

Stratigraphic Control on the Lateral Distribution of Hydrothermal Dolomites away from Major Fault Zones*

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Search and Discovery Article #50277 (2010)

Posted July 19, 2010

* Adapted from an oral presentation at AAPG Annual Convention and Exhibition, New Orleans, Louisiana, USA, April 11-14, 2010

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Abstract

Hydrothermal dolomite (HTD) reservoirs are known as prolific hydrocarbon producers in many parts of the world. In many cases, exploration strategies focus on the seismic expression of a sag related to Reidel shear along basement rooted faults, with the general model being that reservoir quality dolomites are centered near the fault zones. Evaluation of published examples of these reservoirs, however, suggests there is a secondary control on the lateral development of reservoir quality rock away from the major fault zones. Detailed core analysis of HTD reservoirs in the Albion-Scipio trend of the southern Michigan Basin suggests that the lateral development of reservoir quality away from the faults is due to a combination of primary facies and the sequence stratigraphic framework.

Production from the Ordovician Trenton and Black River formations (T/BR) in the Albion-Scipio trend has exceeded 125 MMBO since the mid-1950's and nearly 40 new discoveries have been made around the trend in the past three years. Exploration methods continue to be centered on seismic sags observed in 3-D surveys, but initial development and subsequent enhanced production of these reservoirs will require detailed geological interpretation to avoid the close step-out dry holes often associated with these reservoirs. Initial evaluation of some 30 T/BR cores in and around the Albion-Scipio trend indicates that reservoir quality dolomitization moves laterally away from the major fault planes primarily in the TST of probable 4th order high frequency sequences. Reservoir quality is best developed in bioturbated open ramp wackestones to packstones where the burrow galleries have been differentially filled with coarser-grained sediment due likely to storm deposition (i.e. tubular tempestites). The Cruziana-type burrows have been preferentially

dolomitized with coarsely crystalline sucrosic dolomite, resulting in high permeability pore networks that are distributed in three dimensions throughout the depositional facies. Secondary reservoirs exist in grainstones interpreted as more localized carbonate shoals. Isotopic and fluid inclusion analyses in both units support the interpretation of the dolomitizing fluids being related to the major, fault centered HTD events. Understanding of how HTD fluids can migrate laterally along preferential facies or stratigraphic intervals should aid in the development of production and enhanced-production strategies for these types of reservoirs.

Selected References

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Significance

- Hydrothermal dolomite (HTD) reservoirs are prolific hydrocarbon producers in many parts of the world
- Exploration strategies focus on seismic expression of faults and associated “sag” interval
- Primary depositional facies are a secondary control on lateral distribution of HTD reservoirs
- Reservoir quality dolomites are more predictable within a sequence stratigraphic framework

Notes by Presenter: As we know, HTD reservoirs are prolific hydrocarbon producers. Historically exploring for these reservoirs has predominately been centered around the seismic expressions of faults and overlying sag interval. However, to better predict the distribution of dolomite away from the faults, an increased understanding of the primary depositional facies and the sequence stratigraphic framework needs to be captured.



Key Points

- Vertical distribution of HTD is concentrated along fault corridors
- Lateral distribution of HTD can be attributed to:
 - Primary depositional facies
 - *Cruziana*-type burrowed facies are preferentially dolomitized increasing reservoir quality
 - Improved reservoir quality was observed in association with probable 4th order high frequency sequences

Notes by Presenter: In addition to a structural control, there is a stratigraphic control on the lateral distribution of reservoir quality HTD. The lateral stratigraphic control can be attributed to the primary depositional facies specifically the cruziana type burrowed facies. Also, improved reservoir quality was observed in association with probable 4th order sequences.



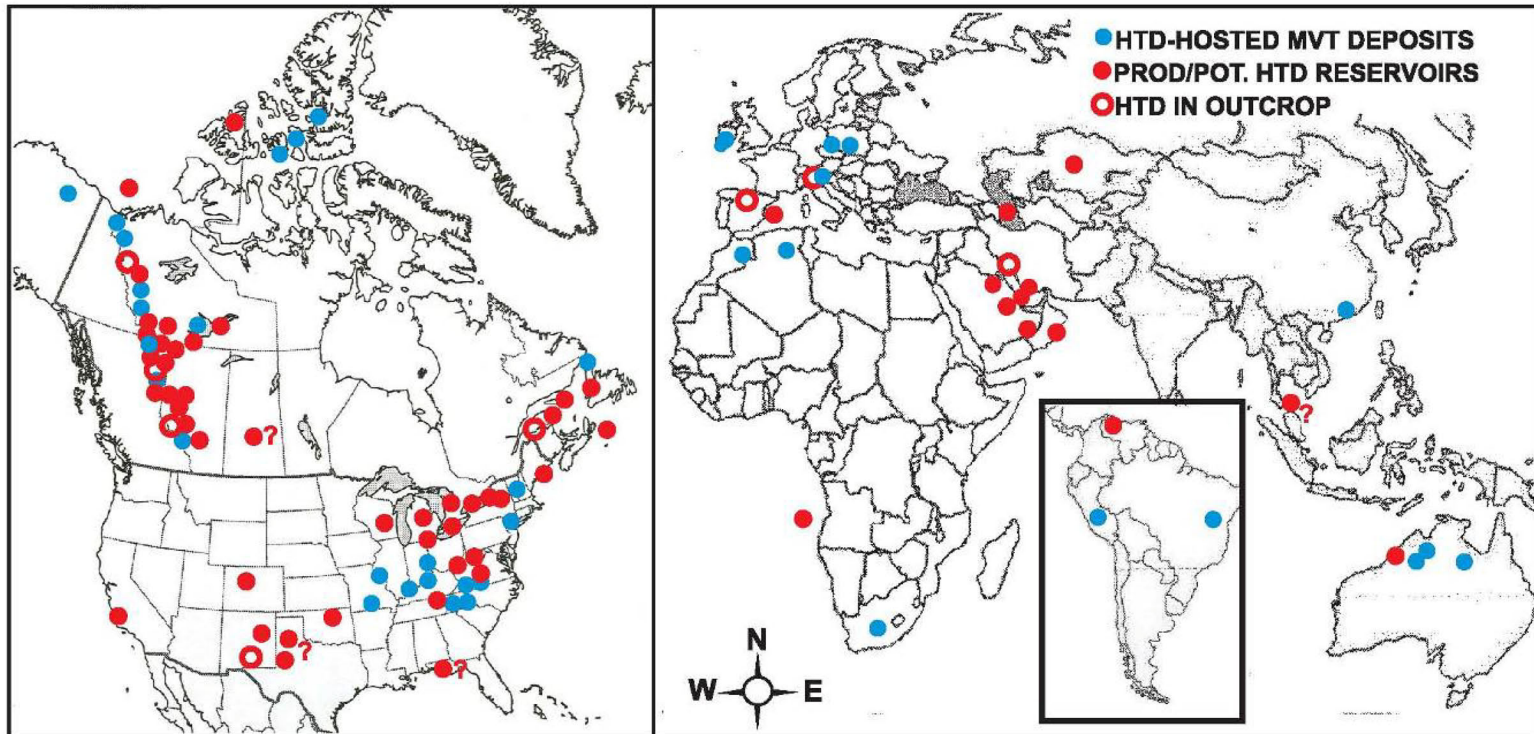
Outline

- Geologic Background
 - Stratigraphy
 - Hydrothermal Dolomite
- Structural Control
- Stratigraphic Control
 - Primary Depositional Facies
 - Sequence Stratigraphic Framework
- Distribution
- Conclusions



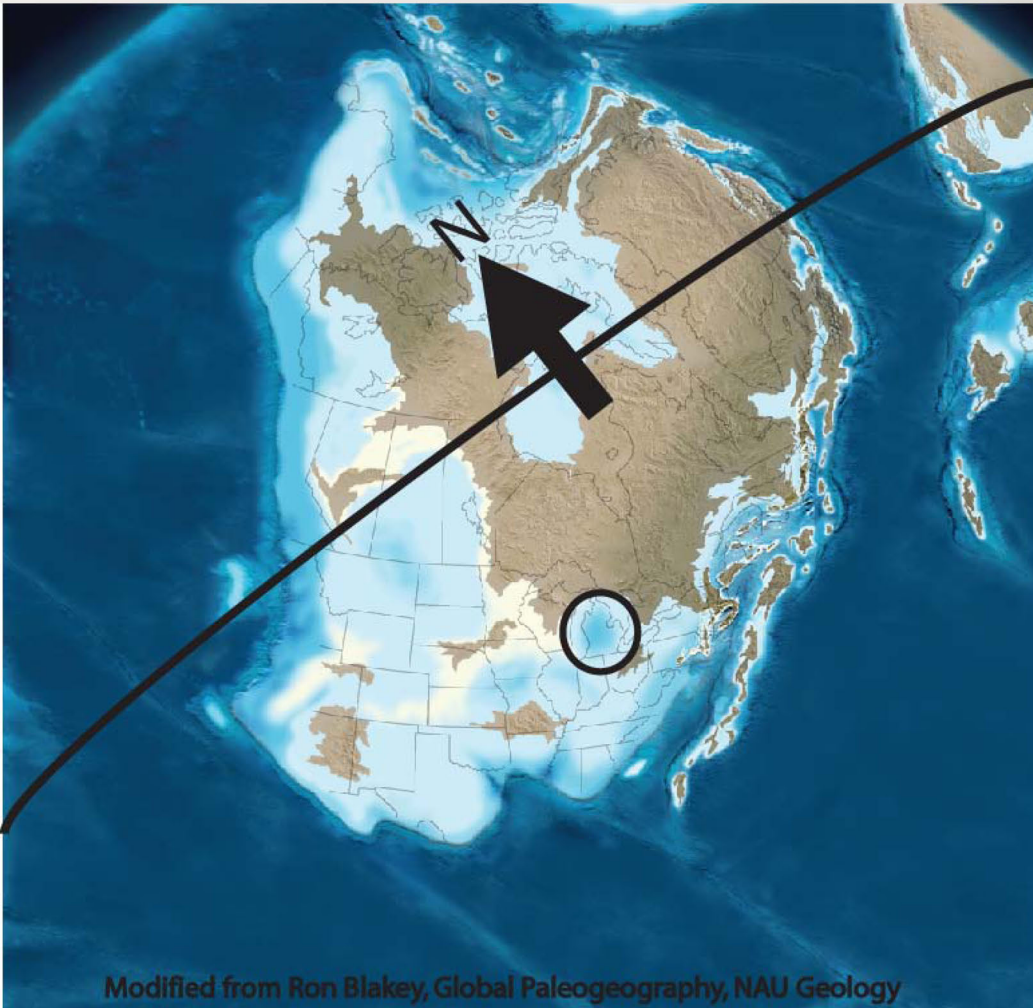
Geologic Background

Global distribution of HTD hydrocarbon reservoirs





Geologic Background

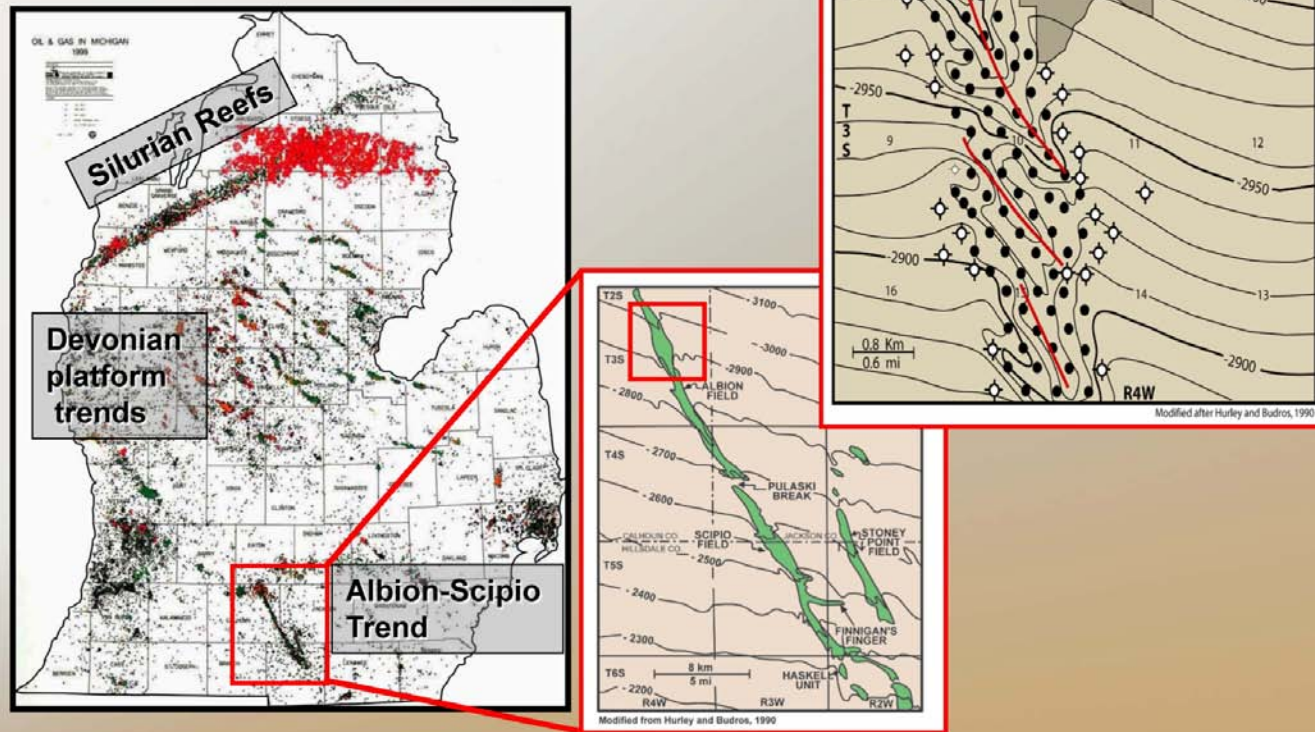


- Michigan Basin was situated at ~20° S during Ordovician
- Covered by a shallow intracratonic sea
- Depositional environment: low declivity carbonate ramp

Modified from Ron Blakey, Global Paleogeography, NAU Geology

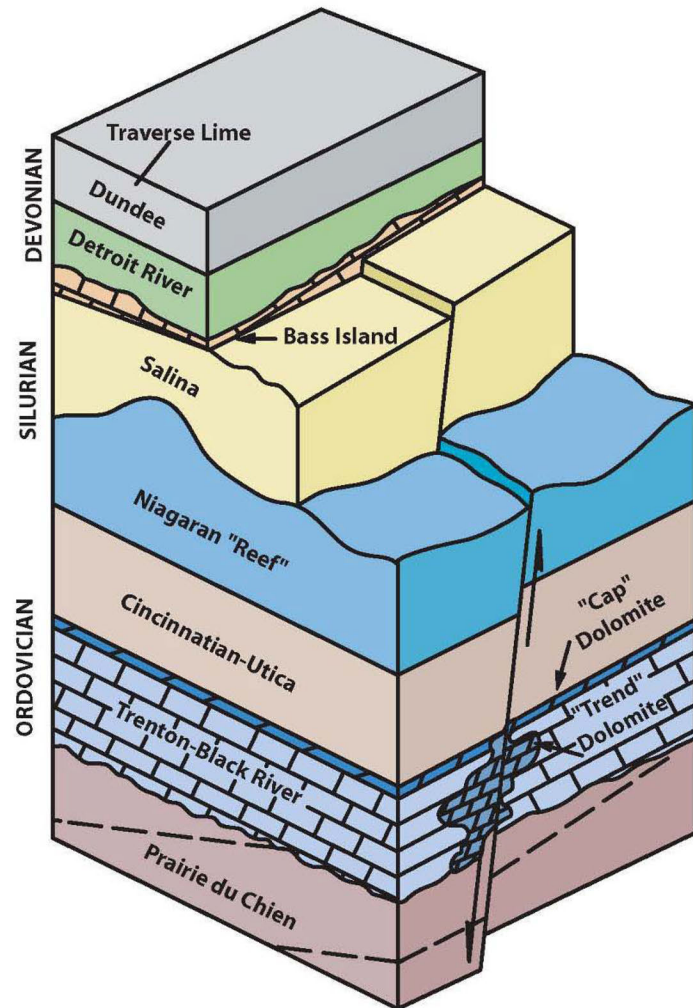


Geologic Background

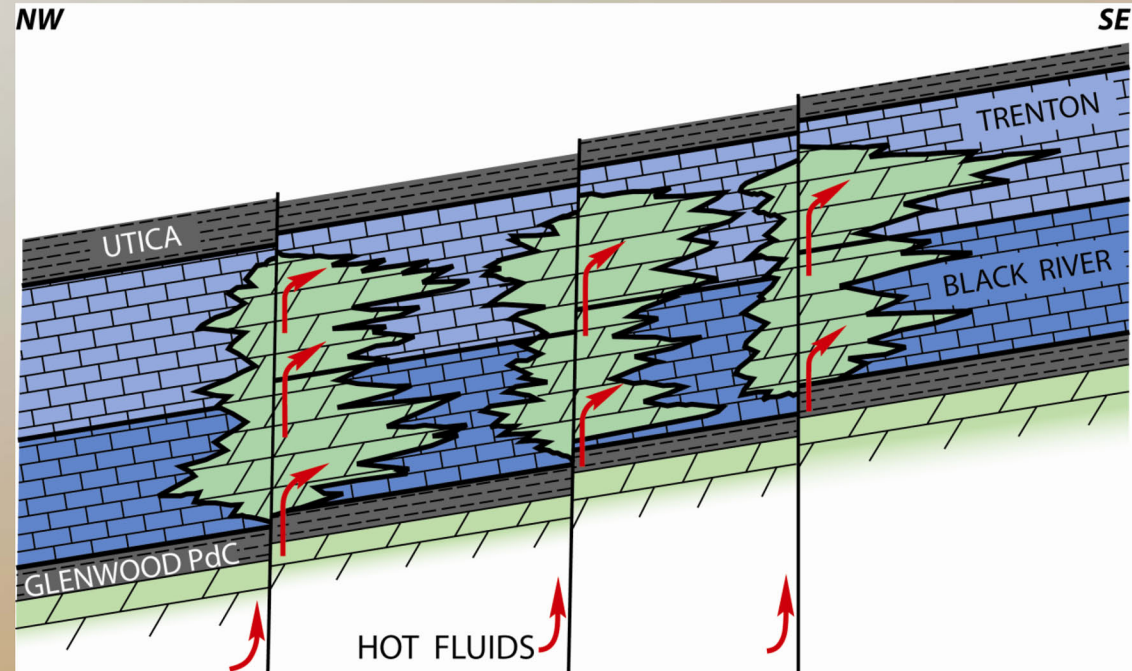


Notes by Presenter: There are several major hydrocarbon trends in the Michigan Basin that can be seen on the production map: the Silurian Niagaran reef trend, the Devonian platform trends, and the focus of this study, the Ordovician Albion-Scipio Trend. The Albion-Scipio is an elongate, linear trend that is 30 miles long but only one mile wide. This geometry is related to basement wrench faulting which forms a series of en echelon synclinal sags. As you can see, farther you step away from the major fault trends, the less pervasive the dolomitization resulting in poor reservoir quality thus decreasing production (dry holes).

Generalized Stratigraphy



Modified from Hurley and Budros, 1990

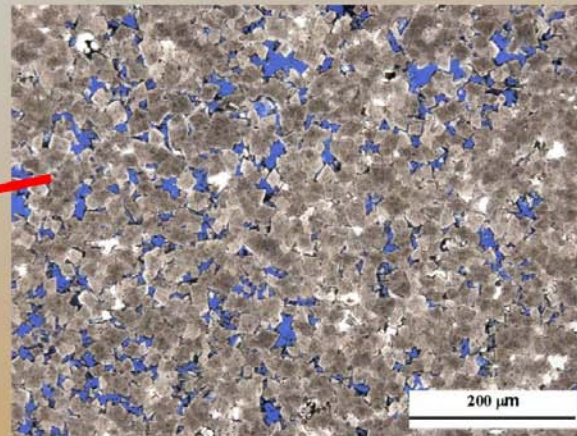
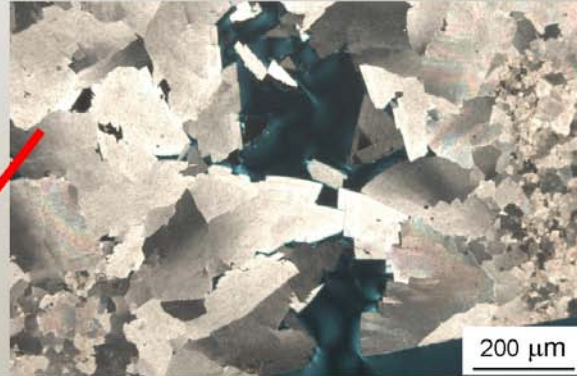


Modified from Hurley & Budros, 1990



Classic HTD texture

Hergert #2, Hillsdale Co., Permit #22196

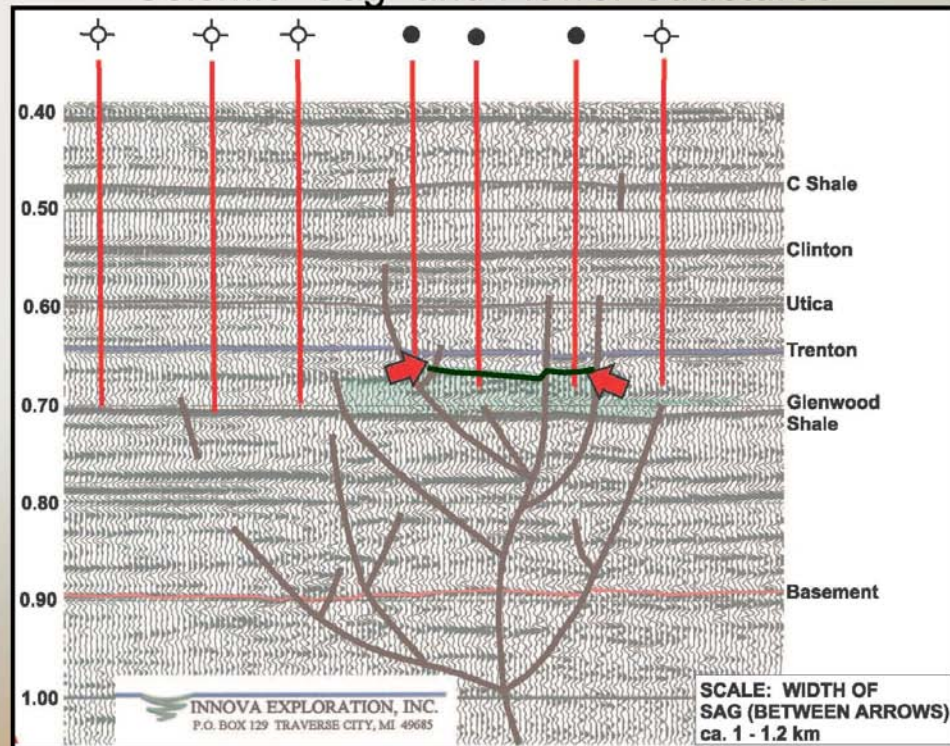


Notes by Presenter: Here are examples of HTD from core and thin sections. In this study, I observed from core two main of hydrothermal dolomite fabrics. As a refresher, hydrothermal dolomite is a result of subsurface fluid flow of higher temperature than the ambient temperature of the host rock. So looking at the core photo, you can see blocky white colored saddle dolomite. In the thin section, you can see that the curved rhombs can sometimes create large pore space or completely occlude the fractures. In contrast, sucrosic dolomitization often enhances porosity.



Structural Control

Seismic “Sag” and Flower Structures

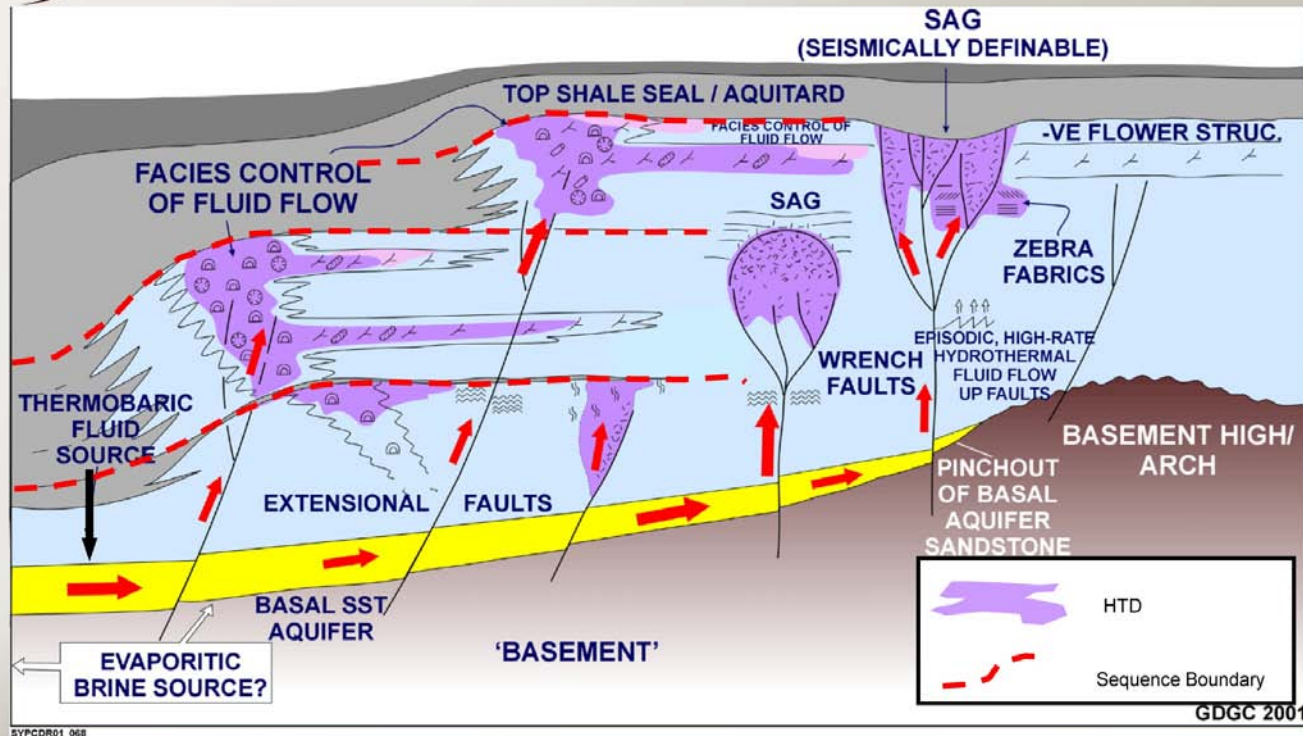


Davies and Smith, 2006

Notes by Presenter: Seismic line across narrow, linear Albion-Scipio trend (see Figures 22-23) in Michigan (Ordovician, Trenton/Black River reservoir) showing interpreted negative flower structures associated with wrench faulting. In this example, the sag is marked with arrows. The three productive wells are in the middle of the “green” zone directly beneath the structural sag. Historically, exploration methods have centered around identifying these “sag” and flower structures in the seismic data. From this seismic line across the Albion-Scipio trend, you can see the interpreted faults (represented by the black lines) and the sag feature is marked by the red arrows. Here the productive wells are in the middle of the “green” zone directly beneath this sag feature.



HTD Distribution Model

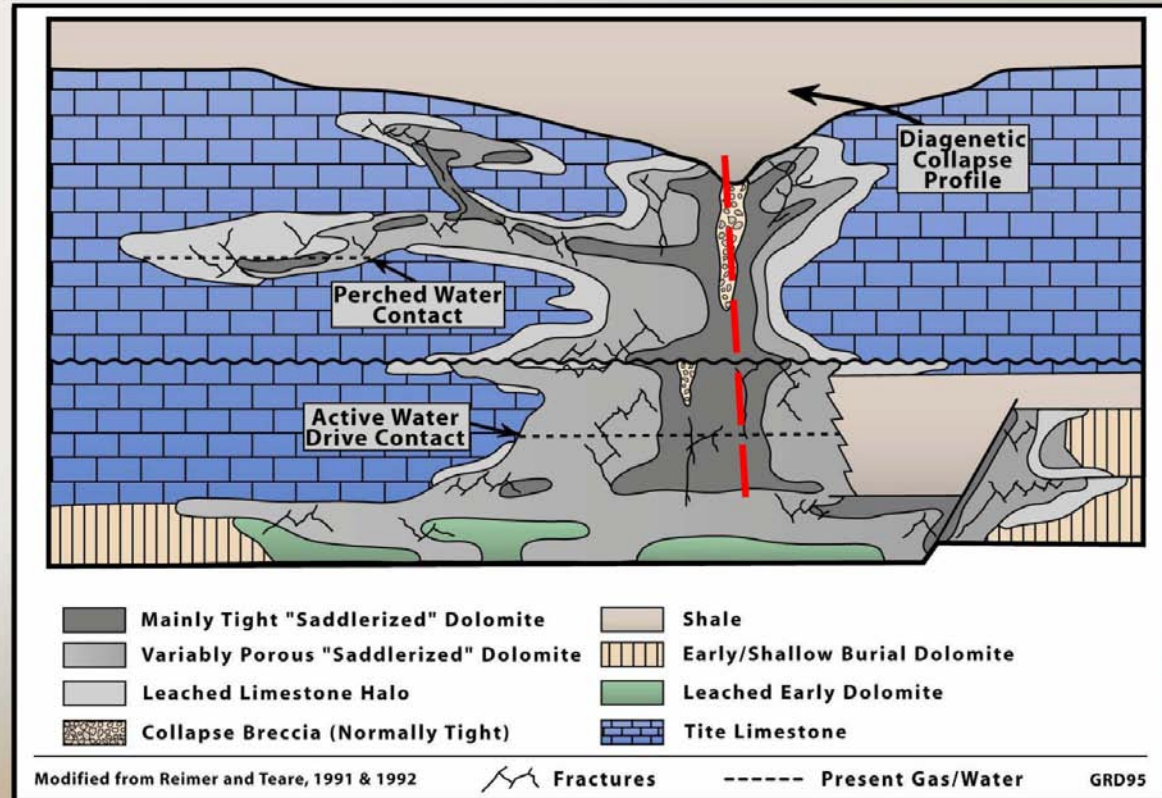


Graham Davies model for HTD in Devonian of Western Canada

Notes by Presenter: Thermobaric – term coined by Graham Davies to indicate combination of elevated temperature and pressure. This is a schematic representation of the possible distribution patterns of hydrothermal dolomite. As I just showed, this is the seismically definable sag and associated flower structure. This model also captures a stratigraphic component or control associated with certain primary depositional facies and at times, sequence boundaries. As you can see, fluids move vertically along faults but dolomitize zone extends laterally away from the faults to varying extents laterally to varying extent.



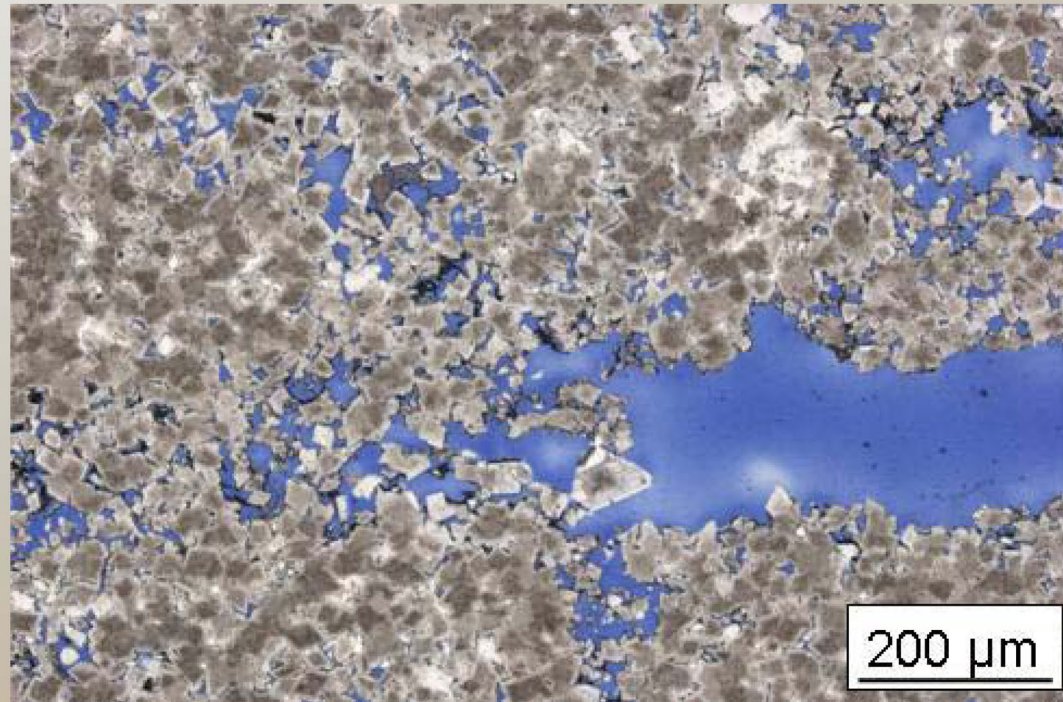
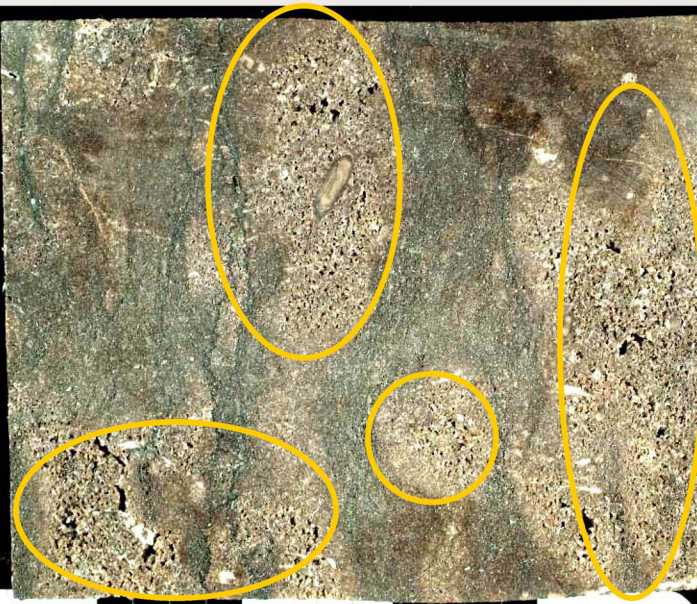
Stratigraphic control on lateral variability in HTD reservoirs (Slave point field, Western Canada, Devonian)

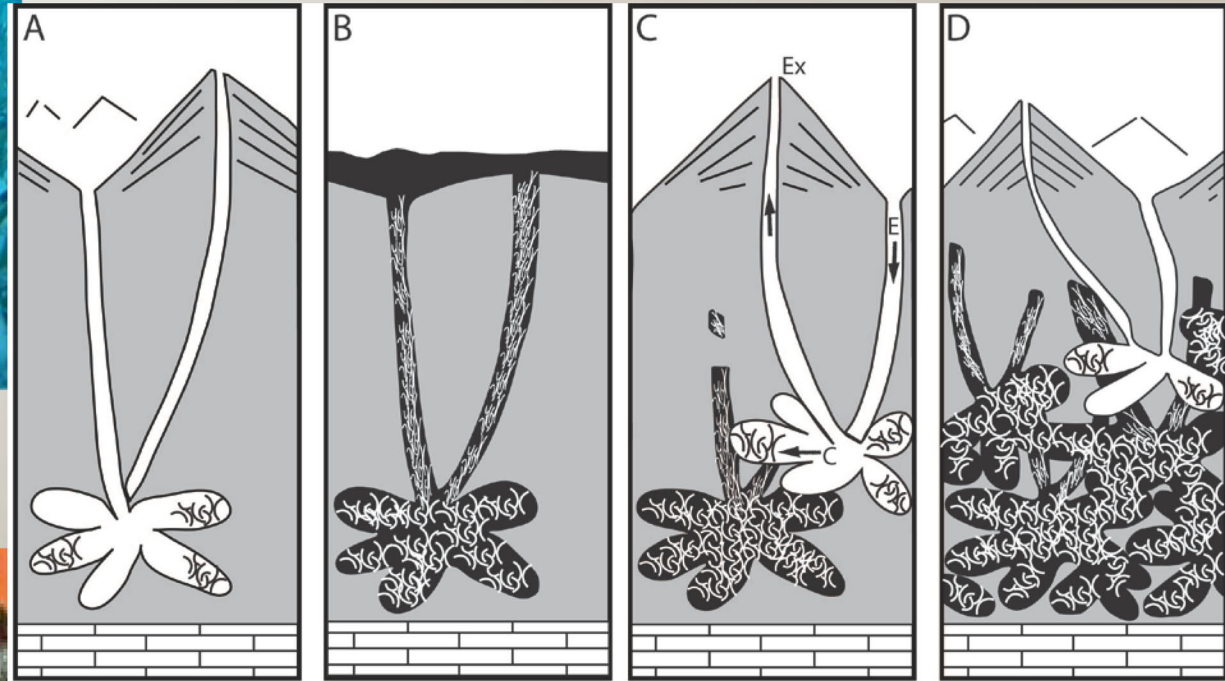


Notes by Presenter: Schematic diagram of Devonian HTD reservoirs in western Canada. Note the lateral variability in the development of HTD reservoir facies due to stratigraphic control.

You can see that often dolomitization in close proximity to a fault will completely occlude any porosity. However, the farther away you move from the major fault the more likely dolomitization will enhance porosity and it's these lateral extensions of the dolomitized zone that are the better reservoirs.

Burrowed Facies

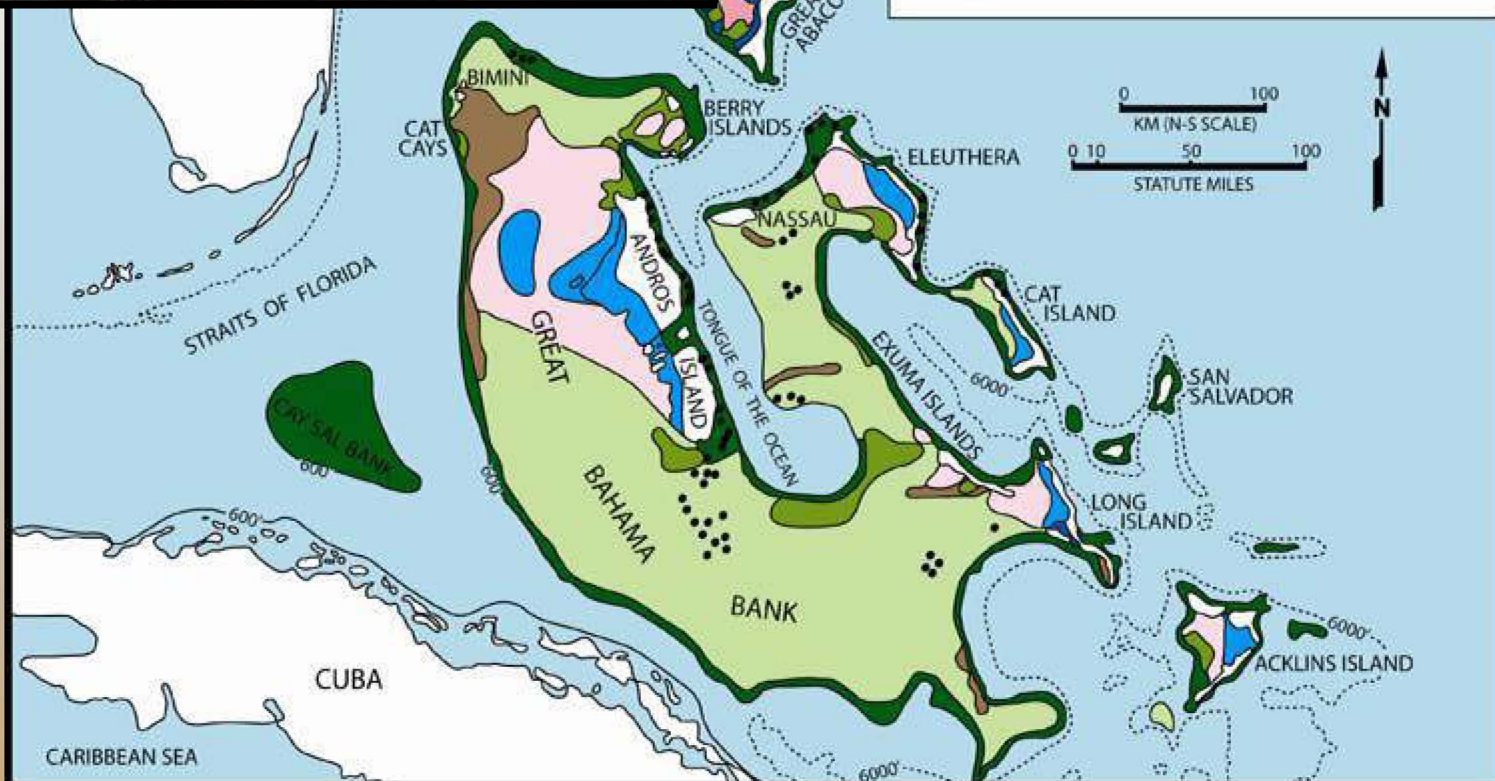
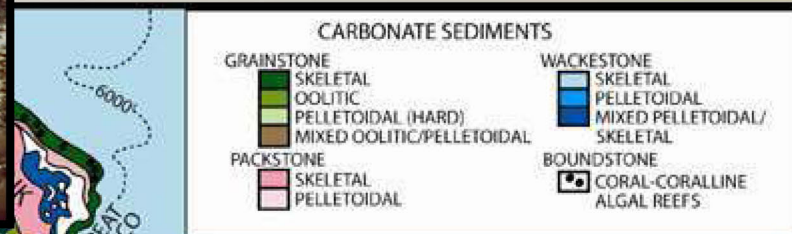




Modified after Tedesco and Wanless, 1991



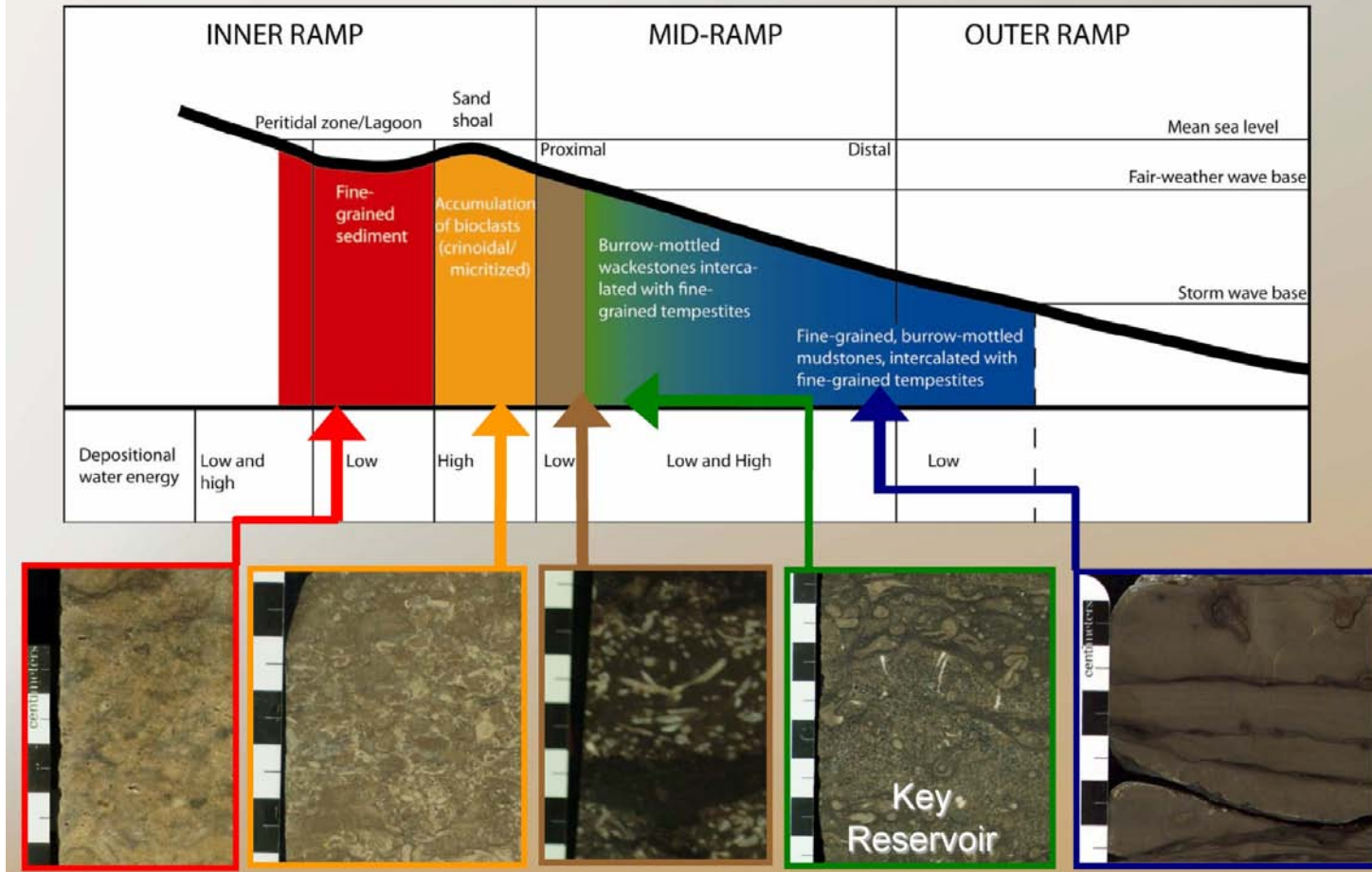
Shinn, 1983



Enos and Perkins, 1977



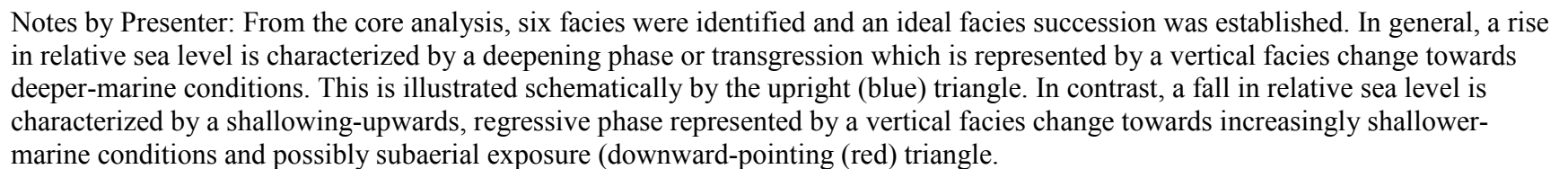
Albion-Scipio Depositional Facies



Notes by Presenter: Profile view which represents the environments of deposition of the Albion Scipio Trend. In addition to the burrowed facies, I have identified five additional facies that represent a shallowing upward sequence.



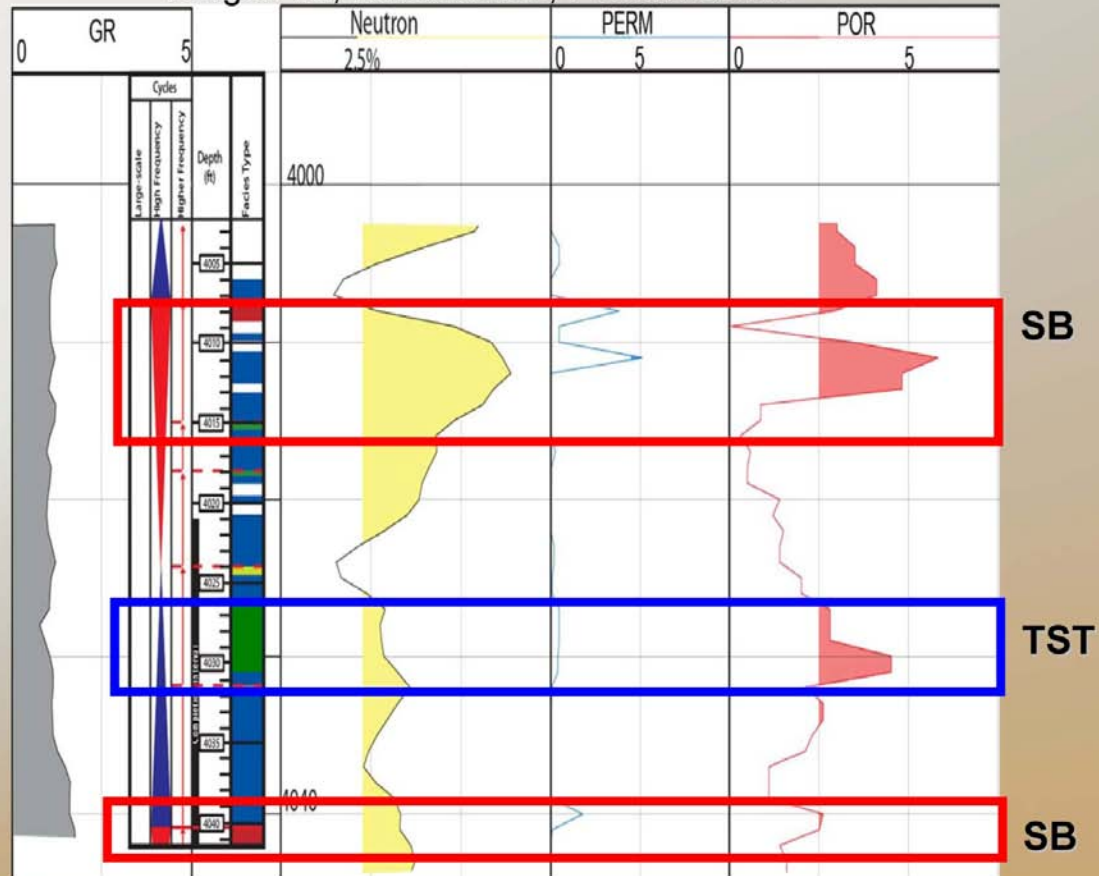
		Mudstone
		Wackestone
		Packstone (Mud)
		Packstone (Grain)
		Grainstone





Integrated Core Analysis

Hergert #2, Hillsdale Co., Permit #22196



Notes by Presenter: When you look at the primary depositional facies and their sequences in association with the porosity and permeability logs, I noticed a general trend of improved reservoir quality (increased porosity and perm streaks) associated with probable 4th order sequence boundaries. Two main observations: 1) in association with burrowed facies there is improved poro/perm and 2) at 4th order sequence boundaries there is enhanced poro/perm, possibly related to exposure events.



Acknowledgements

- Contributing Authors
 - G.M. Grammer, D.A. Barnes, R. Gillespie, W.B. Harrison III, J.E. Thornton
- Michigan Geological Repository for Research and Education
- RPSEA & AAPG Grants-in-Aid
- My Colleagues and Friends
 - Audrey Varga, Bailey Beitscher, Brittany Davis

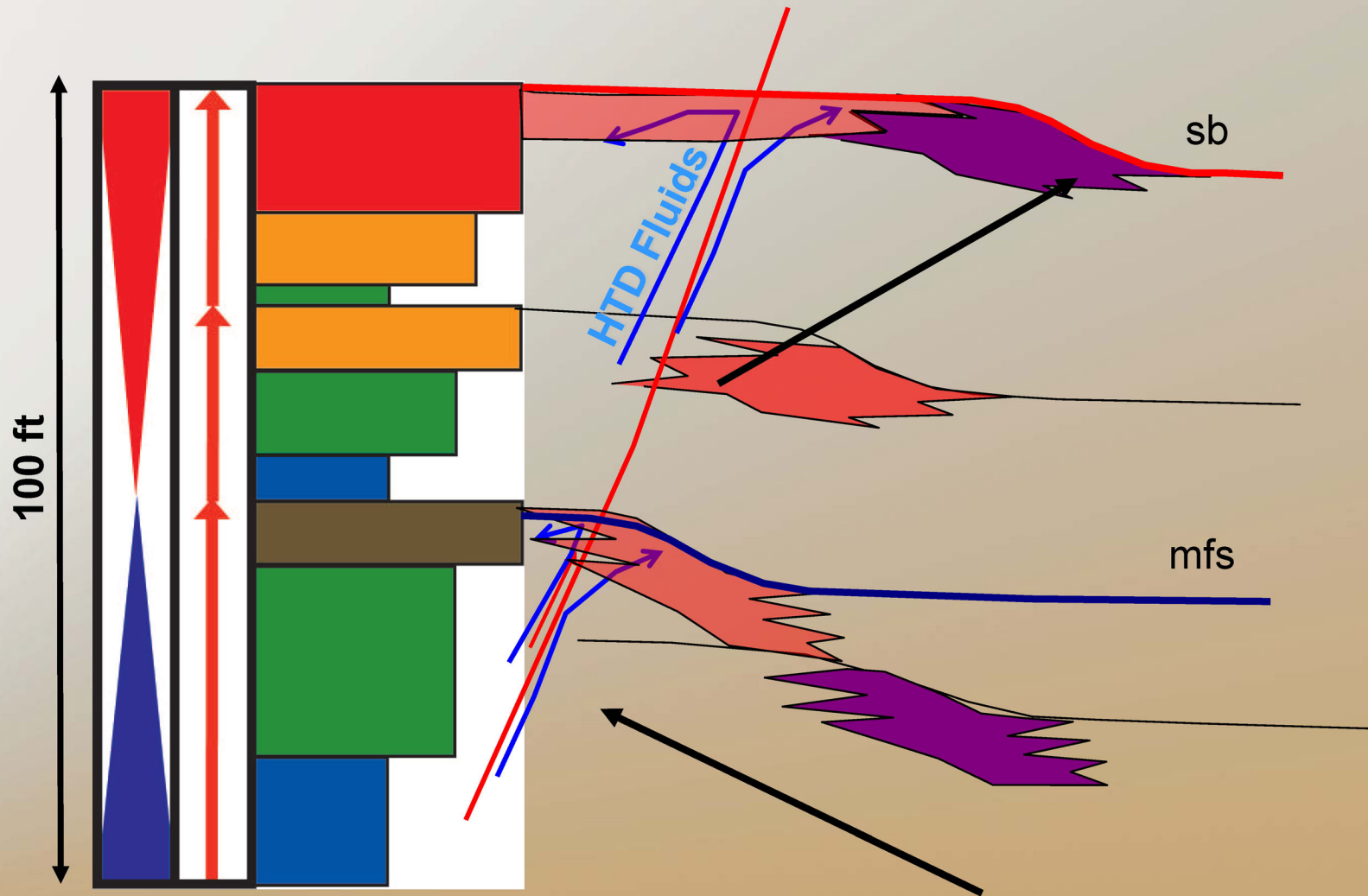


Conclusions

- There is both a structural and stratigraphic control on HTD reservoirs
- Lateral distribution of HTD can be attributed to:
 - Primary depositional facies
 - *Cruziana*-type burrowed facies are preferentially dolomitized increasing reservoir quality
 - Improved reservoir quality was observed in association with probable 4th order high frequency sequences
- Predicting intervals of improved reservoir quality can be done in association with environments of deposition and sequence stratigraphic framework



Summary Model





QUESTIONS?