Stratigraphic Control on the Lateral Distribution of Hydrothermal Dolomites away from Major Fault Zones: Part 2*

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Search and Discovery Article #50964 (2014)**
Posted May 30, 2014

*Adapted from an oral presentation given at Tulsa Geological Survey dinner meeting, May 5, 2014.
Please refer to Search and Discovery Article #50277 (2010) for Part 1 of this composite article by Dr. Grammer and his co-workers.

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Abstract

Hydrothermal dolomite (HTD) reservoirs are well known as prolific hydrocarbon producers in many parts of the world. In almost all 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. When evaluating many of the published examples of these reservoirs in detail, however, it appears that there is a secondary control on the lateral development of reservoir-quality rock away from the major fault zones. Detailed core-based 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 combination of primary facies and the sequence stratigraphic framework.

Production in the Albion-Scipio trend has exceeded 125 MMBO since the mid-1950’s, and there have been over 20 new discoveries around the trend in the past few years. Exploration methods continue to be centered on seismic sags observed in 3-D seismic surveys, but the initial development and subsequent enhanced production of these reservoirs will require more detailed geological interpretation to avoid the close step-out dry holes often associated with these types of reservoirs. Detailed evaluation

of some 30 cores in the Albion-Scipio trend indicates that reservoir-quality dolomitization moves laterally away from the major fault planes in the transgressive portions of probable 4th order high-frequency sequences. Reservoir quality is best developed in highly 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 *Thalassinoides*-type burrows have been preferentially dolomitized with coarsely crystalline sucrosic dolomite, resulting in high permeable pore networks that are distributed in 3 dimensions throughout the depositional facies. Isotopic and fluid-inclusion analyses 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.

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Research Partnership to Secure Energy for America

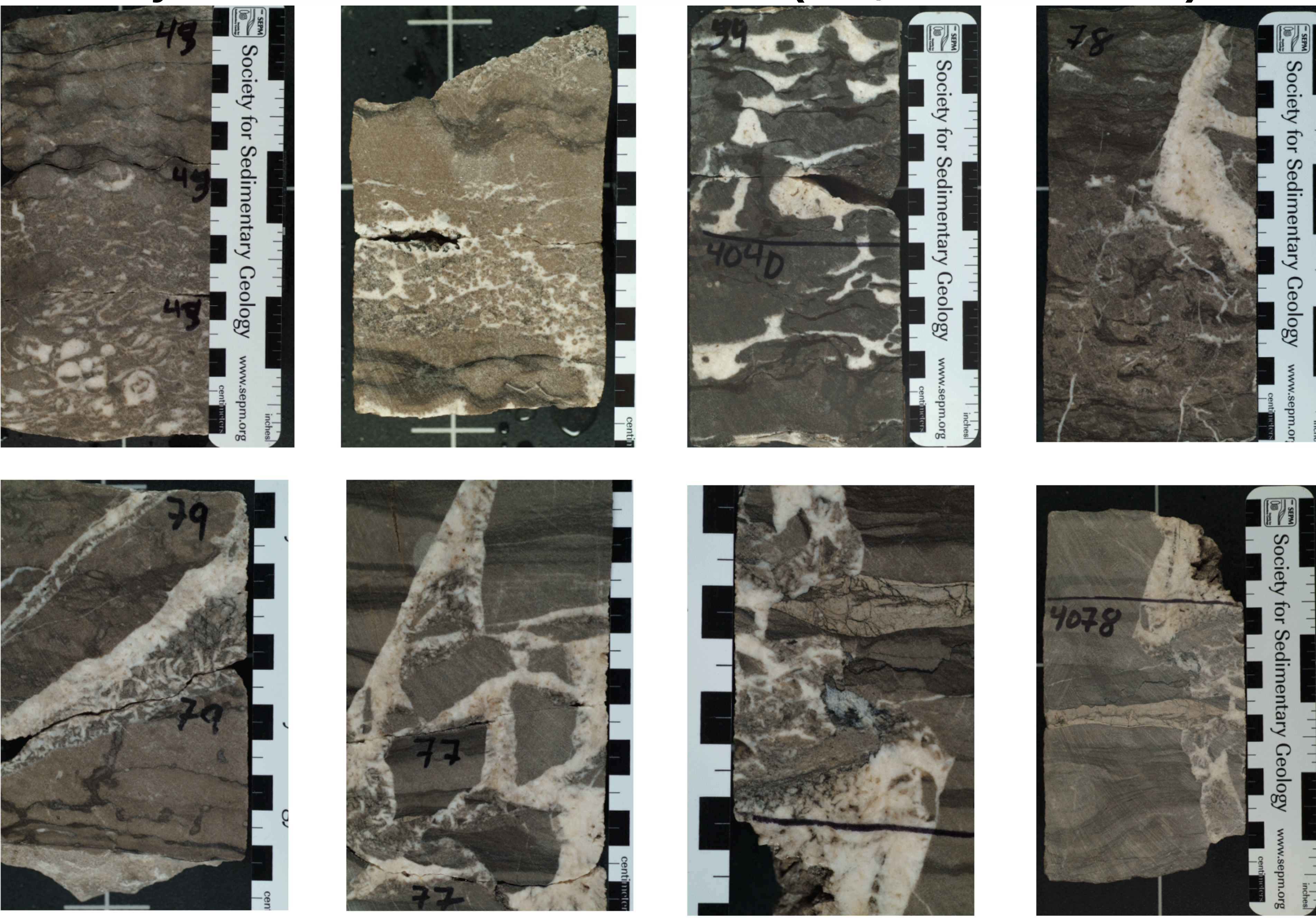
Hydrothermal Dolomite (HTD)

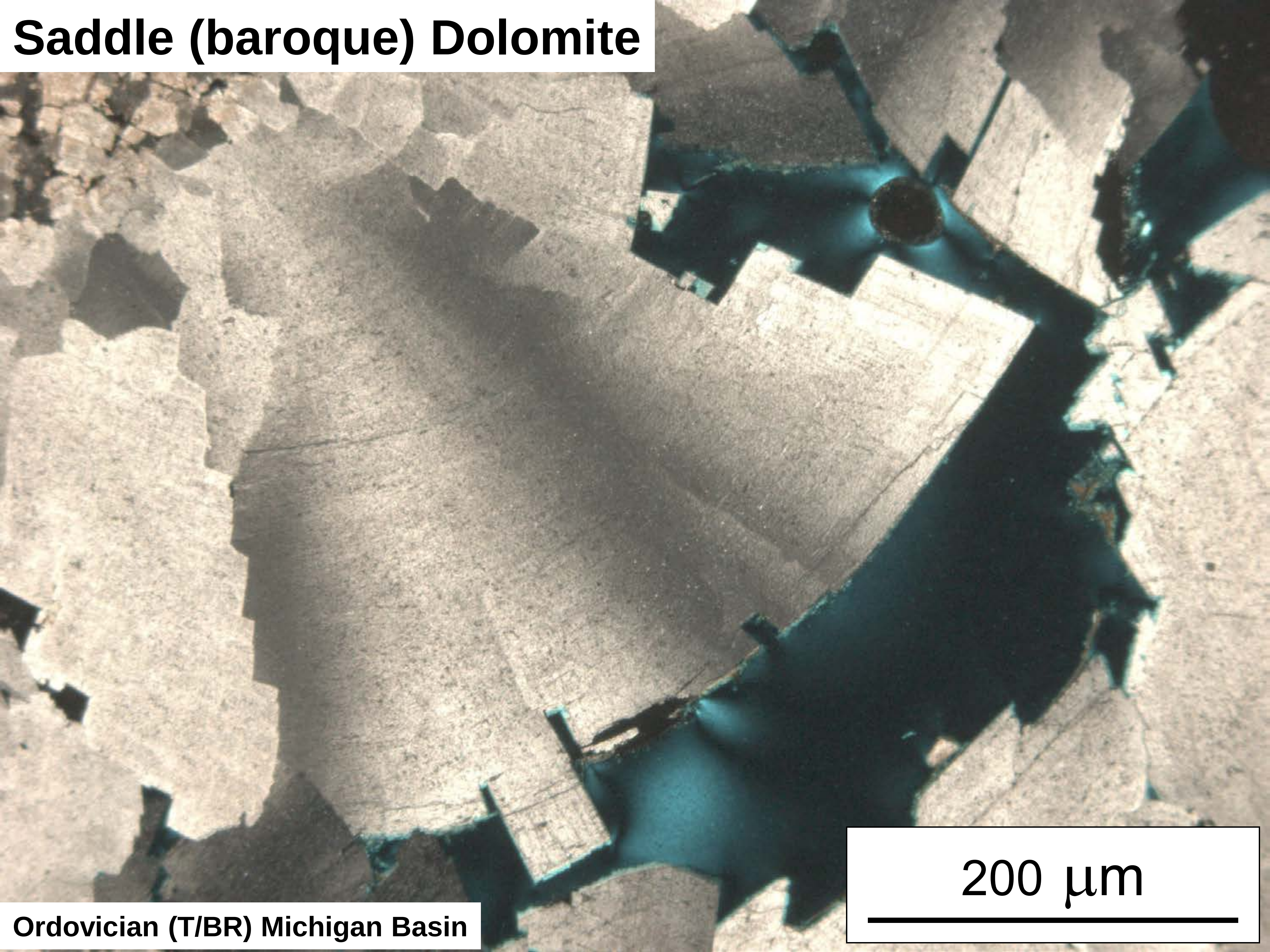
"dolomite and associated minerals and fabrics formed as a result of introduction or flow of a subsurface fluid that has higher temperature than the ambient temperature of the host rock"………..G.K. Davies (2000)

from White (1957)

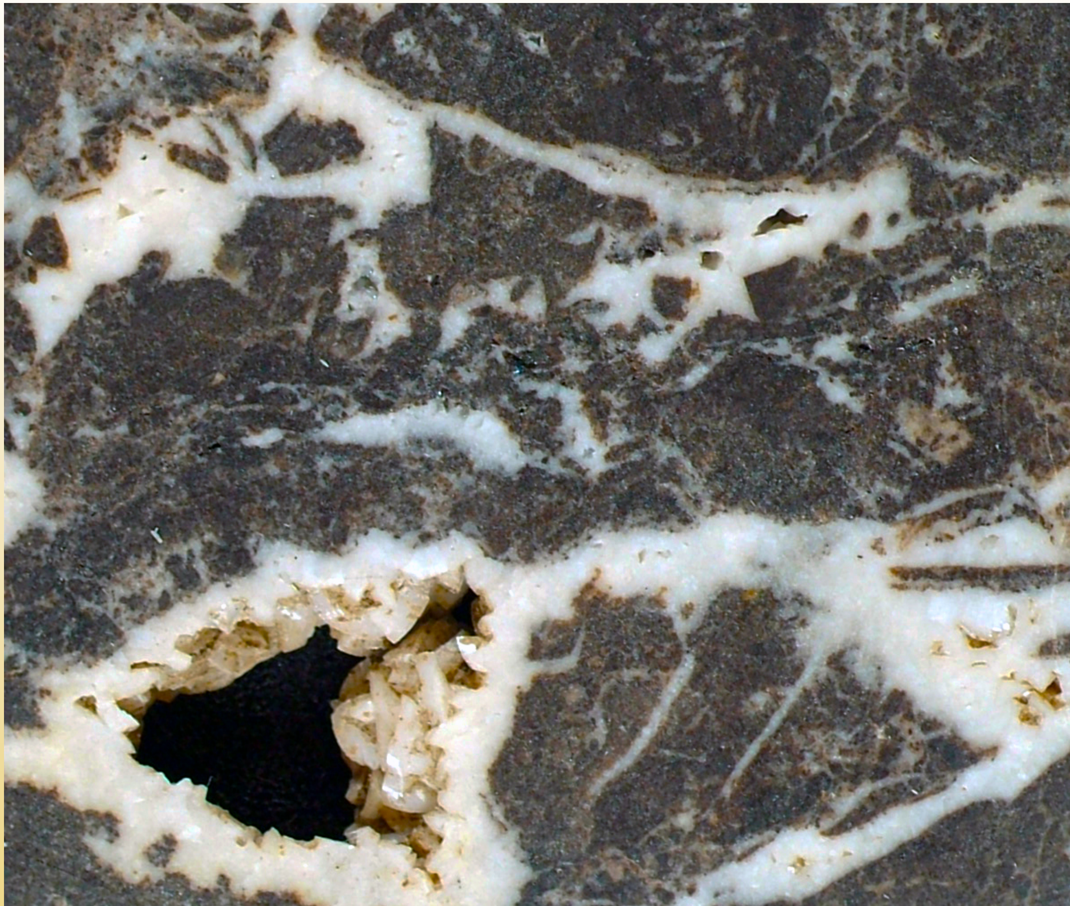
"aqueous solutions that are warm or hot relative to the surrounding environment"

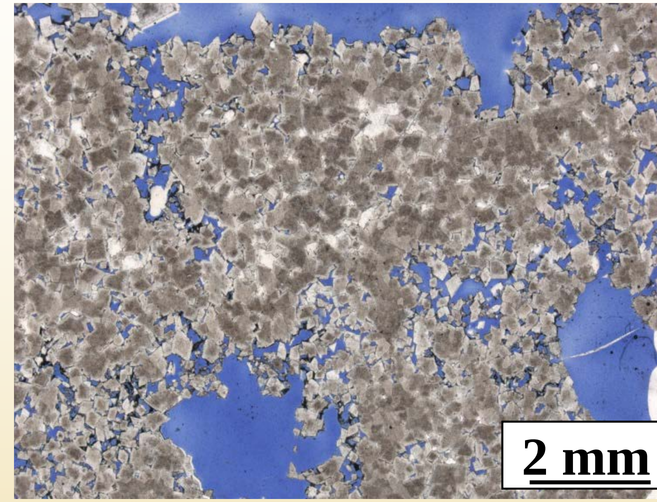
Hydrothermal Dolomite Fabrics (MB, Dev and T/BR)

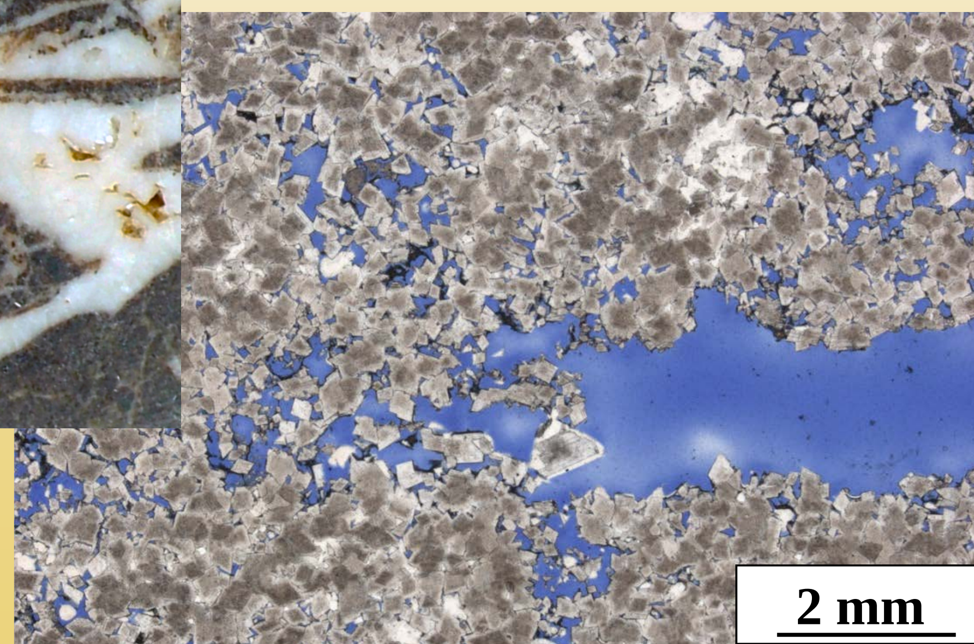



Saddle (baroque) Dolomite
Ordovician (T/BR) Michigan Basin
200 μm

Hydrothermal Dolomite Reservoirs are often Very Productive







Examples of Hydrothermal Dolomite Reservoirs (estimated reserves)

1. Western Canada Sedimentary Basin (WCSB) - Devonian

   30 TCF

2. Lima Trend of Ohio and Indiana (Ordovician)

   > 500 MMBO and 2 TCF

3. Albion-Scipio Trend (Ordovician, Michigan)

   > 150 MMBO

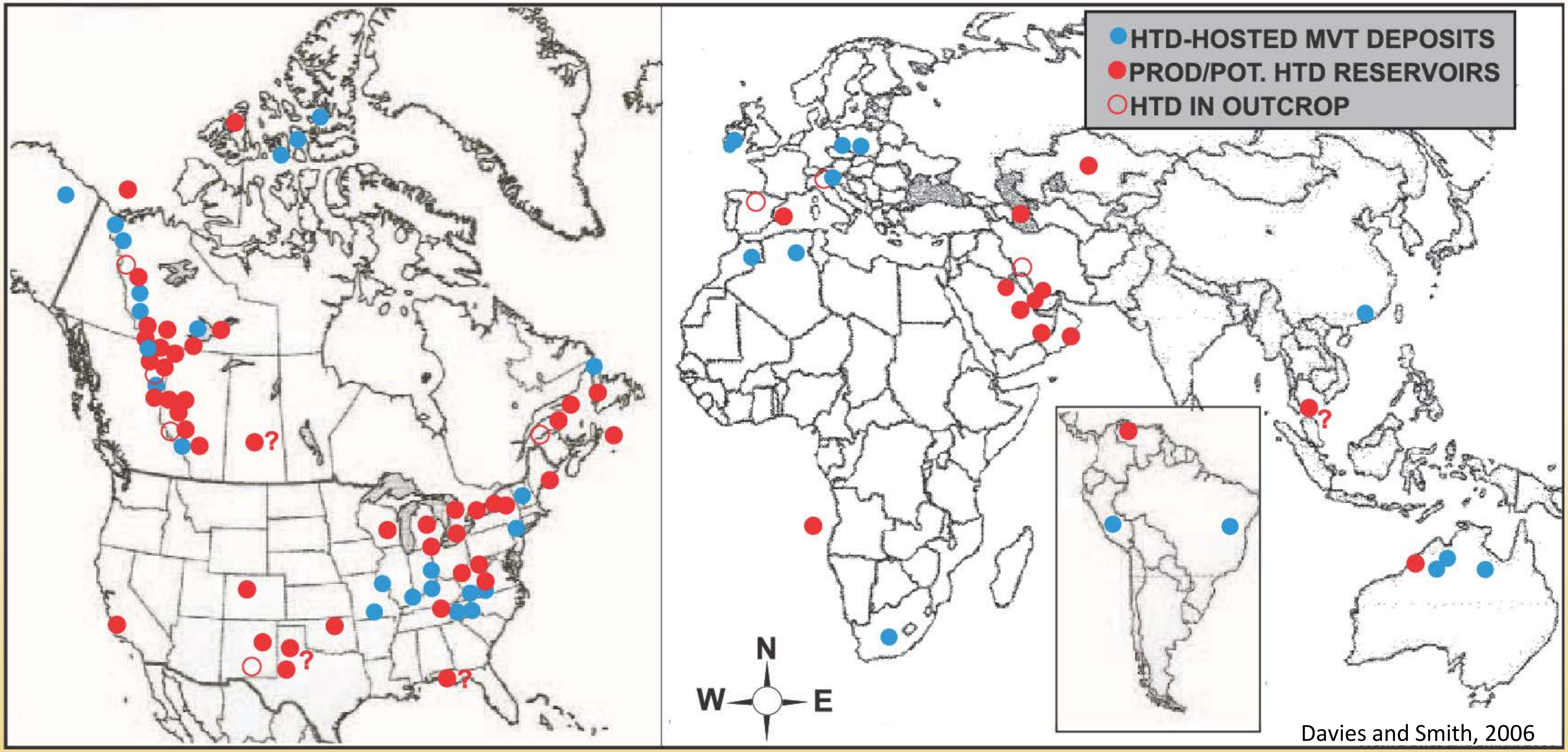
4. Ontario (Ordovician)

   23 MMBO and 42 BCF

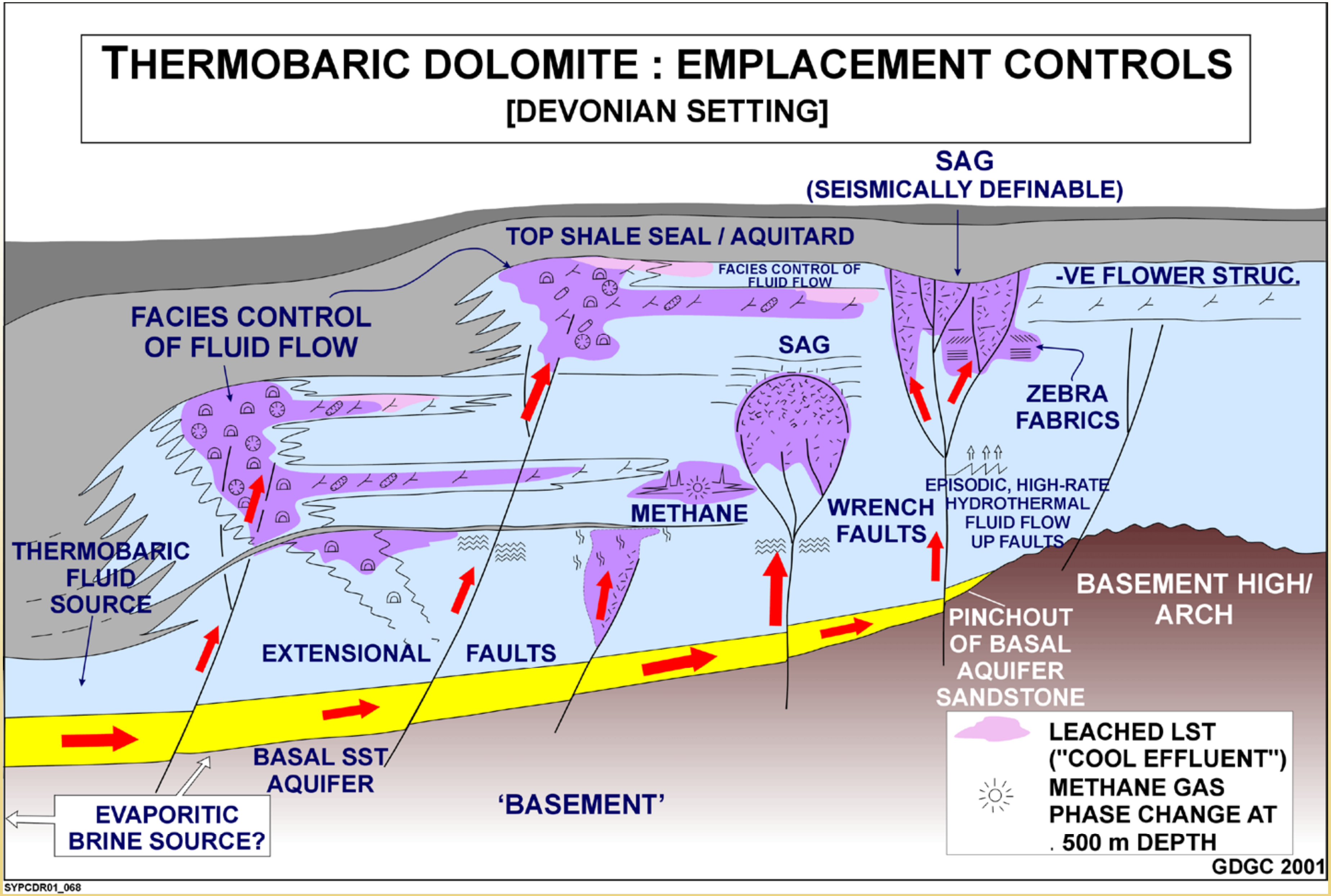
5. Ghawar Field (Jurassic, Saudi Arabia)

   55 billion barrels est. cumulative production

Hydrothermal Dolomite Mineralization

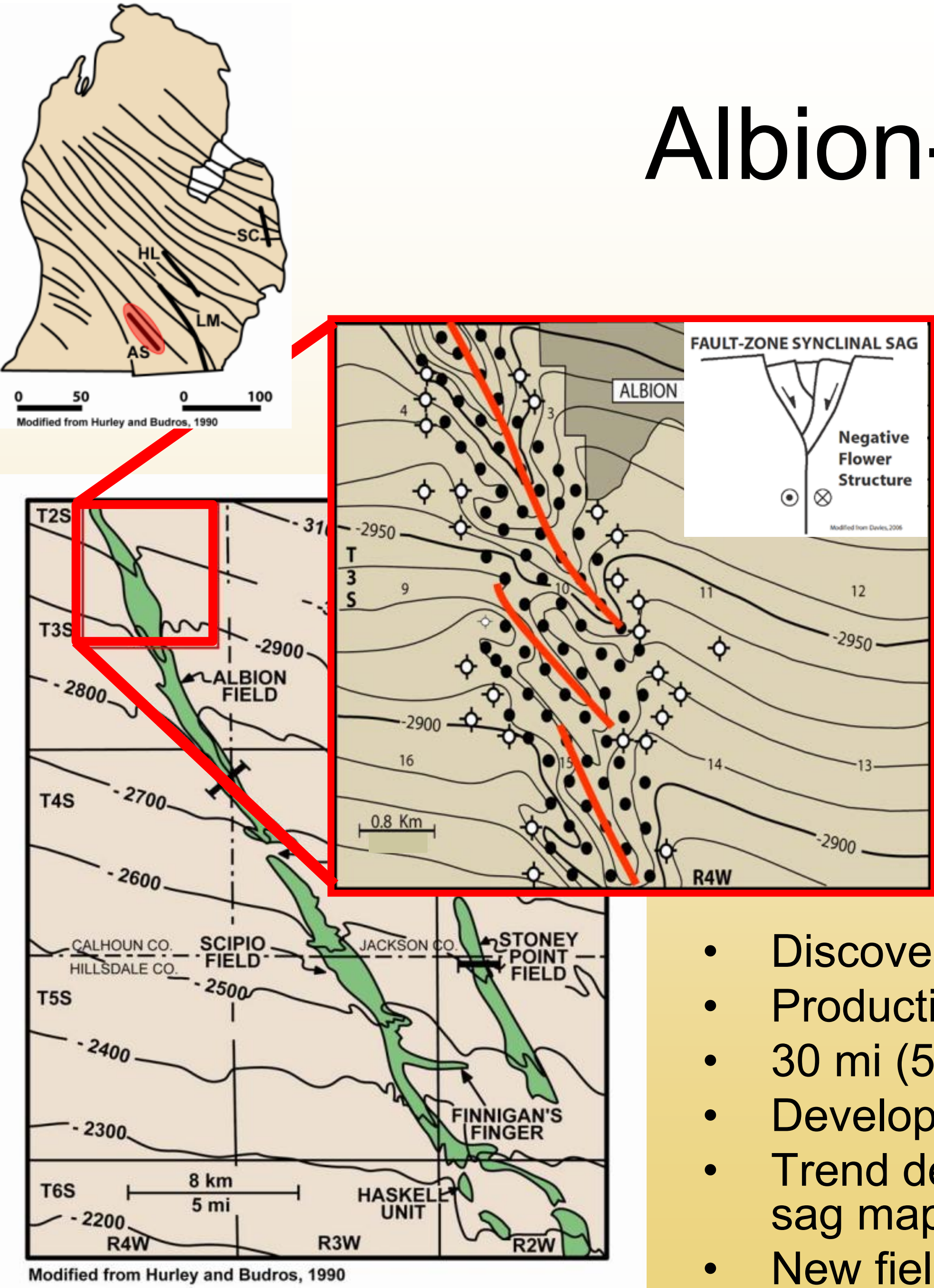


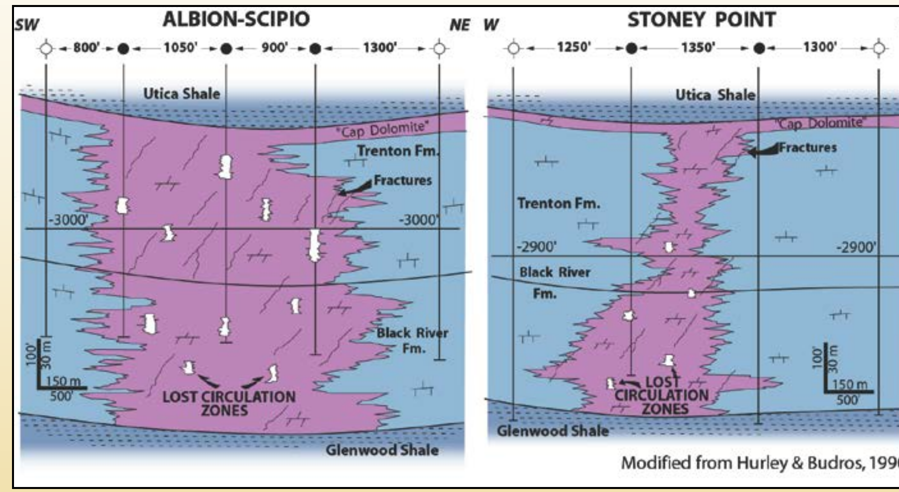
- High T, P Mg-bearing fluids migrate from underlying aquifers vertically along fault conduits
- Local dolomitization of host limestone enhances **φ**, **K**



Graham Davies model for HTD in Devonian of Western Canada

Albion-Scipio Trend

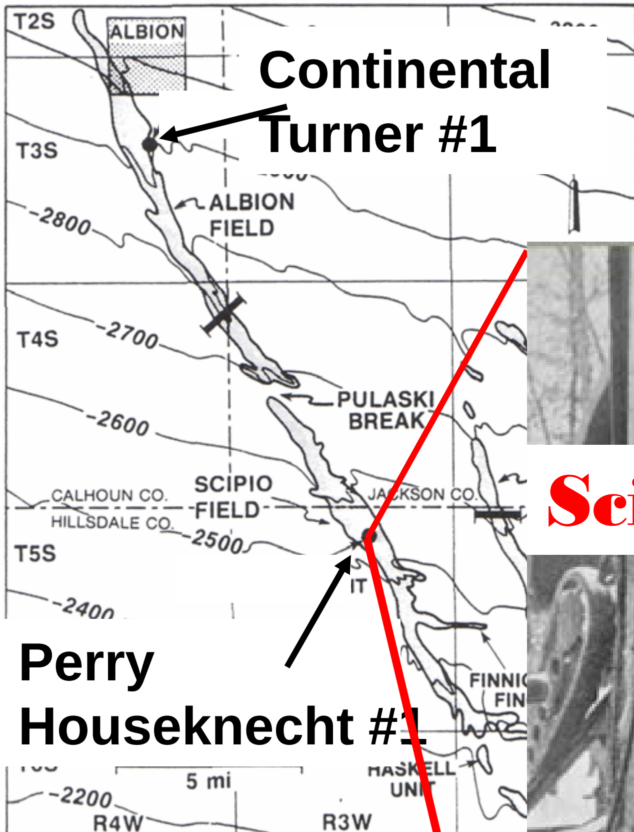


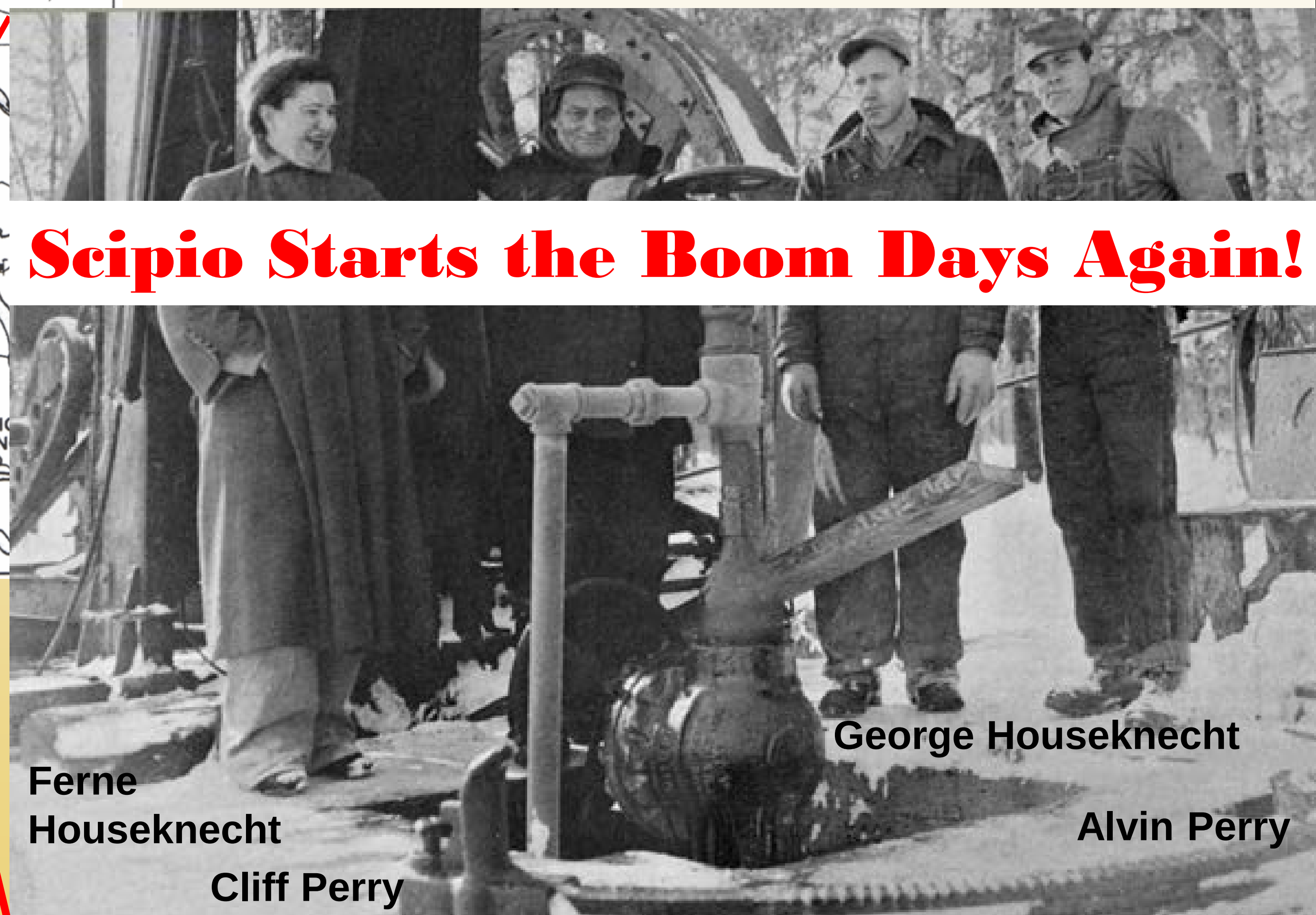


- Discovered in 1957
- Production: >147 MMBO, 260 BCF (A-S)
- 30 mi (50 km) **x** 1 mi (1.6 km)
- Developed on 20 acre spacing
- Trend development based primarily on structural sag mapping
- New fields (since 2006) produced over 4 MMBO

Discovery: Albion – Scipio Field

January 7, 1957
Discovery well
Perry #1 Houseknecht
On the advice of "Ma" Zulah Larkin

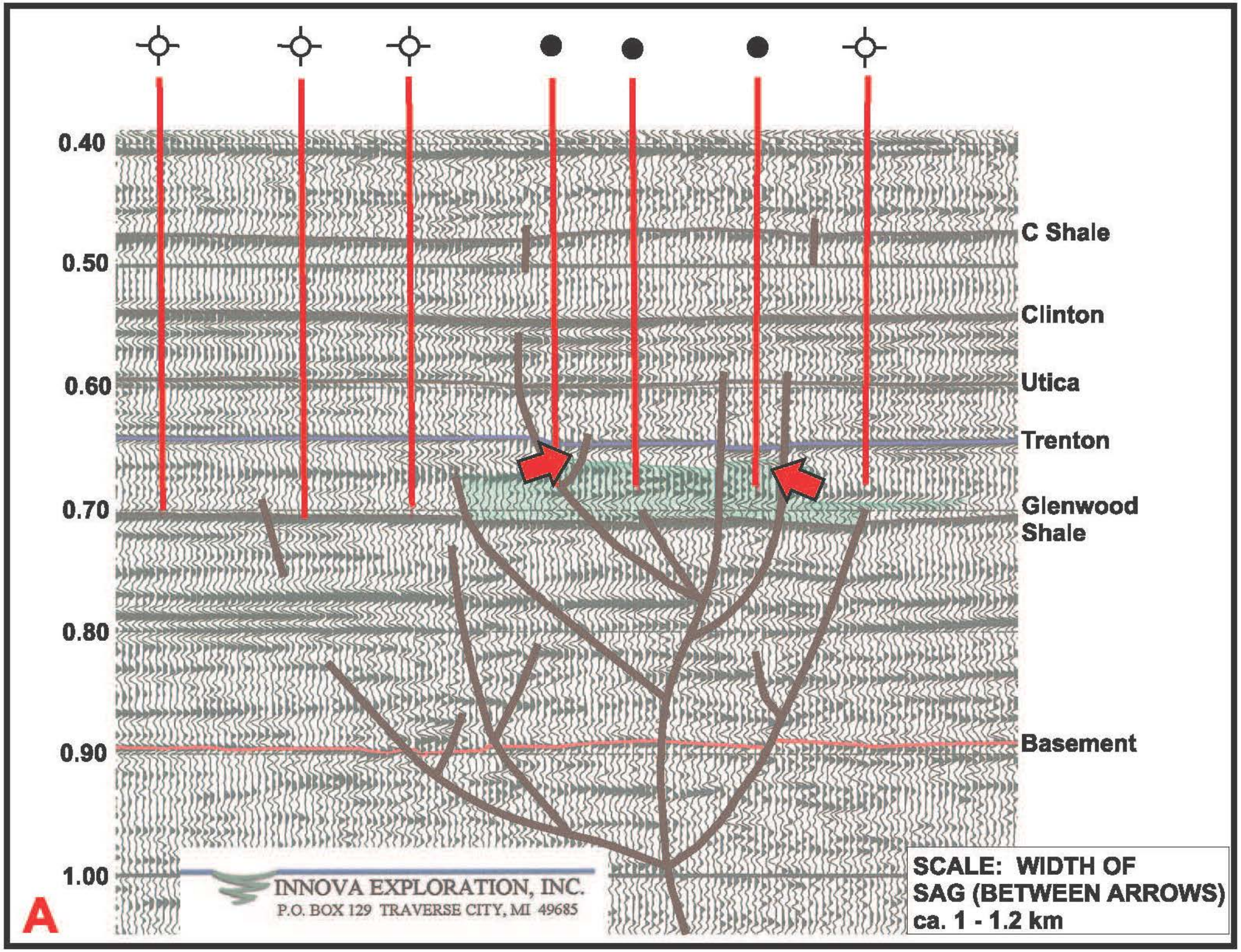




Map:
Hurley and Budros, 1990
Photo:
Westbrook, 1993

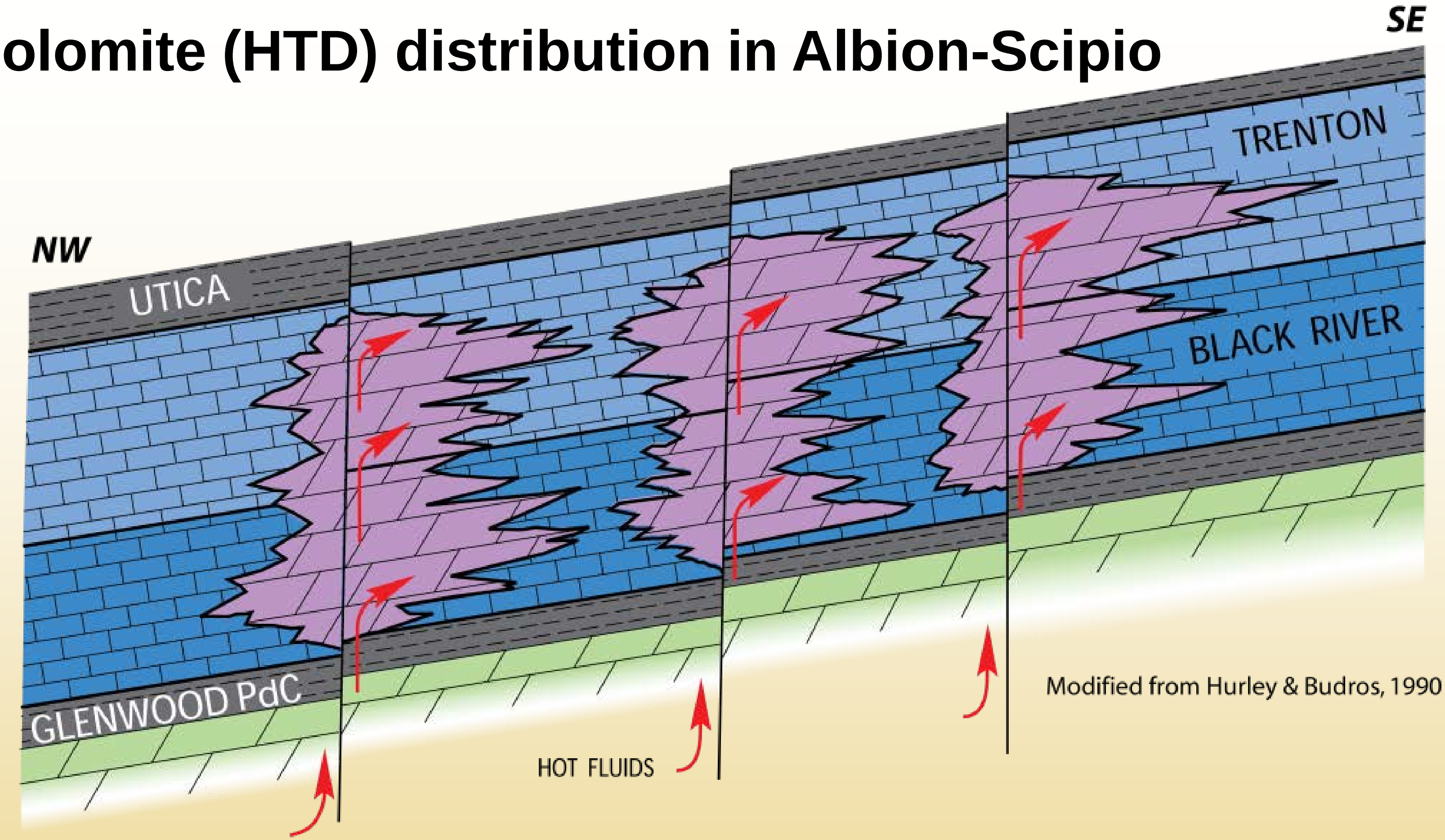
Slide courtesy of Robb Gillespie

Seismic "sag" and negative flower structures (Ord., Michigan)



Courtesy of R. Budros

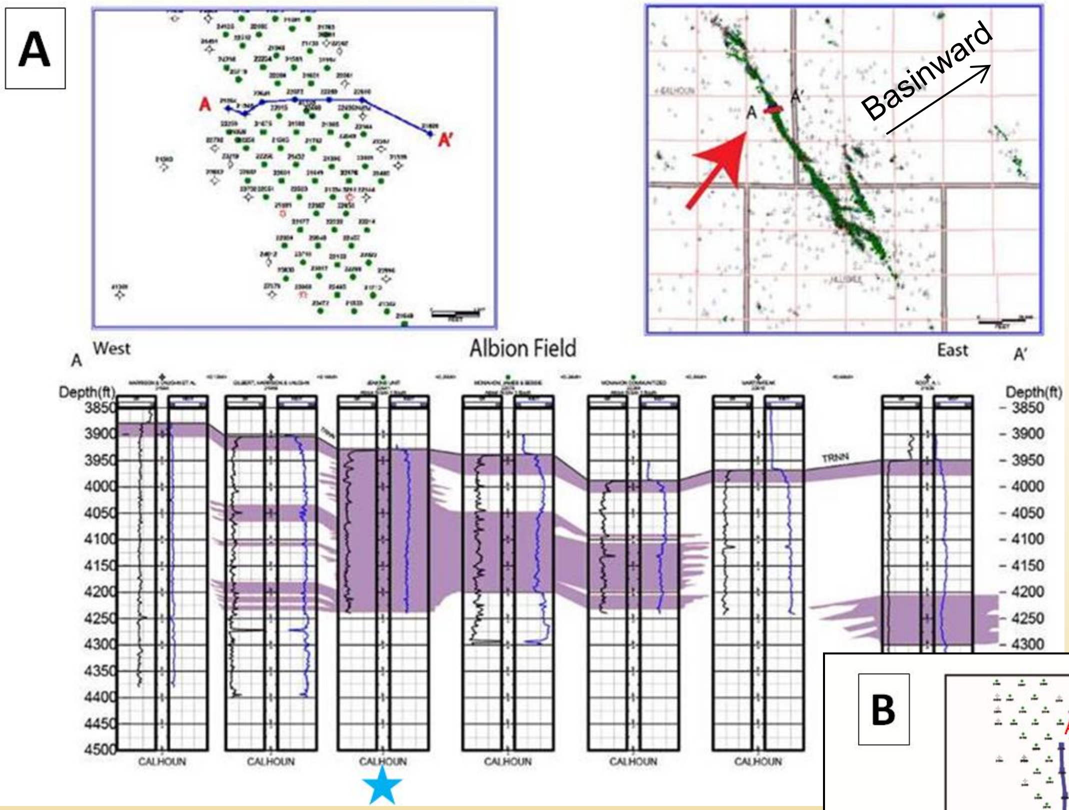
Dolomite (HTD) distribution in Albion-Scipio

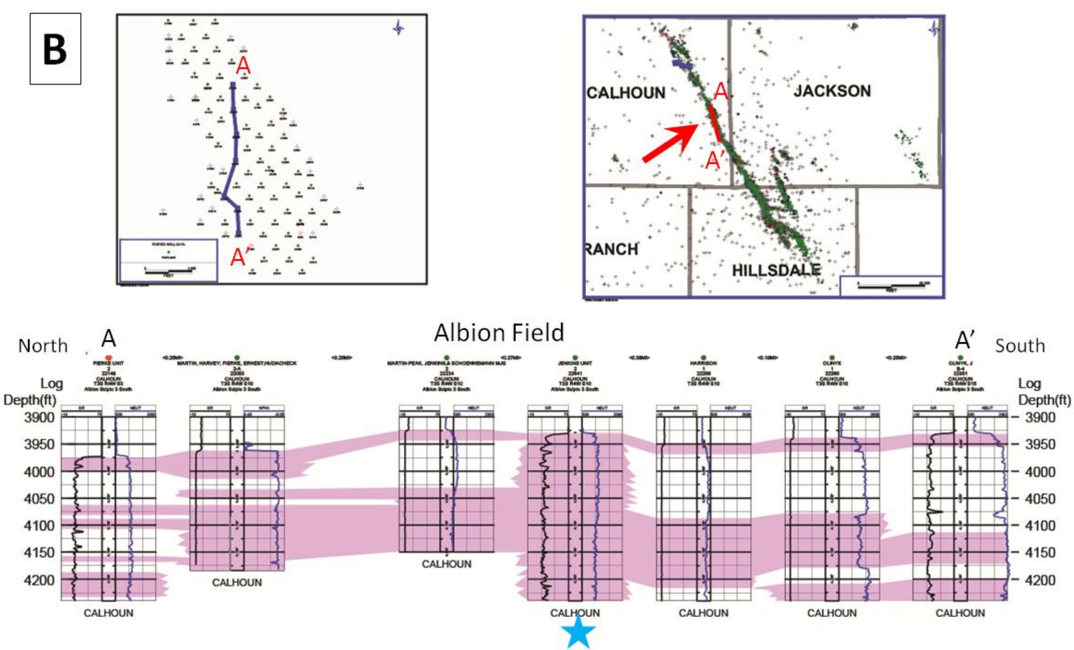


Fundamental Questions

1. What controls lateral variability of HTD away from faults?
2. What are the depositional geometries and facies distributions in the Trenton and Black River Groups?

Lateral Distribution of HTD in Albion Scipio





Dip vs. Strike
Lateral continuity

Grammer et al. (2014)

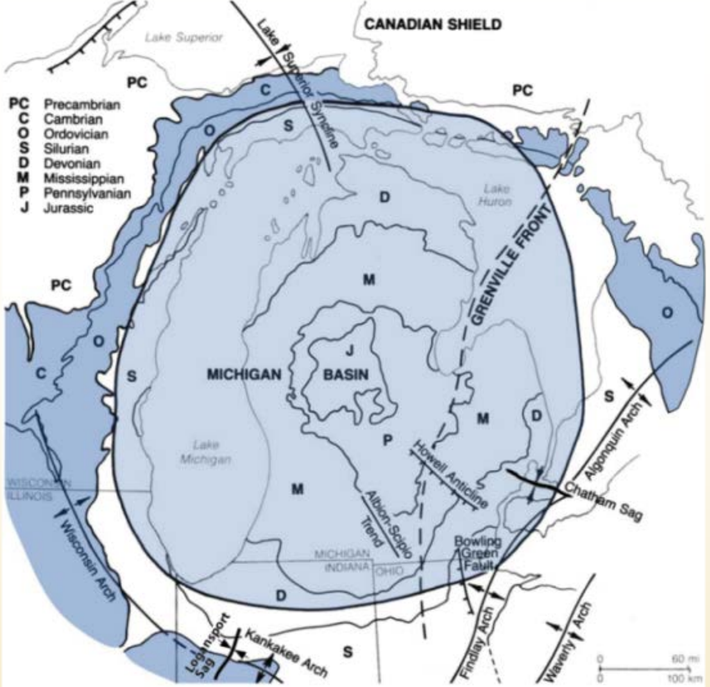
Wapta Mt. (British Columbia)
Photo courtesy of G. Davies

Wapta Mt. (British Columbia)

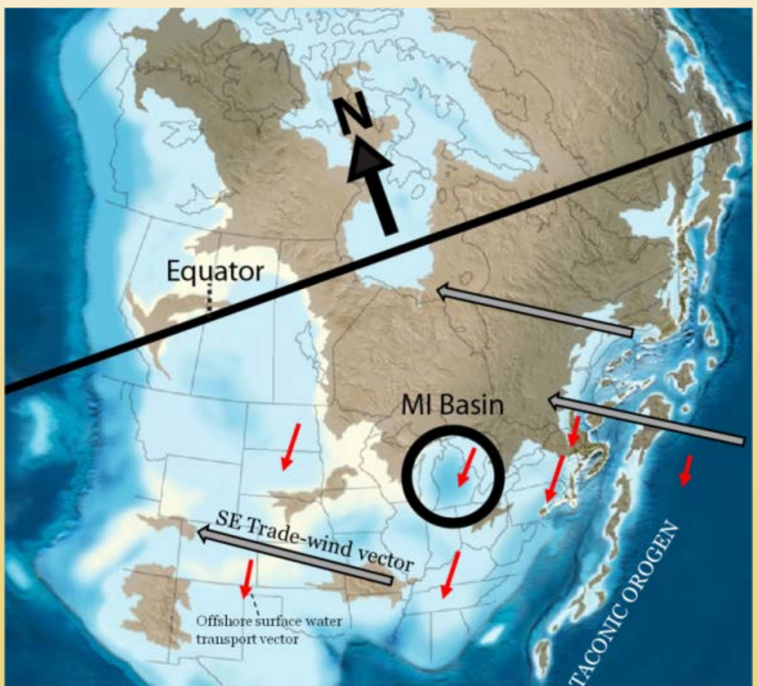
Photo courtesy of G. Davies

Geologic Background

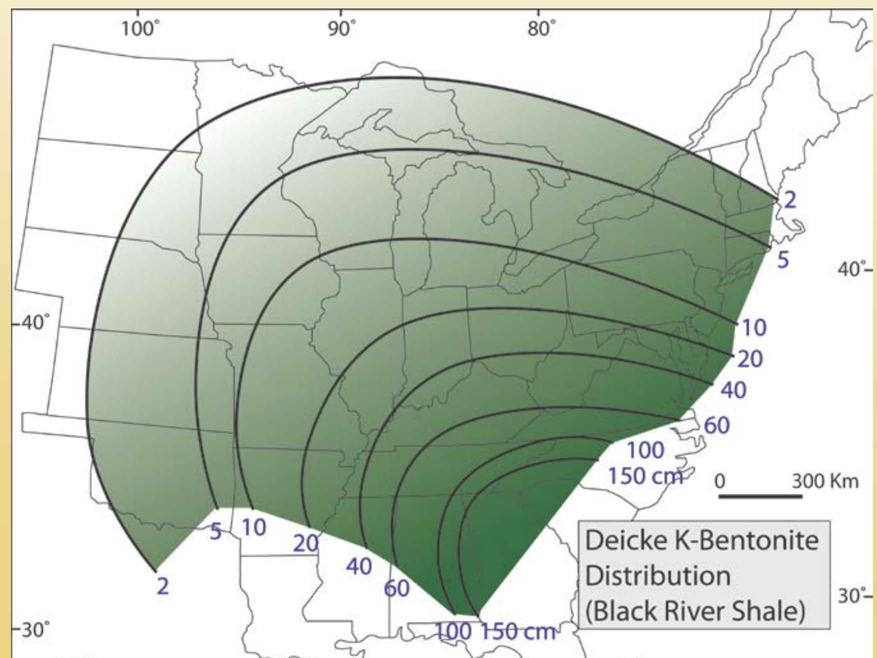
- Middle Ordovician—Mohawkian
- Humid sub-tropical, ~25° Lat.
- Epeiric carbonate platform (ramp)
- Volcanic ash from Taconic orogeny



Modified from Ives, 1960; and Catacosinos *et al.*, 1990

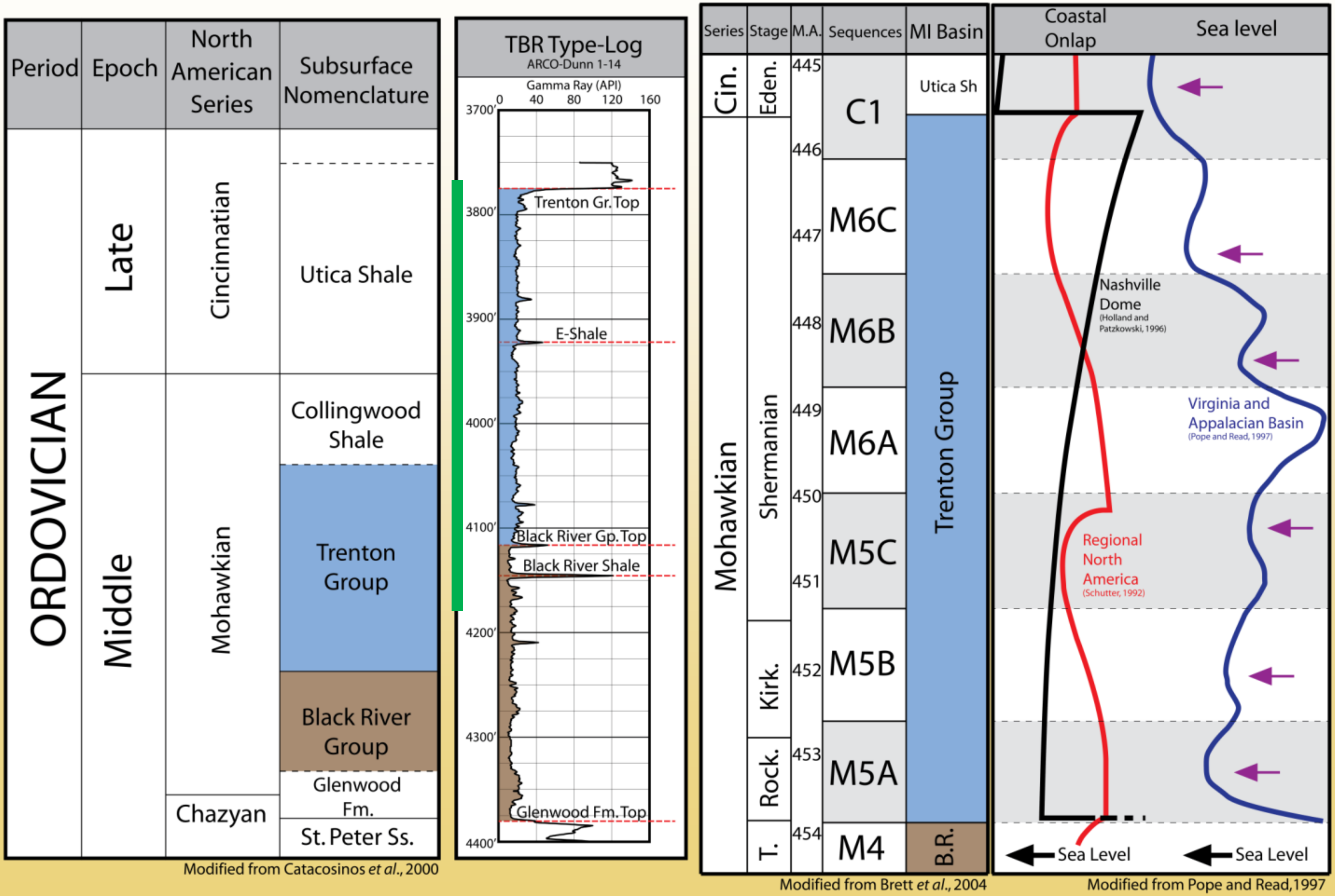


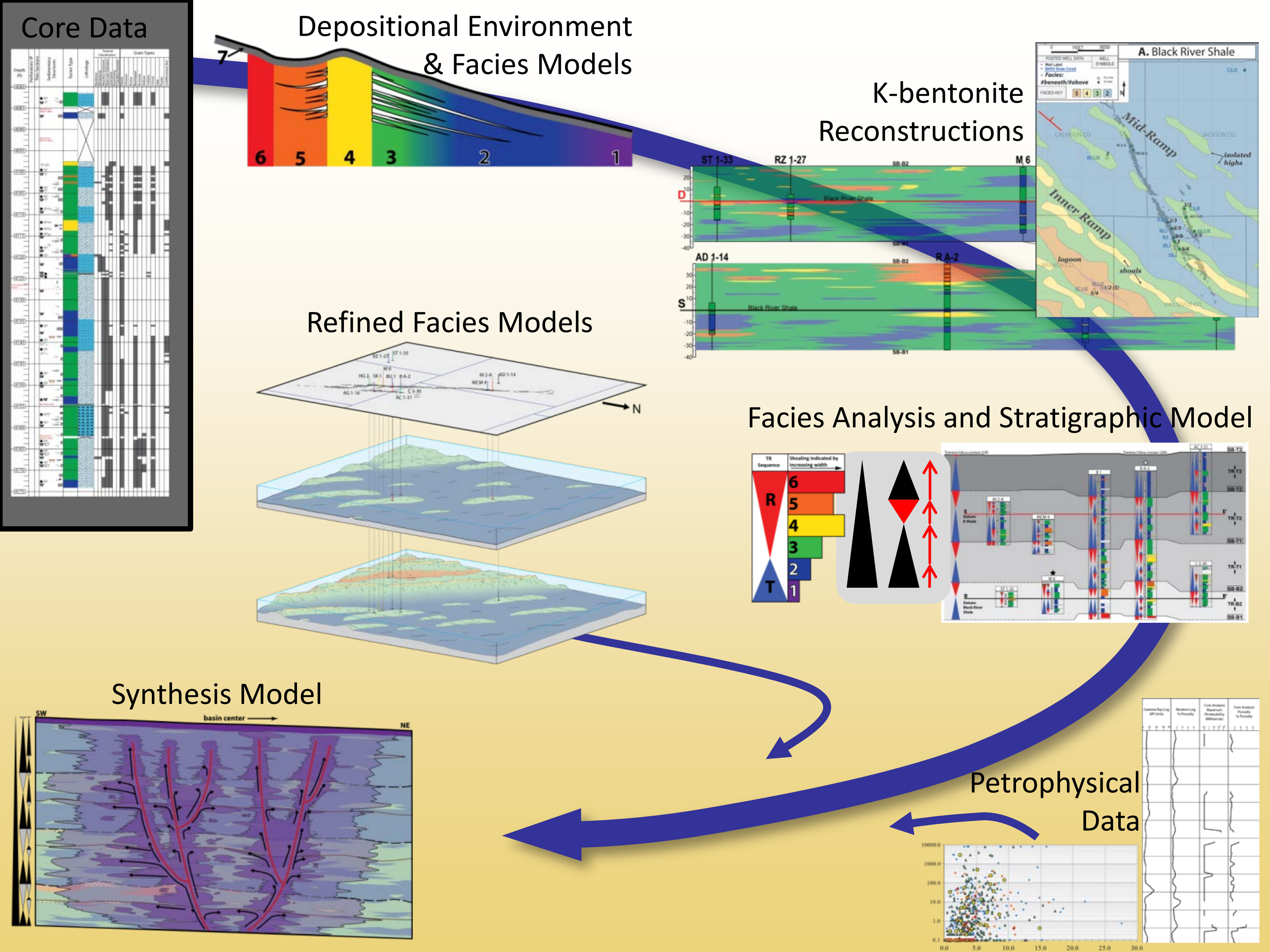
After Blakey NAU Geology; McKerrow *et al.*, 1991; and Ettensohn *et al.*, 2002



After Huff, et al. 1996

Geologic Background




Core Data
Depositional Environment
& Facies Models
7
6
5
4
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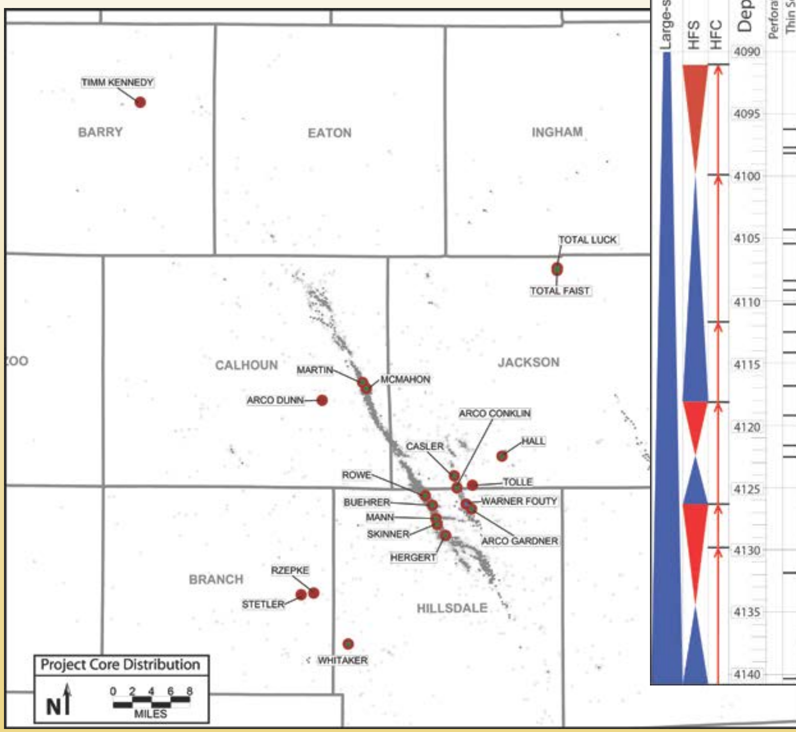
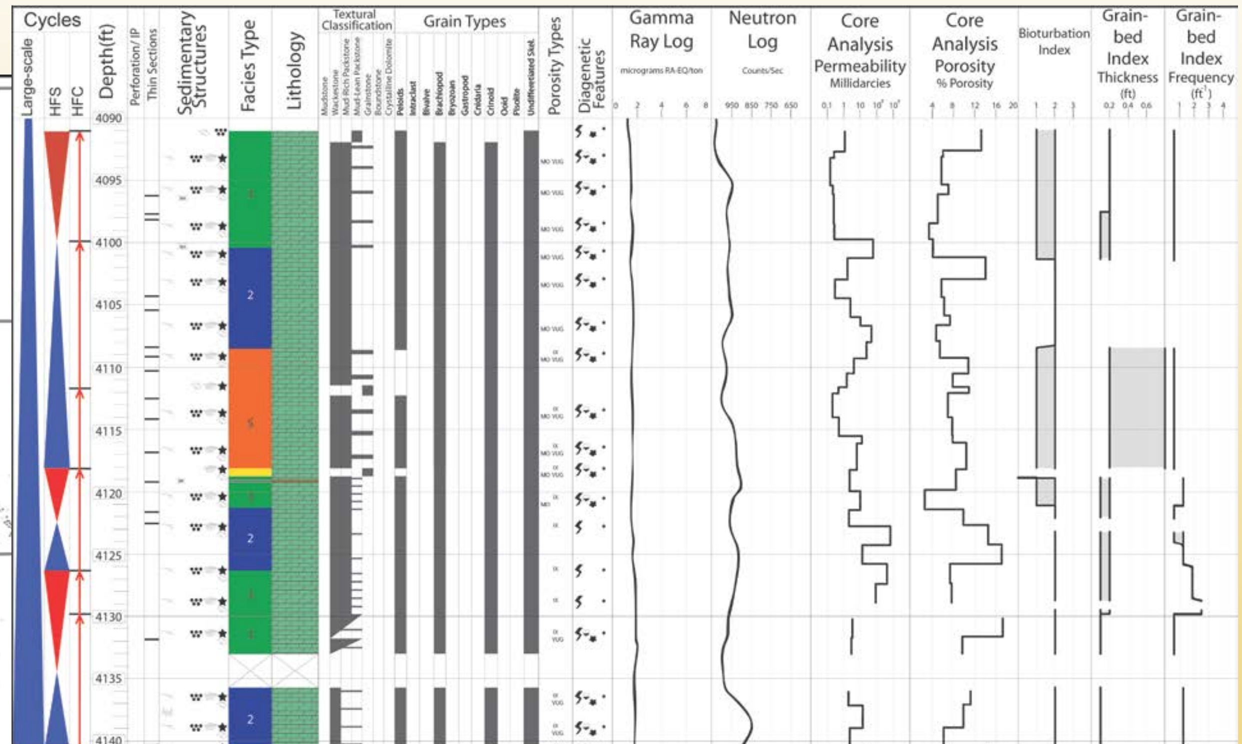
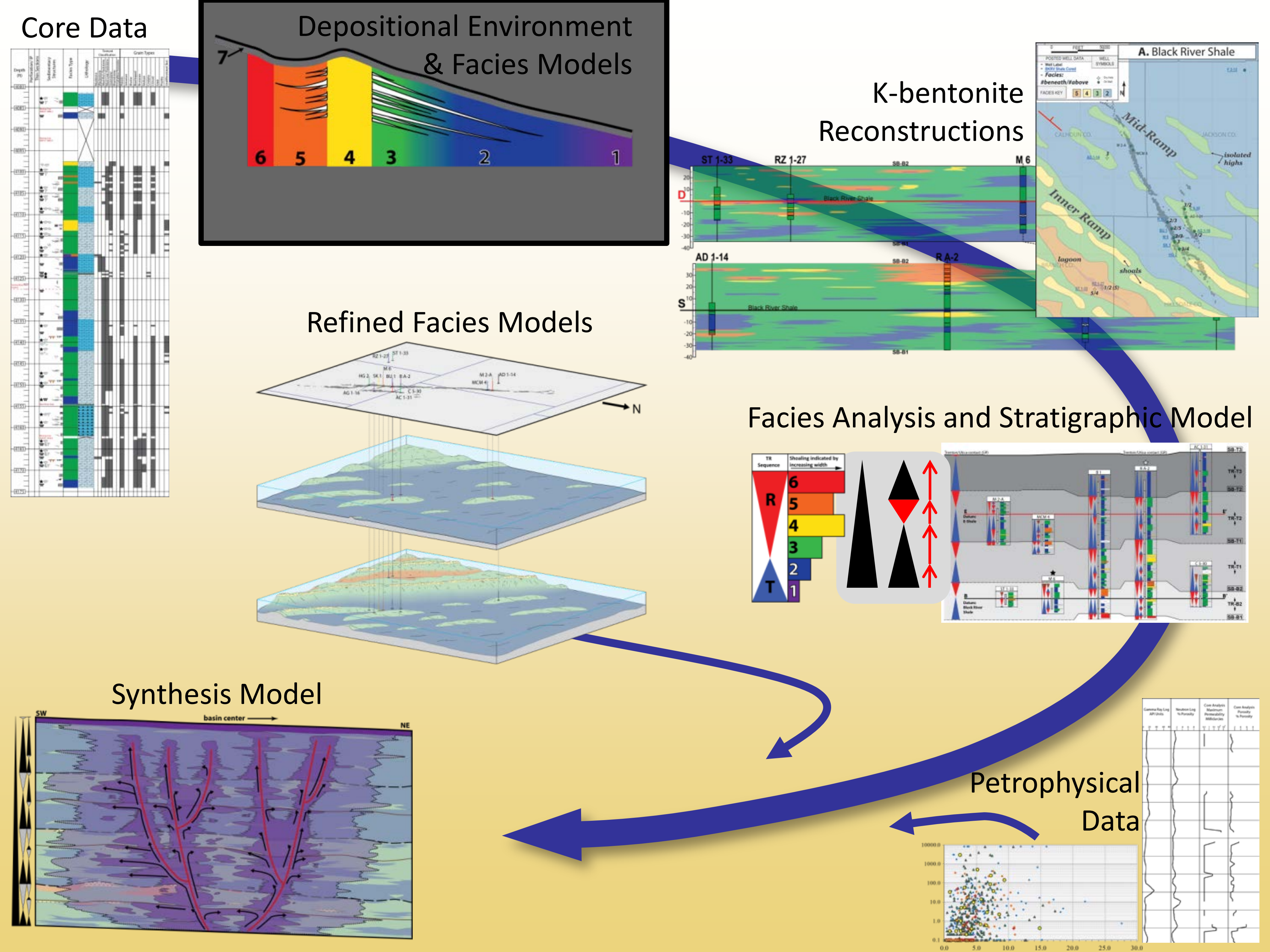
1
K-bentonite
Reconstructions
A. Black River Shale
Mid-Ramp
Inner Ramp
isolated highs
lagoon
shoals
ST 1-33
RZ 1-27
M 6
AD 1-14
R A-2
Black River Shale
Refined Facies Models
N
Facies Analysis and Stratigraphic Model
TR Sequence
Shoaling indicated by increasing width
R
T
Synthesis Model
SW
basin center
NE
Petrophysical
Data

Core Description

- Study included detailed analysis of 20 cores (> 2700 linear feet)
- Lithology, Dunham texture, sedimentary structures, grain type, pore types and pore architecture tied to permeability and sonic log velocity.







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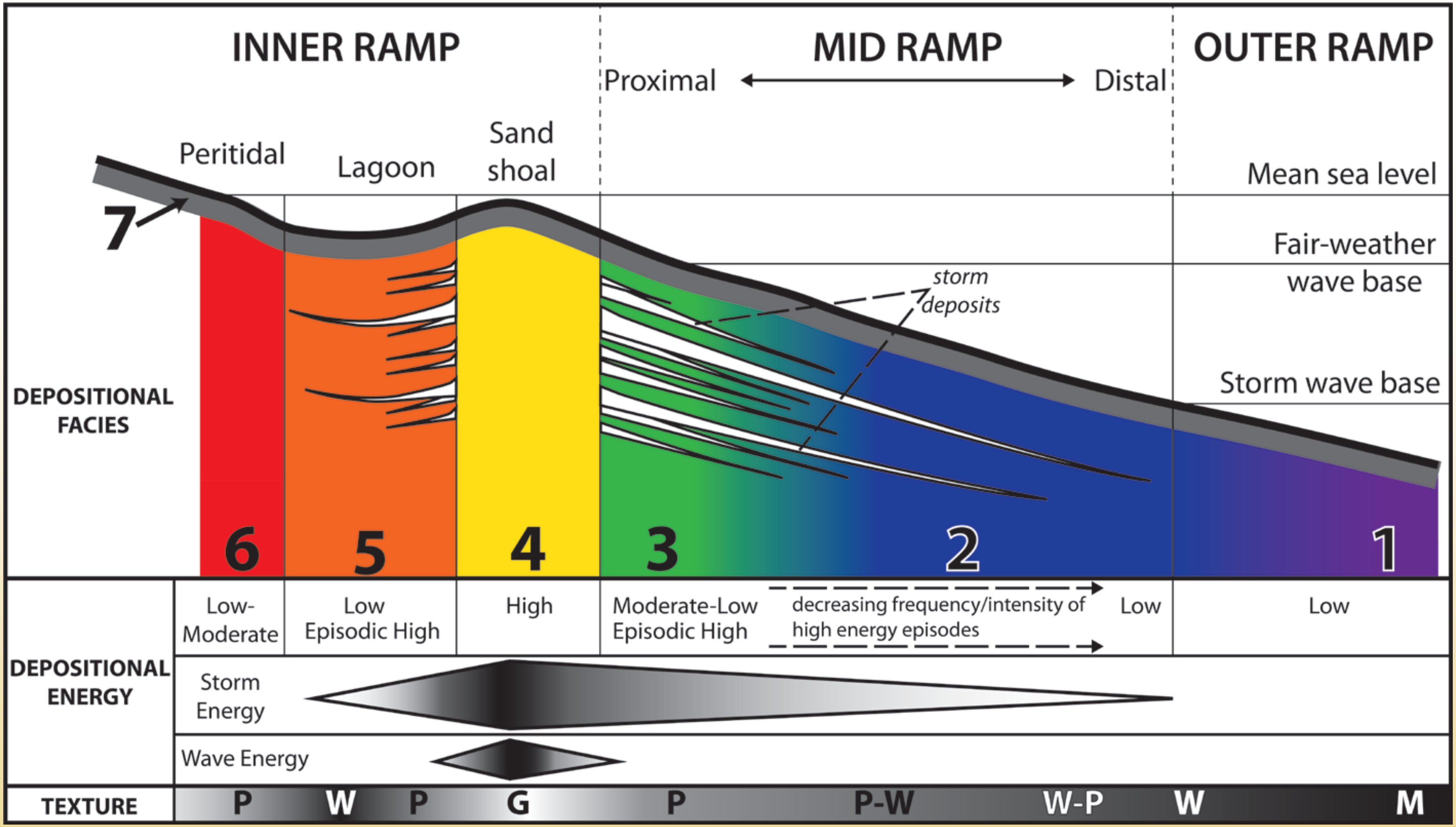
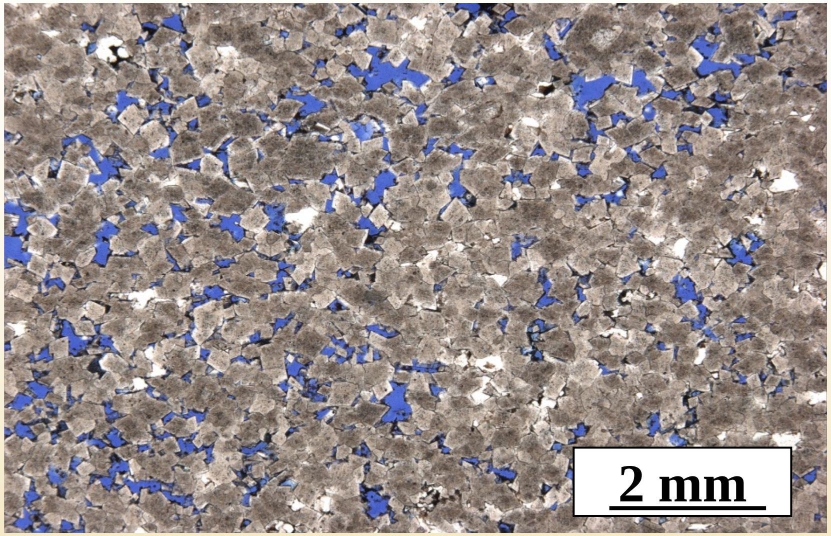
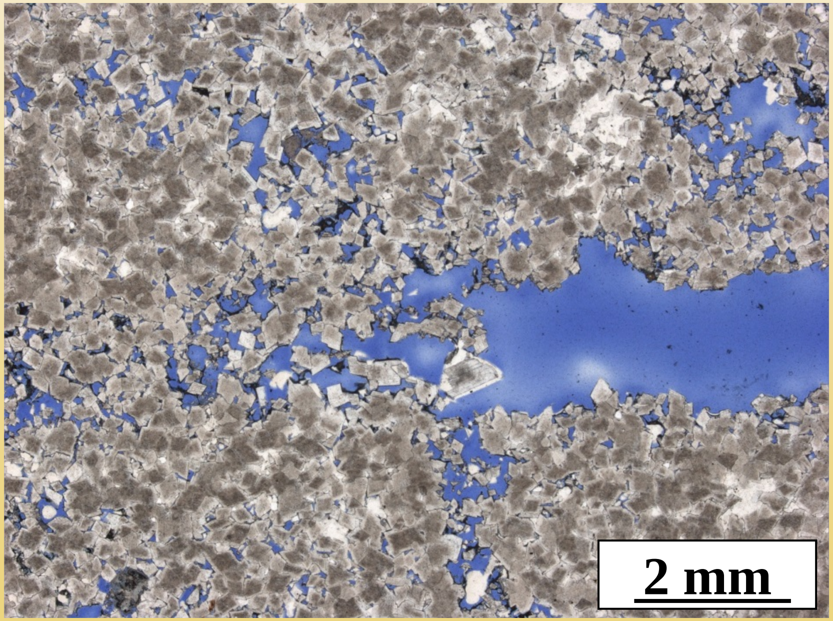


- Depositional environments and facies associations of TBR interval as a whole
- Defined by texture, grain type and abundance, and sedimentary structures
- General framework for examining and modeling TBR deposits

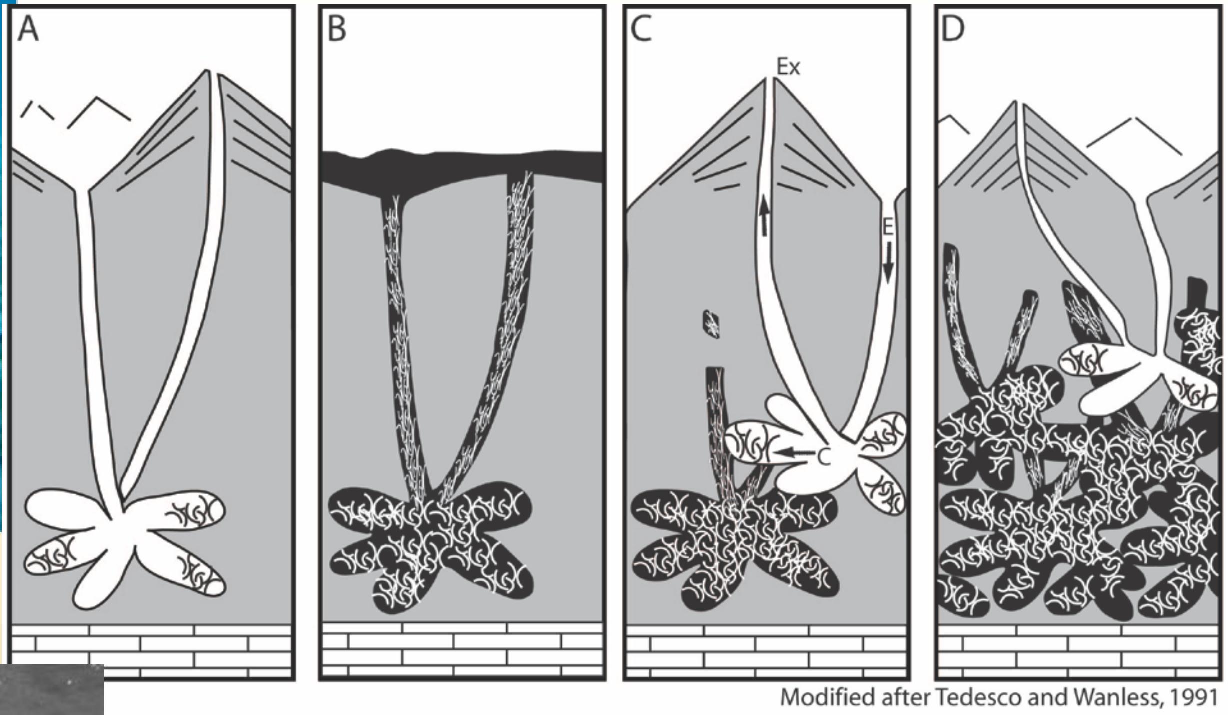
Burrowed Facies - Primary stratigraphic reservoir

Scale in centimeters





Callianassa burrows and “tubular tempestites”

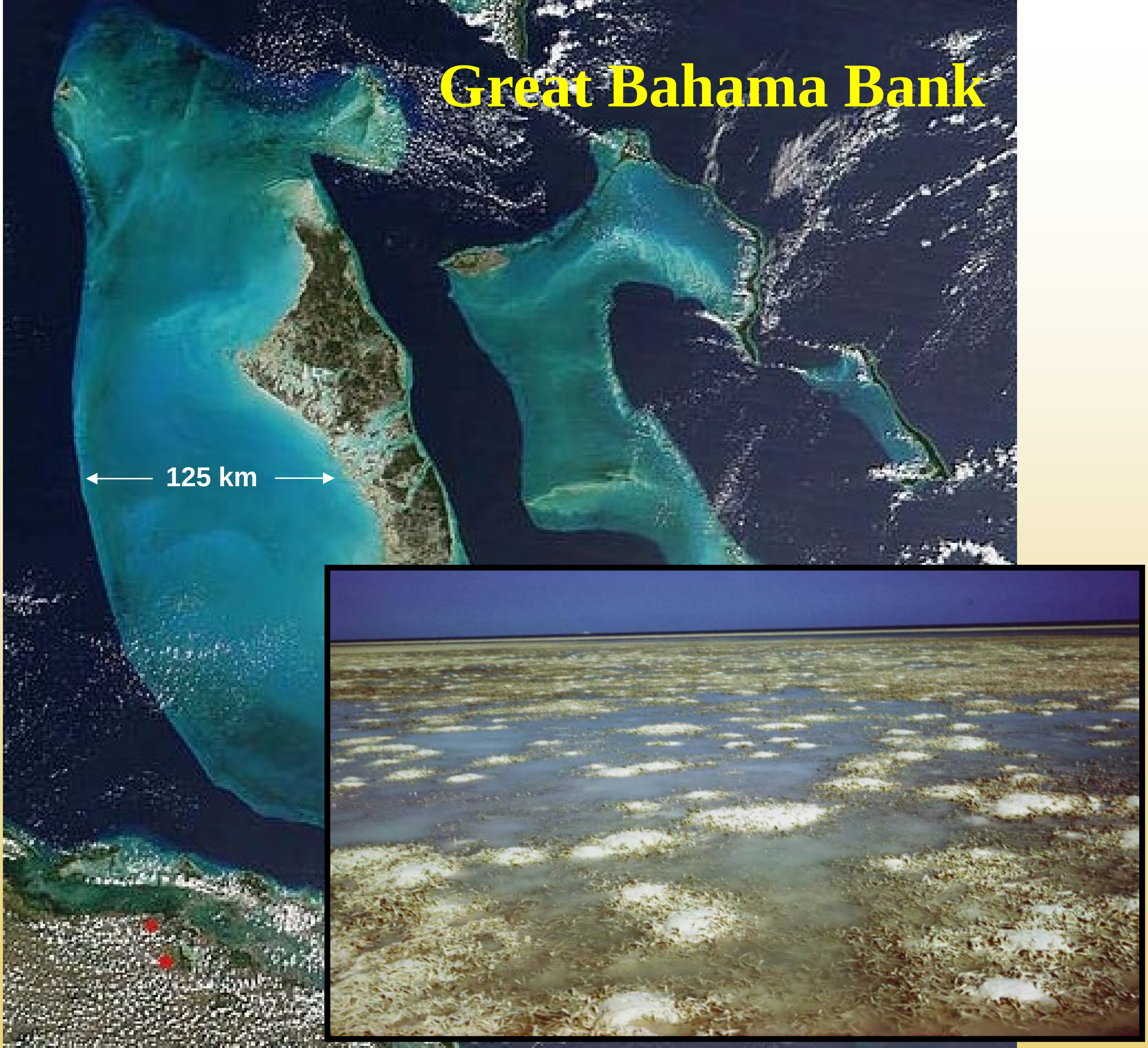


Repeated burrowing and filling of burrows with coarse-grained sediment produces 3-D network of high porosity and high permeability

Shinn, 1983

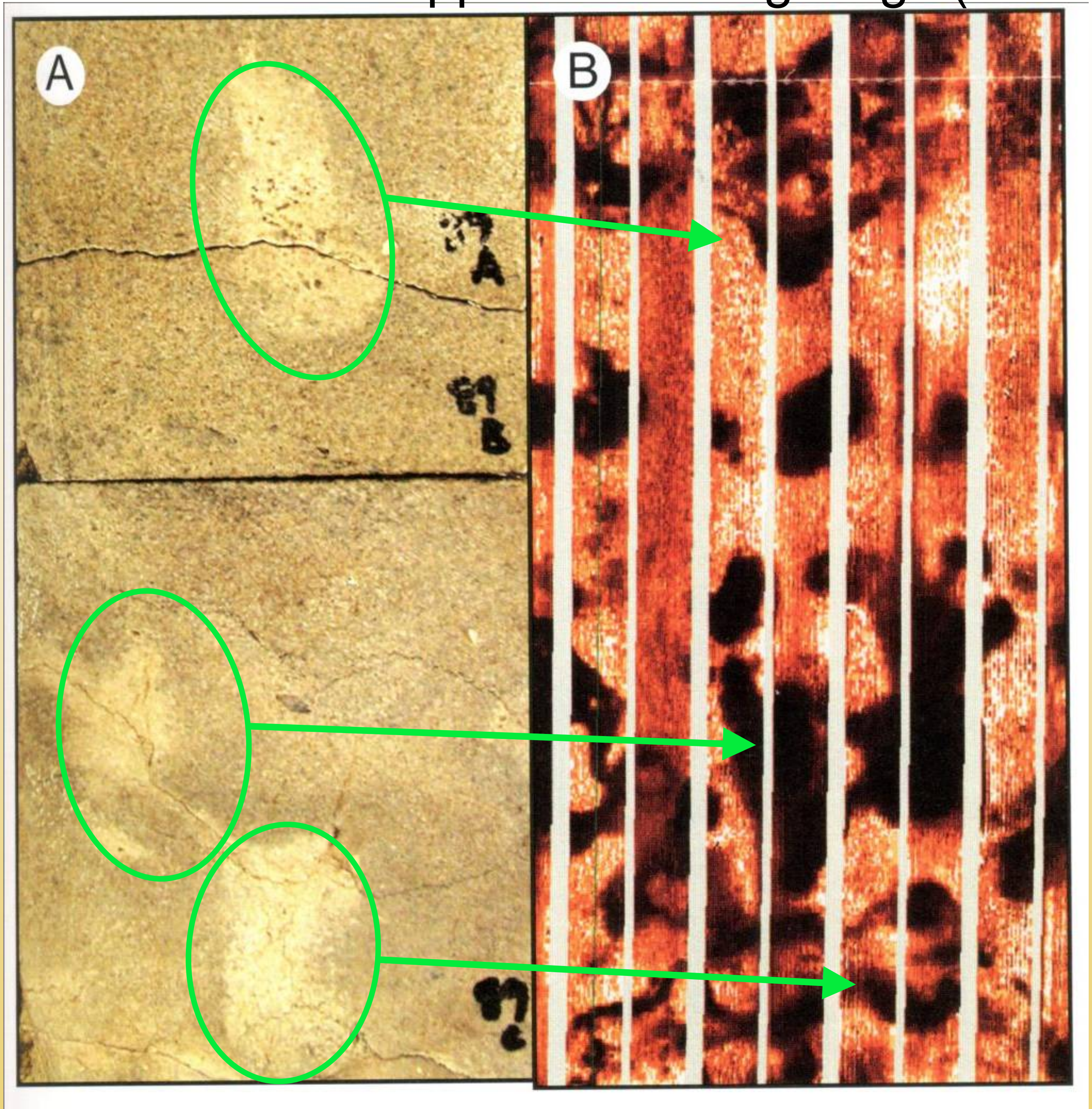
Modern Analog

Potential for extensive aerial distribution of facies



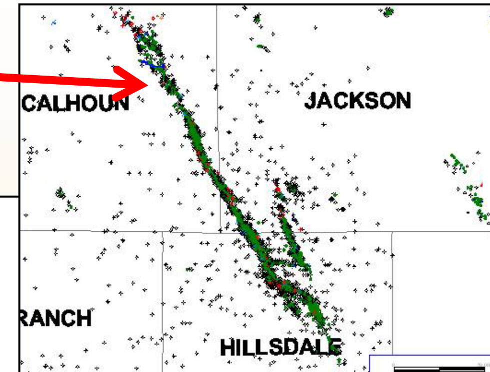
Differential cementation in burrowed facies

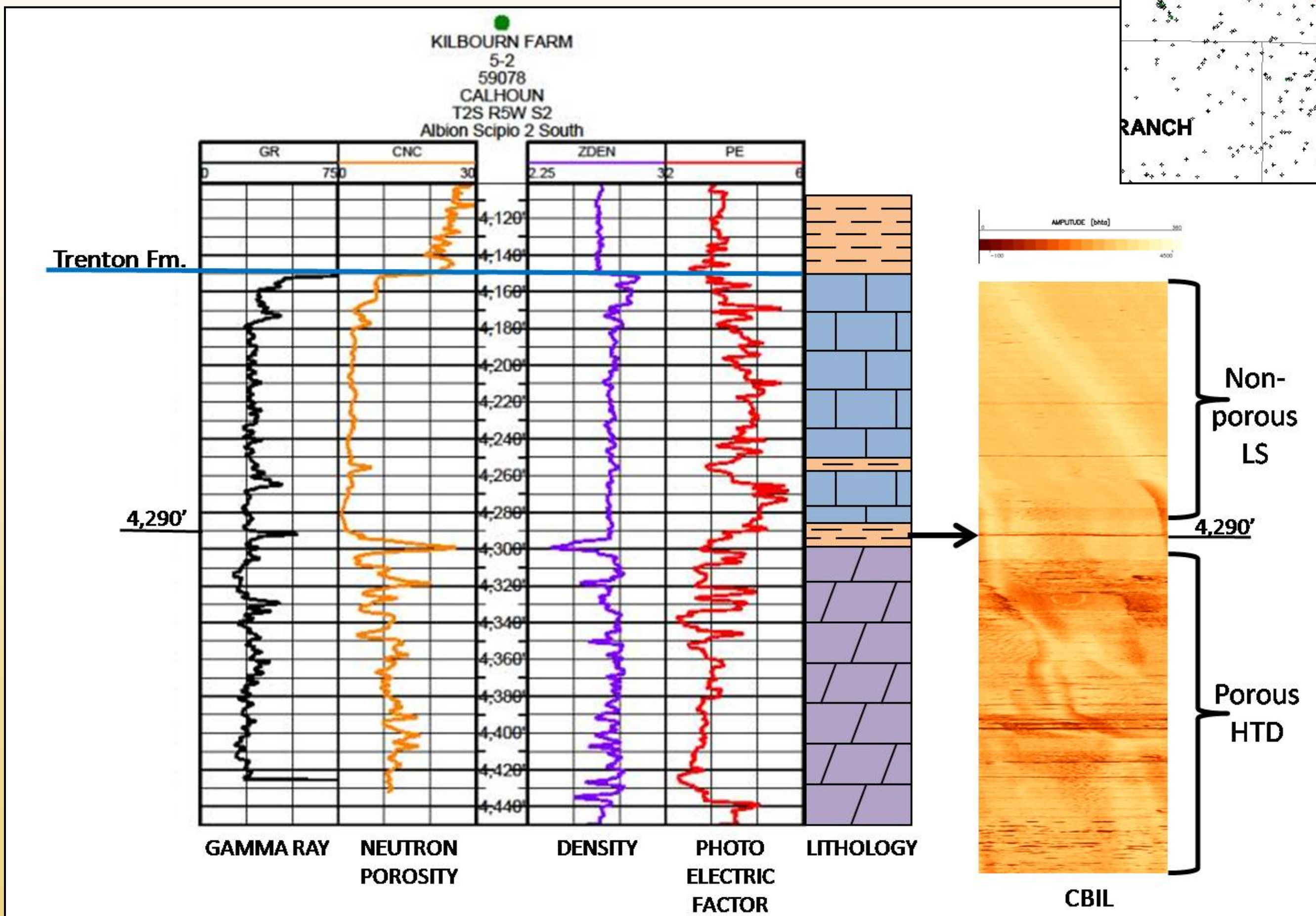
Burrowed facies apparent in image logs (resistivity)



Rupple and Jones (2006)

Thin Shales/K-bentonites as permeability baffles/barriers?

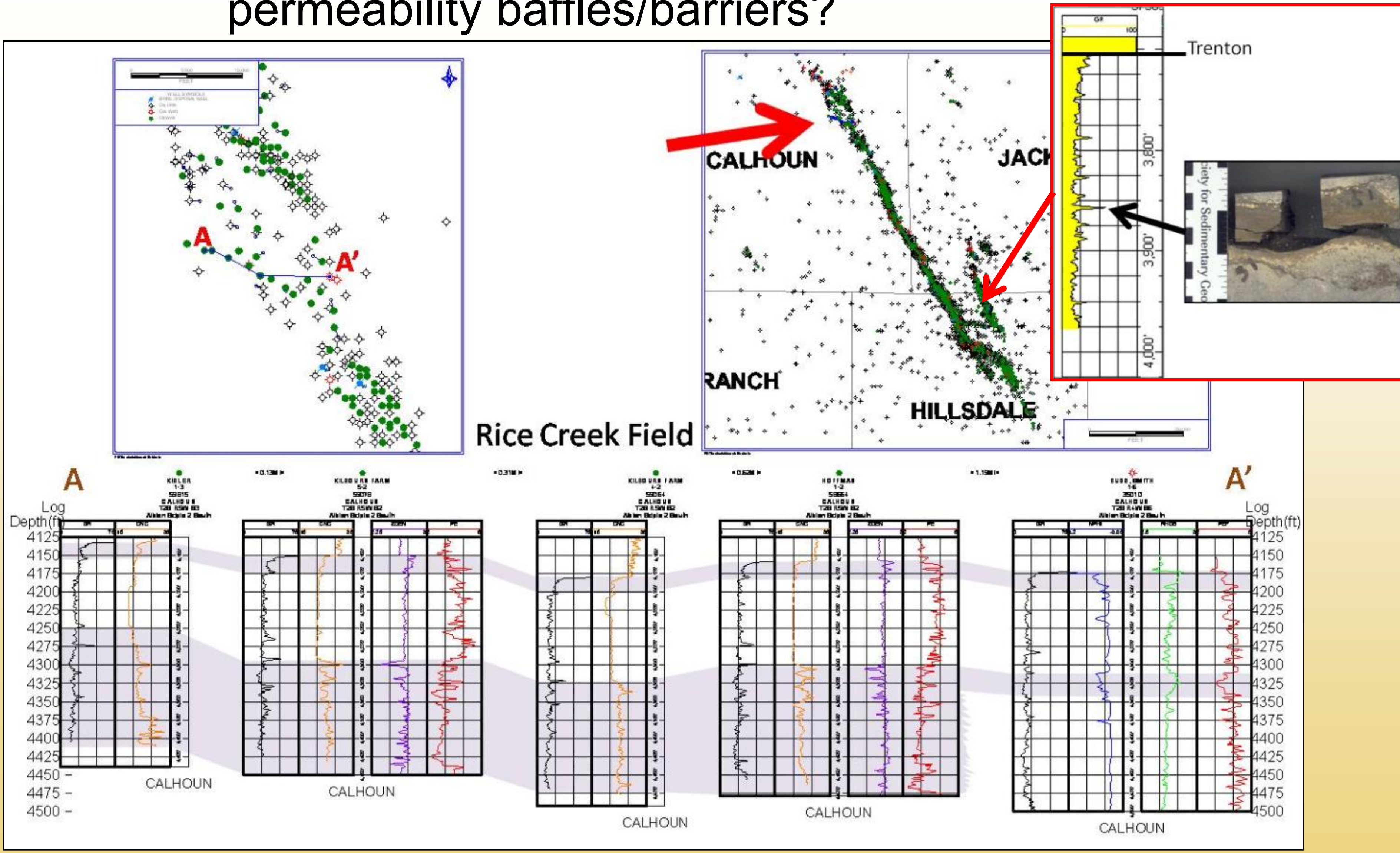




Porous HTD pooled directly beneath a thin seam of 'clay'.

Thin Shales/K-bentonites as permeability baffles/barriers?

Arco-Conklin 1-31 Well

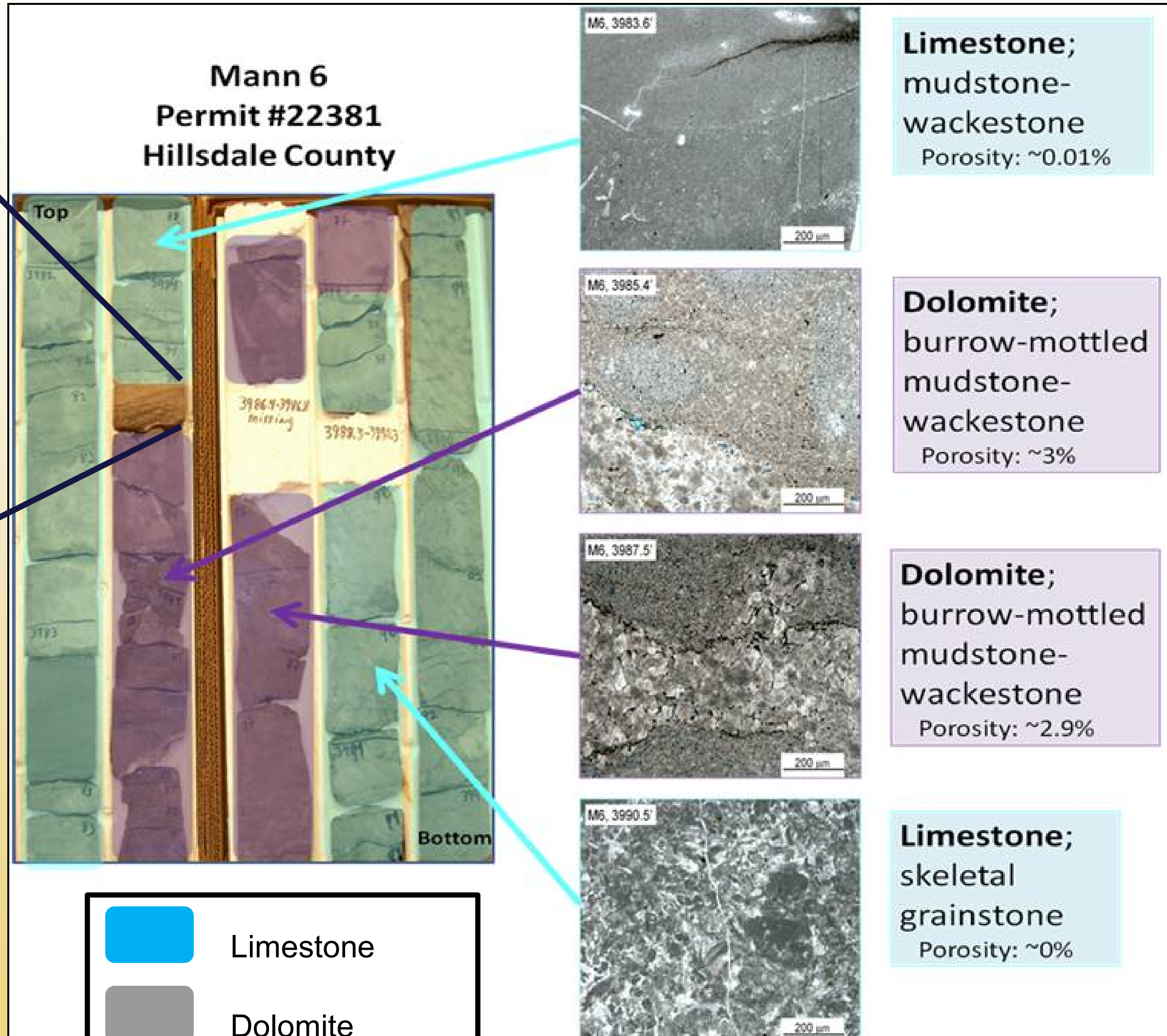


X-section of five Rice Creek wells all exhibiting pooled dolomite beneath the same gamma ray spike. All produce hydrocarbons from the dolomitic interval.

'E' Shale from Stoney Point Field correlates to thin baffles in Rice Creek Field.

Dolomite Beneath Thin 'Shale'

- 2-3 centimeter thick 'shale'
- 43 wt% carbonate, 35 wt% K-feldspar, 9 wt% clay, 7 wt% quartz
- 4 foot interval of dolomite
- Dolomitized facies with porosity in burrows as well as surrounding matrix.

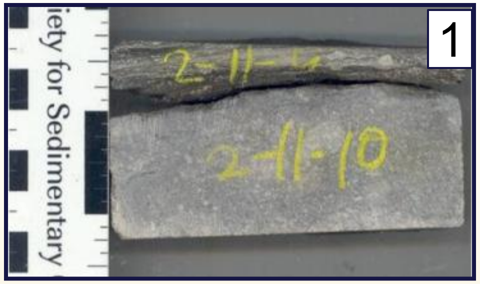


Limestone

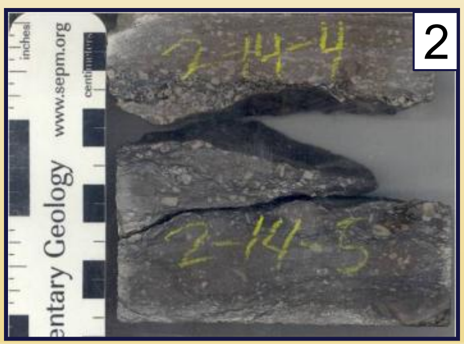
Dolomite

Shale

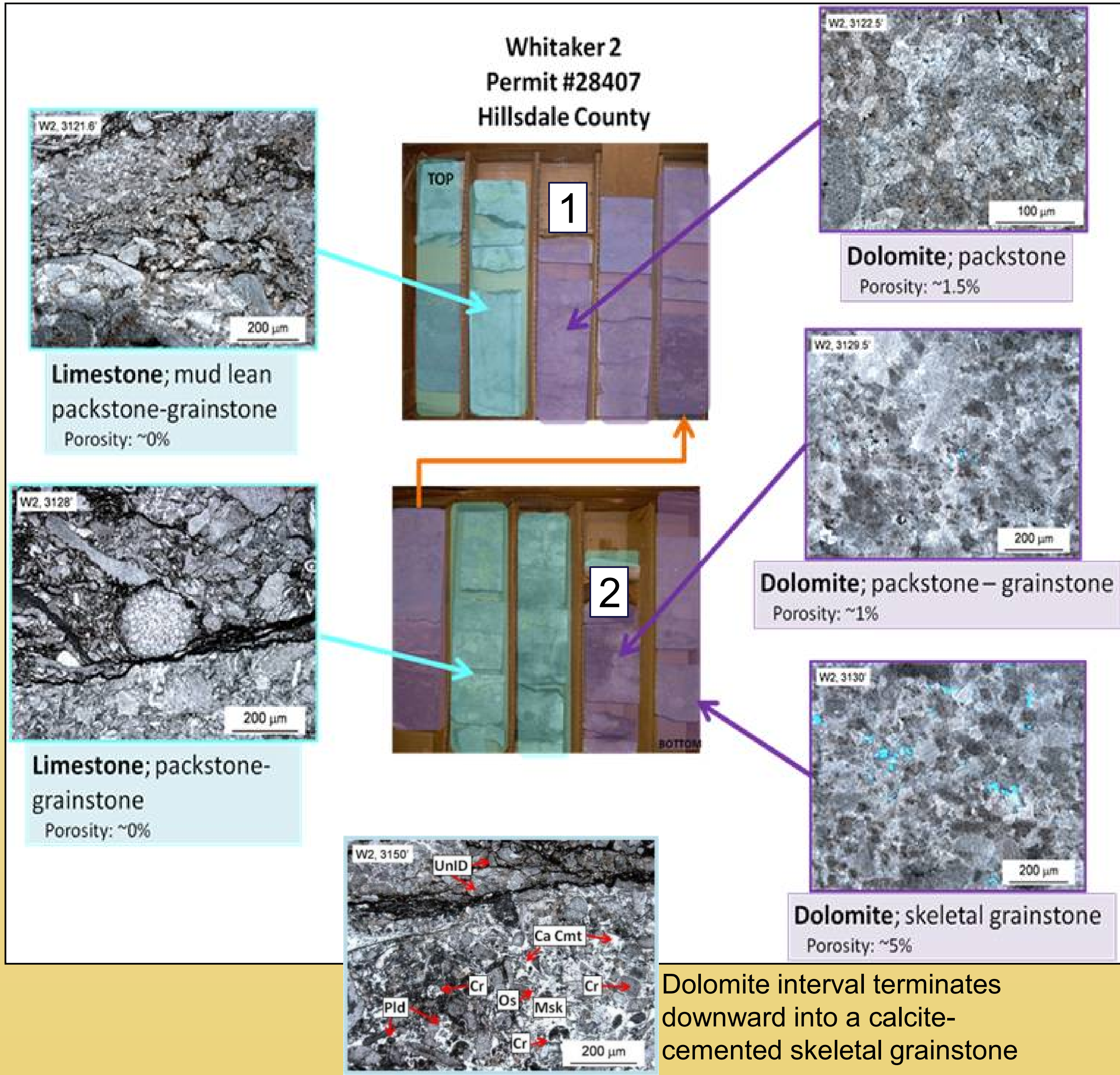
Multiple Dolomite Intervals Beneath Thin 'Shales'



- 46 wt% clay, 5 wt% carbonates, 32 wt% K-feldspar, 6 wt% quartz
- 4 foot dolomite interval below

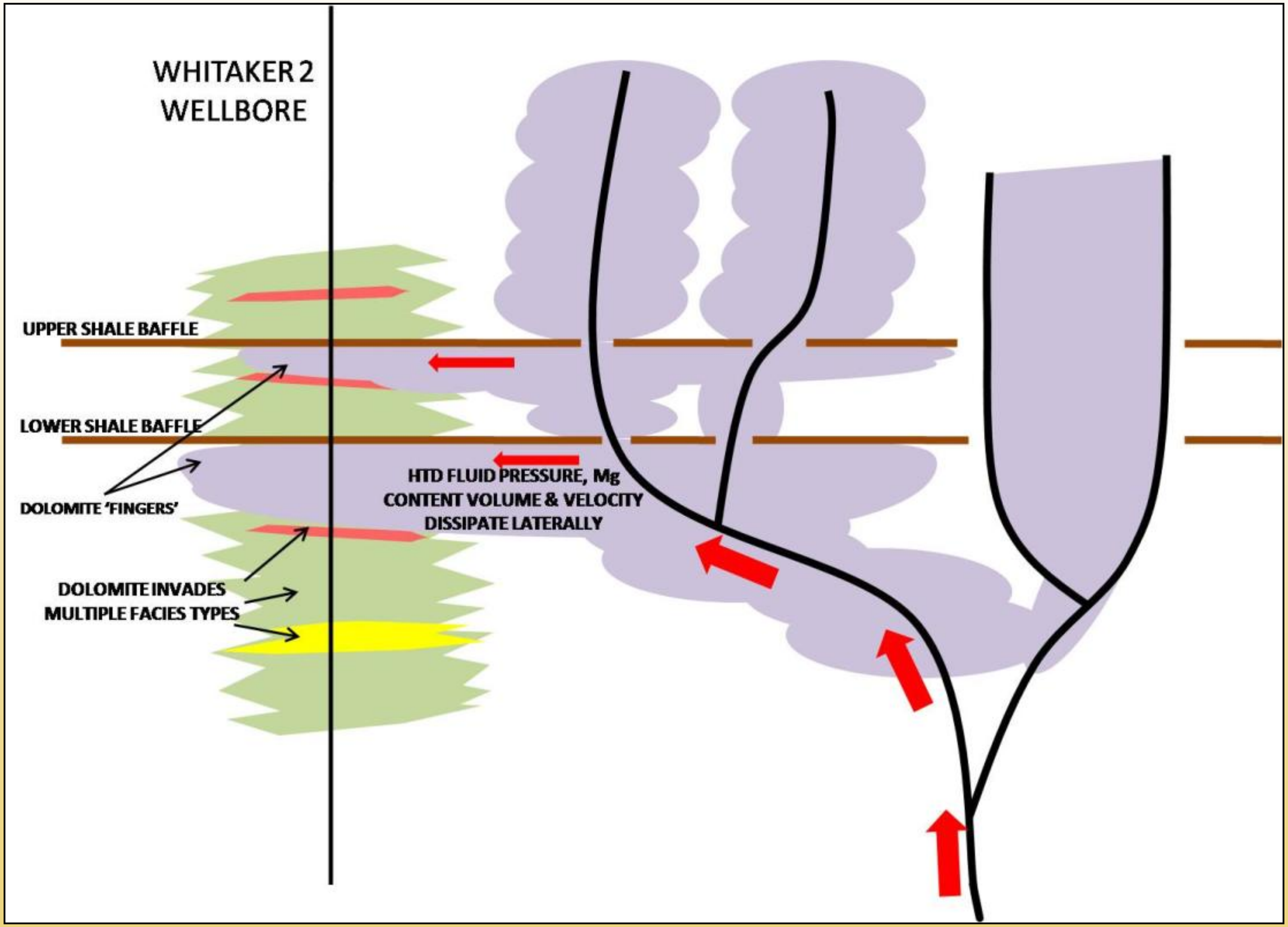


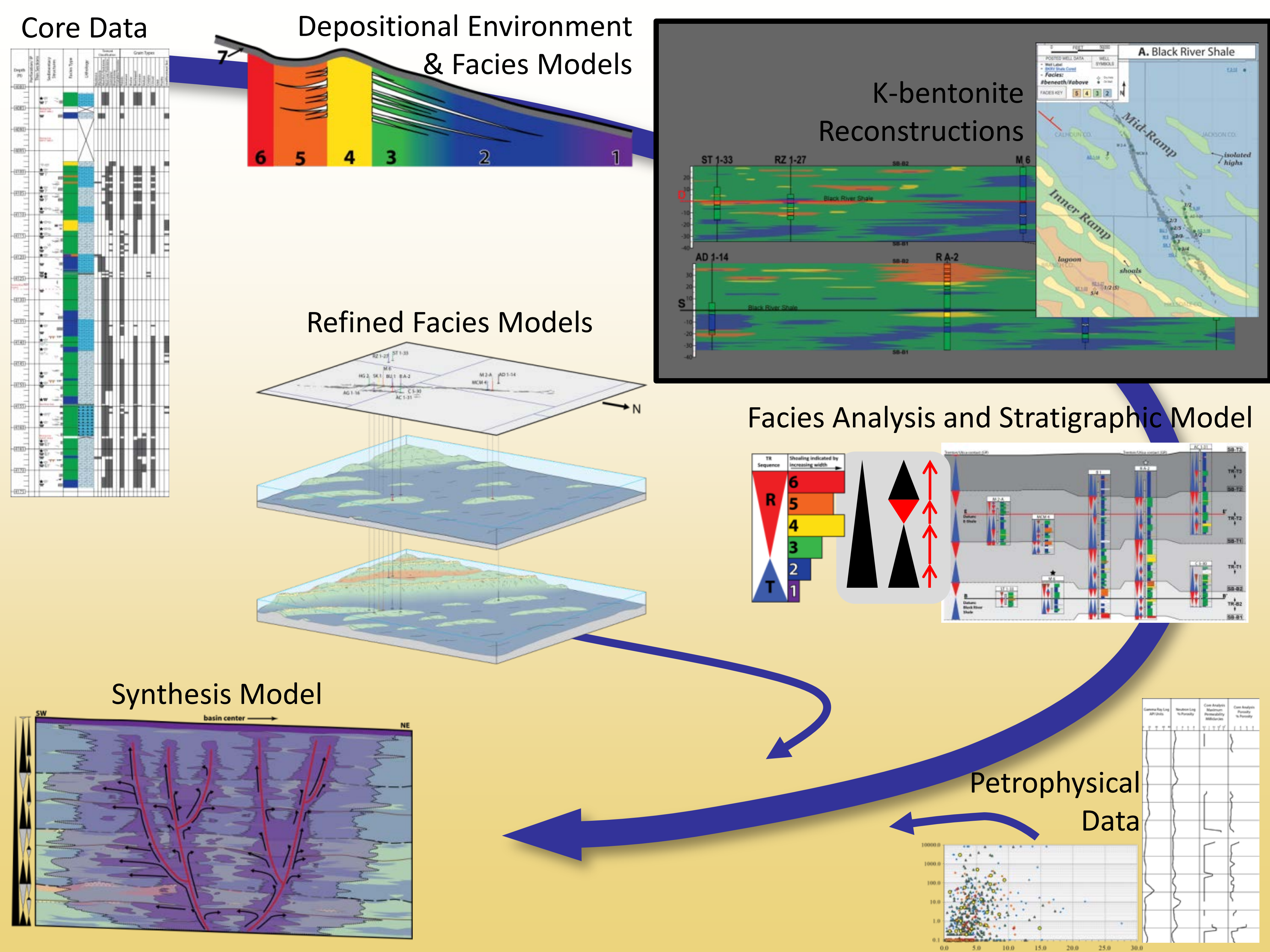
- 19 wt% clay, 39 wt% carbonates, 29 wt% K-feldspar, 5% quartz
- 20 foot dolomite interval below



Dolomite interval terminates downward into a calcite-cemented skeletal grainstone

HTD Model showing influence of thin "shale" stringers





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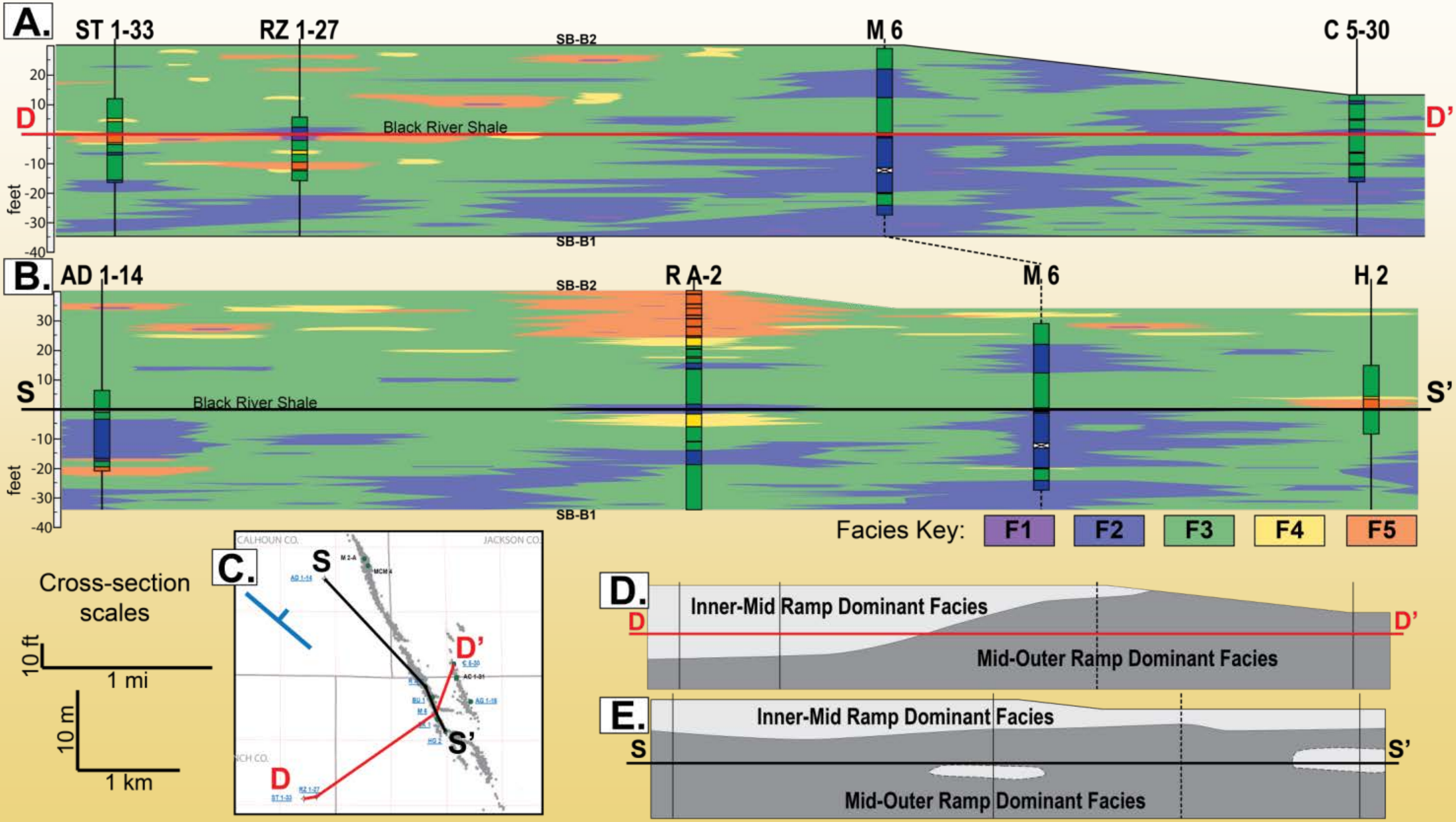
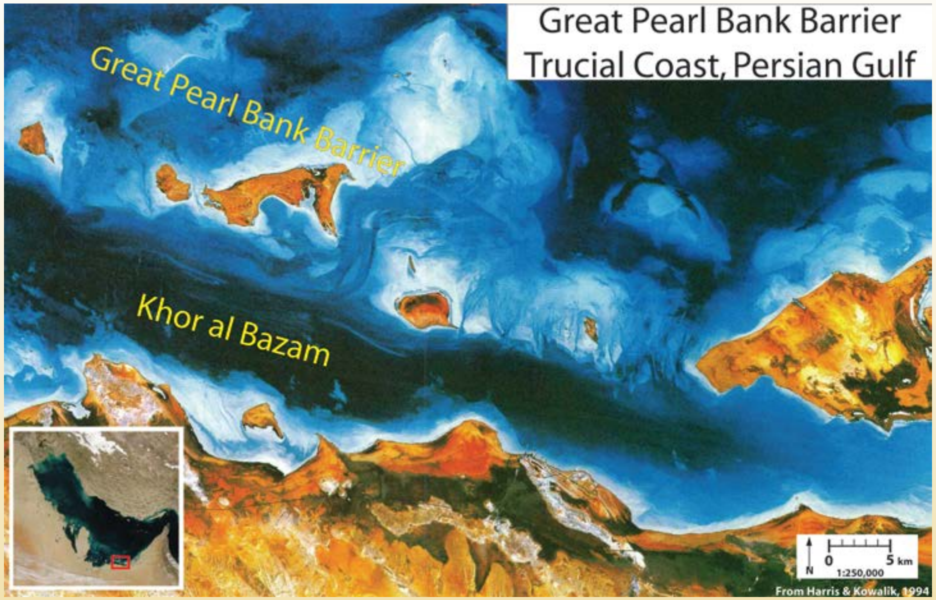
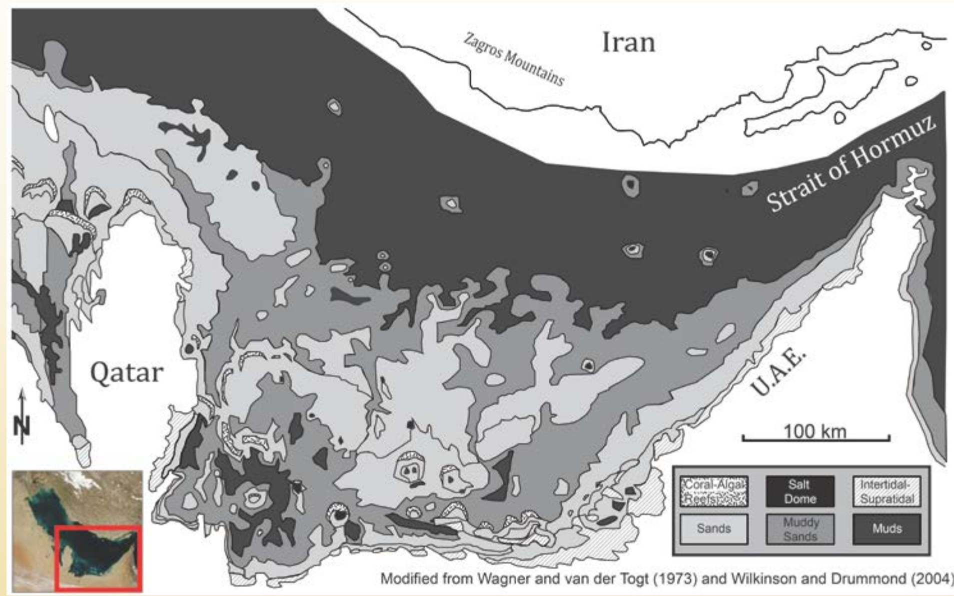
R
T
Synthesis Model
SW
basin center
NE
Petrophysical Data

K-bentonite Facies Reconstructions



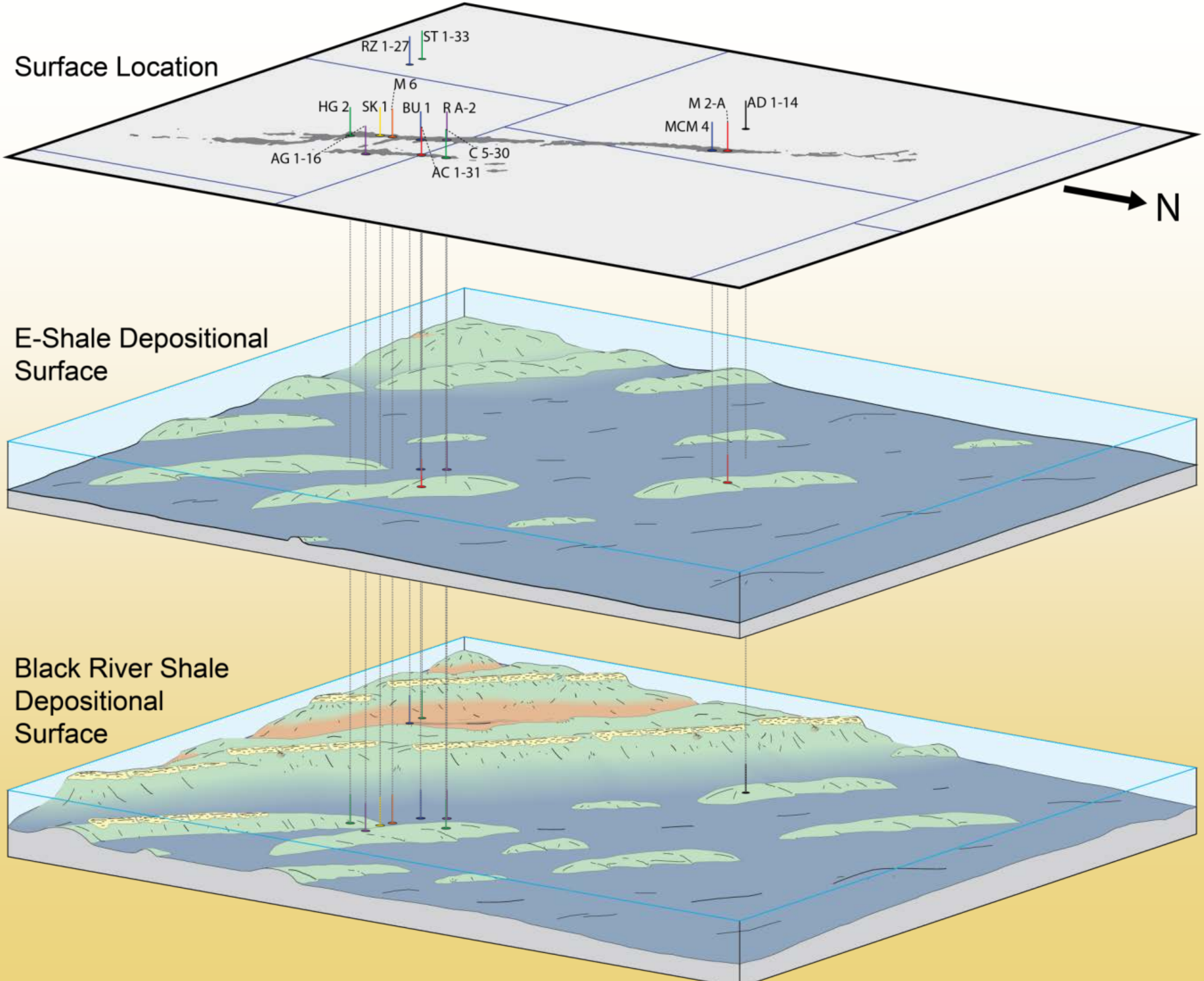
Modern Depositional Analog: Great Pearl Bank, Persian Gulf



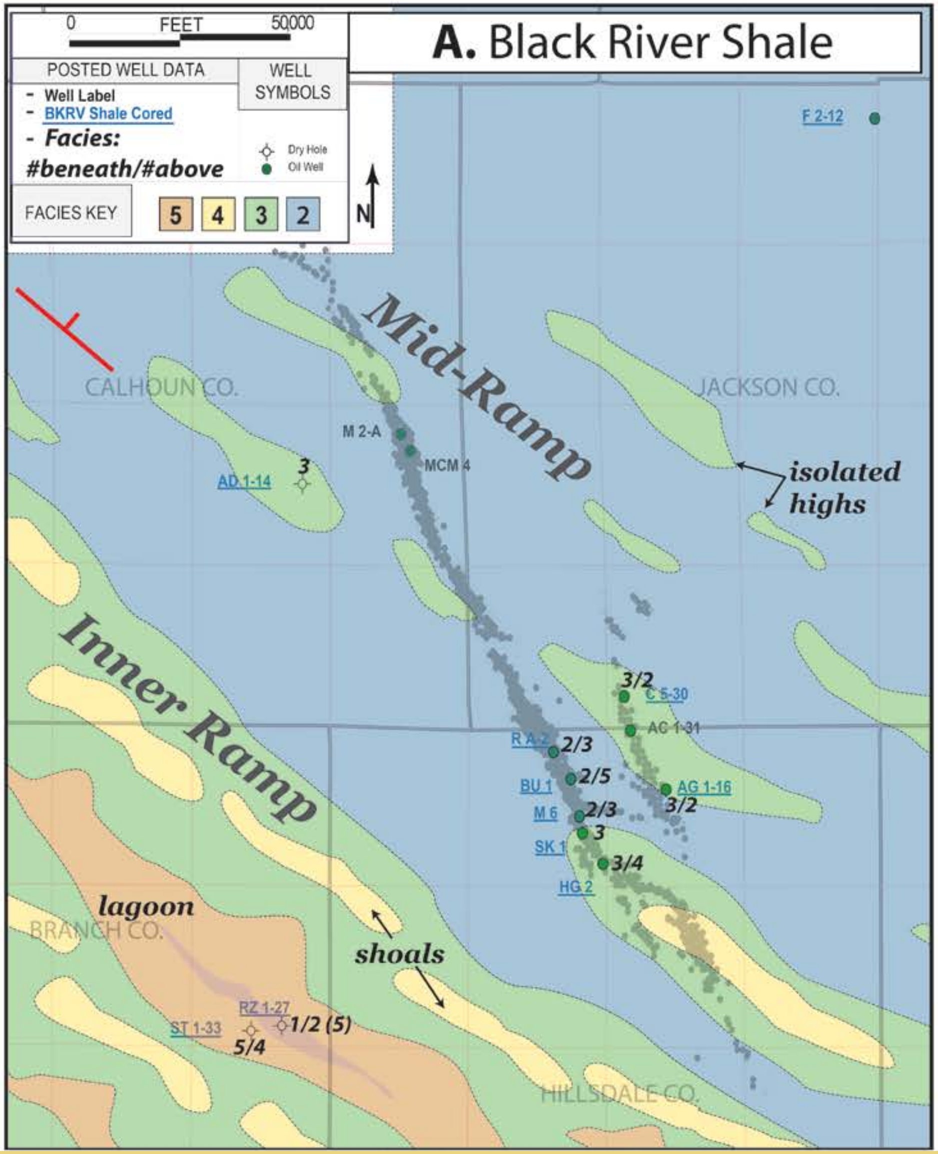


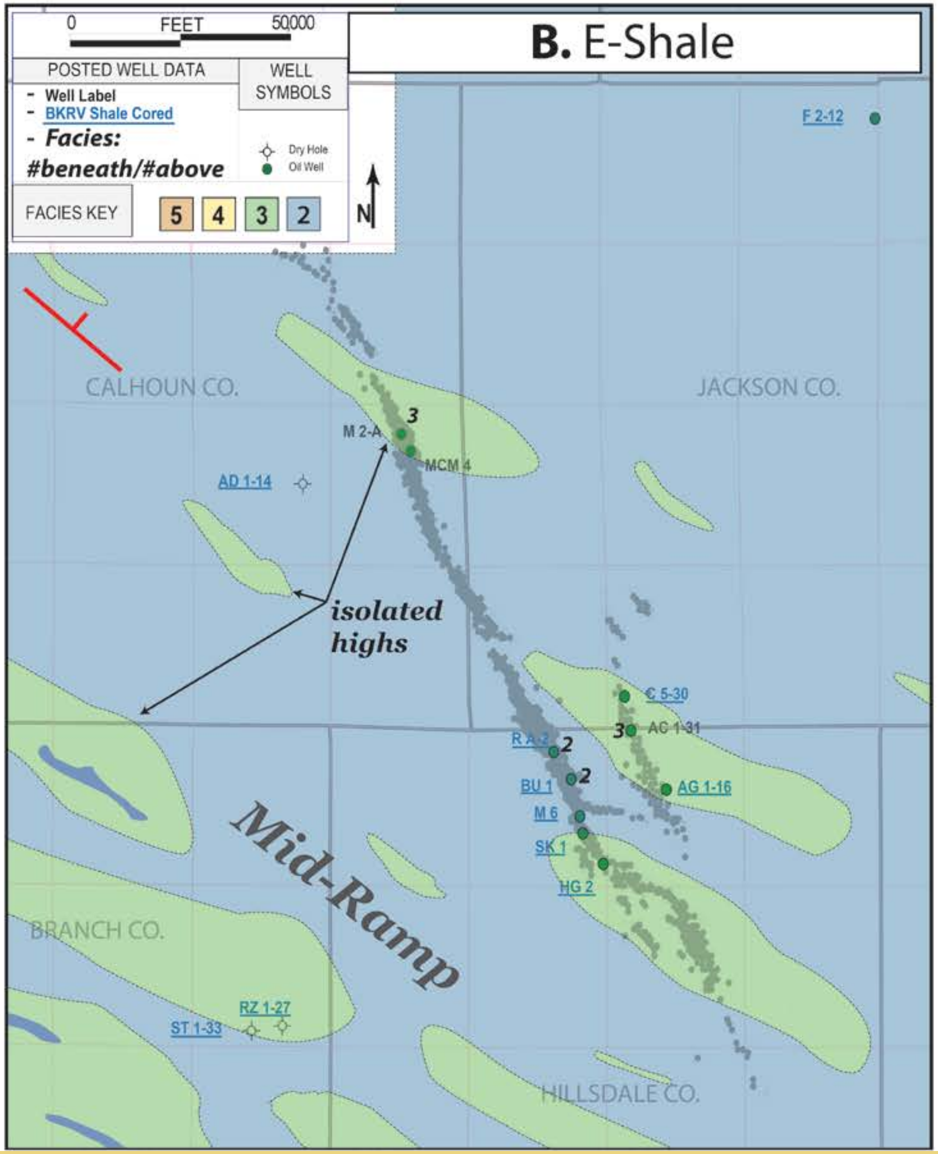
- Arid carbonate shoal-ramp
- Strike elongate facies geometries:
  - foreshoal
  - shoal
  - shoal-protected/restricted lagoon
  - peritidal and tidal flat
- Heterogeneous facies distributions

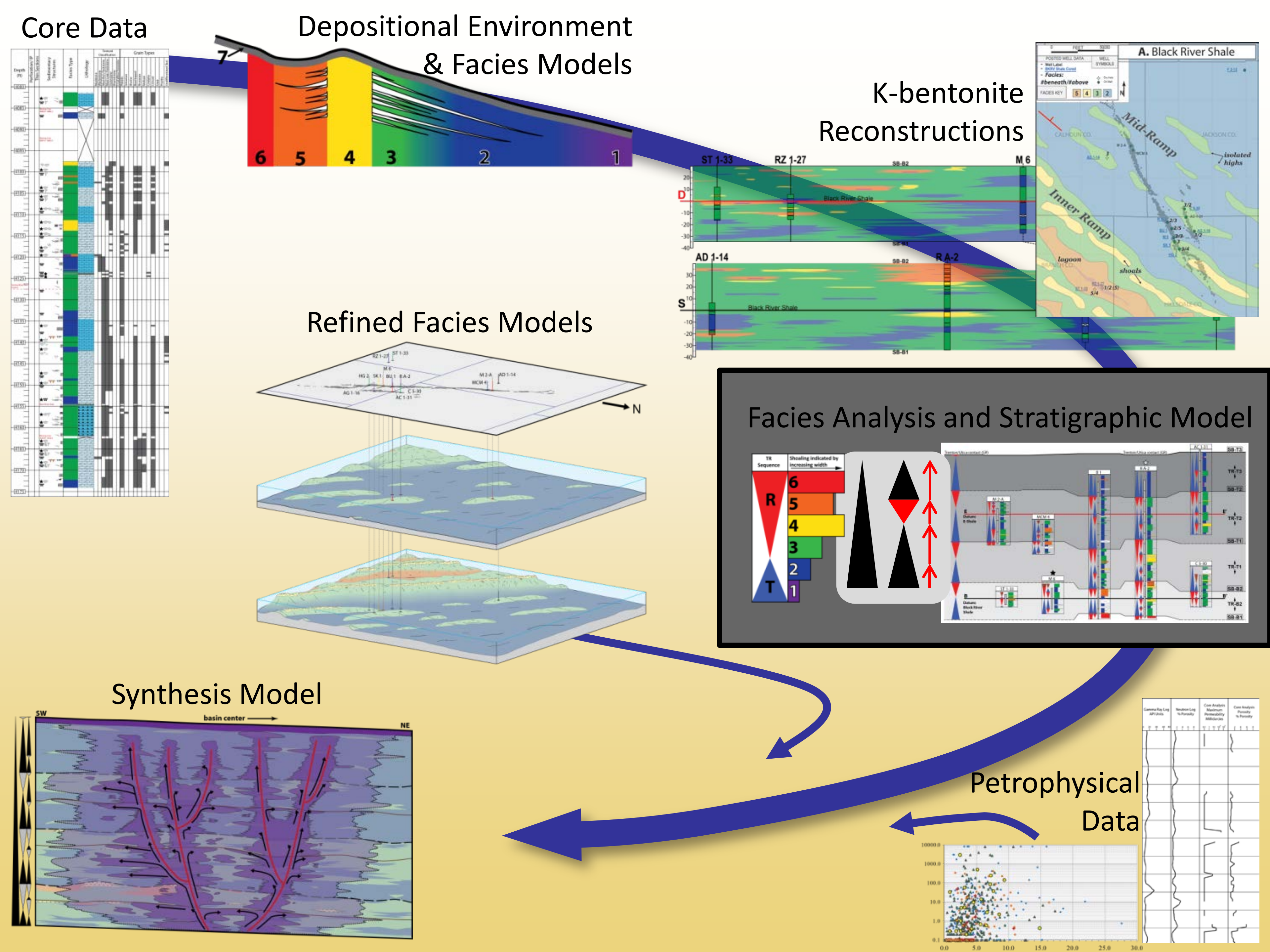
**Strong similarities between modern GPB and TBR facies types, geometries, and distributions


Surface Location
RZ 1-27
ST 1-33
M 6
HG 2
SK 1
BU 1
R A-2
AG 1-16
C 5-30
AC 1-31
M 2-A
AD 1-14
MCM 4
N
E-Shale Depositional Surface
Black River Shale Depositional Surface

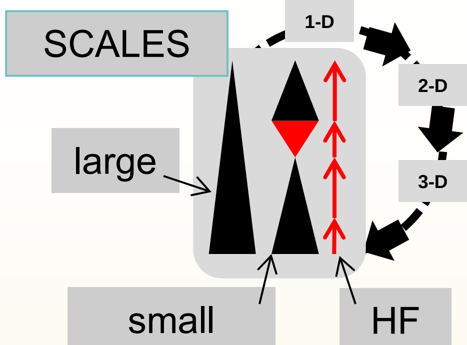
K-bentonite Facies Reconstructions

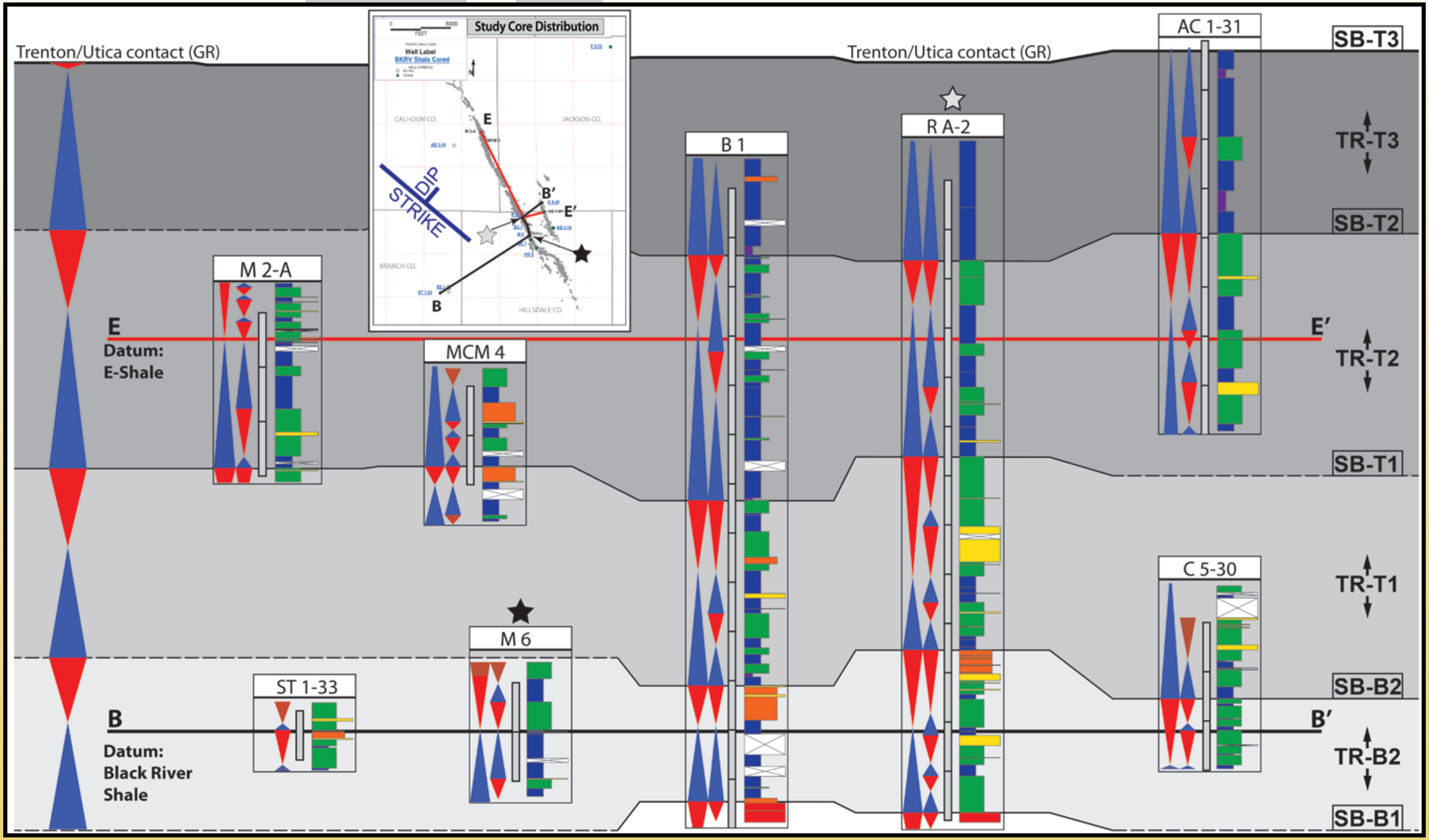


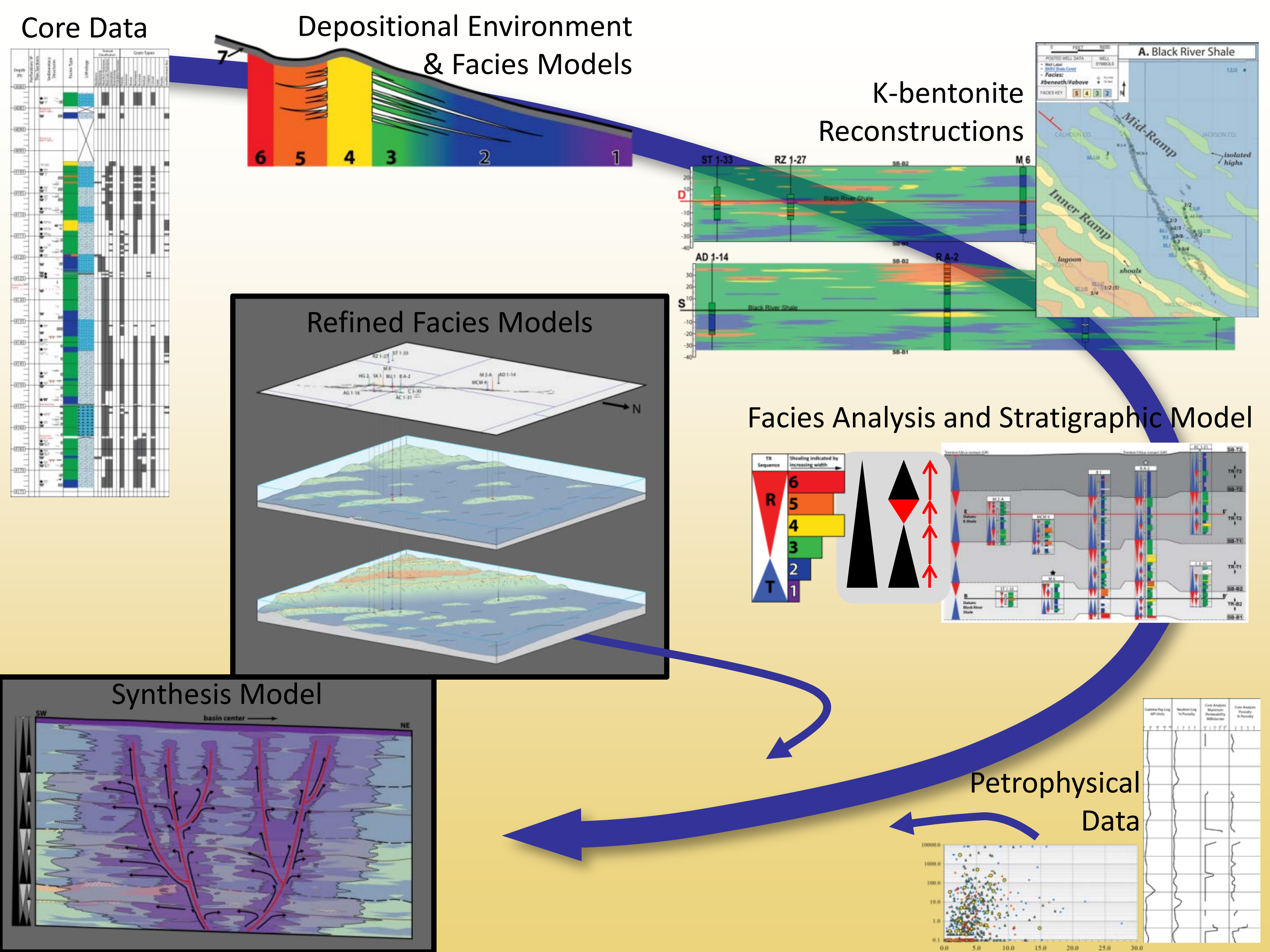



Core Data
Depositional Environment
& Facies Models
7
6
5
4
3
2
1
K-bentonite
Reconstructions
ST 1-33
RZ 1-27
M 6
AD 1-14
R A-2
Black River Shale
A. Black River Shale
Mid-Ramp
Inner Ramp
lagoon
shoals
isolated highs
Refined Facies Models
N
Facies Analysis and Stratigraphic Model
R
T
Synthesis Model
SW
basin center
NE
Petrophysical
Data

Stratigraphic Framework







Core Data
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7
6
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4
3
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1
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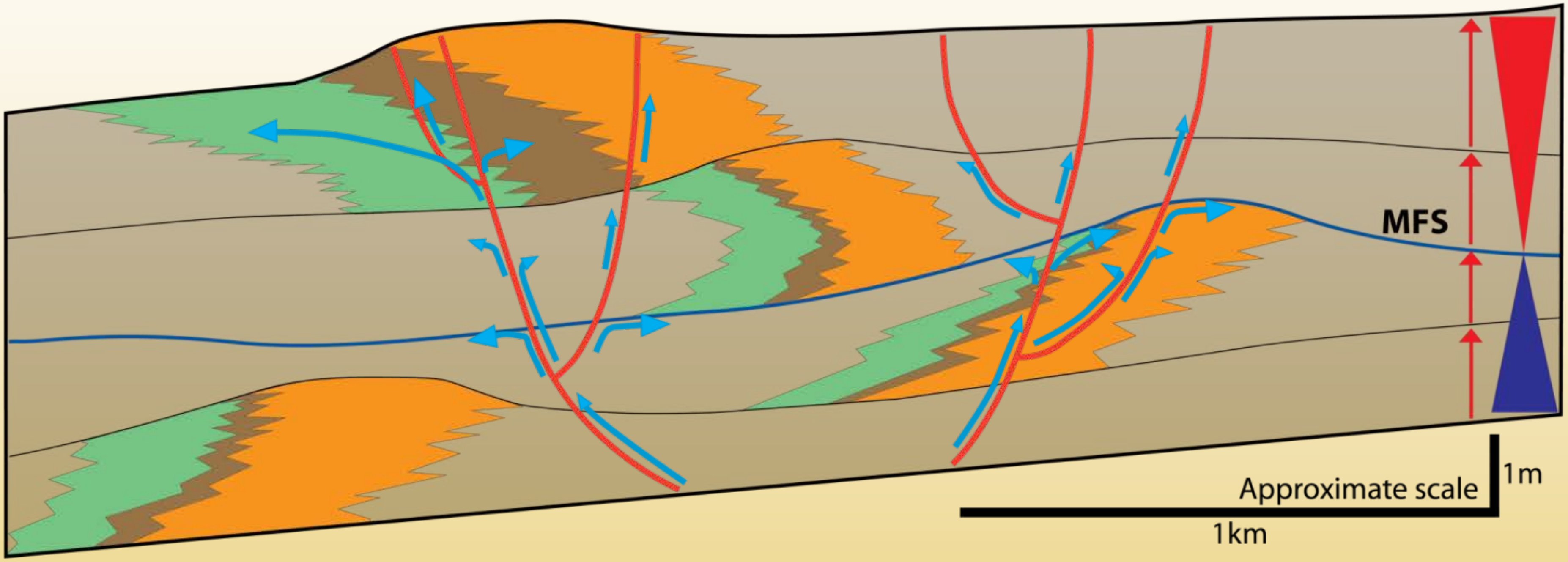
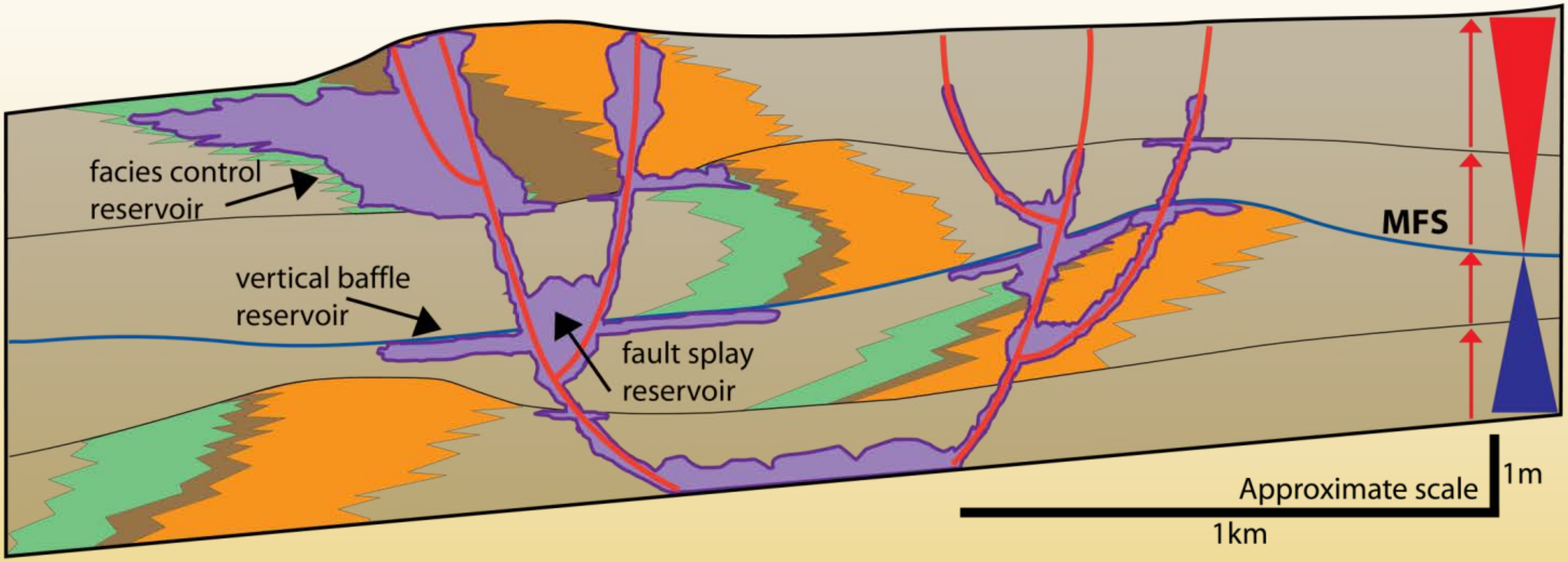
Sequence Stratigraphic Control on HTD Reservoirs



***Summary*:**

– HTD (Φ, **K**) distribution is controlled by <u>primary fabric</u> and <u>depositional geometries</u> (lateral) in addition to structural surfaces (vertical).

Sequence Stratigraphic Control on HTD Reservoirs



***Summary*:**

– HTD (Φ, **K**) distribution is controlled by <u>primary fabric</u> and <u>depositional geometries</u> (lateral) in addition to structural surfaces (vertical).

Summary - Key Points

1. Vertical distribution of HTD is concentrated along fault corridors
2. Lateral distribution of HTD can be attributed to:
   - Primary depositional facies
   - *Thallassinoides*-type burrowed facies are preferentially dolomitized increasing reservoir quality
   - Improved reservoir quality was observed in association with probable 4th order high frequency sequences
   - Local permeability barriers (vertical)
3. Facies mosaic (depositional model) and sequence framework enhance potential development (especially horizontal and multi-laterals)
4. Facies control on heterogeneity – whole core vs. plug analysis: Things to think about!