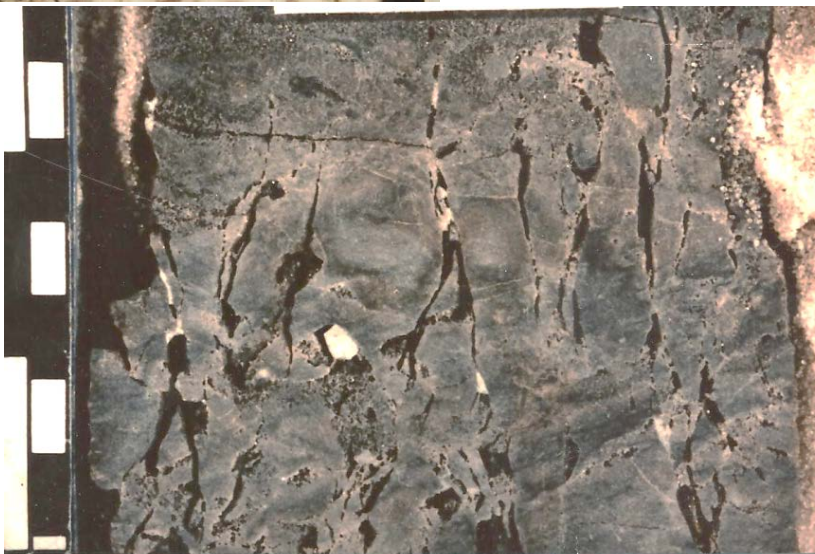
X2.5

Modified from Saller and Yaremko, 1994



Wabamun dolomites are generally sparsely fossiliferous wackestones & mudstone.

Fractures & brecciation are common & related to dissolution during hydrothermal dolomitization



## 2 generations of dolomite: most rocks are mixtures

**Early replacive:** Dull green fluorescence; Before fracturing

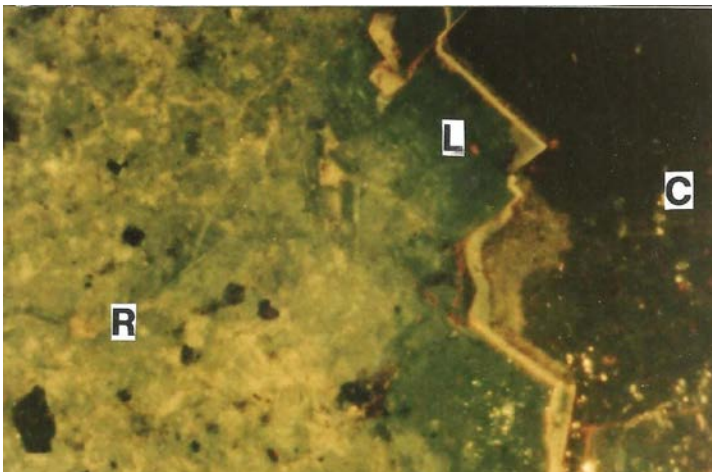
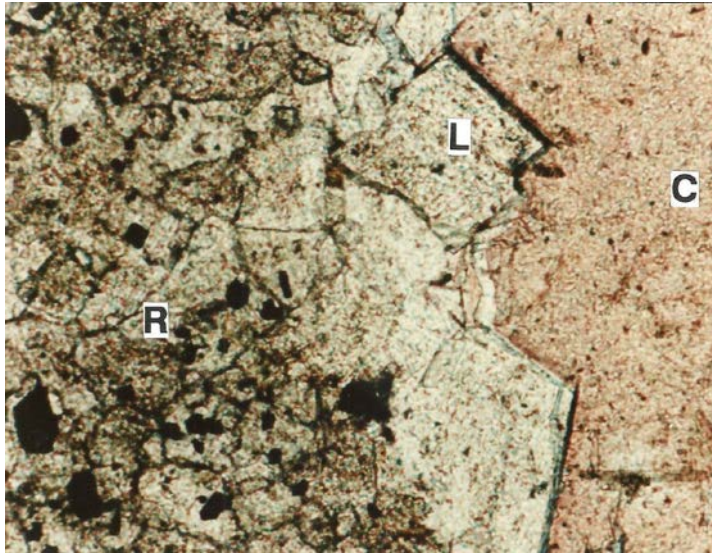
**Late, hydrothermal: replacive & pore-lining cement**

Black & yellow fluorescence; Before and after fracturing

Late pore lining dolomite cement

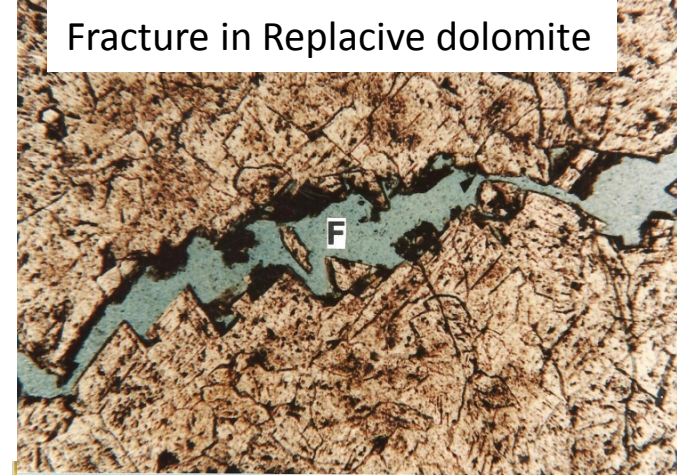
(L) overgrows replacive dolomite (R).

The rest of the large pore was filled by even later calcite cement (C)

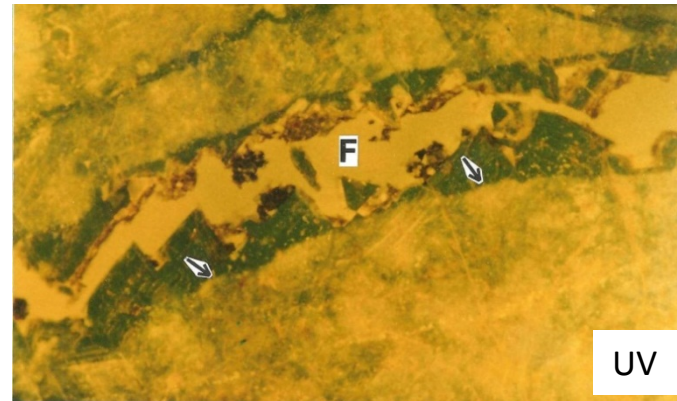


UV

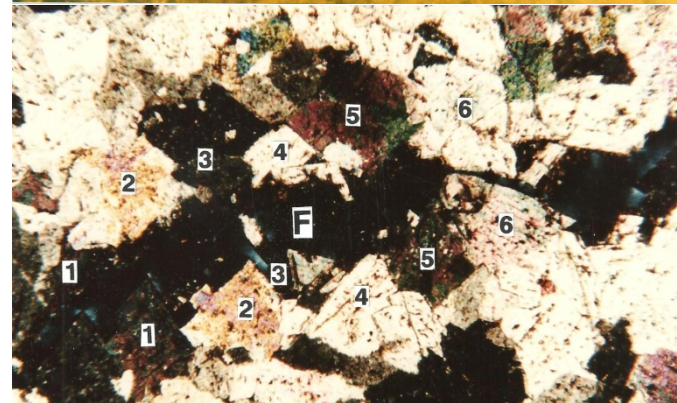
Fracture in Replacive dolomite



Late dolomite cement fills part of fracture



UV



Extinction of dolomite crystals on both sides of fracture matches, indicating dolomite before fractures

# Stable Isotope Compositions of Wabamun Limestones and Dolomite

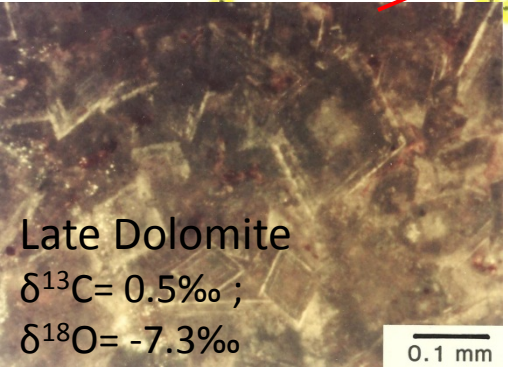
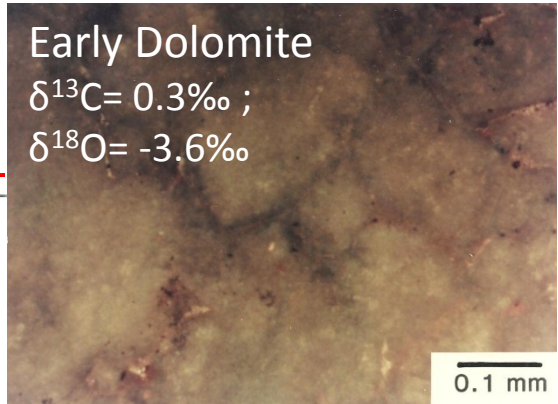
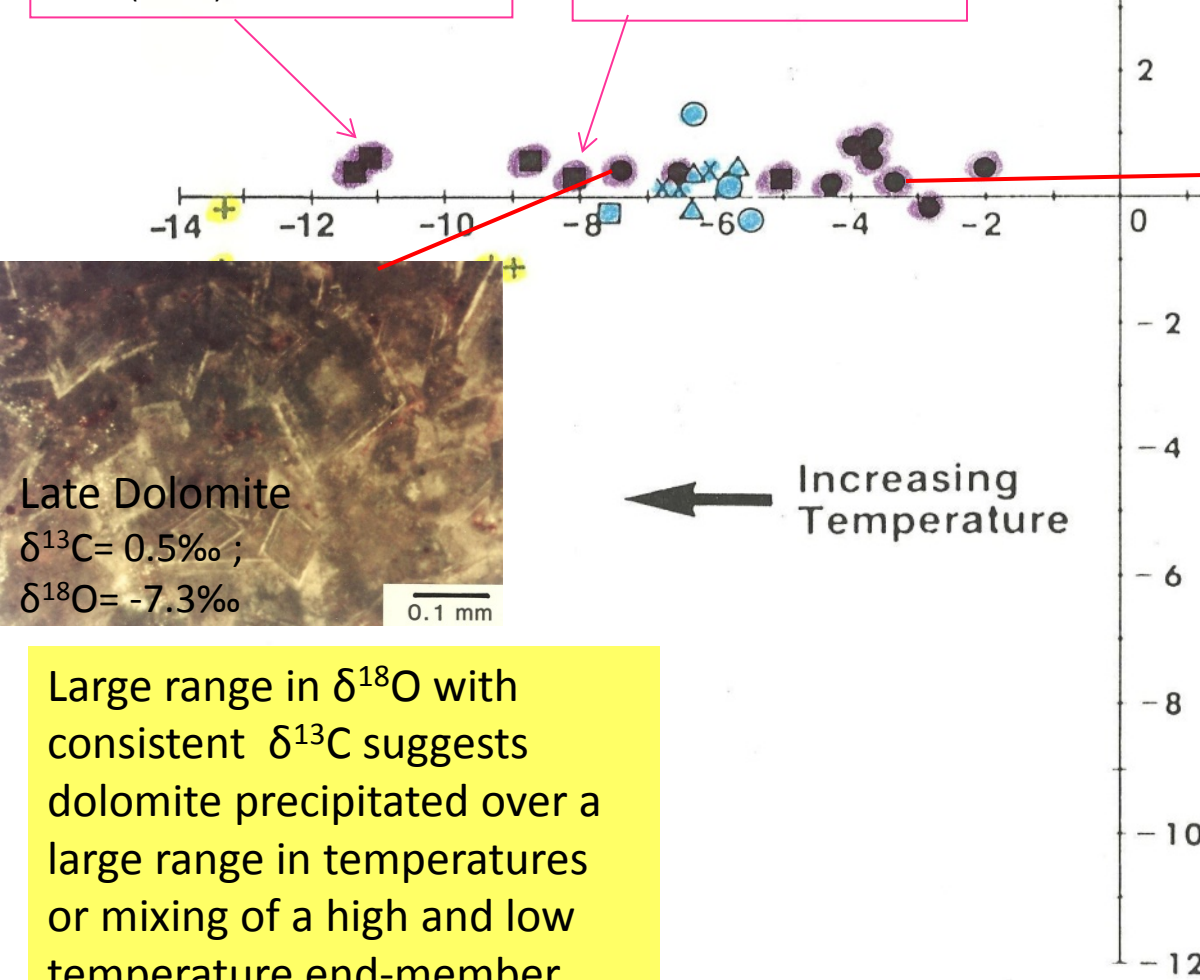
Hitchon and Friedman, 1969, Alberta Basin  
Devonian waters are +3 to +7

Fluid Inclusions Wabamun  
Peace River Arch  
(Packard et al, 1989, 1992)

$\delta^{18}\text{O}_{\text{(water)}} = +3\text{‰}$  ~150°C

$\delta^{18}\text{O} = +5\text{‰}$  ~135°C

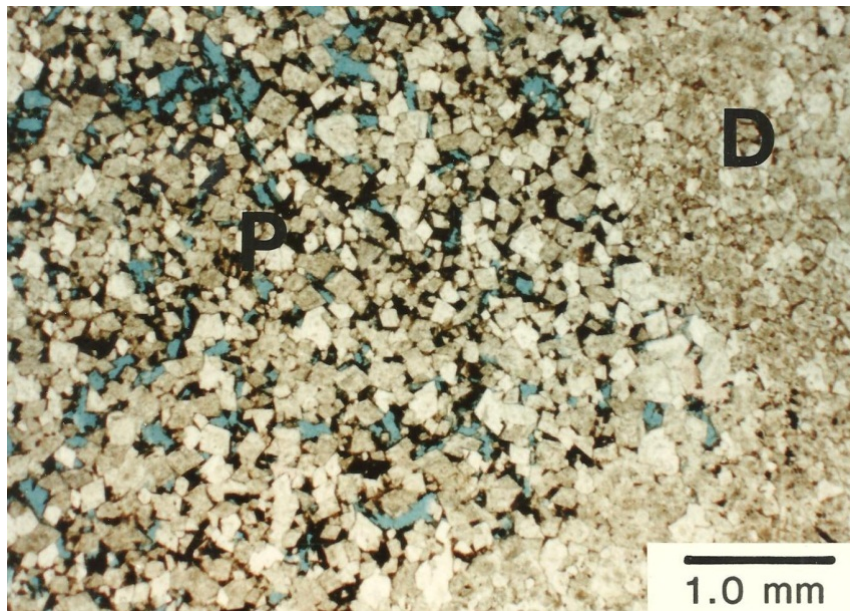
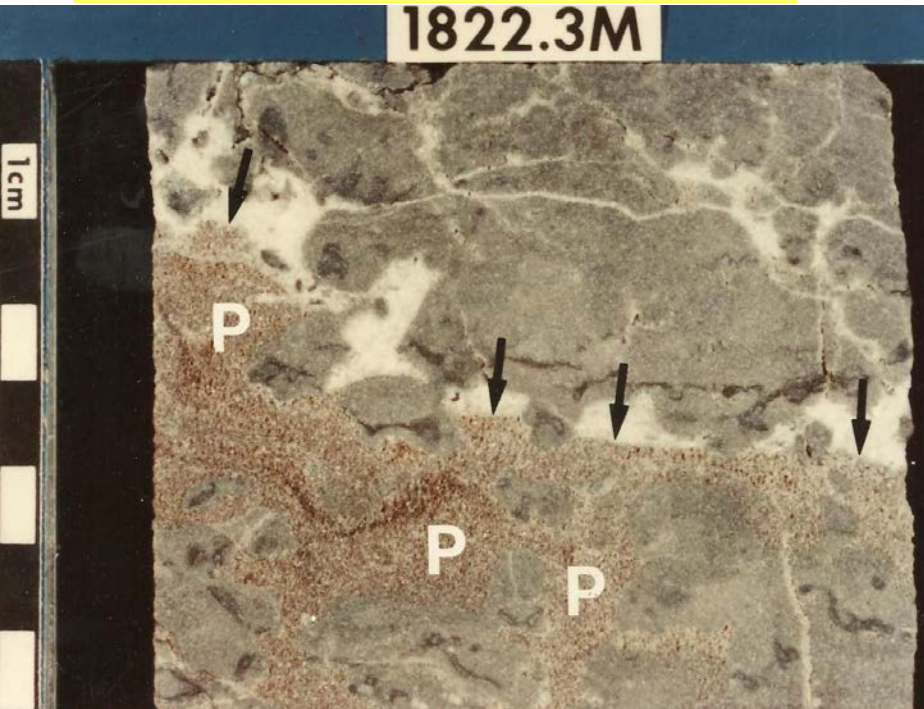
Th= 80-150°  
Tf= 23-29 % equiv NaCl



- Dolomite 6-20 Well
- Limestone 6-20 Well
- △ Limestone 10-17 Well
- Limestone 2-26 Well
- Dolomite 2-26 Well
- × Limestone 5-33 Well
- + Blocky calcite cements filling fractures

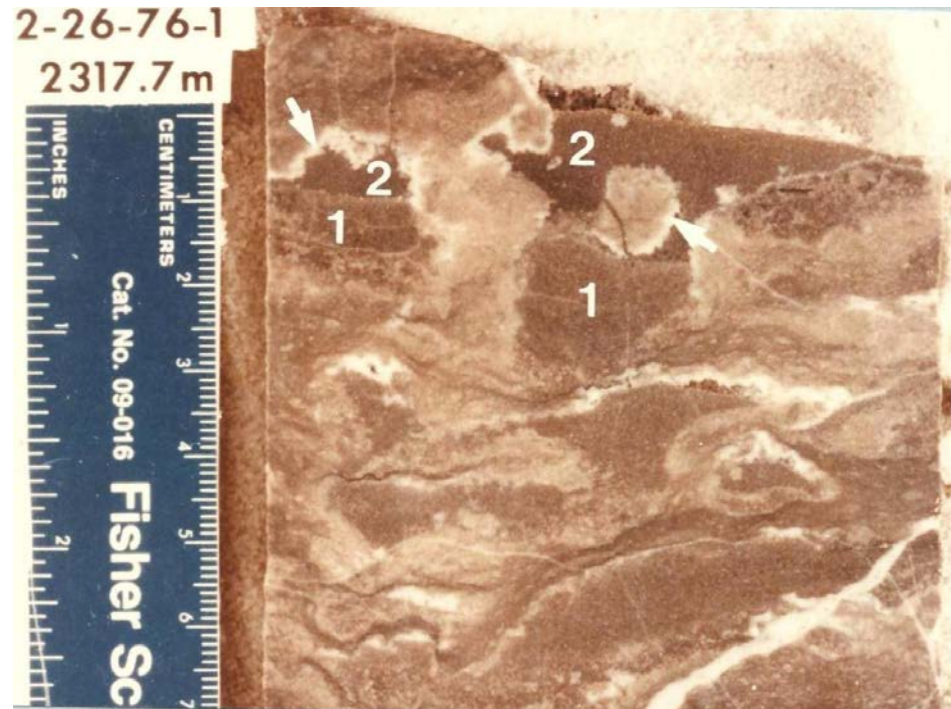
Large range in  $\delta^{18}\text{O}$  with consistent  $\delta^{13}\text{C}$  suggests dolomite precipitated over a large range in temperatures or mixing of a high and low temperature end-member

## Porous geopetal burrow fills (P)



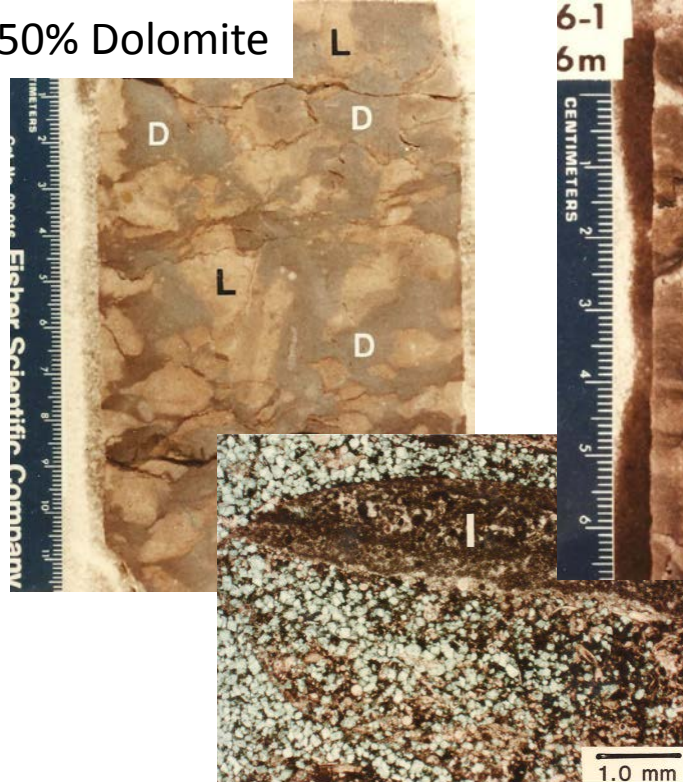
- Burrowed dolomites dominate.
- Some burrow fills are dense
- Some burrow fills have porous sucrosic dolomite
- Some of those porous burrow fills have geopetal structures suggesting dolomite crystals falling into open voids

Modified from Saller and Yaremko, 1994

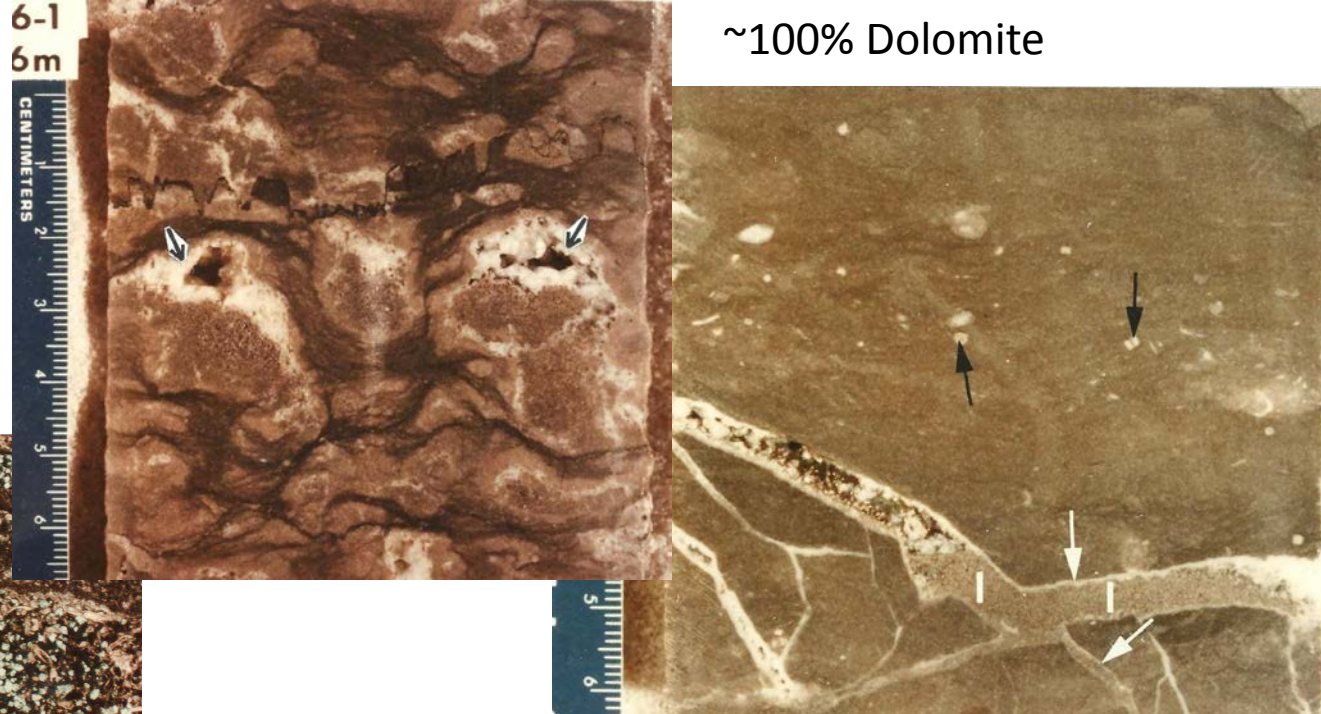


Multiple generations of dolomite crystal fills in certain burrows

~50% Dolomite



~100% Dolomite



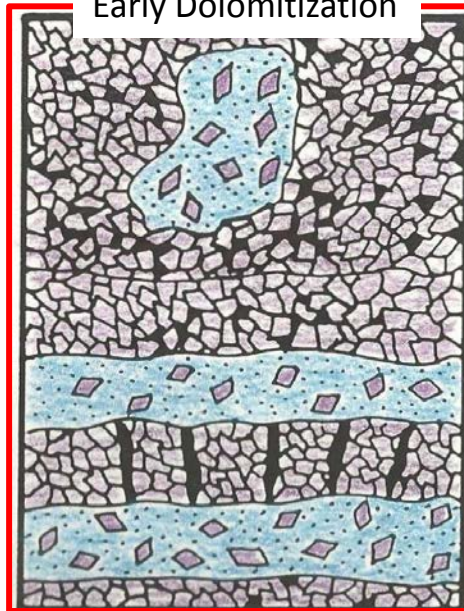
## 2 Stage Process to Create Porous Geopetal Dolomites

X2.5

-  REPLACIVE DOLOMITE WITH INTERCRYSTALLINE POROSITY
-  REPLACIVE DOLOMITE WITH LITTLE POROSITY
-  LIMESTONE WITH DOLOMITE RHOMBS
-  POROUS SUCROSIC DOLOMITE
-  OPEN FRACTURES

Modified from Saller and Yaremko, 1994

Early Dolomitization

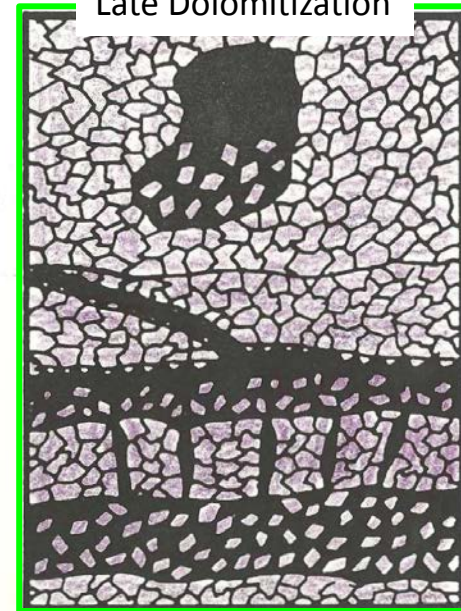


CALCITE  
DISSOLVED



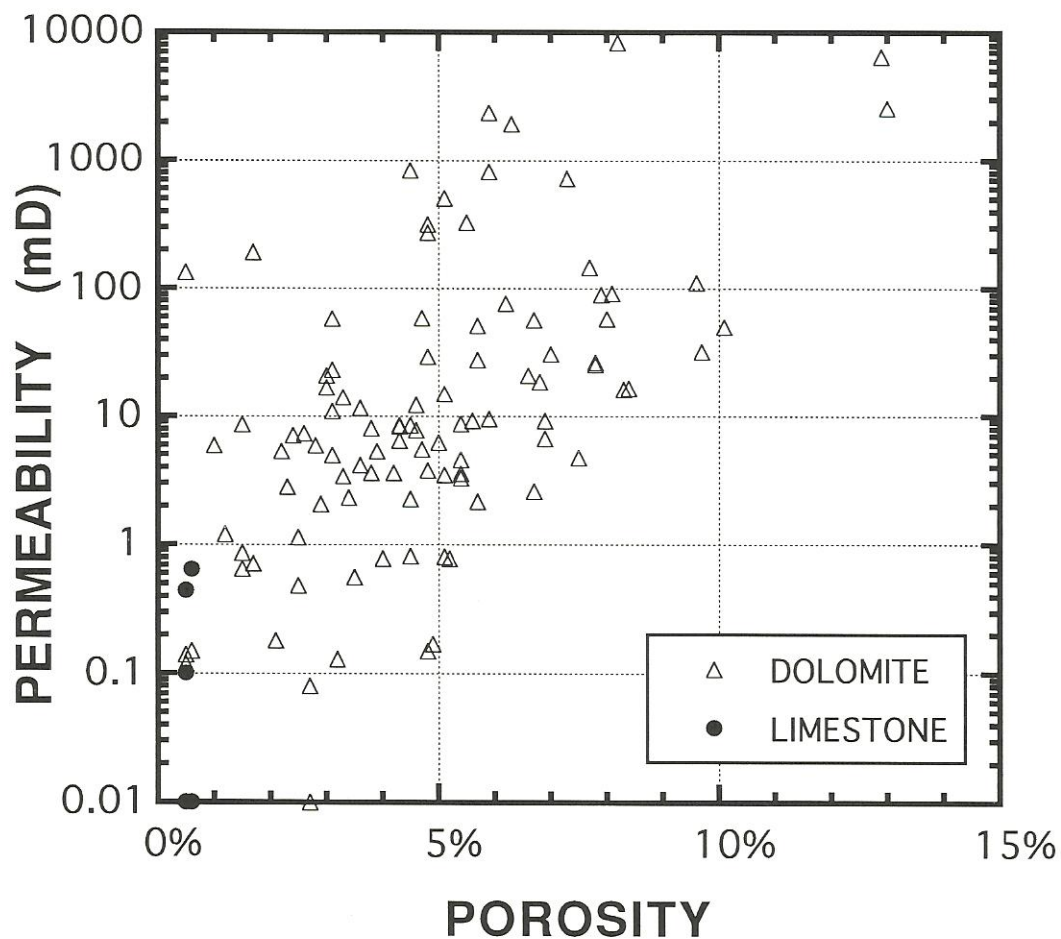
LATE  
DOLOMITE

Late Dolomitization

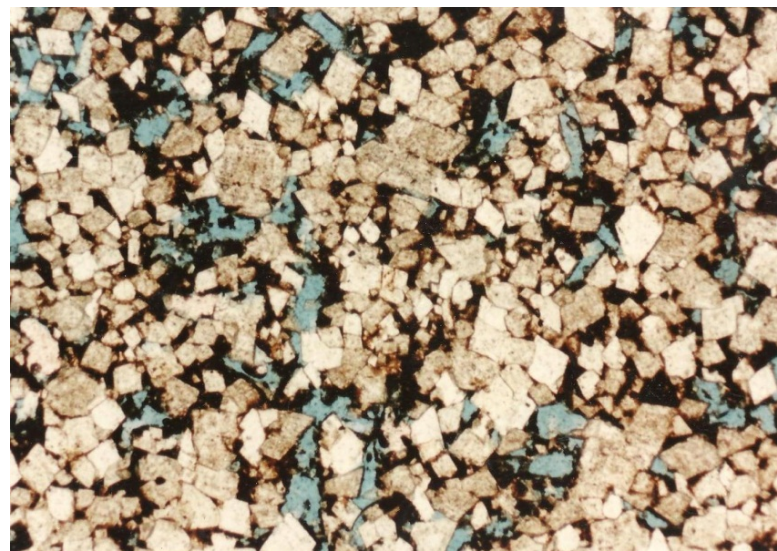
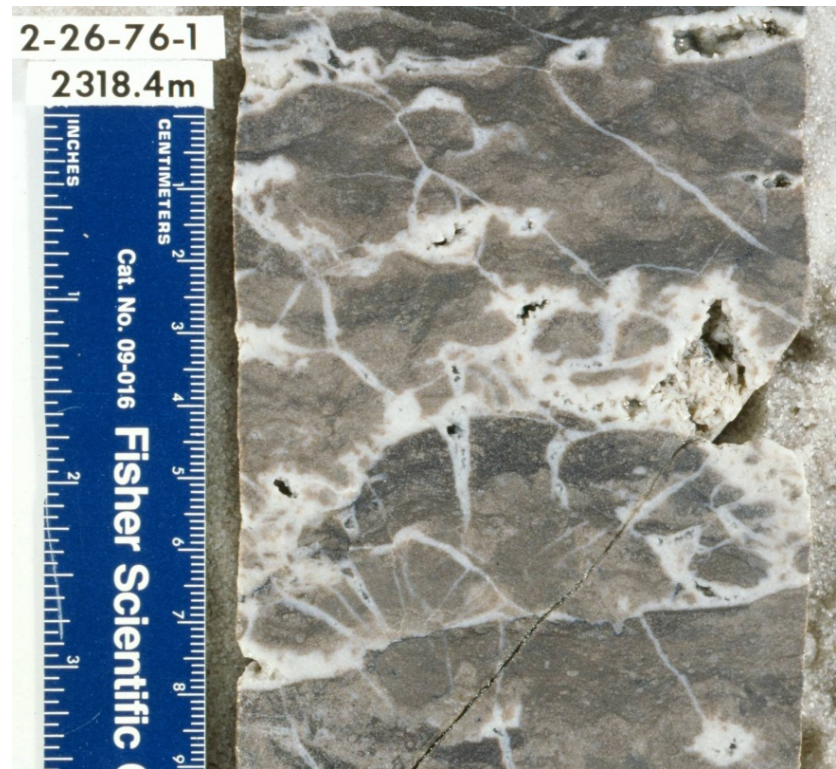


# Wabamun Dolomites have High Vertical & Horizontal Permeability

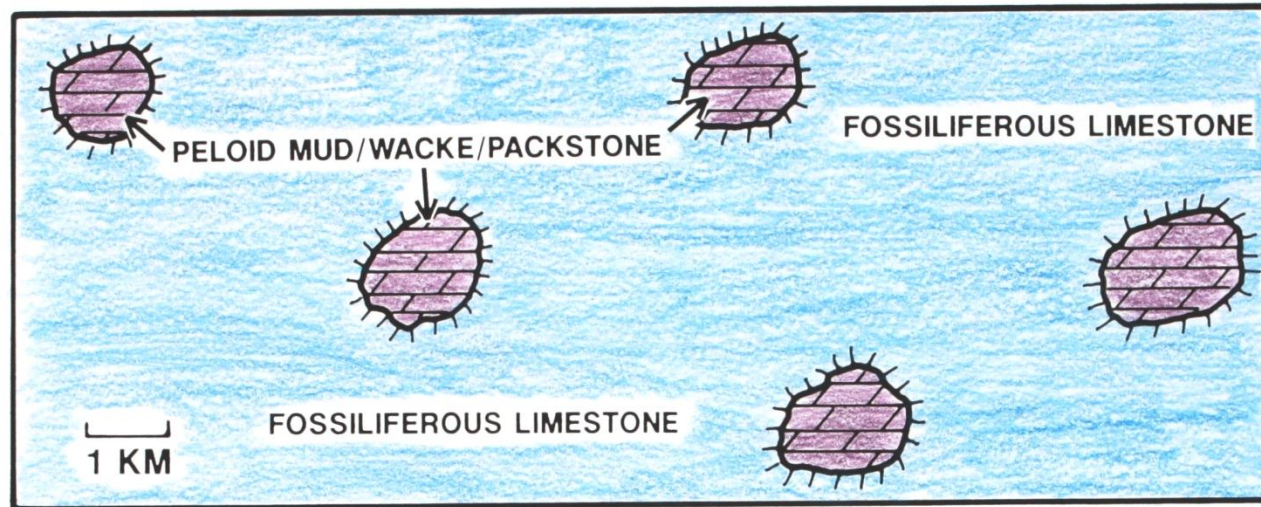
## WABAMUN - PEORIA FIELD



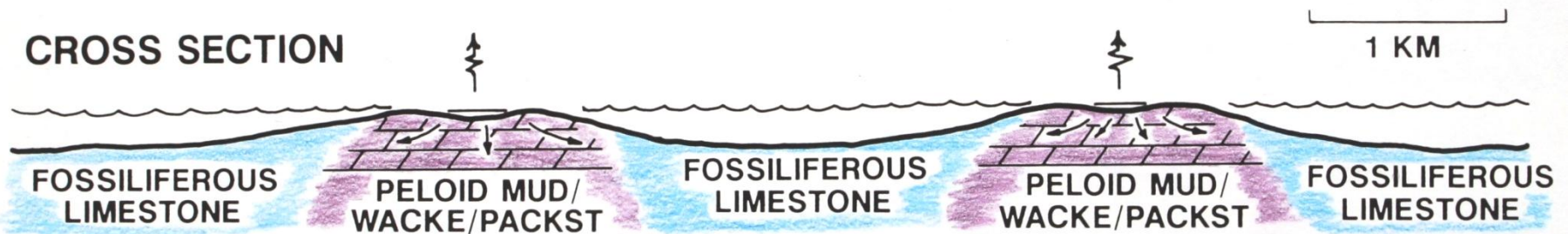
Modified from Saller and Yaremko, 1994



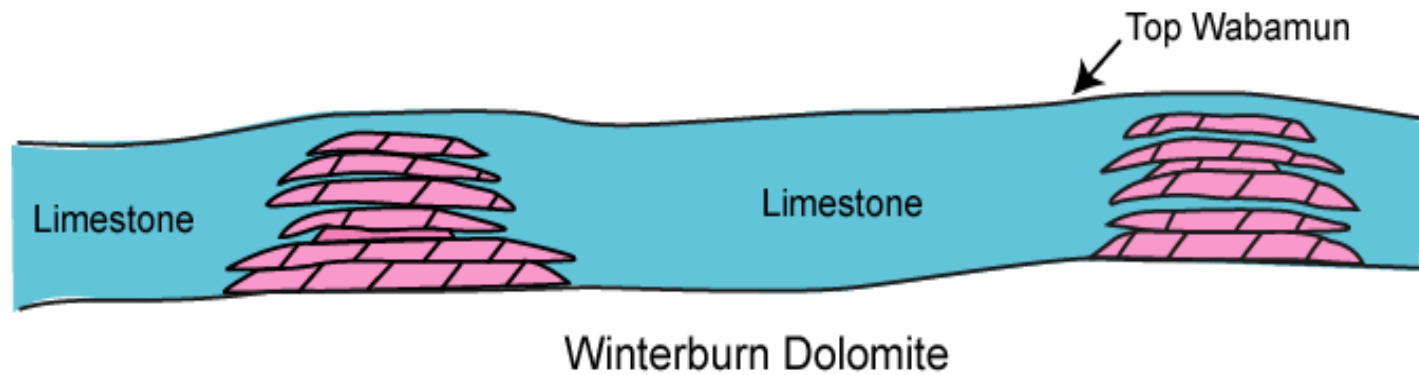
## MODEL FOR EARLY, NEAR-SURFACE DOLOMITIZATION



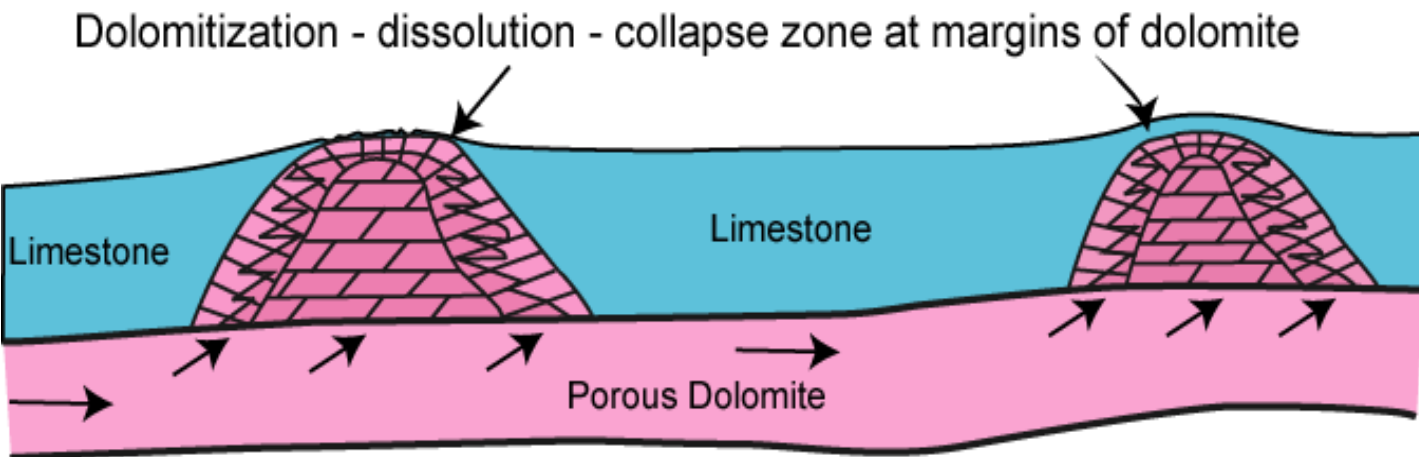
MAP VIEW



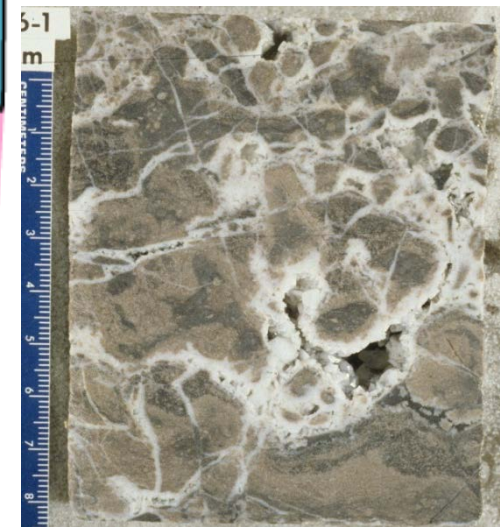
SLIGHTLY RESTRICTED (SLIGHTLY HYPERSALINE) SEAWATER ON DEPOSITIONAL HIGHS  
DOLOMITIZED UNDERLYING STRATA



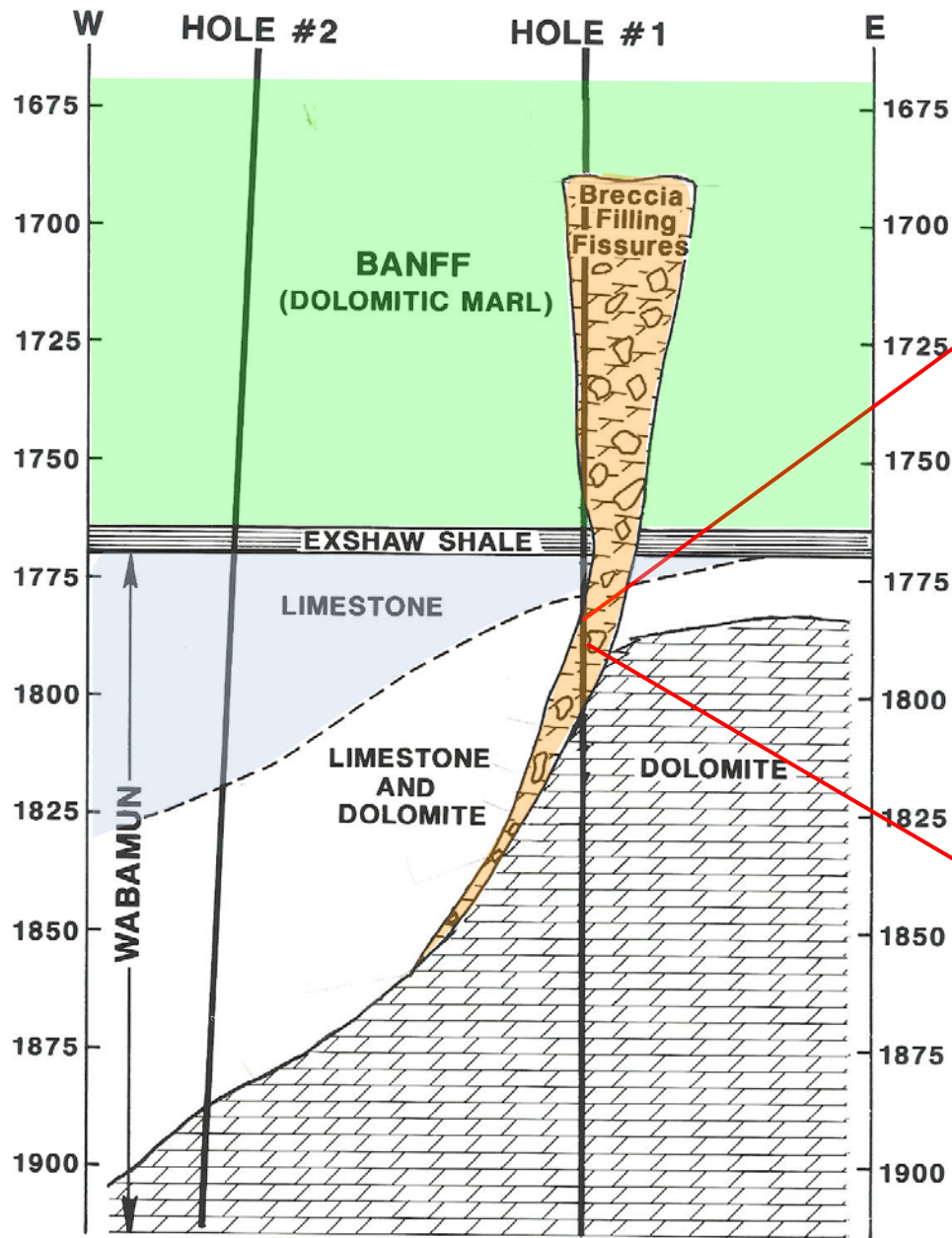
Stage 1: Early dolomitization during shallow burial creates porous, dolomitized areas surrounded by nonporous limestone. Burial compaction preferentially fractures more lithified dolomites.



Stage 2: Late dolomitization and dissolution. Hot burial fluids move through permeable Winterburn dolomite into porous Wabamun dolomite. Burial fluids preferentially dissolve and/or dolomitize limestone adjacent to dolomite.

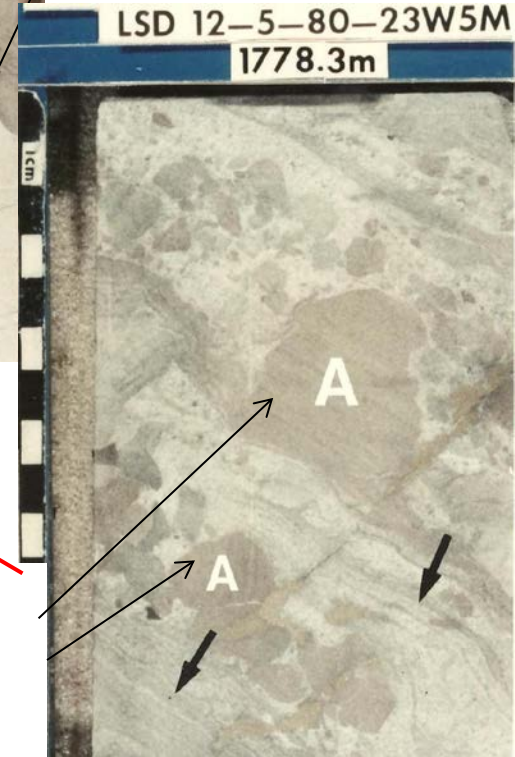
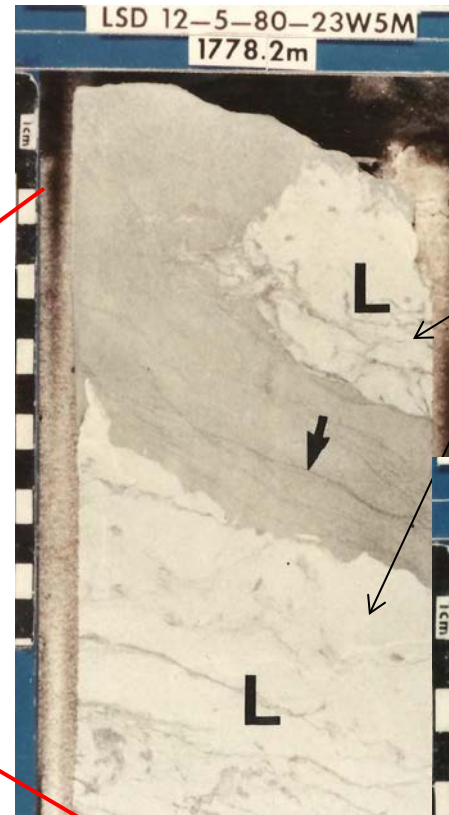


# CDNOXY ET AL NORMANDVILLE 12-5 WELLS

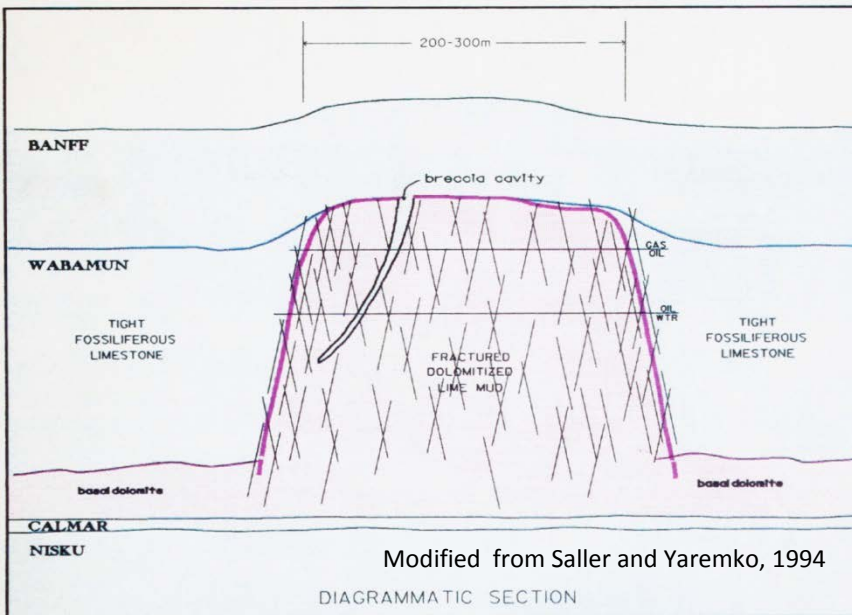


Modified from Saller and Yaremko, 1994

Hydrothermal dissolution resulted in collapse & brecciation including clasts of Banff (A) in a breccia within the Wabamun

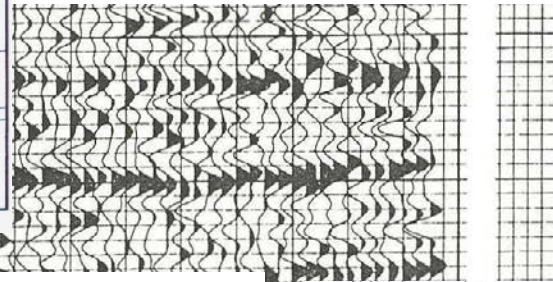


Argillaceous Banff clasts in Banff-like matrix

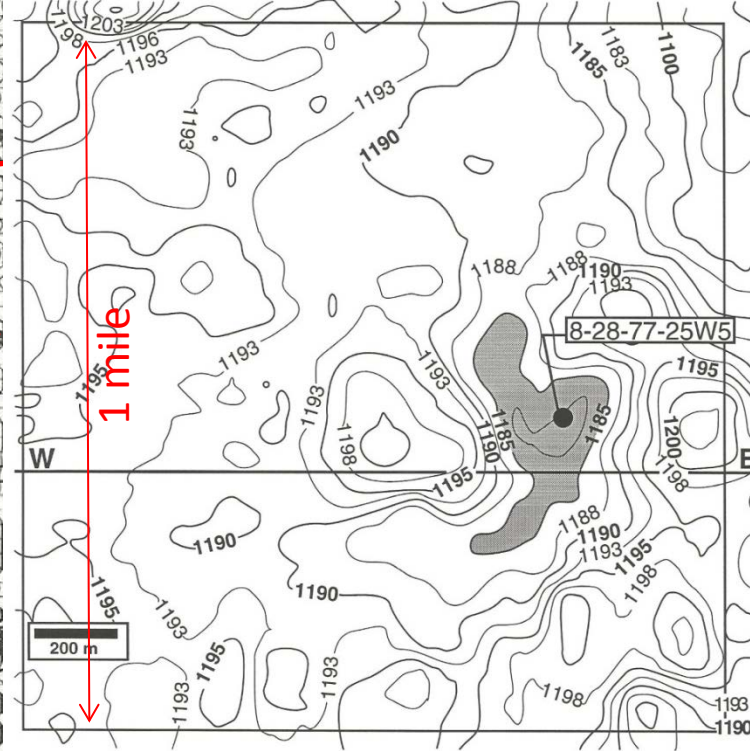
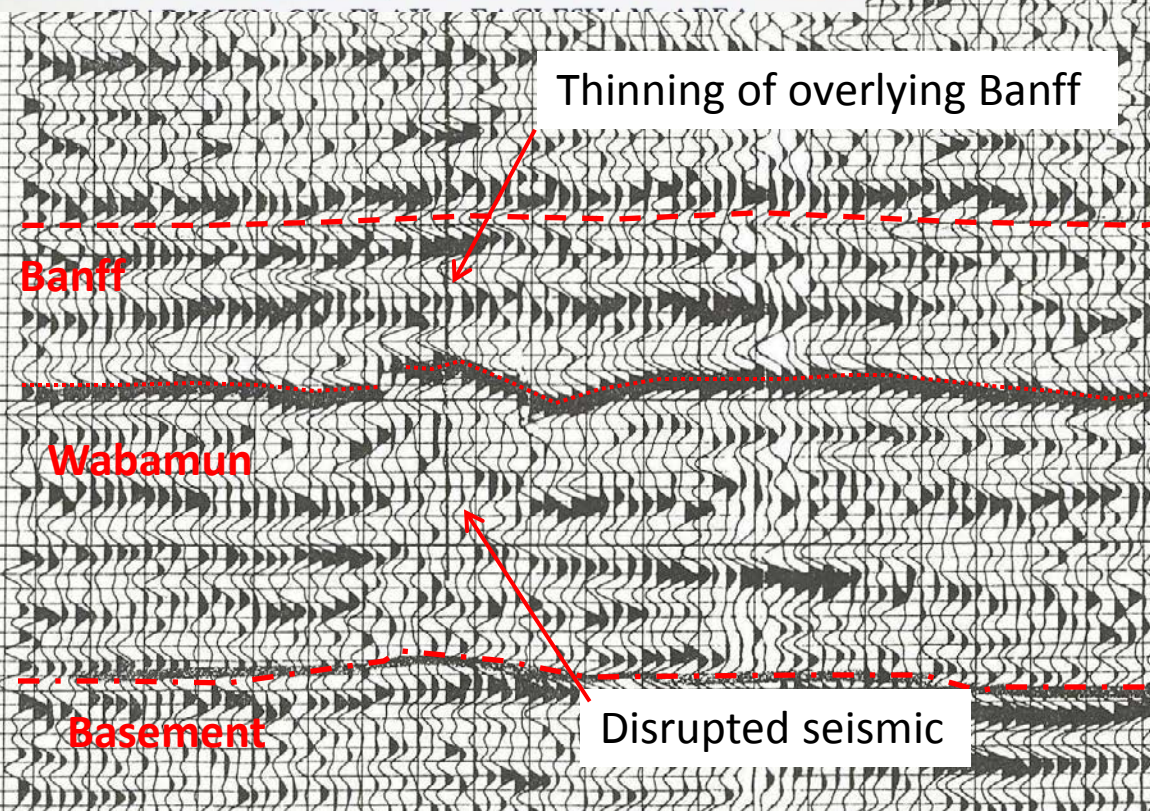


Wabamun dolomites have a distinct seismic signature in 3D data

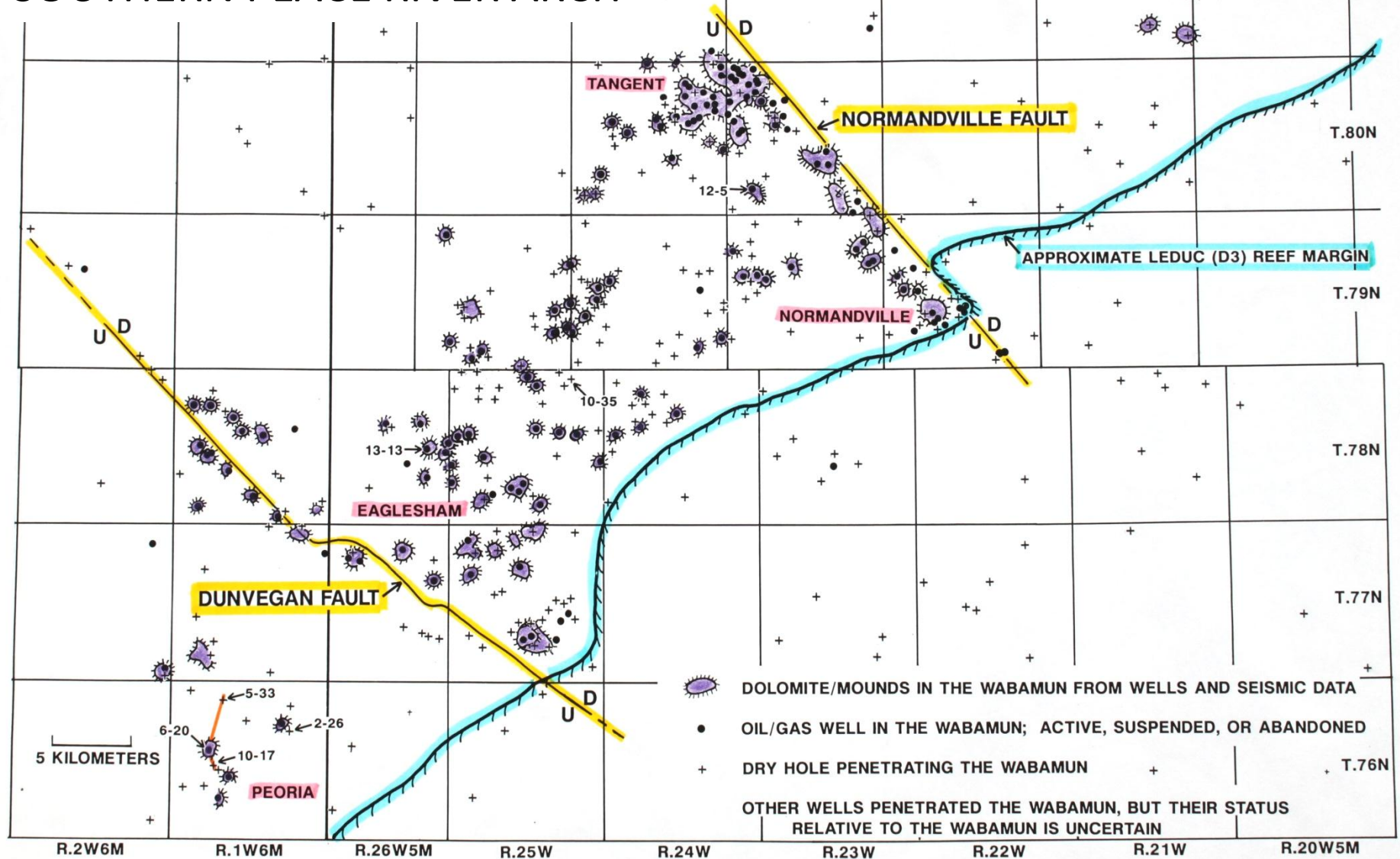
1. Structural high due to differential compaction
2. Thinning of overlying Banff due to early differential compaction
3. Disrupted seismic within the Wabamun



Top Wabamun  
Structure (TWTT, ms)



# DISTRIBUTION OF DOLOMITE IN THE WABAMUN SOUTHERN PEACE RIVER ARCH



Dolomite occurs as isolated patches within Wabamun limestone.  
Some dolomites are adjacent to faults. Most are not.

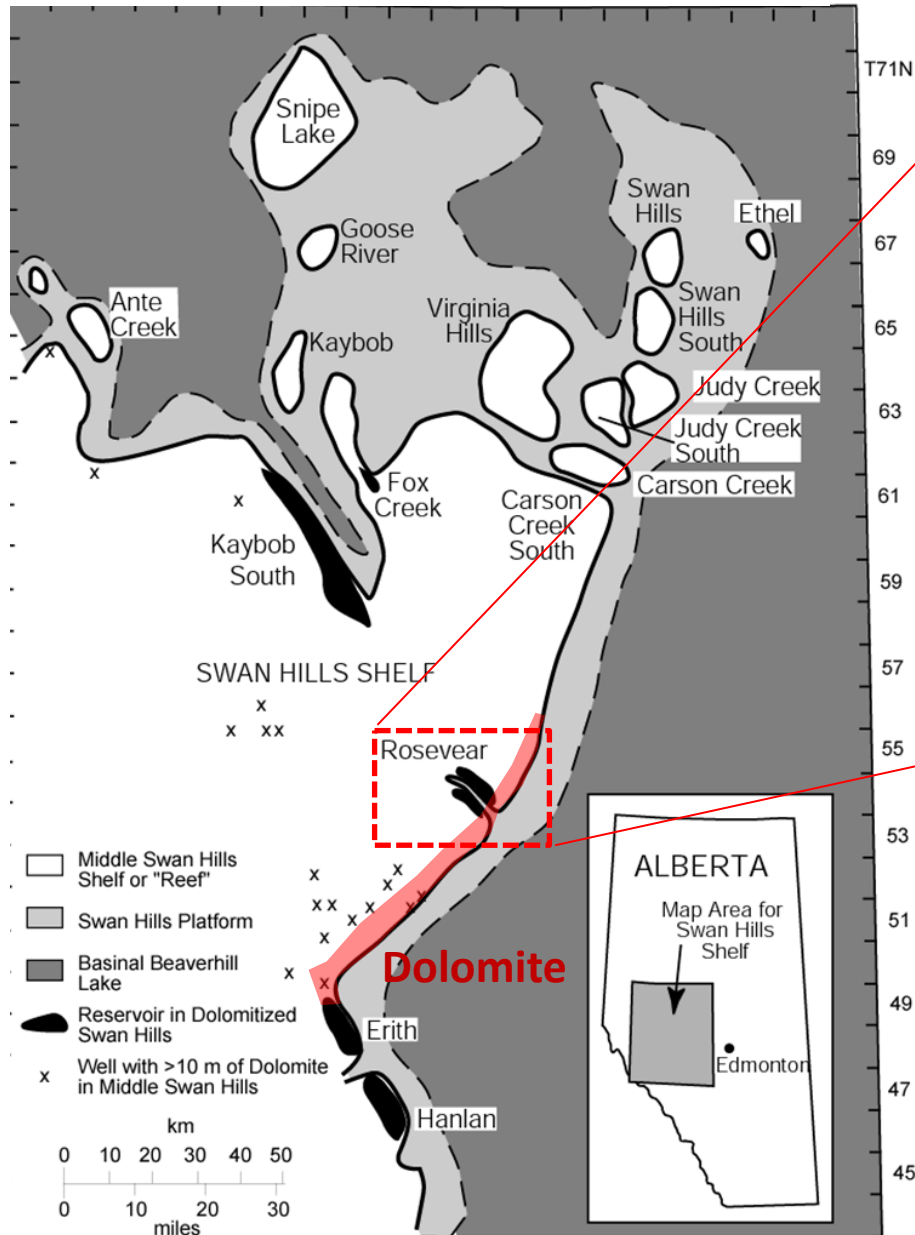
# HYDROTHERMAL DOLOMITE

- Introduction
- Wabamun, subsurface Canada
- **Swan Hills – Rosevear Field, Canada**
- Reinecke Field, west Texas
- Summary & Models (facies and early diagenesis are commonly critical)

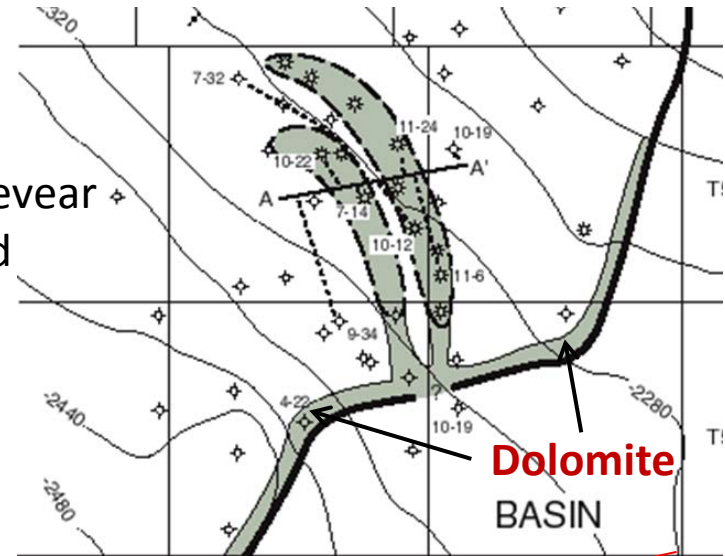


# SWAN HILLS RESERVOIRS, ALBERTA BASIN, CANADA

Porous, hydrothermal dolomites occur in grainstone facies along the margin of the shelf & Rosevear channel



Rosevear  
Field

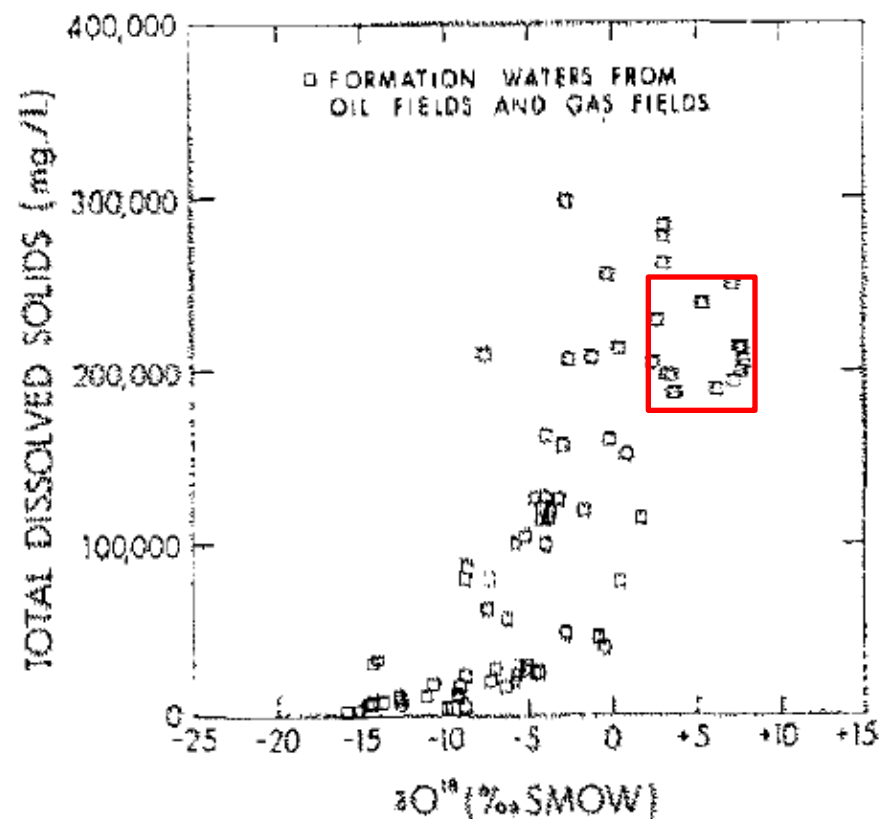


LEDUC	IRETON	WOOD-BEND GROUP
COOKING LAKE		
UPPER SWAN HILLS (Capping Platform)	WATERWAYS FORMATION	BEAVERHILL LAKE GROUP
MIDDLE SWAN HILLS (Platform Reef)		
LOWER SWAN HILLS (Basal Platform)		
Fort Vermilion Formation		ELK POINT GROUP
WATT MOUNTAIN FORMATION		
SHELF	BASIN	

Material in this segment is from: Saller, A.H., Kevin Lounsbury, and Mark Birchard, 2001, Facies Control on Dolomitization and Porosity in the Devonian Swan Hills Formation in the Rosevear Area, West-Central Alberta: Bulletin of Canadian Petroleum Geology, v. 49, p. 458-471.

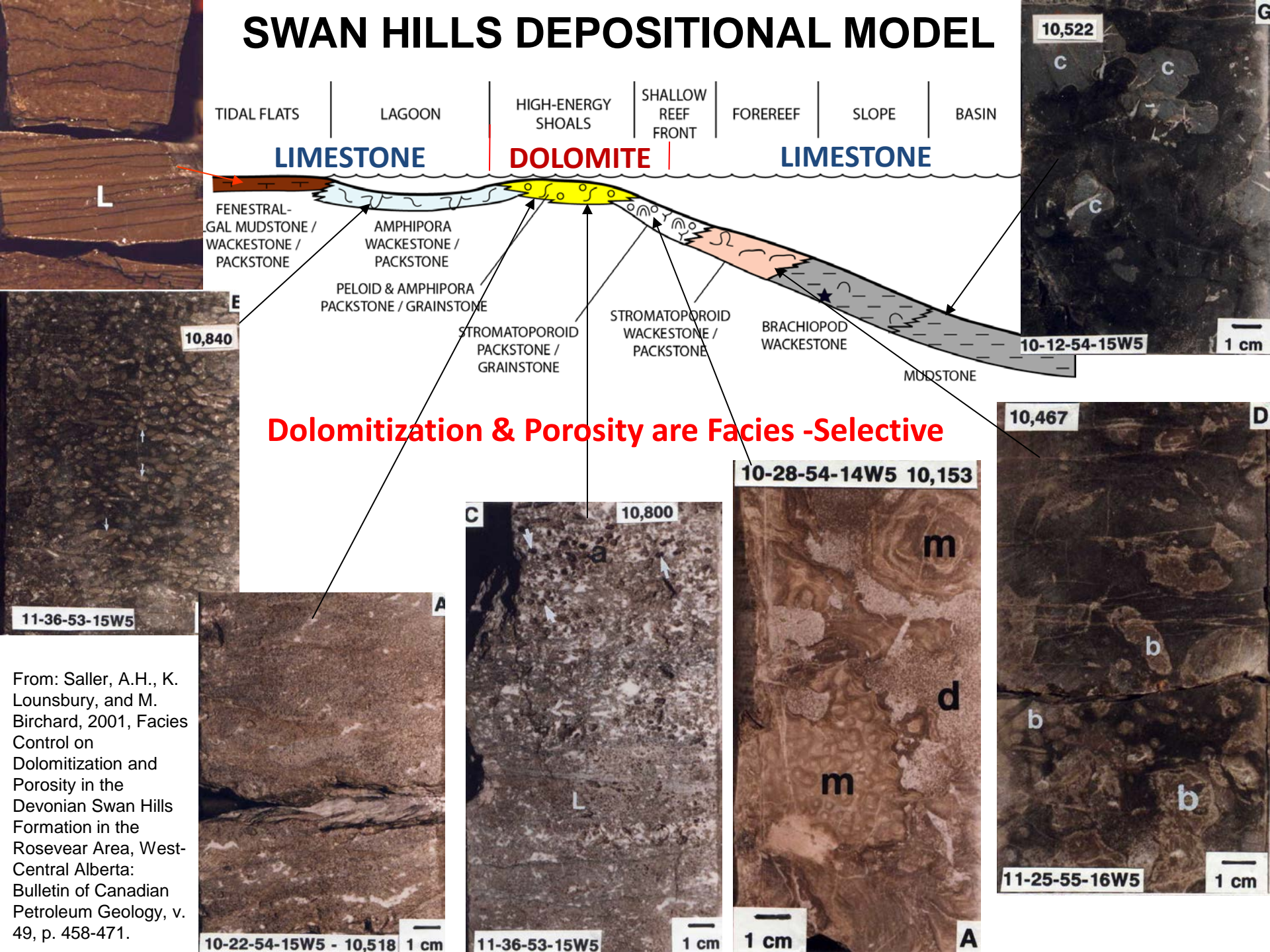
# Geochemistry of Rosevear Dolomites (Kaufman et al., 1990, 1991)

- Fluid Inclusions
  - Th ~ 127-146°C
  - Tf ~ 21-24 wt% equivalent NaCl
- $\delta^{18}\text{O}$  of dolomites -6.2 to -10.3 (PDB)
- $\delta^{18}\text{O}$  values (mean=-7.5‰, PDB)
- Saline waters  $\delta^{18}\text{O}$  of 3-7‰ (Hitchon and Friedman, 1969)
- T = 135°C for  $\delta^{18}\text{O}$  dolomite=-7.5‰, PDB and water  $\delta^{18}\text{O}$ = 5‰ (SMOW)
- All data are consistent with dolomitization involving waters that precipitated halite at high temperatures

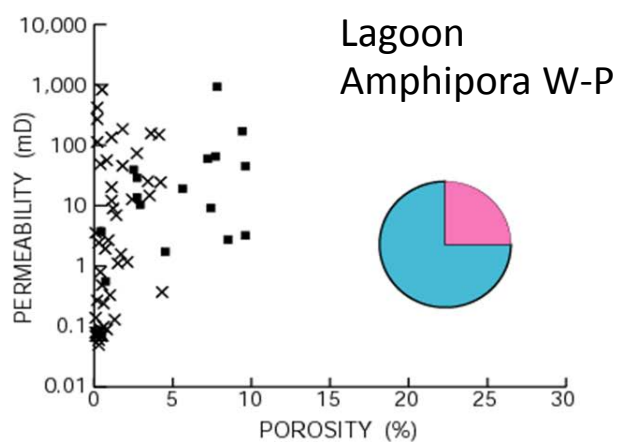
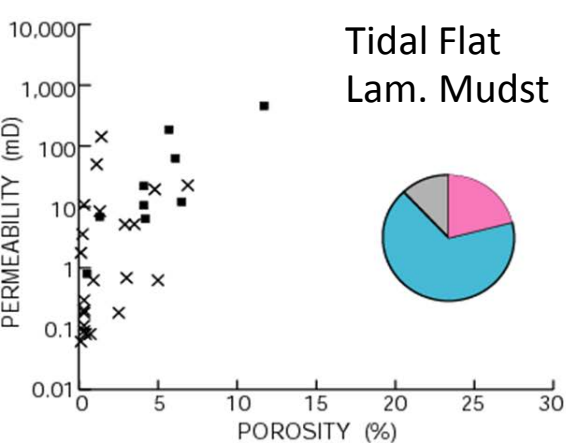


From Hitchon and Friedman, 1969

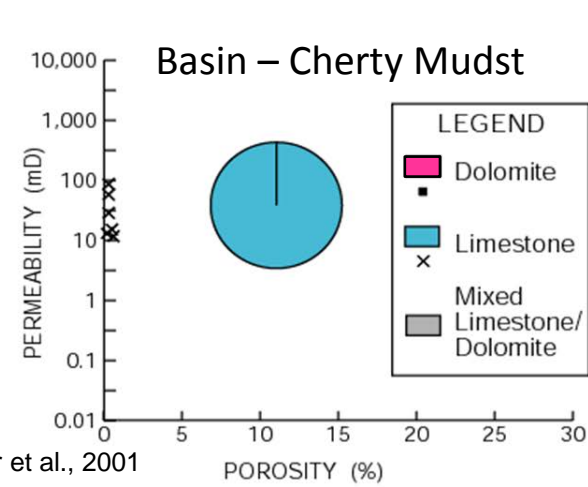
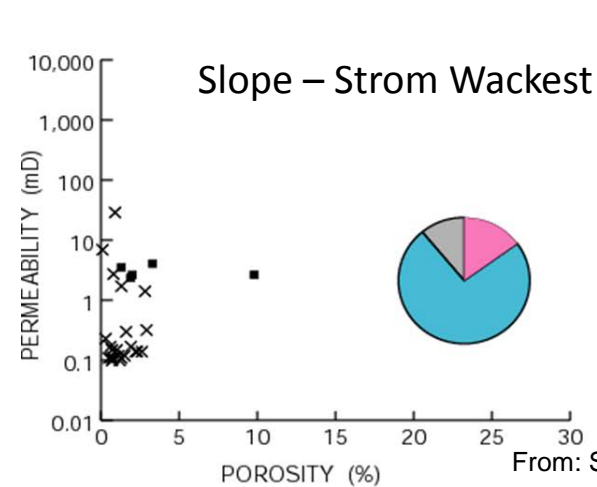
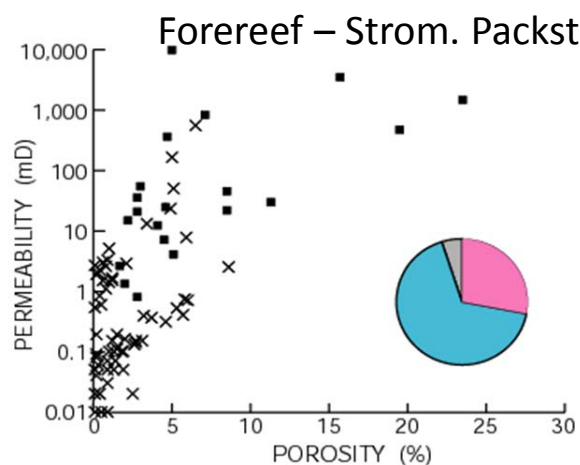
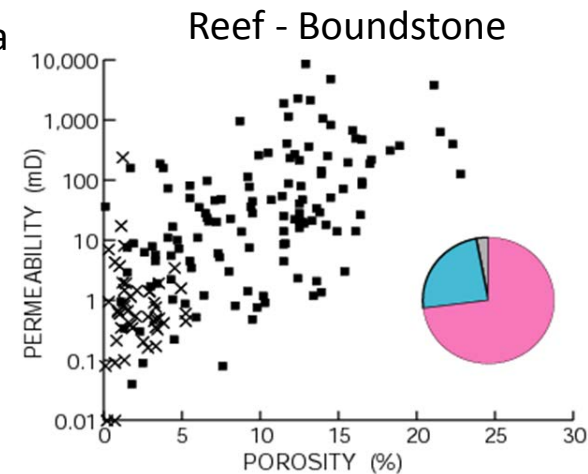
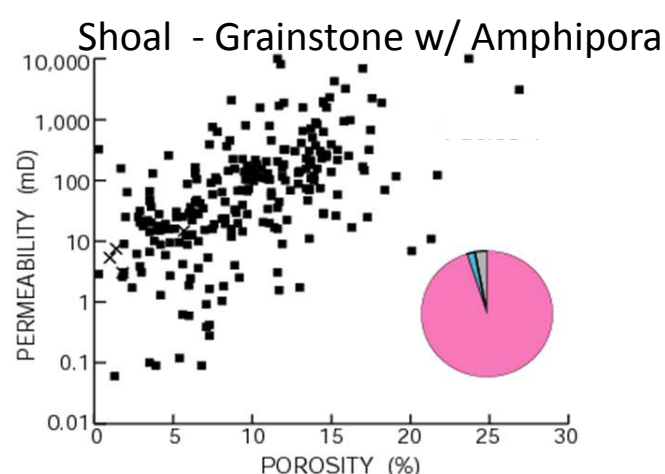
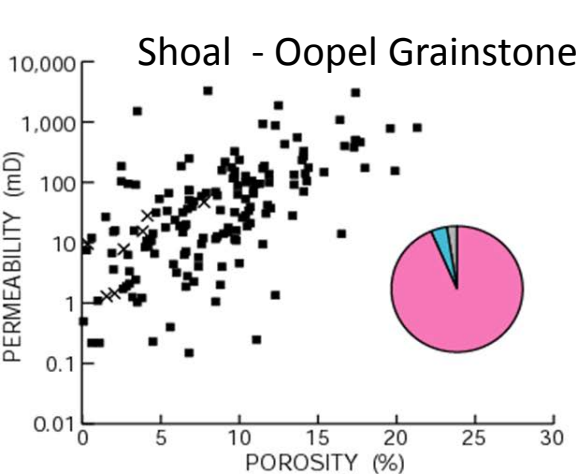
# SWAN HILLS DEPOSITIONAL MODEL



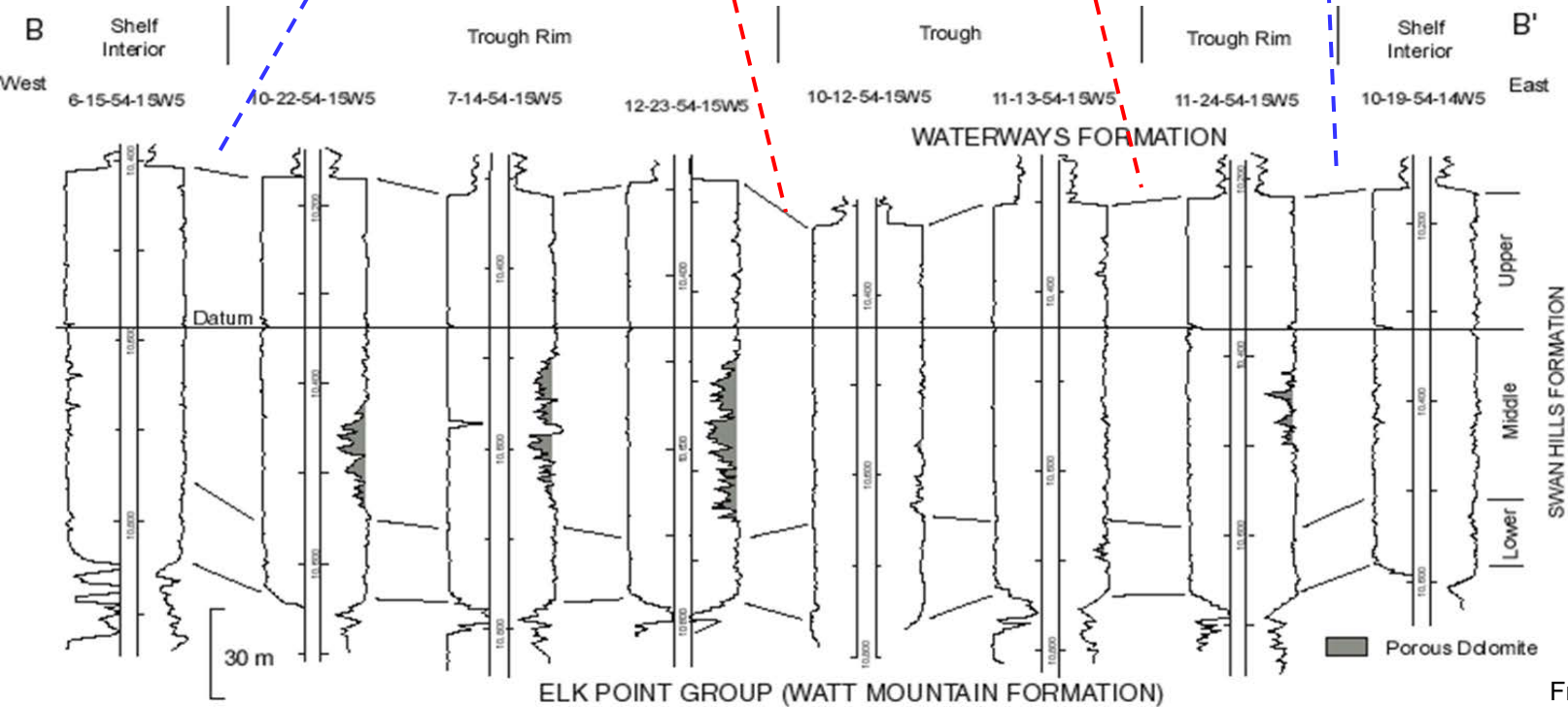
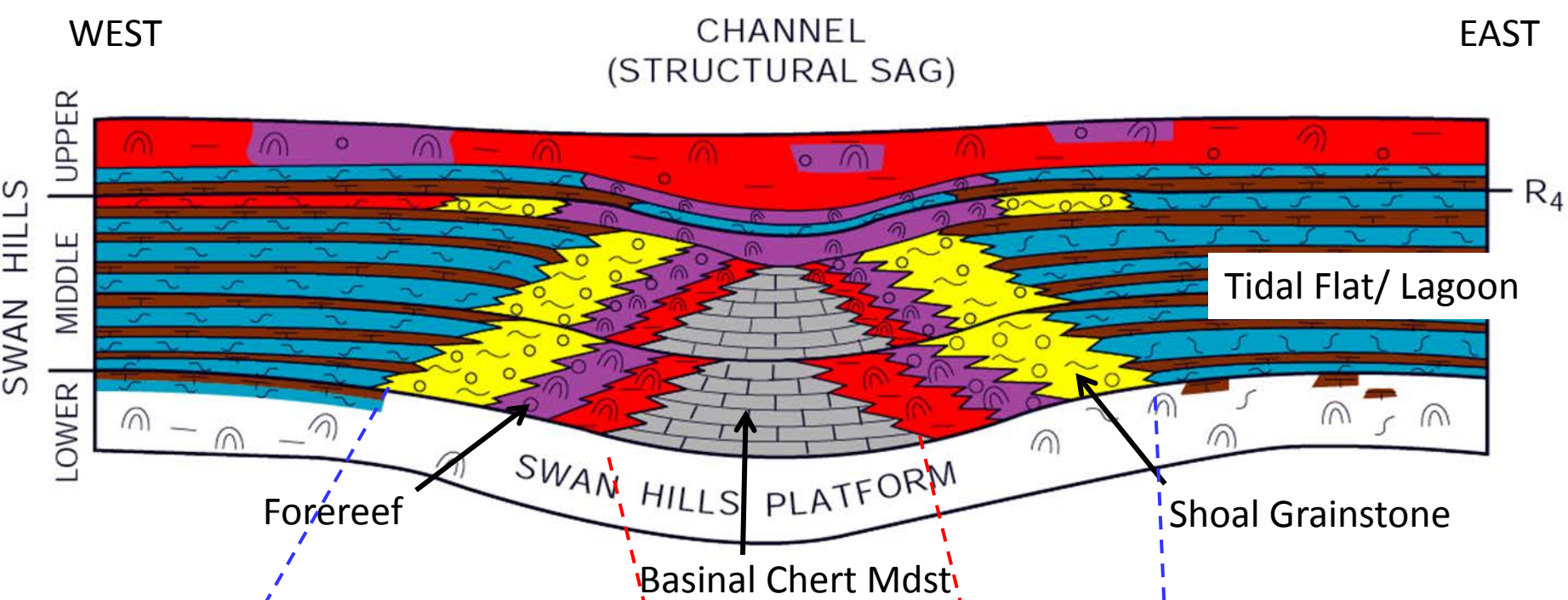
From: Saller, A.H., K. Lounsbury, and M. Birchard, 2001, Facies Control on Dolomitization and Porosity in the Devonian Swan Hills Formation in the Rosevear Area, West-Central Alberta: Bulletin of Canadian Petroleum Geology, v. 49, p. 458-471.



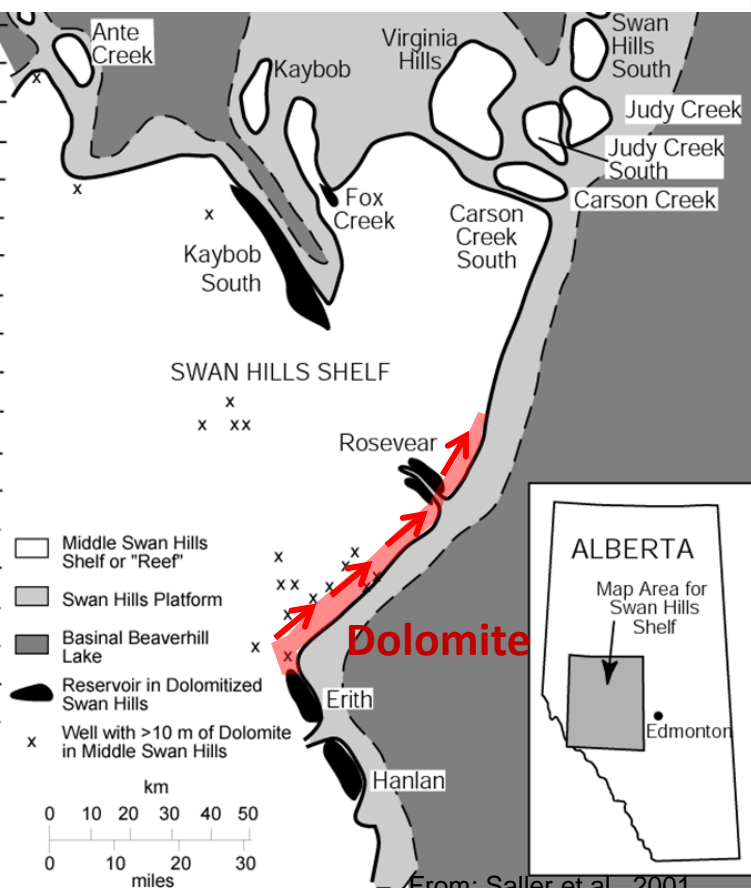
Facies-  
Selective  
Porosity,  
Permeability,  
Mineralogy



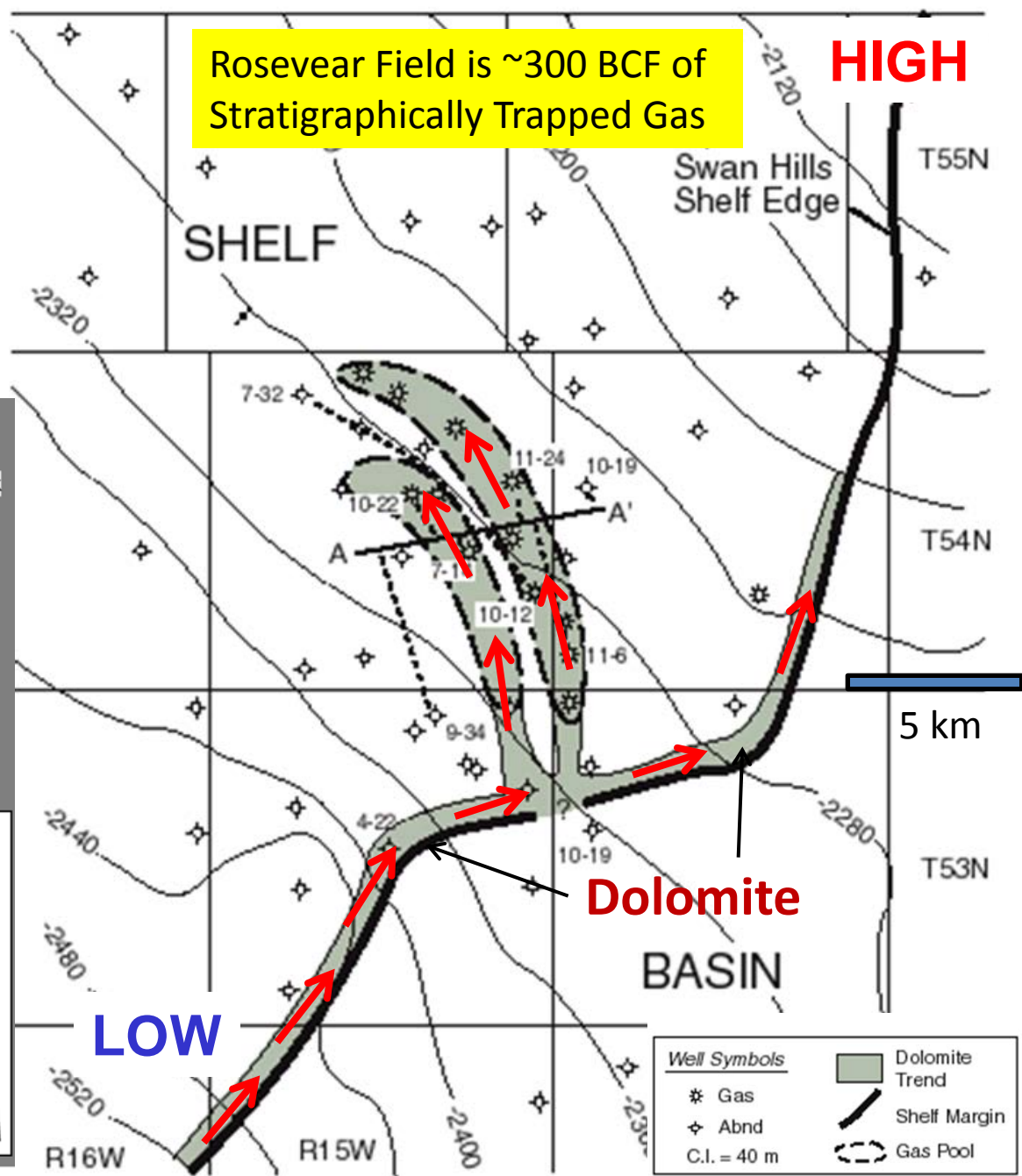
From: Saller et al., 2001



# Hydrothermal Brines Moved Through & Dolomitized Shelf Margin & Embayment Margin Grainstones



## STRUCTURE MAP OF TOP SWAN HILLS

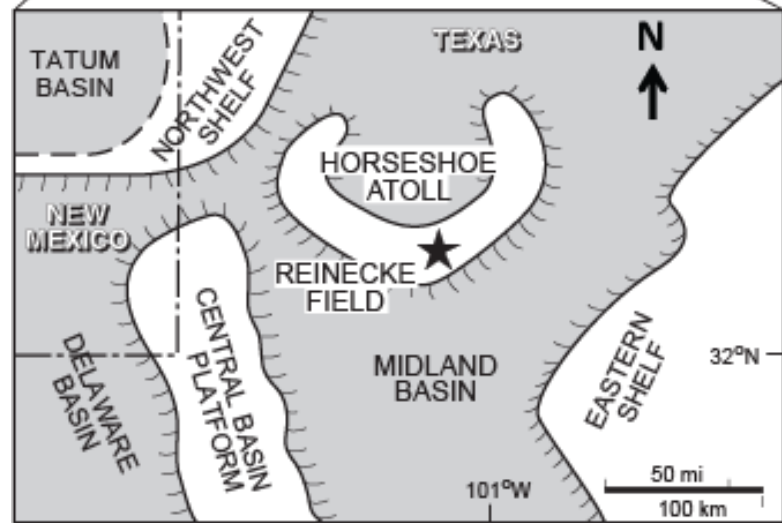


# HYDROTHERMAL DOLOMITE

- Introduction
- Wabamun, subsurface Canada
- Swan Hills – Rosevear Field, Canada
- Reinecke Field, west Texas
- Summary & Models (facies and early diagenesis are commonly critical)

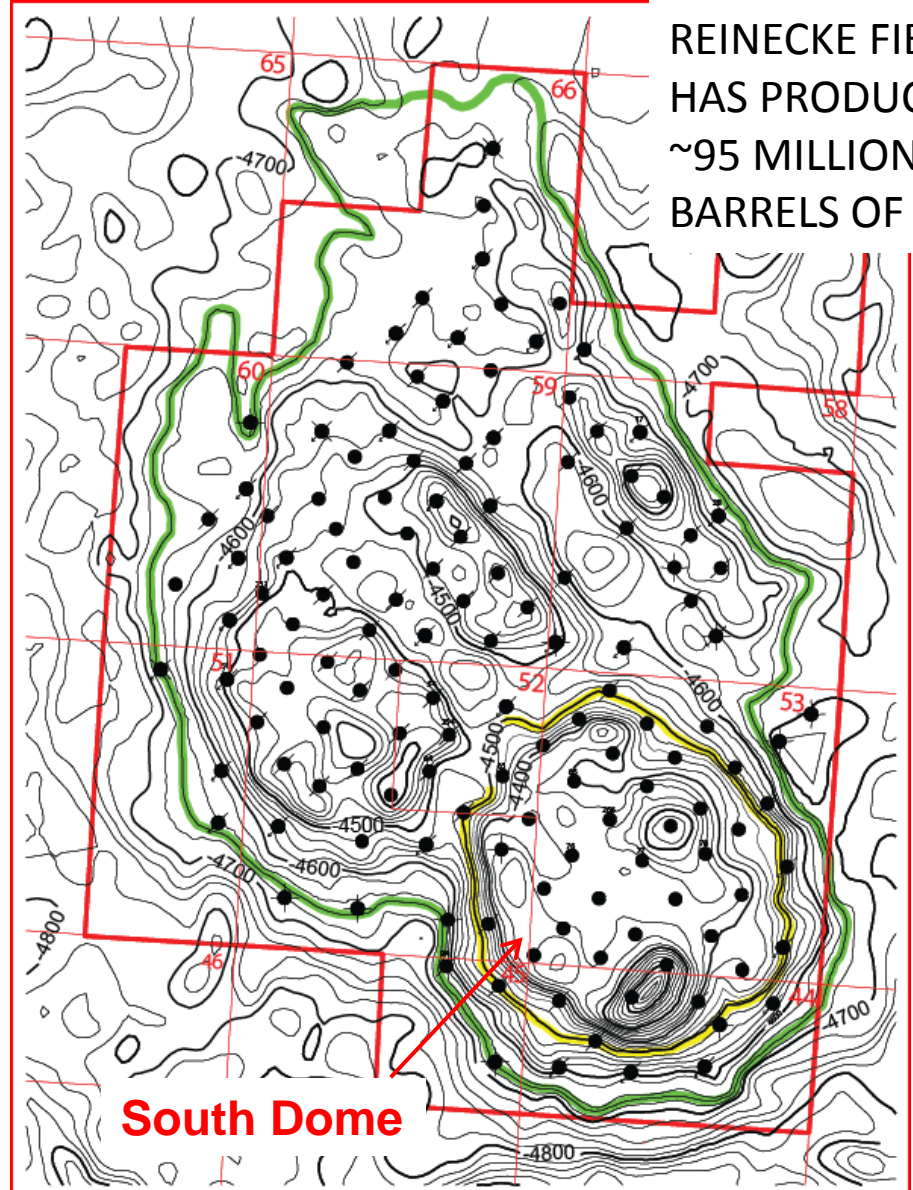


# REINECKE FIELD WEST TEXAS



Shallow-marine Deposition
  Deep-marine Deposition

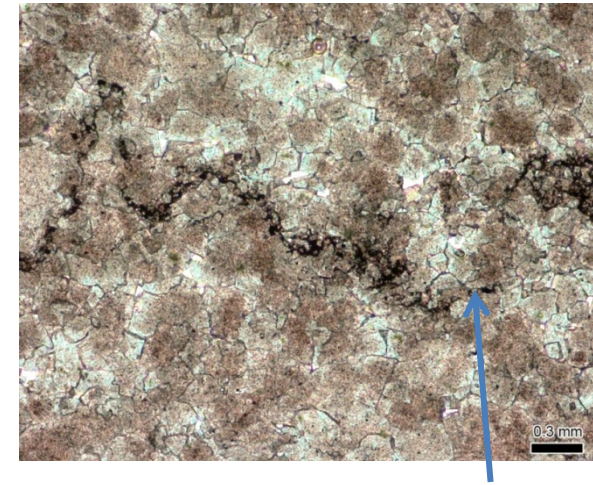
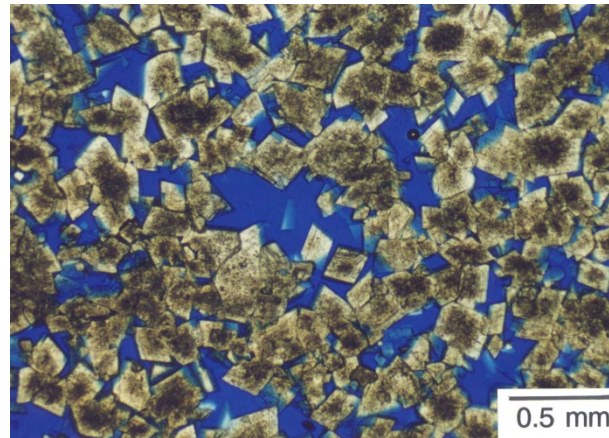
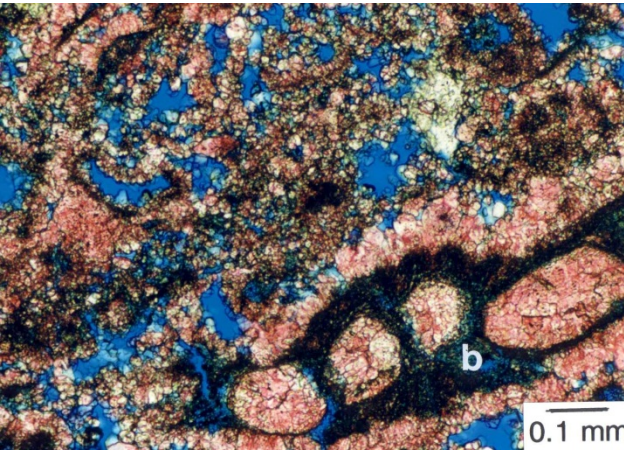
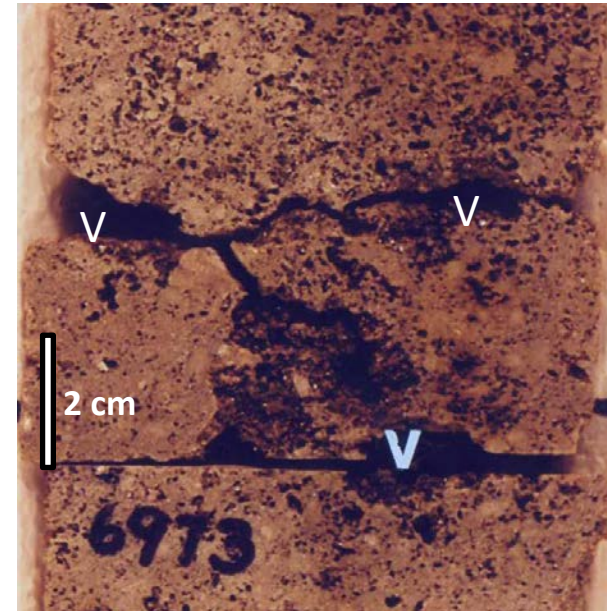
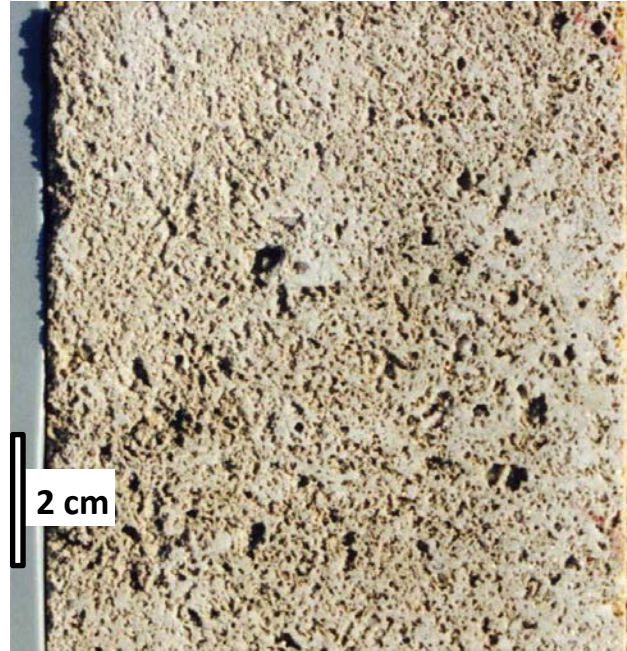
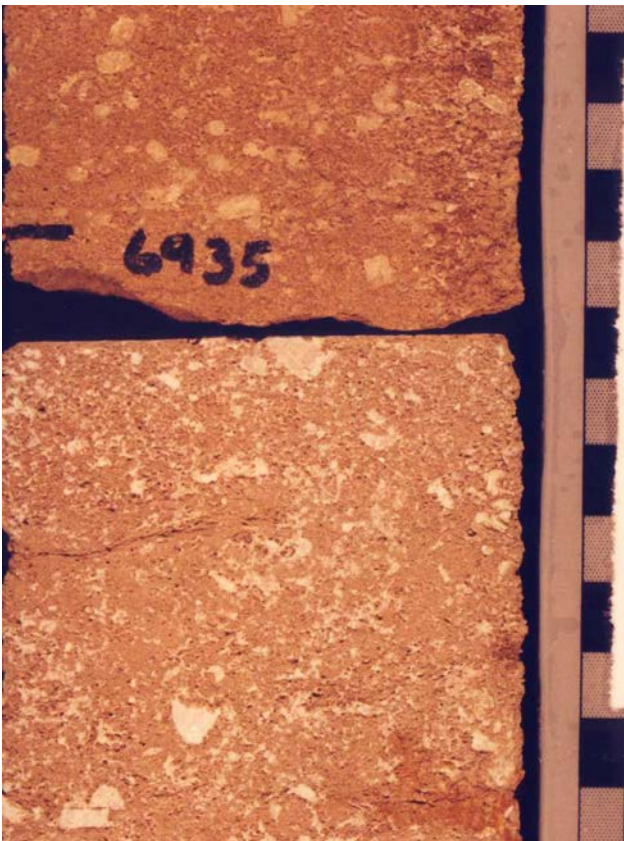
REINECKE FIELD  
HAS PRODUCED  
~95 MILLION  
BARRELS OF OIL



Most material in this section is from Saller, A.H., and J.A.D. Dickson, 2011, Partial dolomitization of a Pennsylvanian limestone buildup by hydrothermal fluids and its effect on reservoir quality and performance: AAPG Bulletin, v. 95, p. 1745 – 1762.

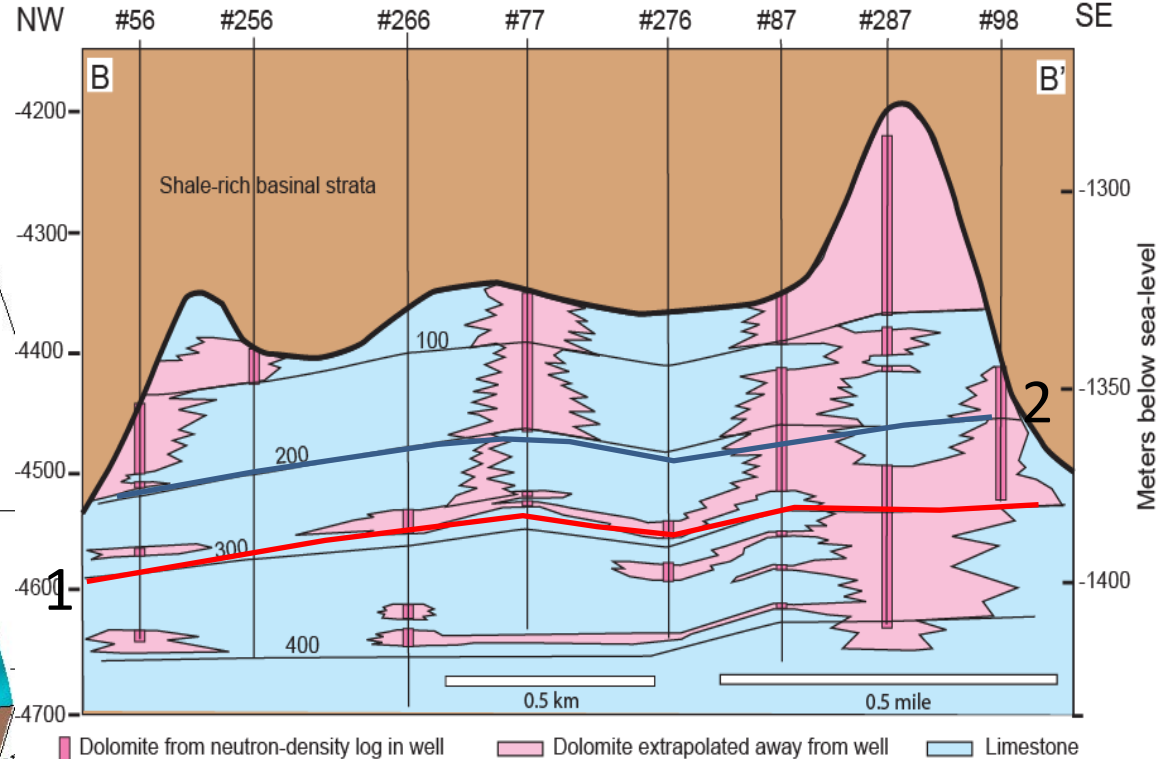
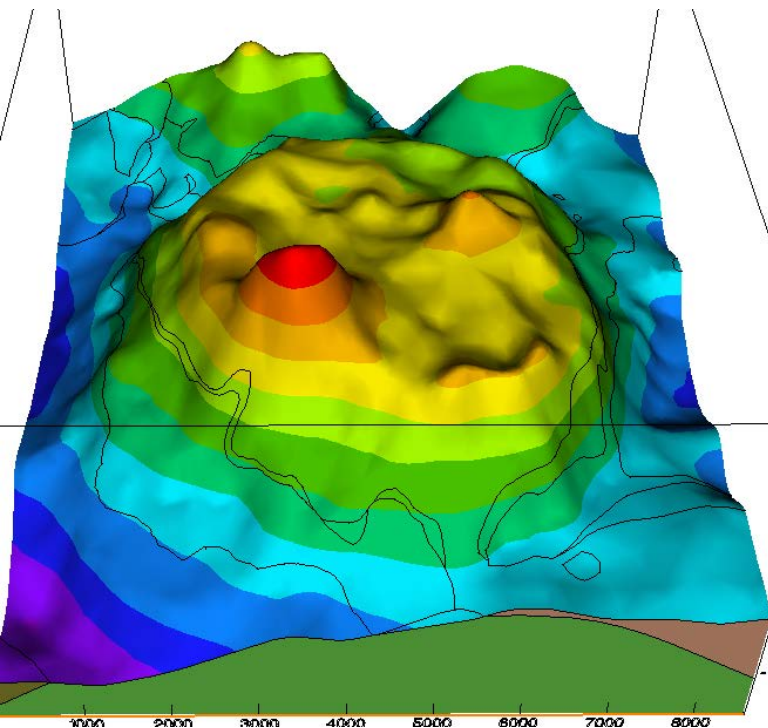
LIMESTONE ~75%

DOLOMITE ~ 25%

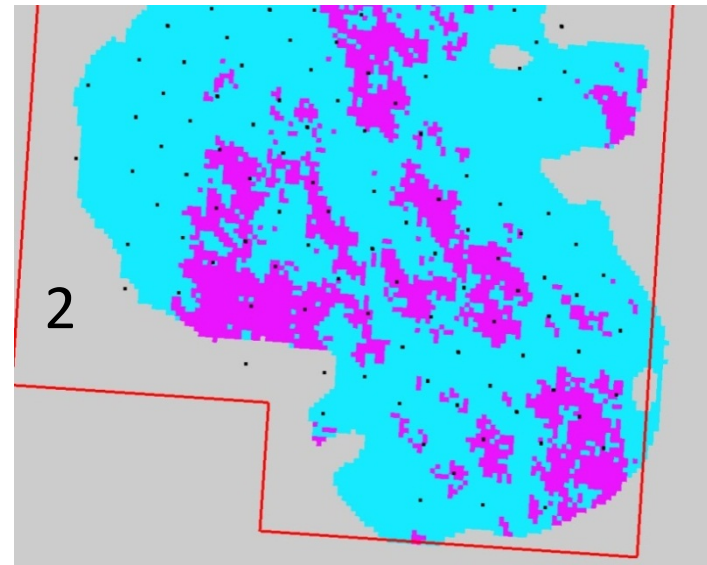
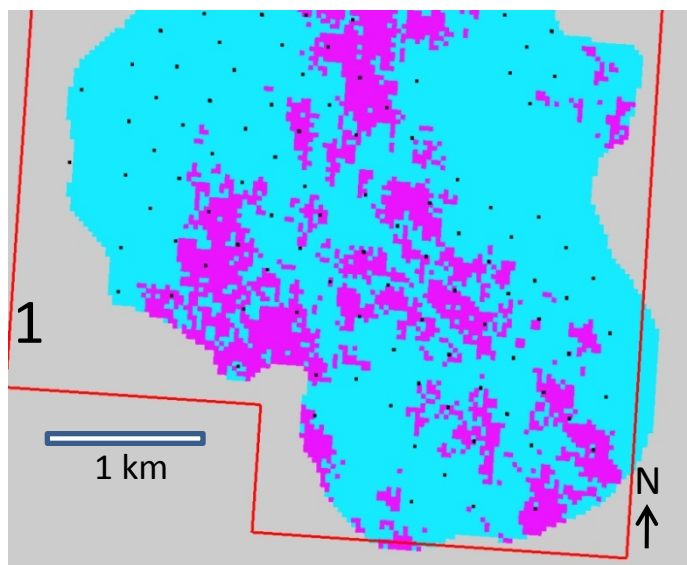


Dolomite overgrowing  
stylolite

Vugs & coarse intercrystalline  
porosity cause high permeability

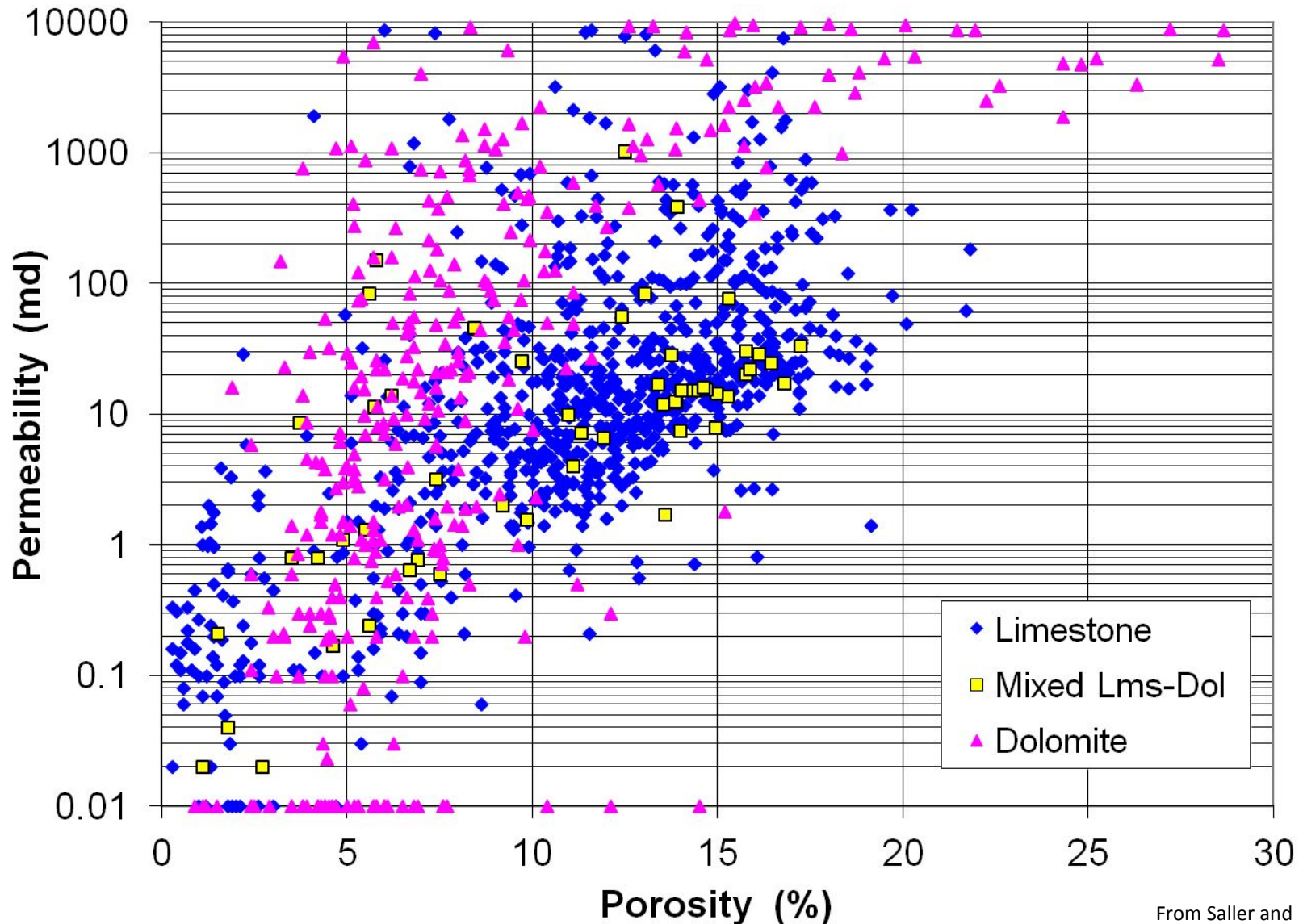


Maps showing modeled distribution of limestone (blue) and dolomite (pink) at horizons 1 & 2 (above). Dots are well control.



Reinecke  
South Dome  
has produced  
~45 Million BO  
from ~ 1 sq mile

# Reinecke Field: Porosity vs Permeability Colored by Lithology



Reinecke#266; 6886.2 ft

Petroleum Inclusion

Plain Light

35µm

Reinecke#266; 6886.2 ft

Petroleum Inclusion

UV Light

35µm

Reinecke#266; 6879.4 ft

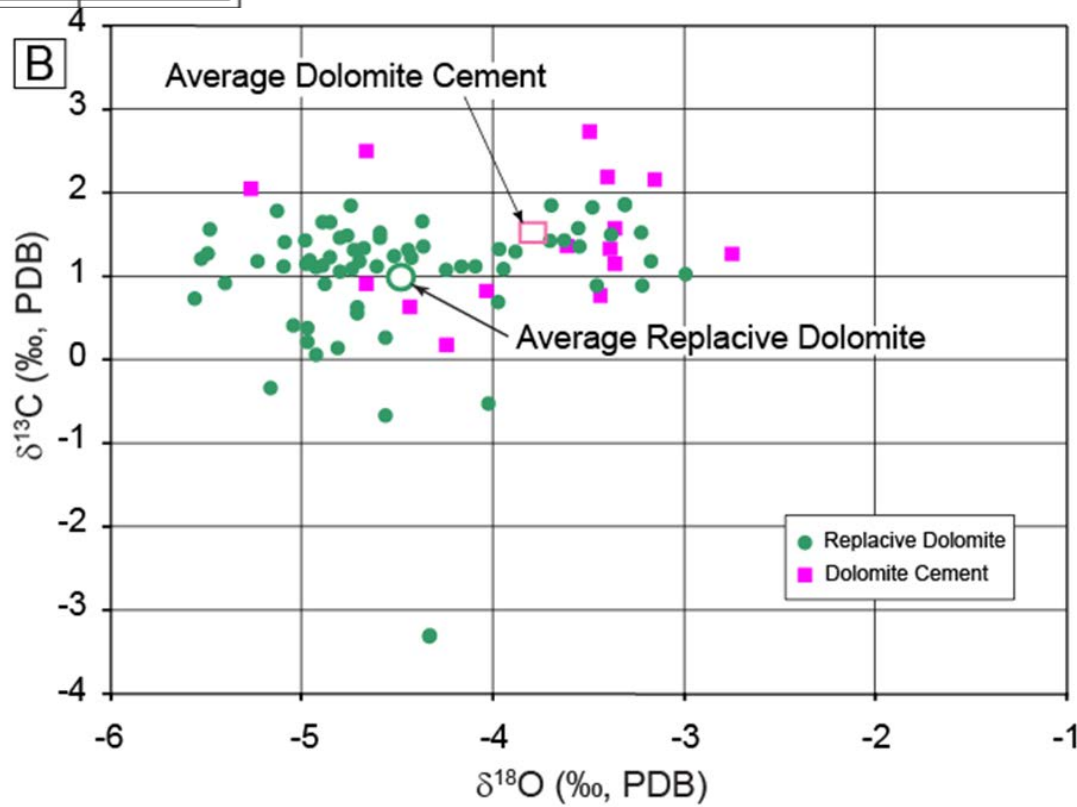
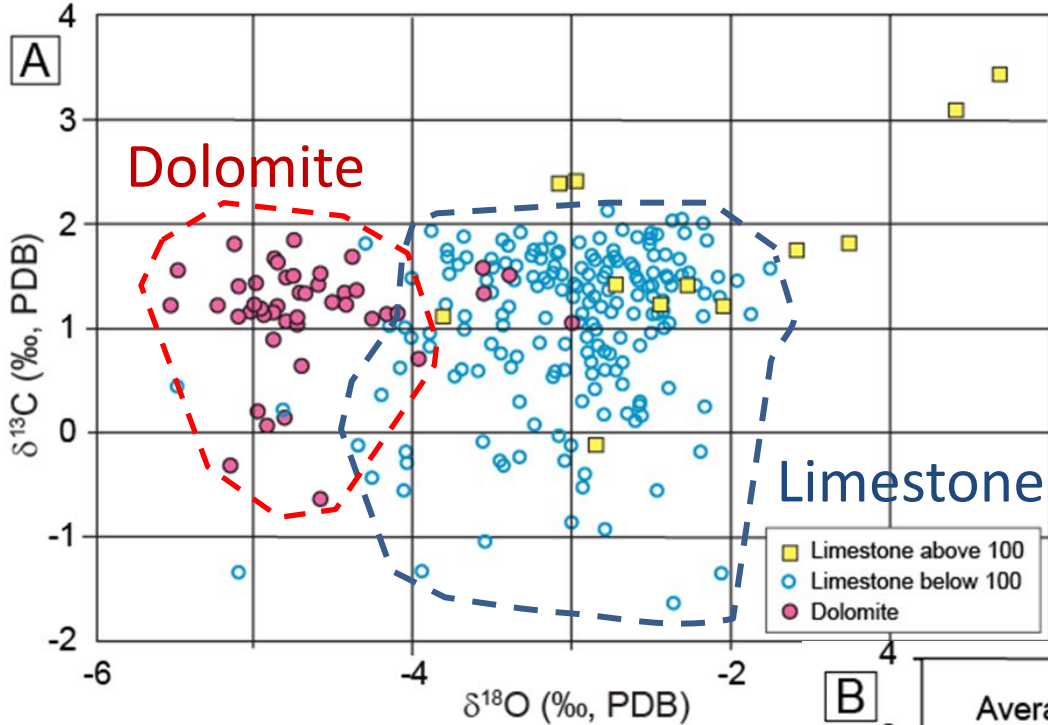
Aqueous Inclusion

Plain Light

35µm

Two-phase fluid inclusions (liquid and vapor) in dolomites have

1. Homogenization temperatures of 90- 120° C
2. Water and hydrocarbons
3. Highly saline waters (TDS of 20- 25 wt%)



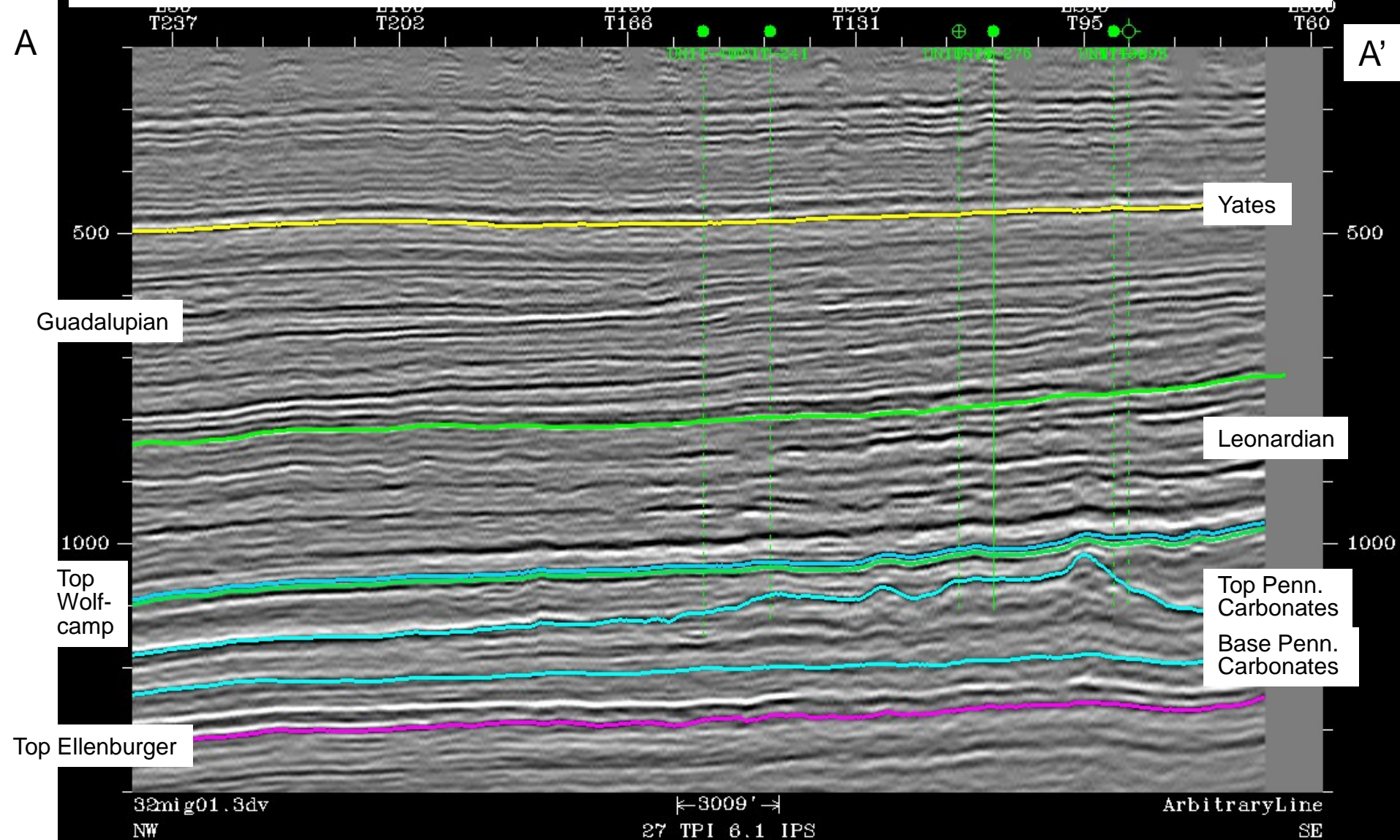
If precipitated from saline Permian Basin waters ( $\delta^{18}\text{O}$  values of +5 to +6 ‰, SMOW: Stueber et al., 1998), Reinecke dolomites ( $\delta^{18}\text{O}$  of -3 to -5.5 ‰, PDB) precipitated at temperatures of **84-118° C** (using equation in Land, 1985)

# SEISMIC LINE OVER REINECKE FIELD

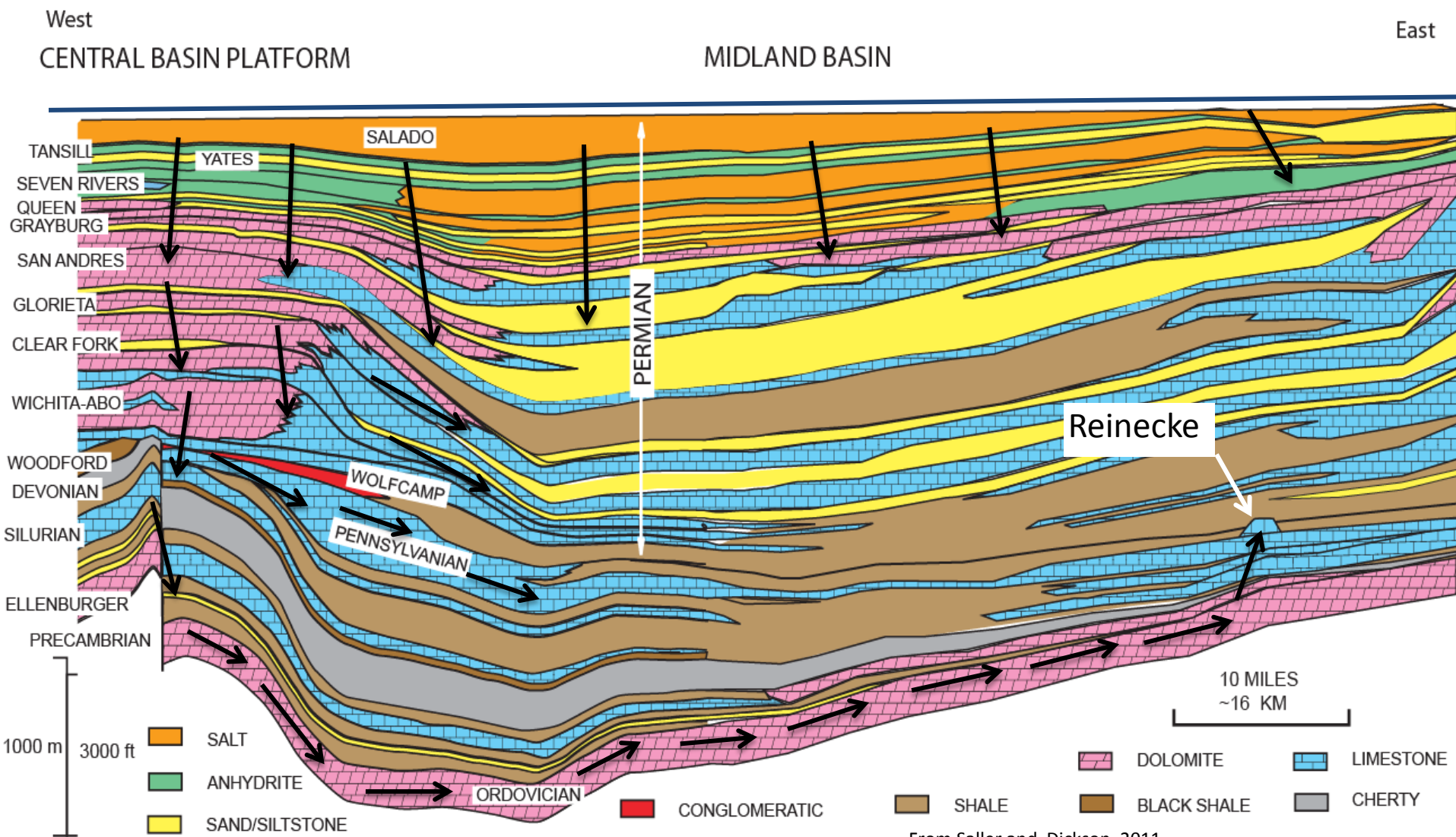
## Note lack of faulting

A

A'

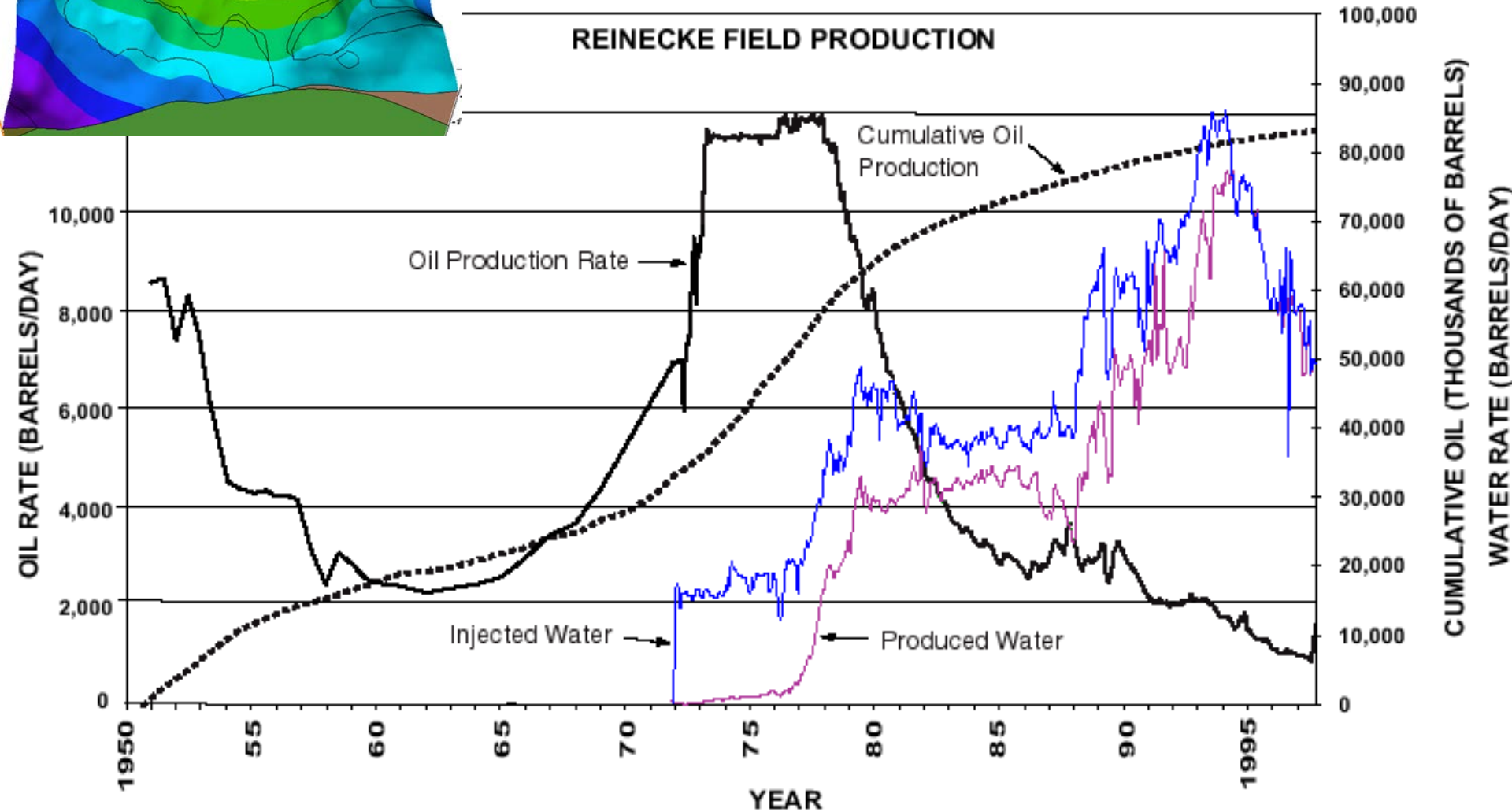
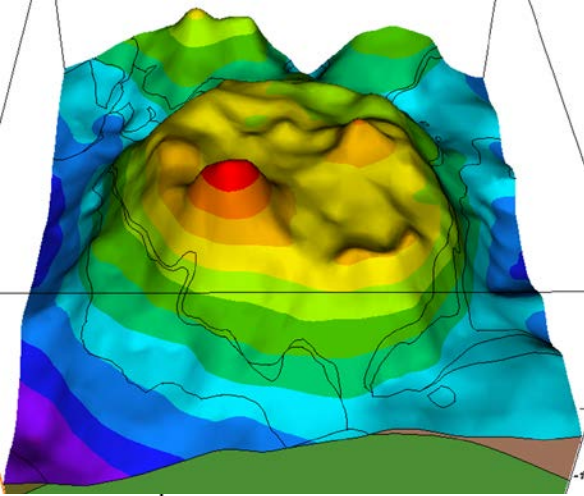


# Hydrothermal Dolomitization occurred by Convective Flow of Dense Brines associated with Halite Precipitation during the Late Permian



From Saller and Dickson, 2011

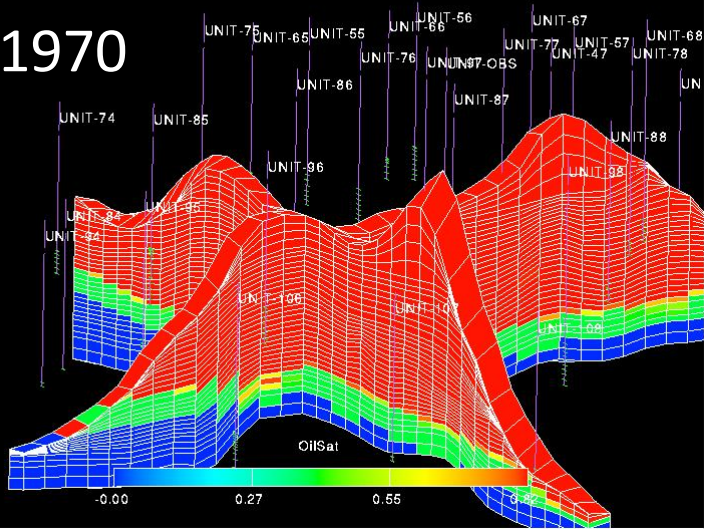
# Reinecke Field



From Saller, A. H., S. Walden, S. Robertson, R. Nims, J. Schwab, H. Hagiwara, and S. Mizohata, 2004, Three-dimensional seismic imaging and reservoir modeling of an upper Paleozoic "reefal" buildup, Reinecke field, west Texas, United States, in Seismic imaging of carbonate reservoirs and systems: AAPG Memoir 81, p. 107– 122.

Reinecke Full Field Simulation

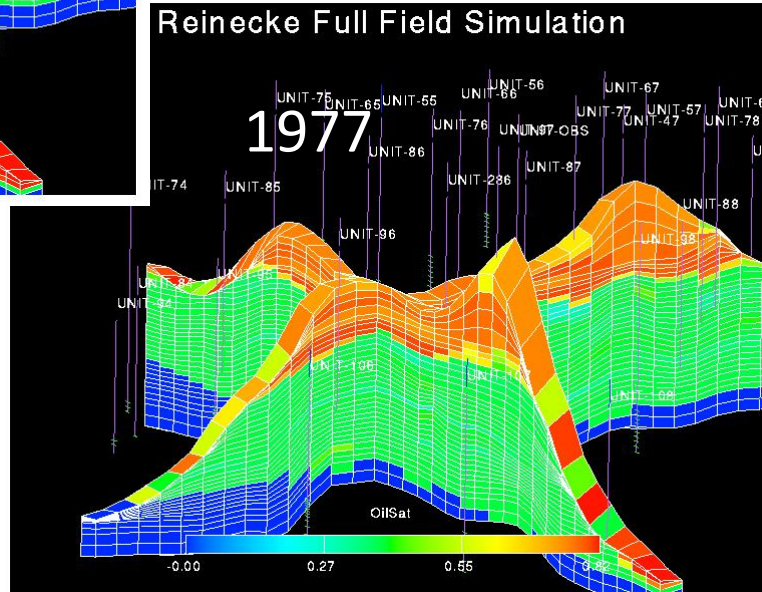
1970



Reinecke Field is a Single Tank.  
During Primary & Secondary Recovery,  
Bottomwater Drive Effectively Pushed  
Oil to Wells at Top of Reservoir  
(Recovery of >50% OOIP)

Reinecke Full Field Simulation

1977

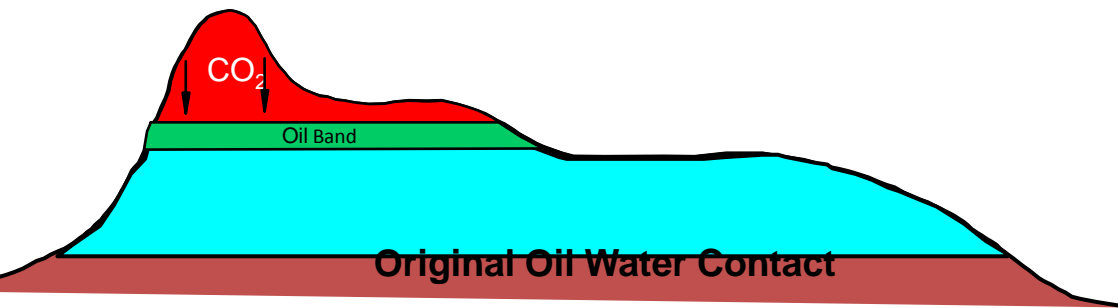
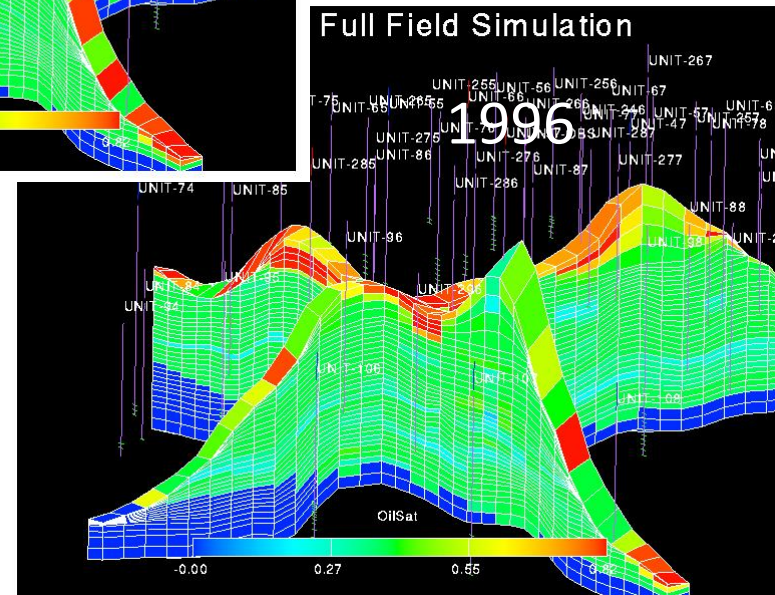


From Saller, A. H., S. Walden, S. Robertson, R. Nims, J. Schwab, H. Hagiwara, and S. Mizohata, 2004, Three-dimensional seismic imaging and reservoir modeling of an upper Paleozoic "reefal" buildup, Reinecke field, west Texas, United States, in Seismic imaging of carbonate reservoirs and systems: AAPG Memoir 81, p. 107– 122.

CO<sub>2</sub> is Now Pushing  
Residual Oil Down To Be  
Banked & Recovered in  
Lower Parts of Reservoir

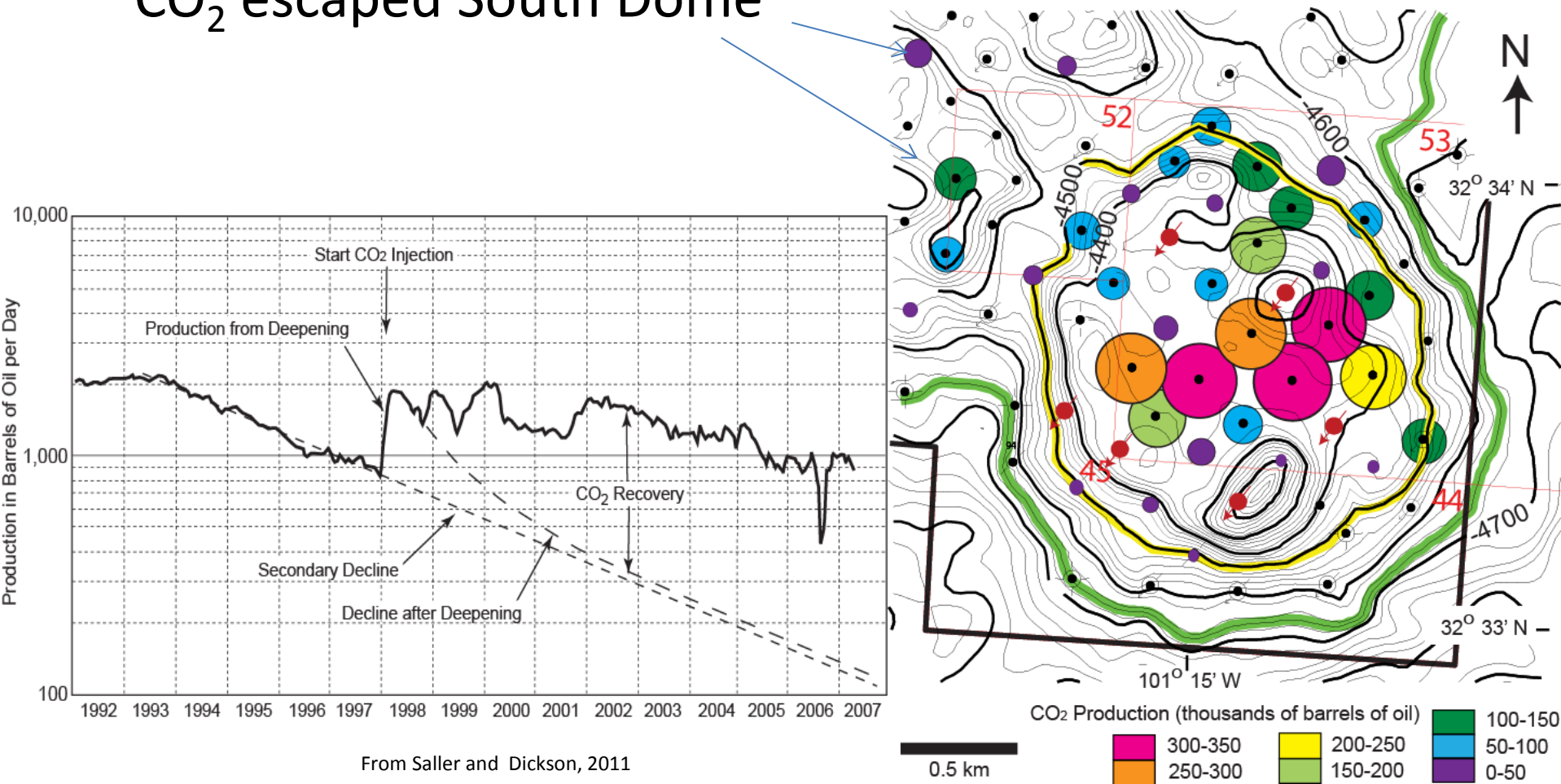
Full Field Simulation

1996



# Crestal CO<sub>2</sub> Flood Produced Residual Oil but Oil Production & CO<sub>2</sub> was Heterogeneous

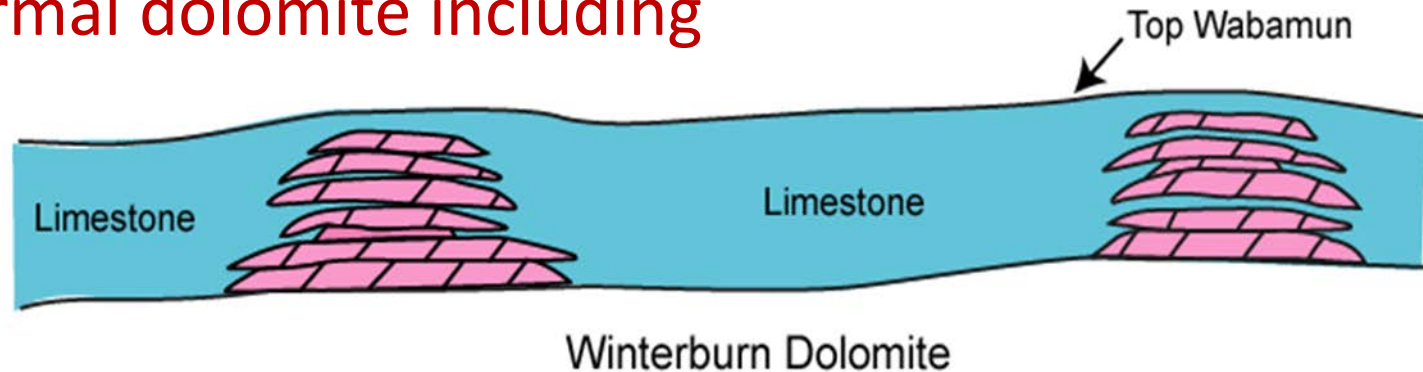
CO<sub>2</sub> escaped South Dome



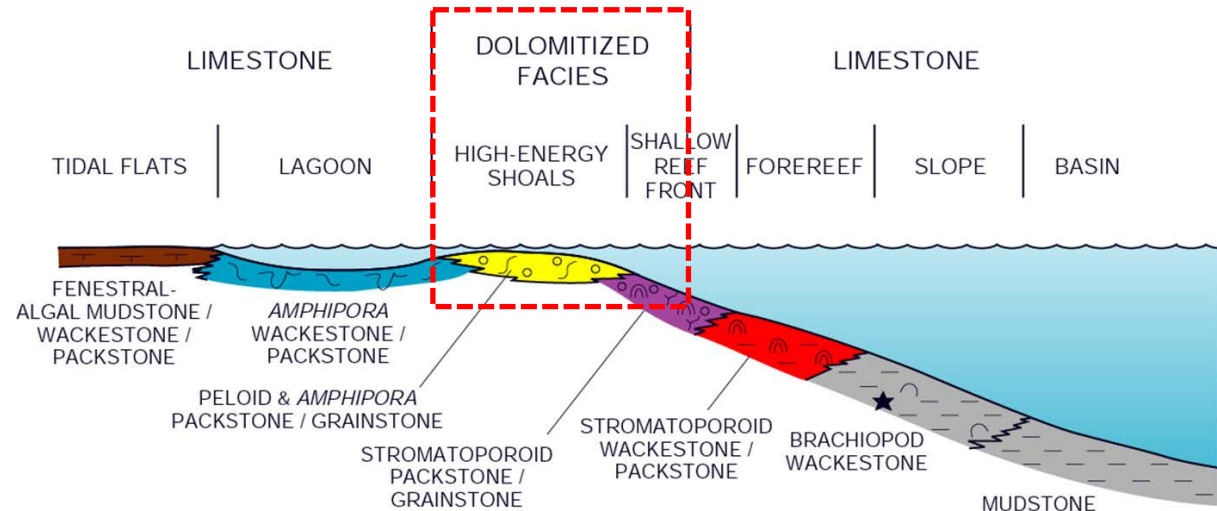
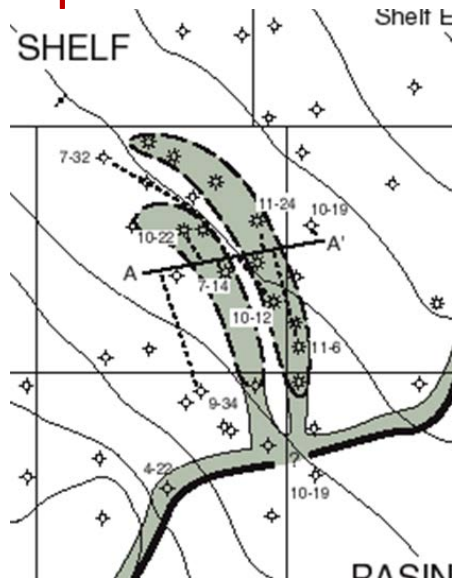
# Hydrothermal dolomites are important hydrocarbon reservoirs in many parts of the world

- Many factors other than faults can control the distribution of hydrothermal dolomite including

## 1. Early Dolomite

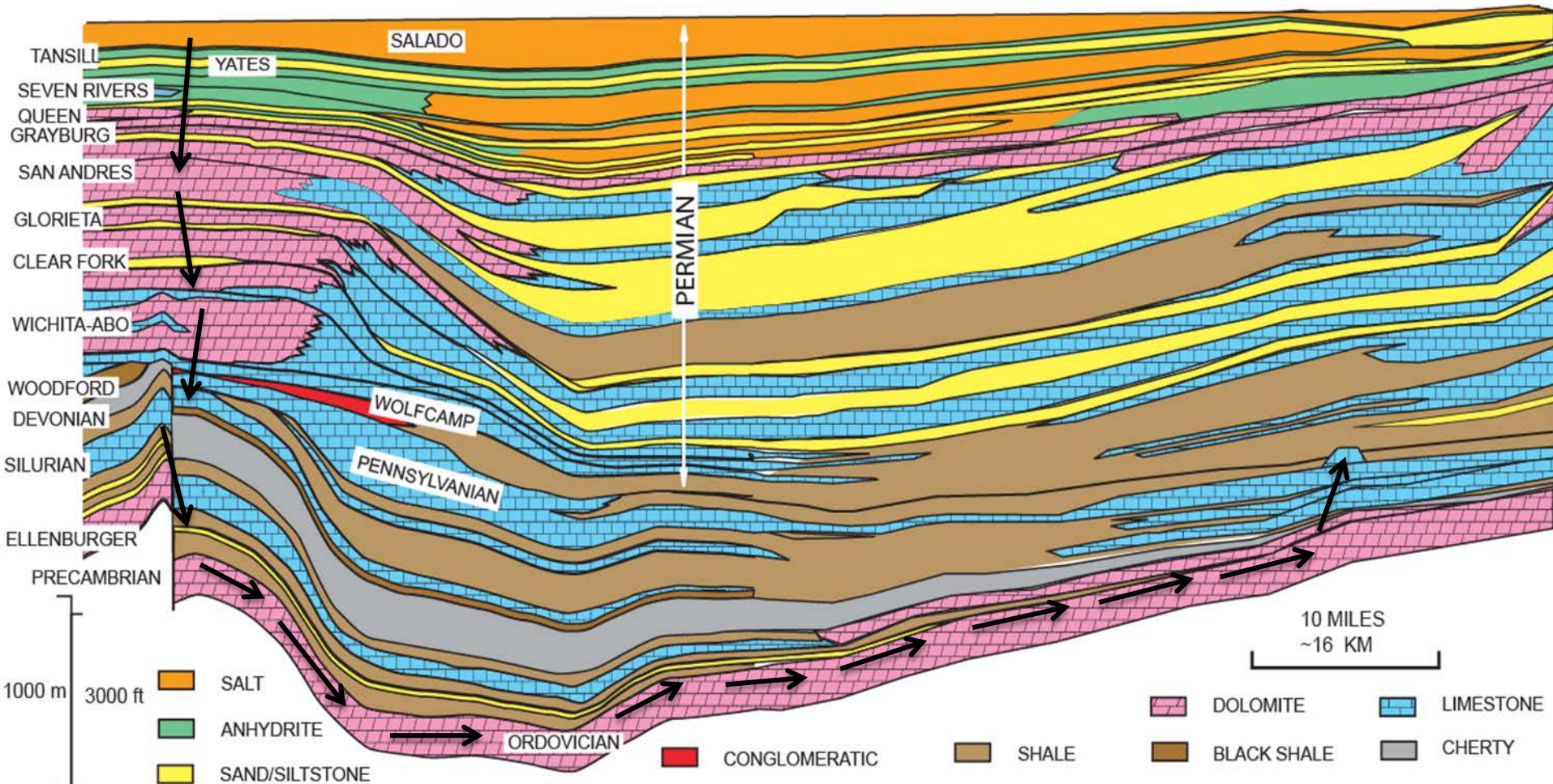


## 2. Depositional Facies



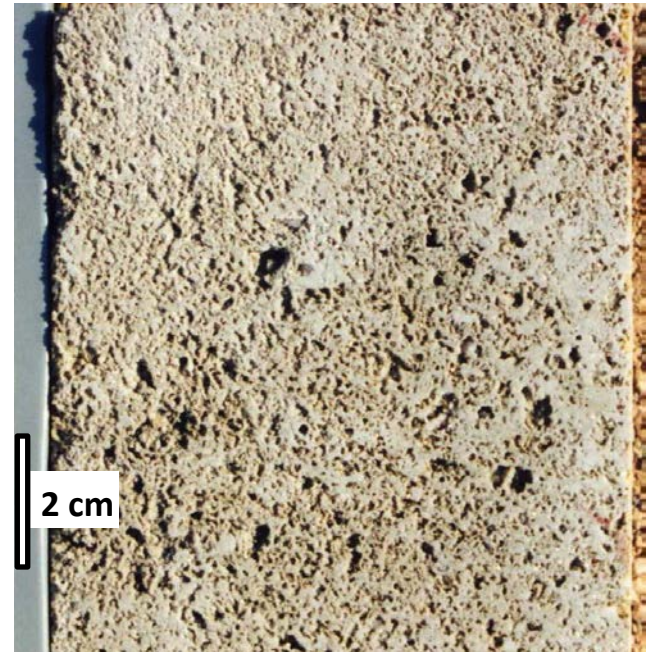
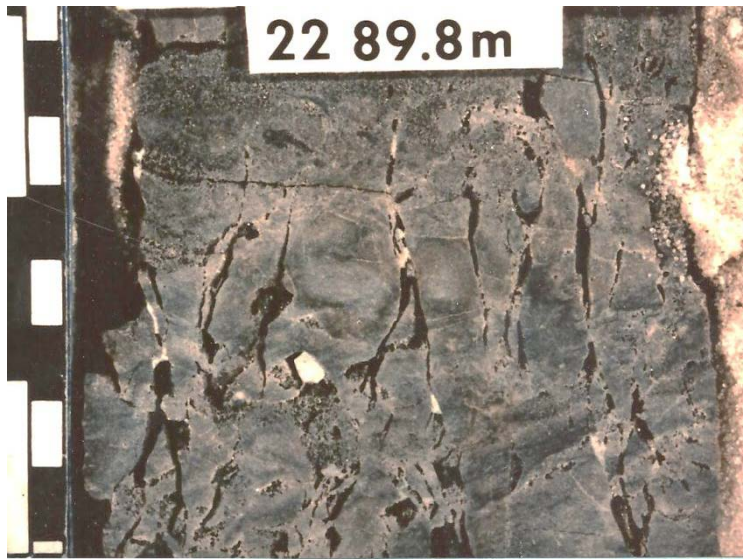
# Factors other than faults controlling distribution

3. High salinity brines in the basin (associated with salt deposition)
4. Convective Flow



# Hydrothermal dolomites have

- Excellent reservoir characteristics (including high horizontal & vertical permeability) because of
  - large crystal size,
  - vugs and fractures



- Careful petrography, collecting geochemical data, and a good understanding of the basin history can help predict hydrothermal dolomite reservoirs in the subsurface



# Thank you

- AAPG, AAPG Foundation, Shell, Cobalt International Energy
- Many wonderful people who worked with me on these projects including:
- Ken Yaremko, Kevin Lounsbury, Mark Birchard, Stan Frost, Ariel Auffant, Jean Hsieh, Skip Walden, Tony Dickson, Scott Beaty, Steve Robertson, Merle Steckel, Brian Ball, Joe Schwab, Alan Stueber, Steve Babcock, Barry Weeks, James Best, Ross Pittman, Ken Mitchell, Tim Anderson, Al Crawford, Linda Shanks, Ata Sagnak, George Moore

