Widespread Hydrothermal Dolomitization of Trenton and Black River Groups, Eastern North America

Taury Smith, Richard Nyahay and Reservoir Characterization Group

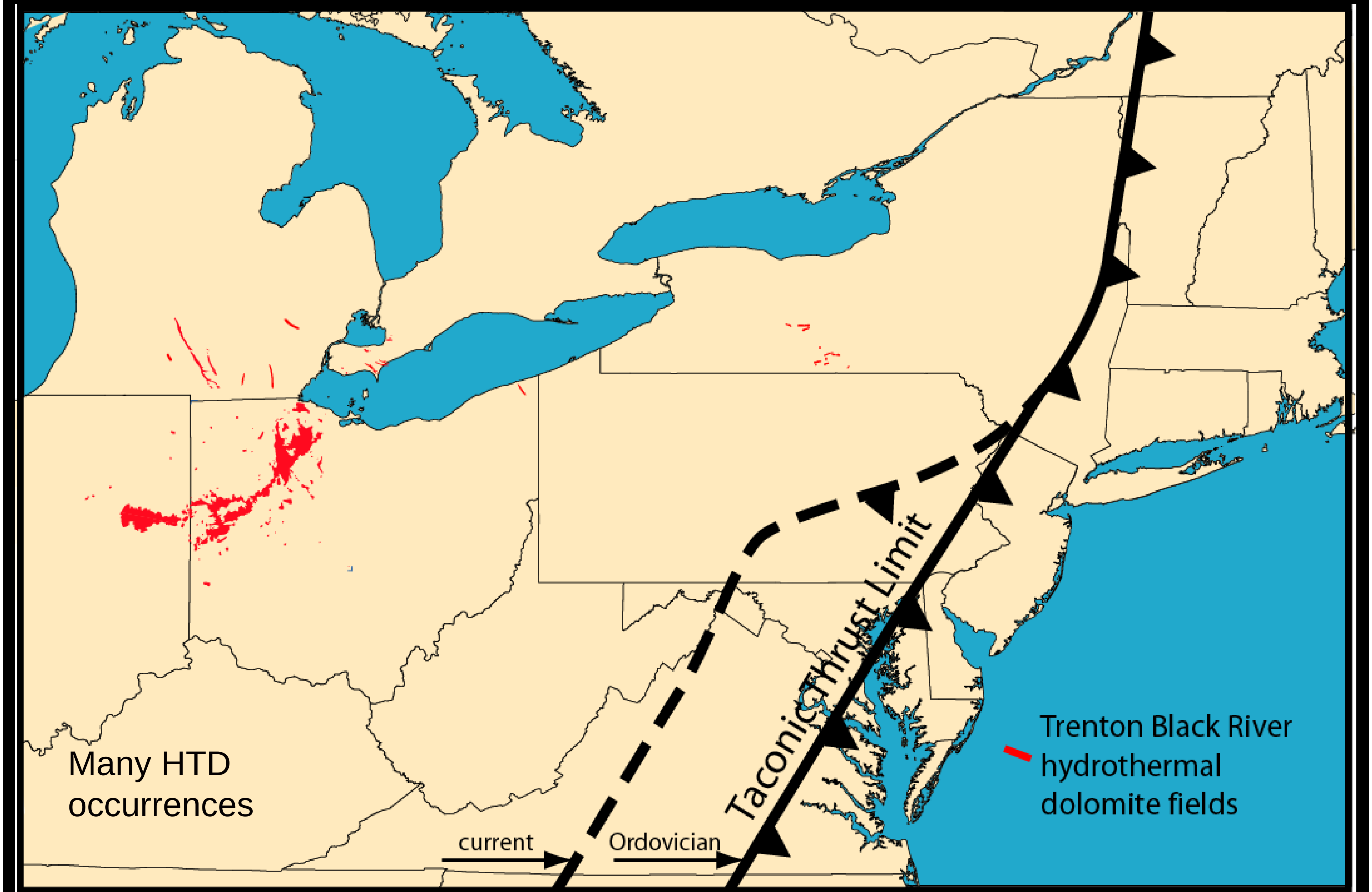
Reservoir Characterization Group at the New York State Museum

NETL

NYSERDA

Introduction

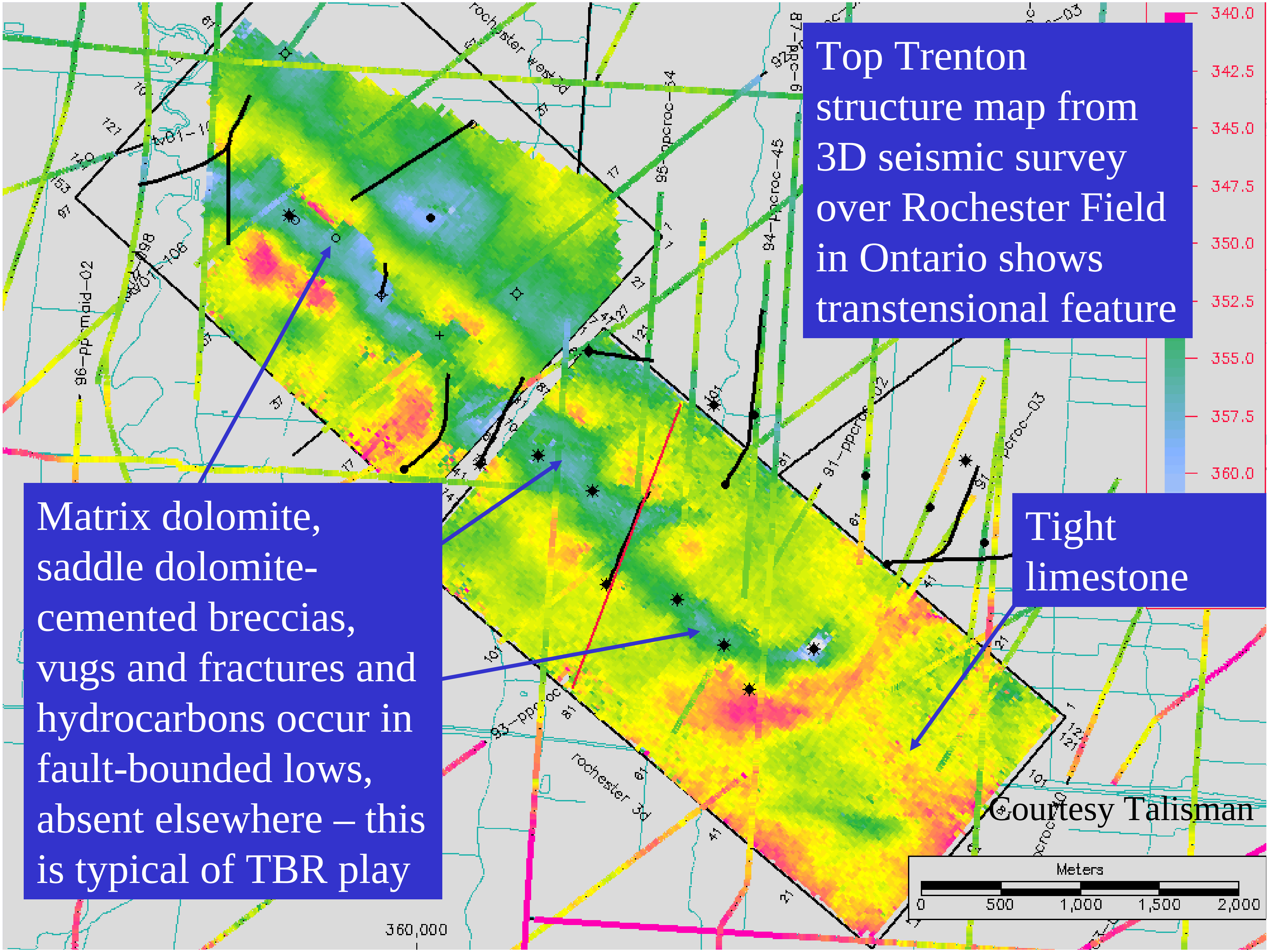
- The Black River play in New York and the recent discoveries MI and OH have rekindled interest in a play that has been around for 120 years
- Much of what will be presented here are the results of of a 5-state study on the Trenton-Black River hydrothermal dolomite play (NY, PA, WV, OH, KY)
- Main goal was to determine the origin of dolomites in producing fields, most of is hydrothermal in origin
- Also did some field studies, some of which will be presented here



Trenton Black River hydrothermal dolomite reservoirs

Structural Settings of Dolomitization

- We sampled dolomites from several structural settings (all linked to basement-rooted faults) to determine they were all of a hydrothermal origin
  - Negative flower structures in NY and Ohio
    - Most with minor offset and faults that die out in Utica
    - One with significant offset that cuts through Silurian section
  - Carbonate platform margin-bounding faults with shale basin (extensional or possibly transtensional)
  - Positive flower structure or impact structure

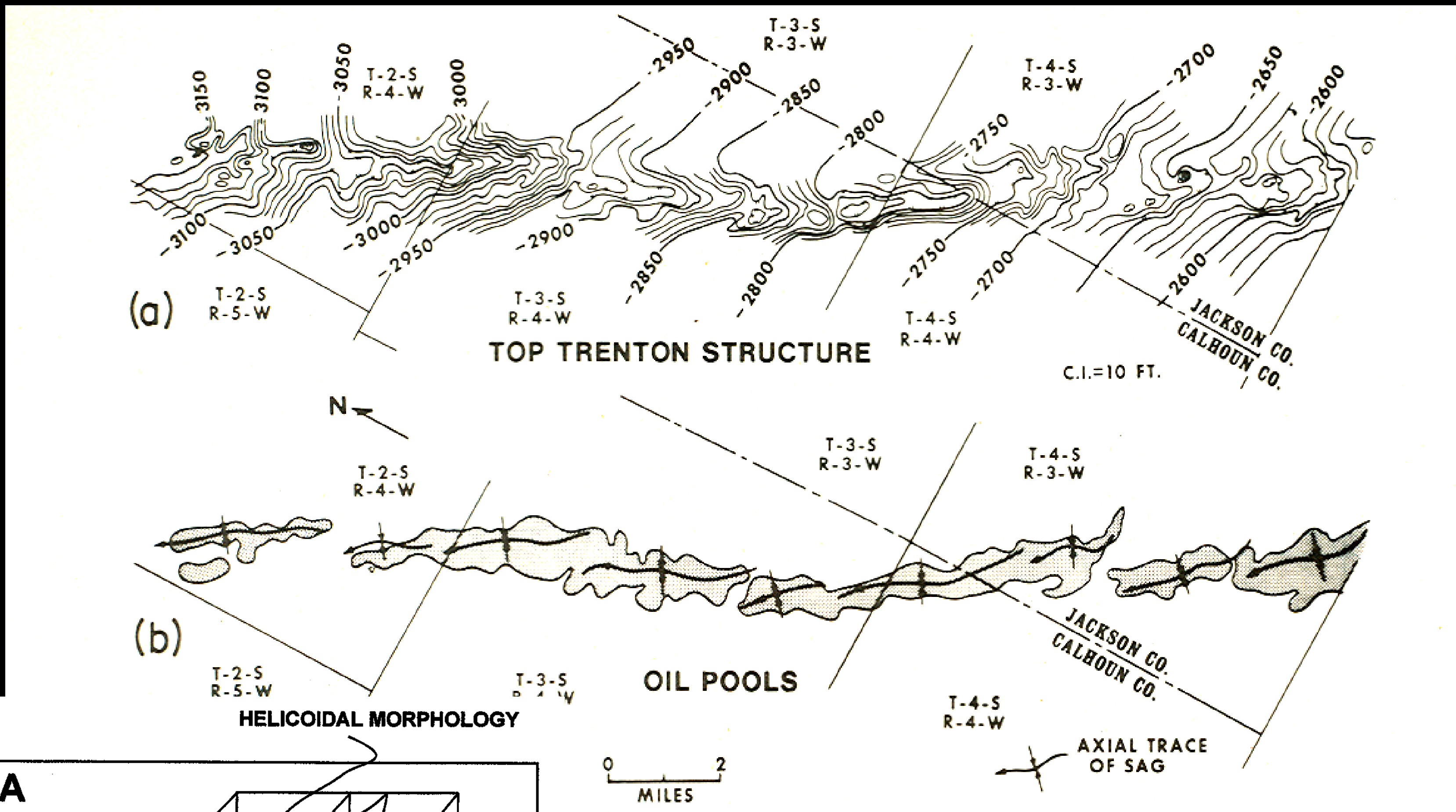


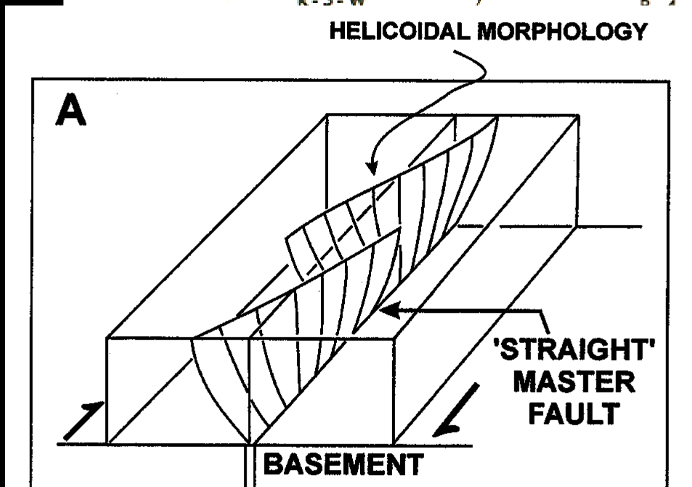
Top Trenton structure map from 3D seismic survey over Rochester Field in Ontario shows transtensional feature

Matrix dolomite, saddle dolomite-cemented breccias, vugs and fractures and hydrocarbons occur in fault-bounded lows, absent elsewhere – this is typical of TBR play

Tight limestone

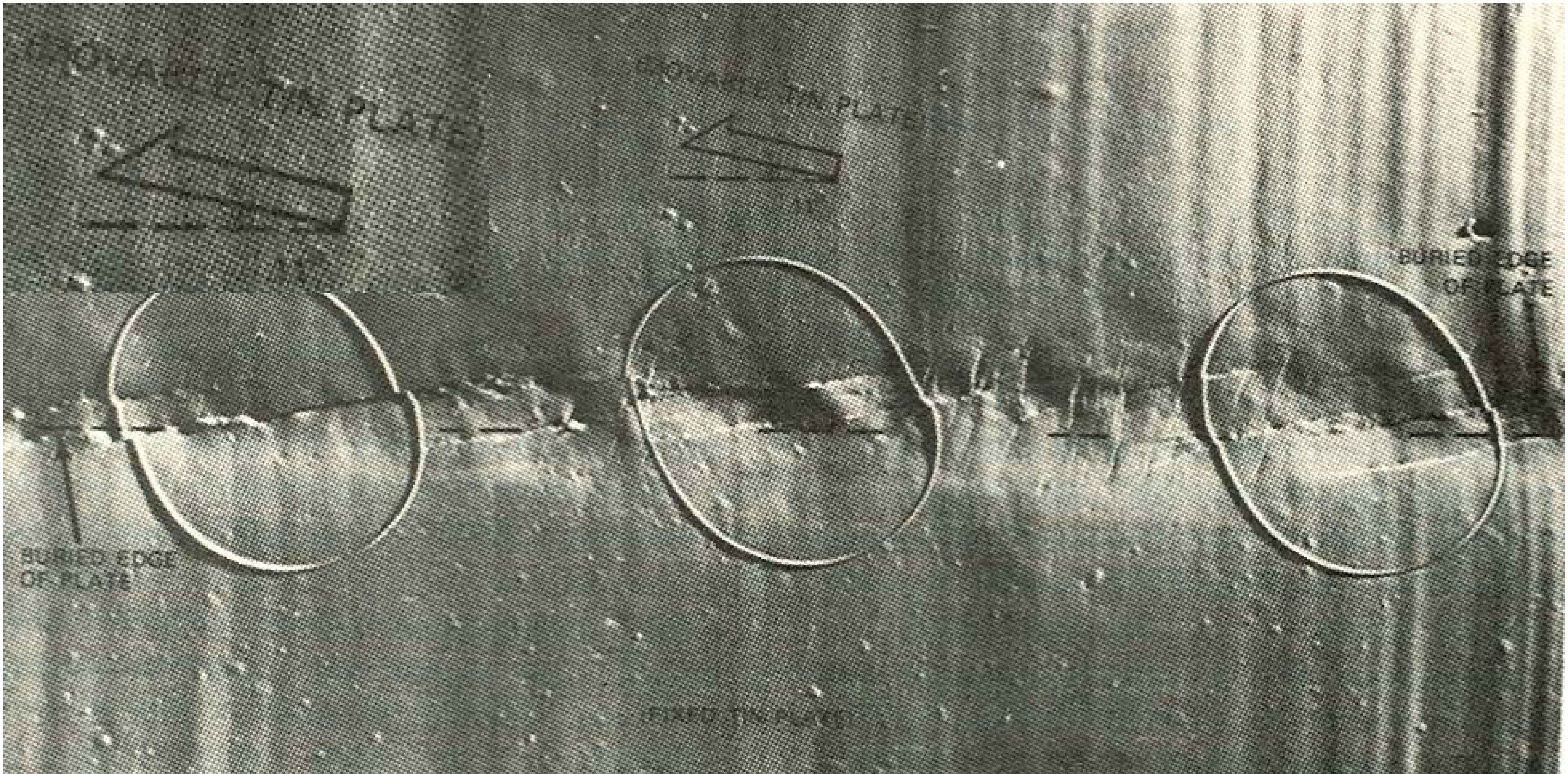
Courtesy Talisman





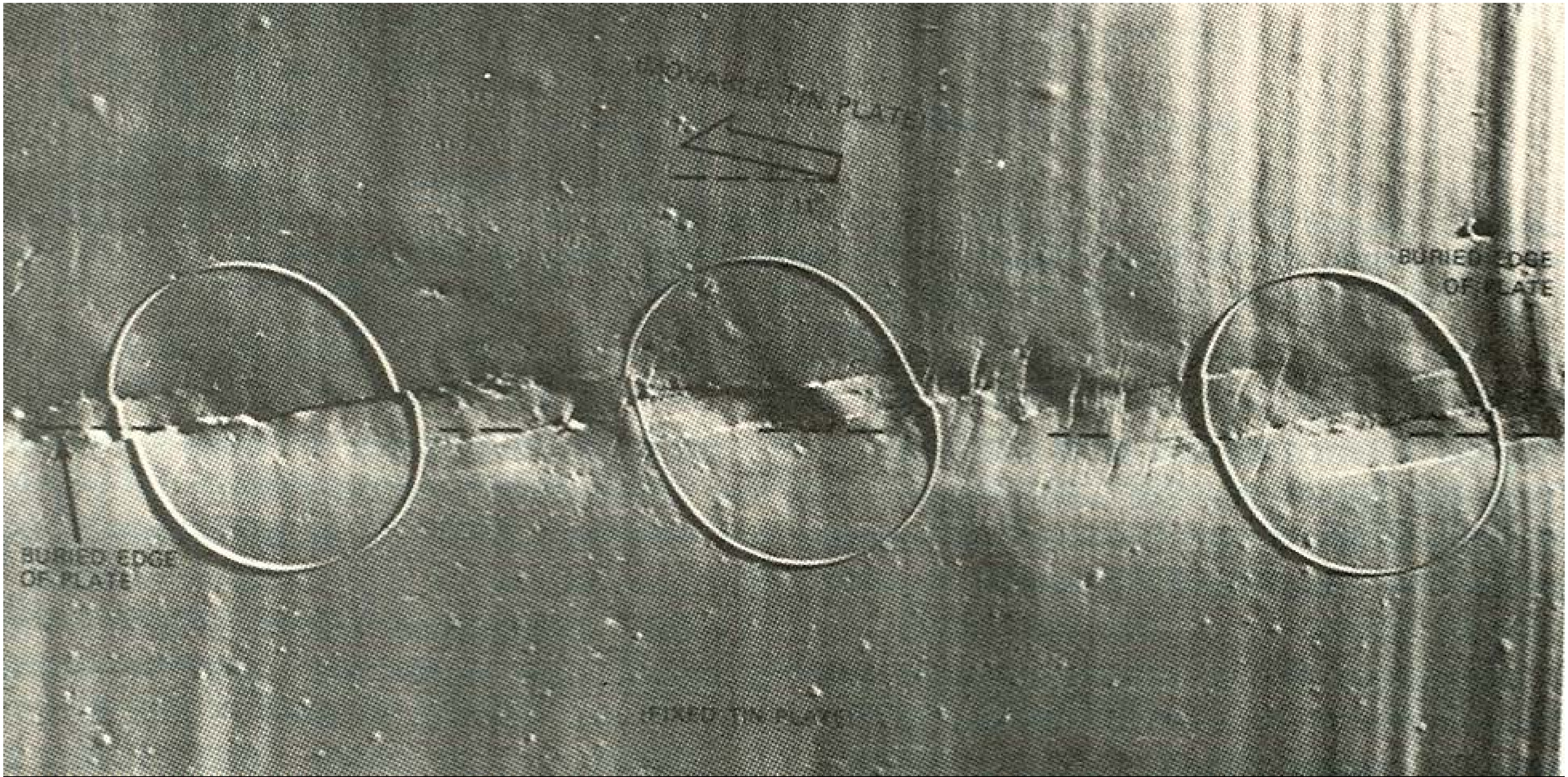
Naylor et al., 1986

Harding, 1974 – Mapped *en echelon* sags in Albion-Scipio Field, noted that they trended at low angle to underlying fault



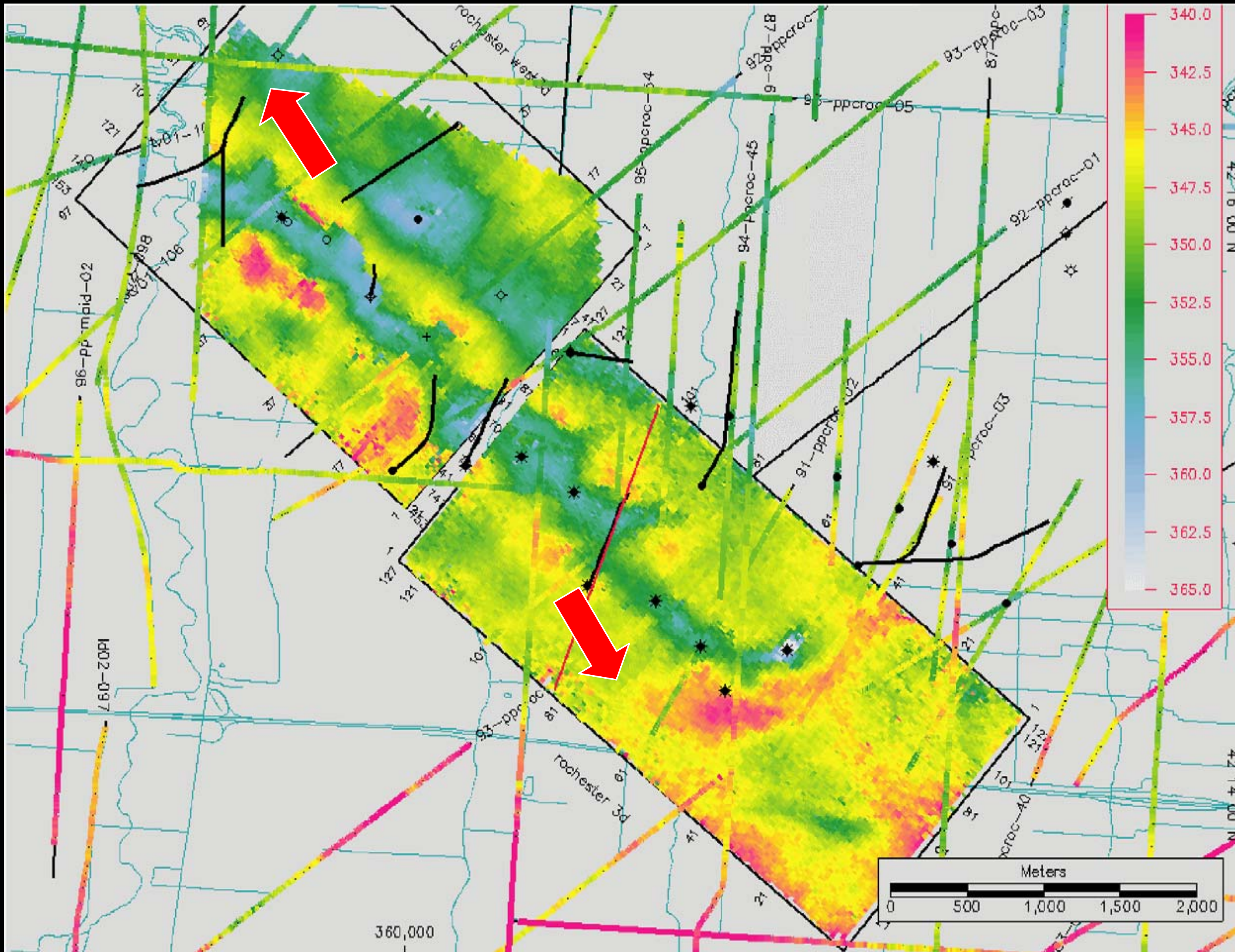
Harding, 1974 – In order to produce the sags found at Albion Scipio, Harding added a component of extension to the fault movement or “oblique divergent slip” at 11º to trend of fault

“Oblique divergent component would have emphasized the extensional effects of the mild deformation and would have tended to open the synthetic fractures, facilitating dolomitization”

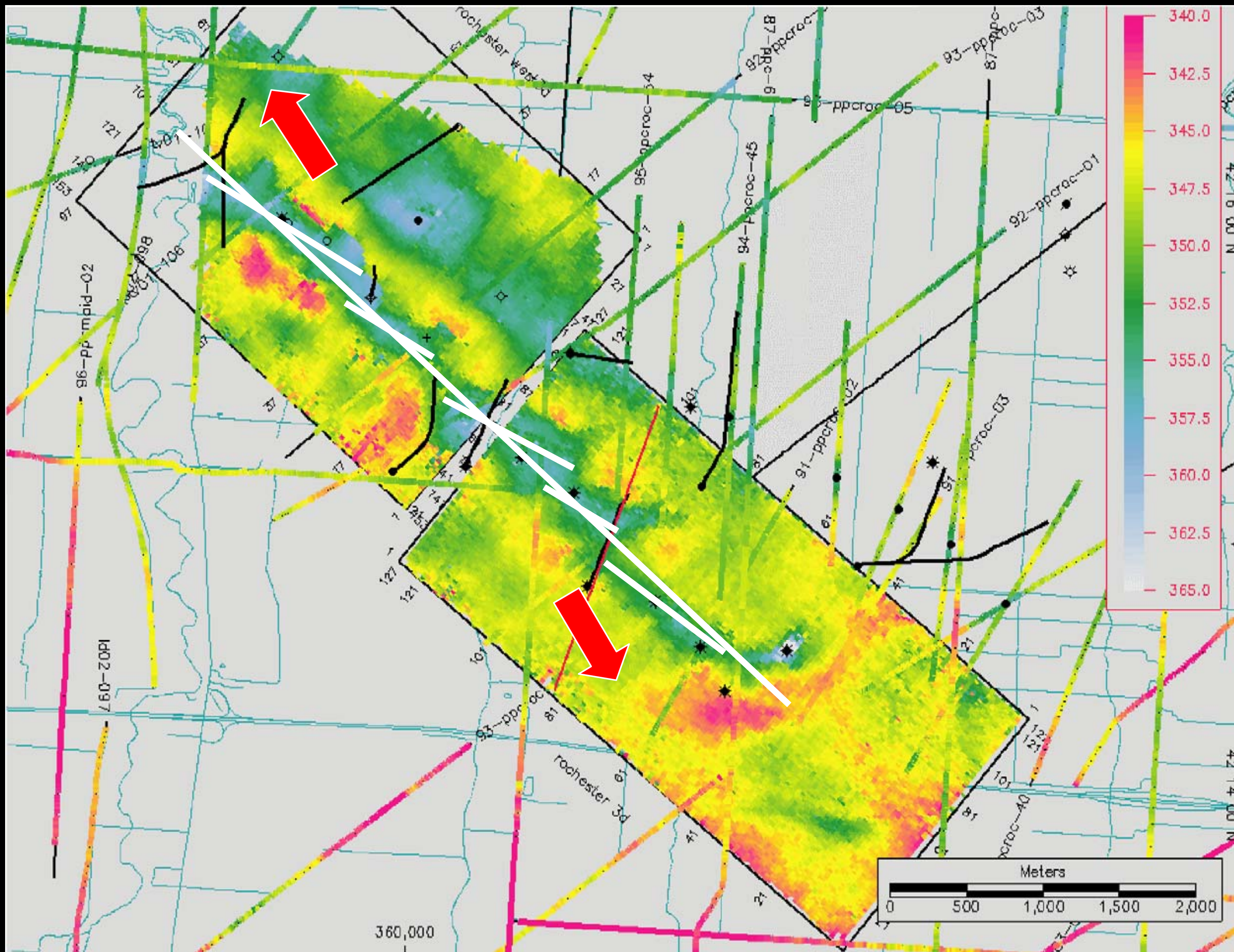


This type of faulting would occur when there was a pre-existing basement fault that was reactivated in an oblique divergent sense

Riedels form at ~5-10º to fault trend

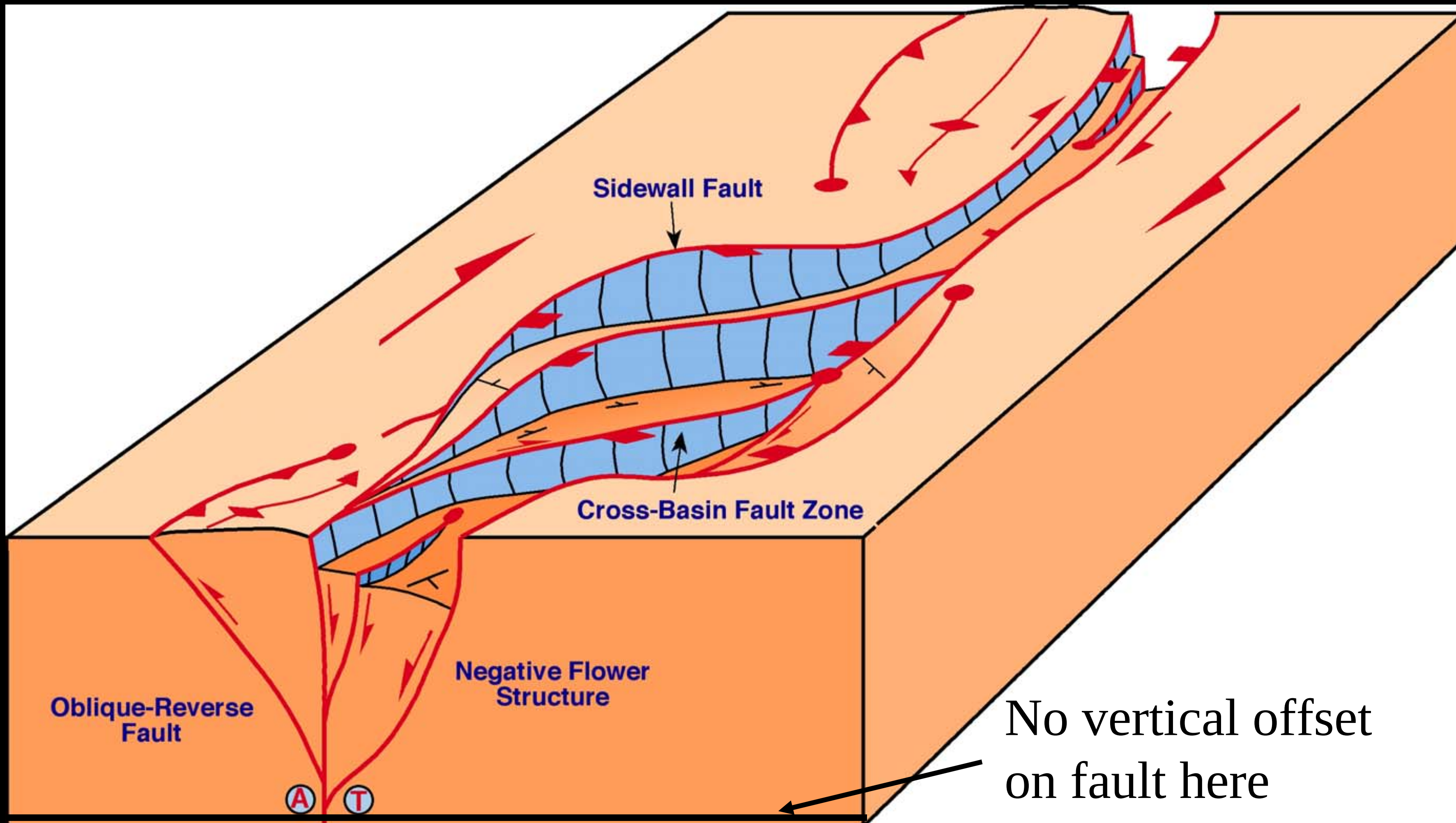


The ~continuous nature of the sag suggests that it formed from NNW-SSE Oblique divergent slip

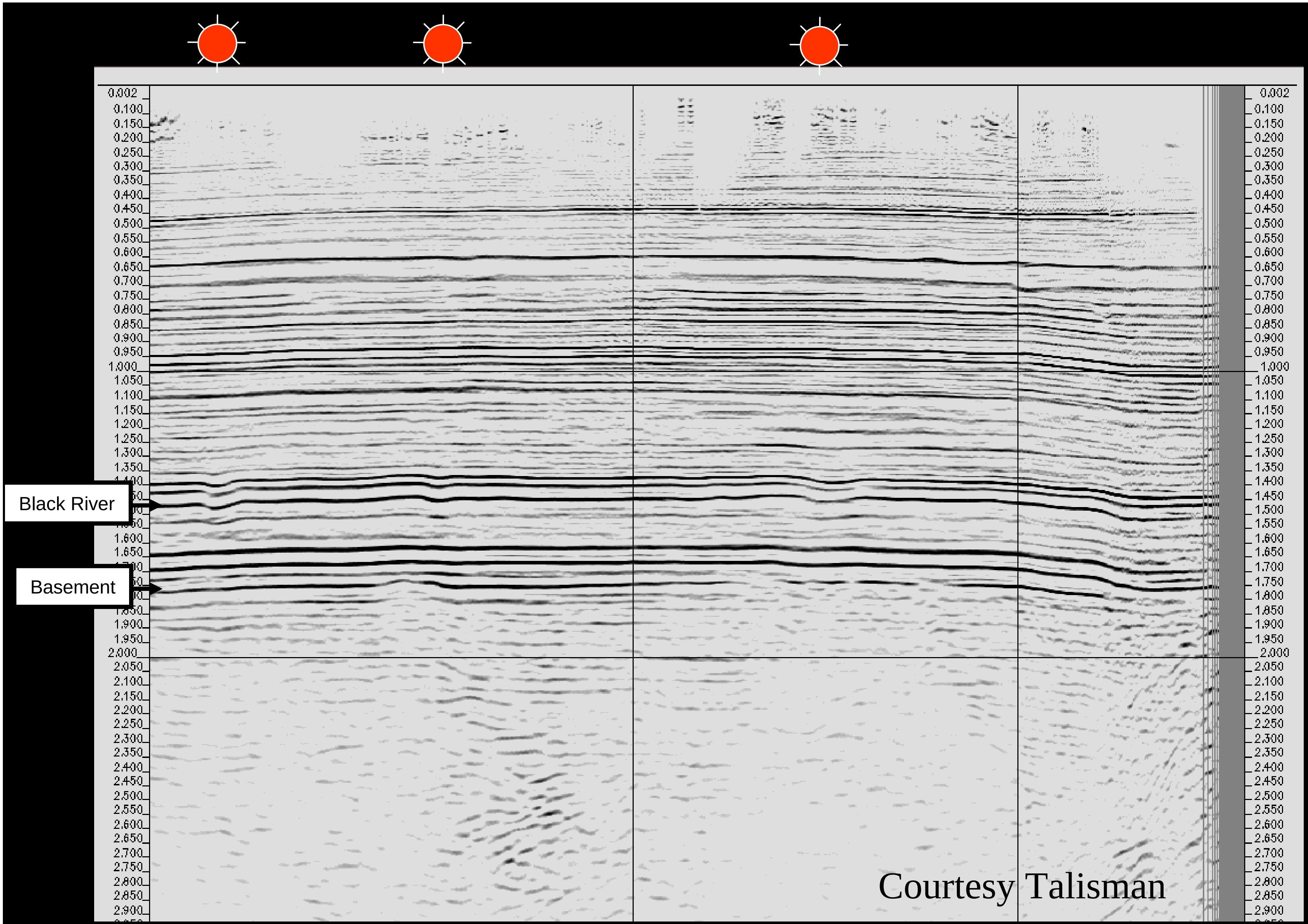


Each sag occurs in a negative flower structure that is linked to an underlying left-lateral transtensional fault

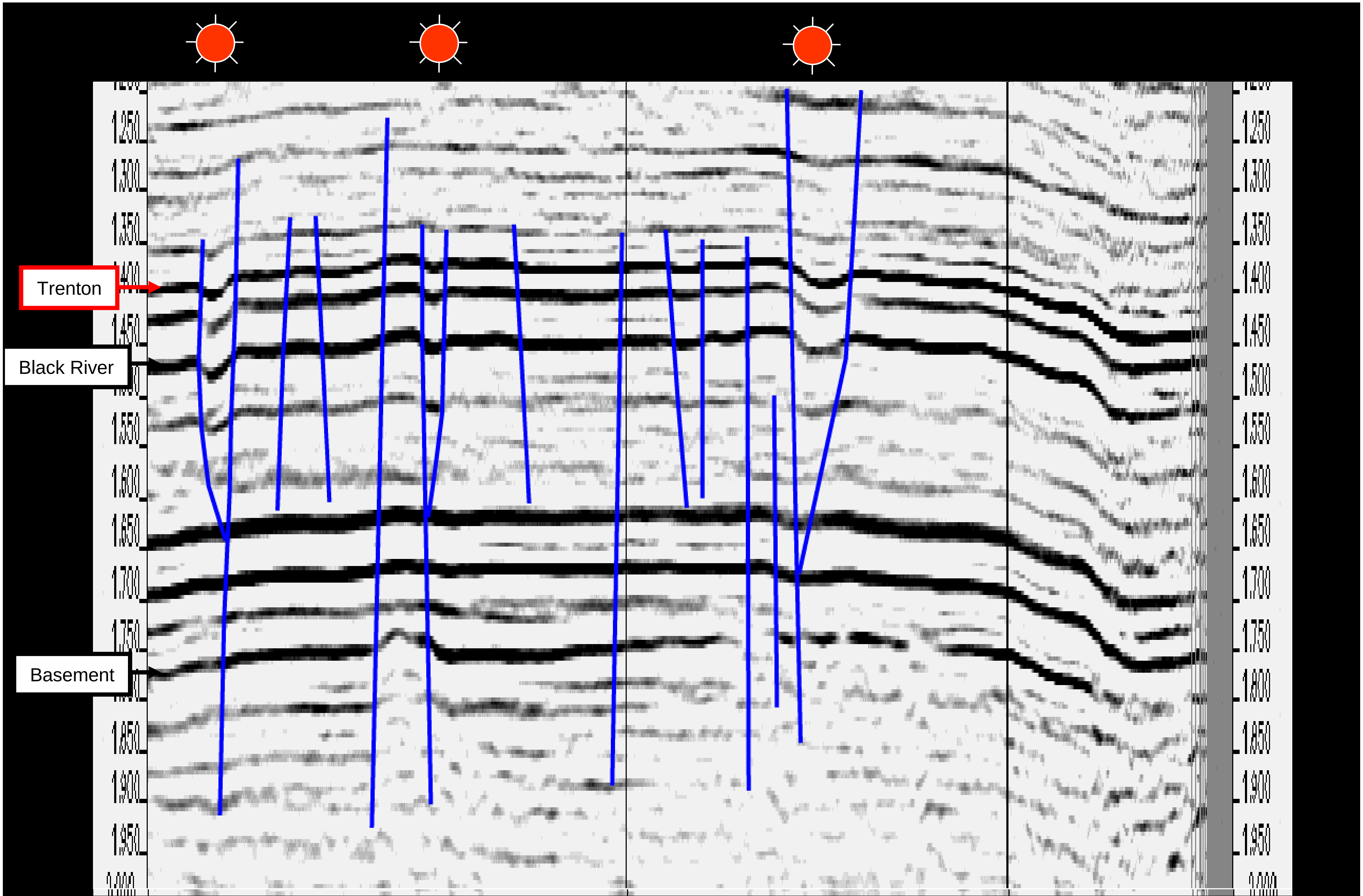
Outcrop analog in Ordovician of Mohawk Valley, NY confirms interpretations



Block Model for transtensional pull apart – Dooley and McClay, 1997 - Note in cross section view that either side of fault zone is not vertically displaced but that significant thinning occurs within fault zone



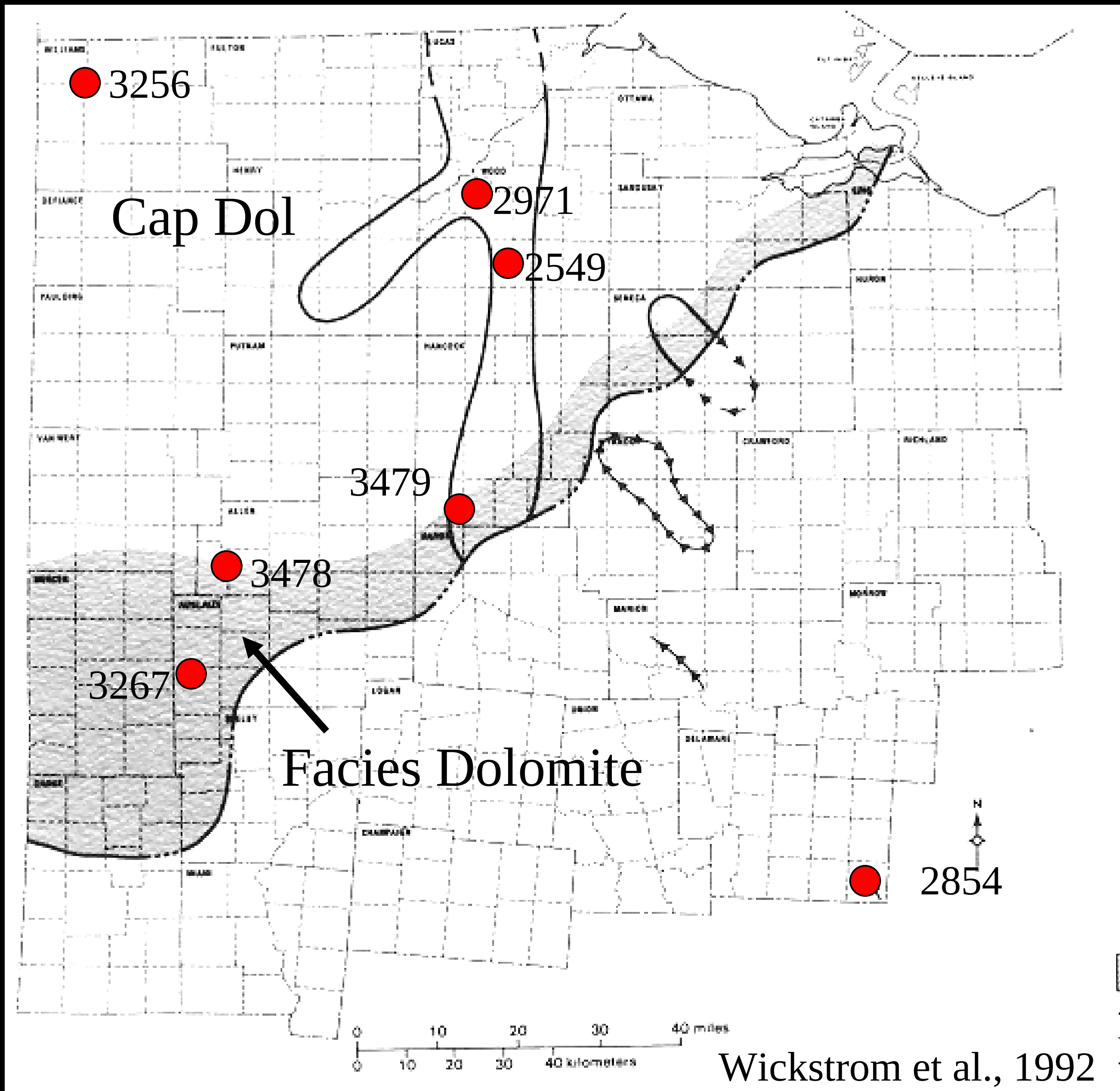
Seismic Line from heart of Black River producing area in NY with three producing wells, each in a separate sag – Basement offset is not obvious

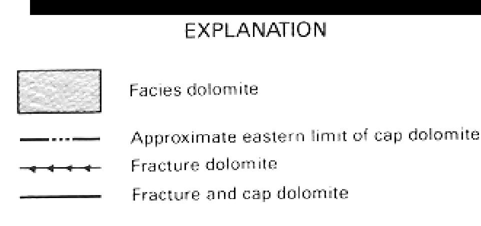


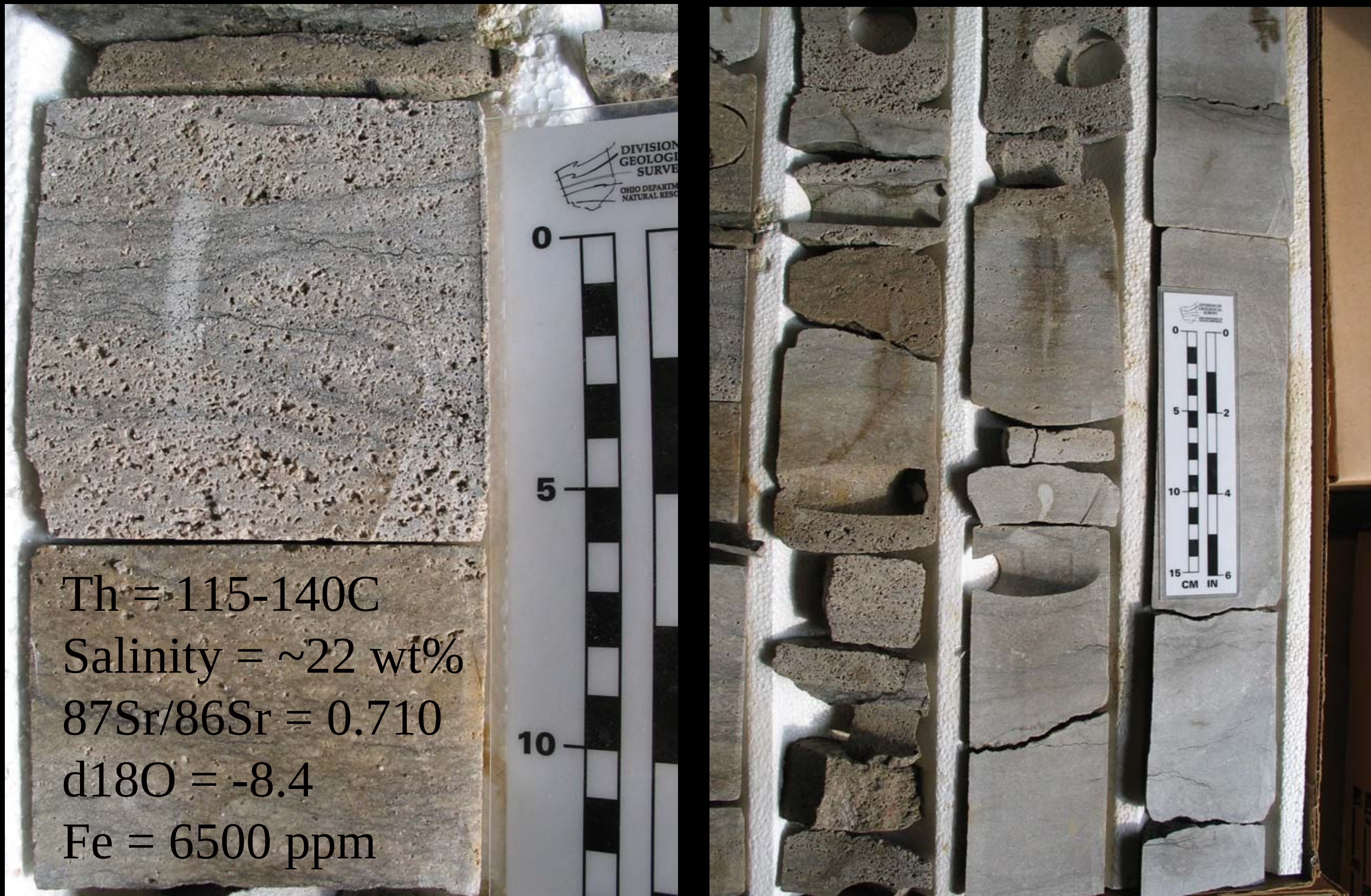
When stretched vertically, basement control becomes clear; sags almost all accommodated in overlying shale suggesting early faulting and alteration

Locations of wells sampled in NW Ohio

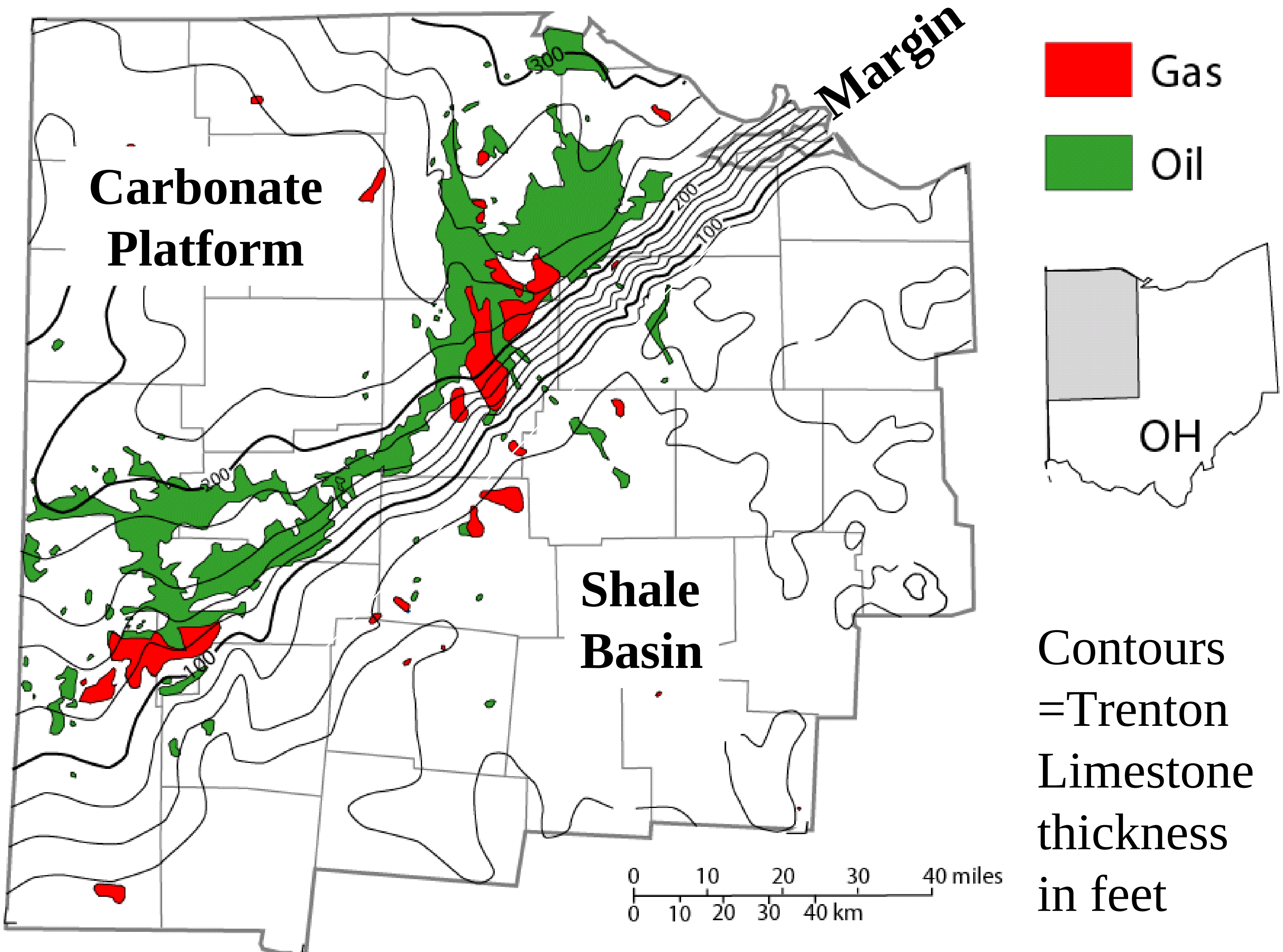
Several in “facies” and “cap” dolomite as well as “fracture” dolomite





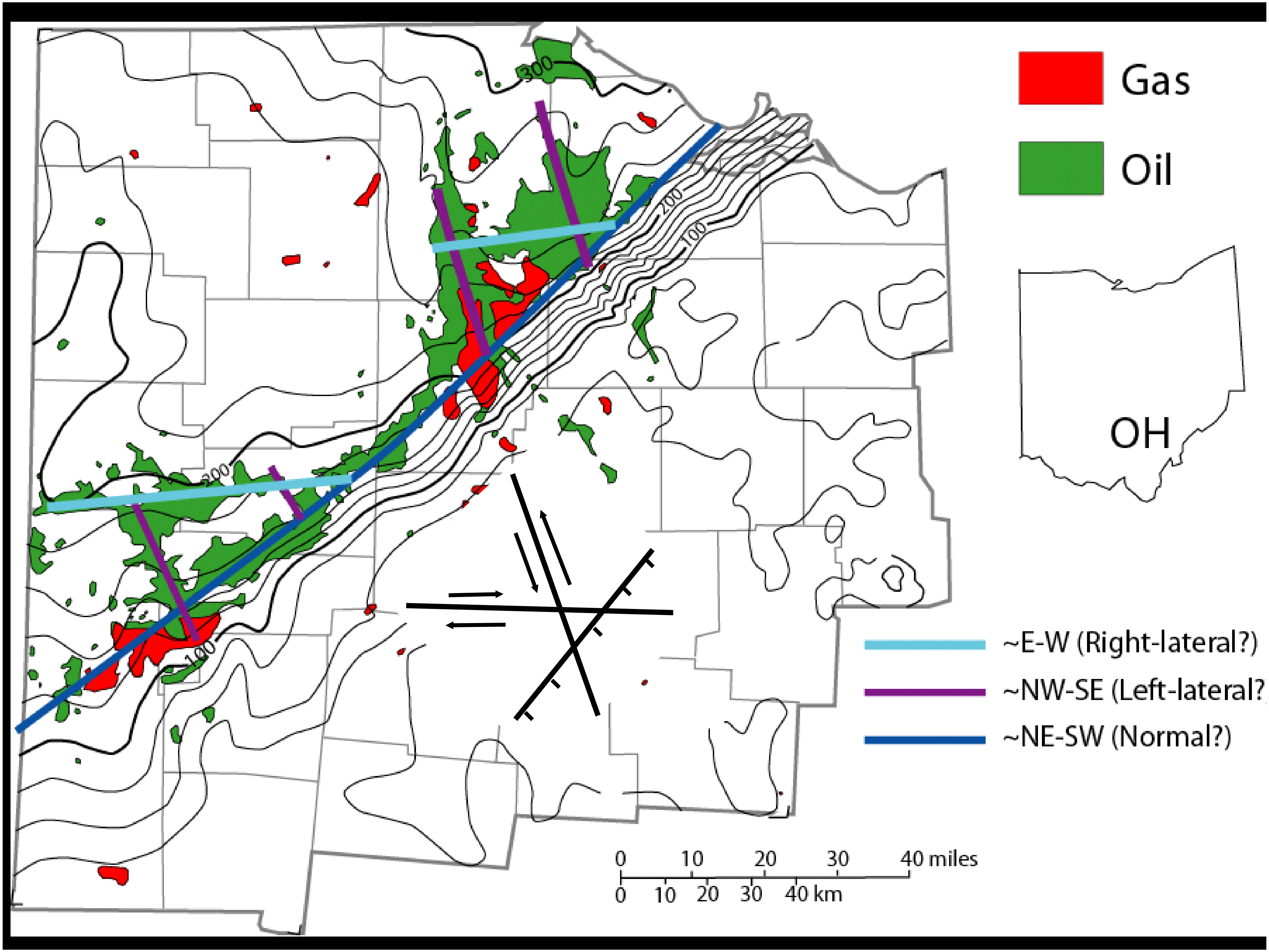


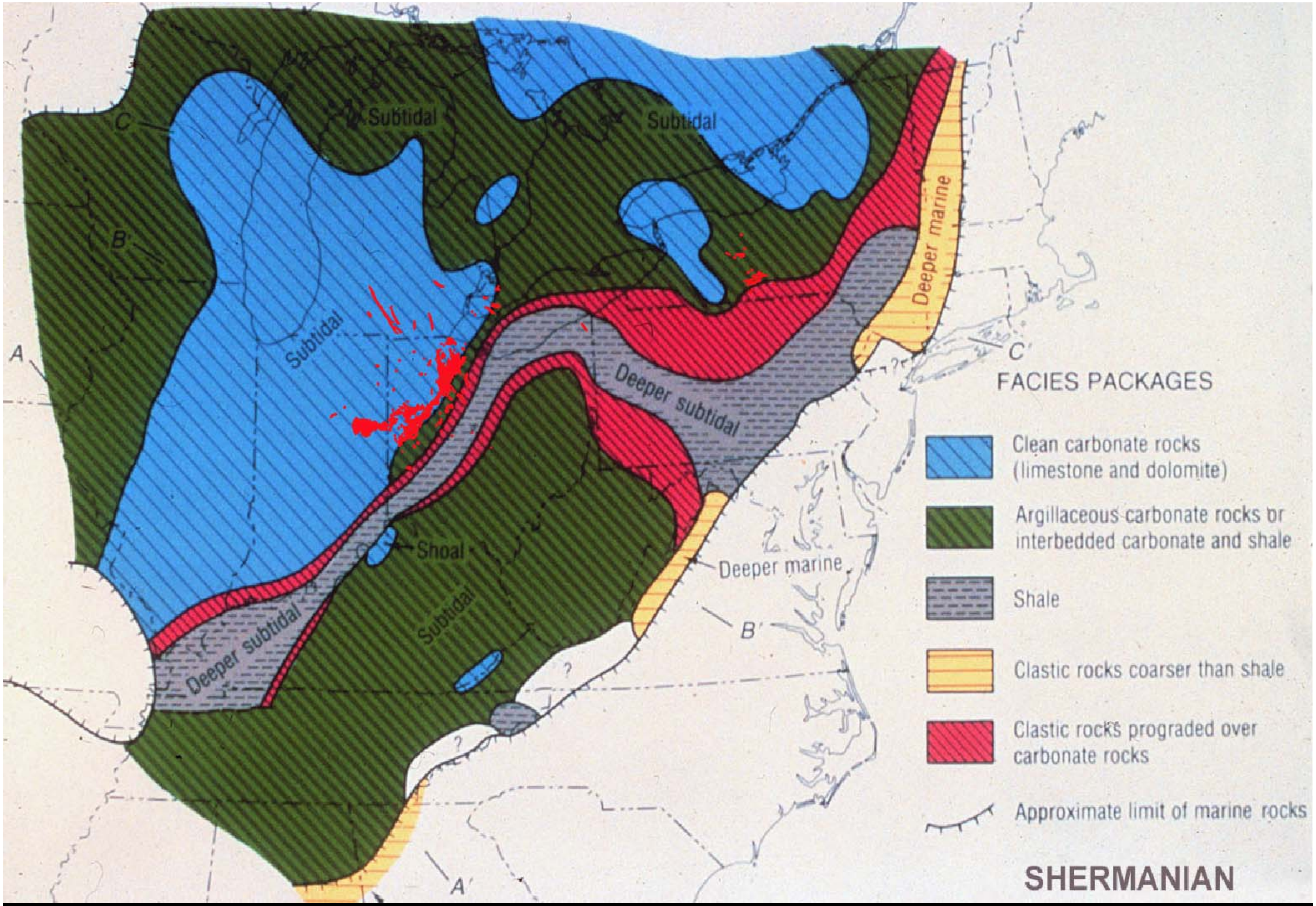
"Facies" Dolomite –occurs along margin of Seebree Trough in OH and IN, matrix porosity, little obvious vug- or fracture-filling white saddle dolomite



Modified from Wickstrom et al., 1992

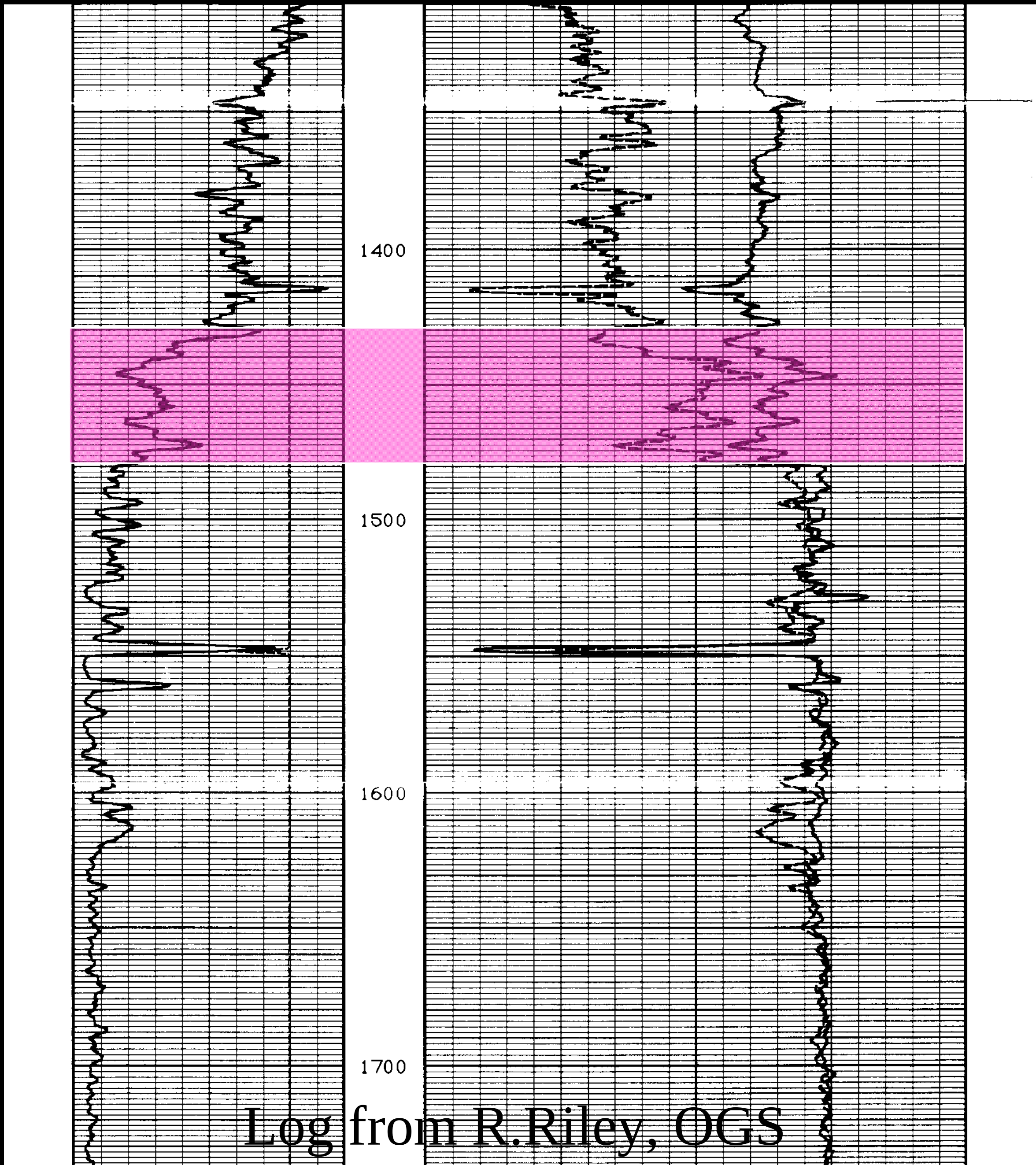
Dolomitization in Trenton occurs along margin with shale basin, around intraplatform wrench faults and at fault intersections


Gas
Oil
OH
300
200
100
~E-W (Right-lateral?)
~NW-SE (Left-lateral?
~NE-SW (Normal?)
0 10 20 30 40 miles
0 10 20 30 40 km



Trenton Depositional Environments with Fields (map from Keith)

Based on this map, it looks like many of the fields occur parallel to the margin of the Seebree Trough. Fields are not confined to the margin, however, and occur both in the Trough and back on the platform – These are commonly oriented at an angle to the margin Trenton-aged structure clearly has an impact

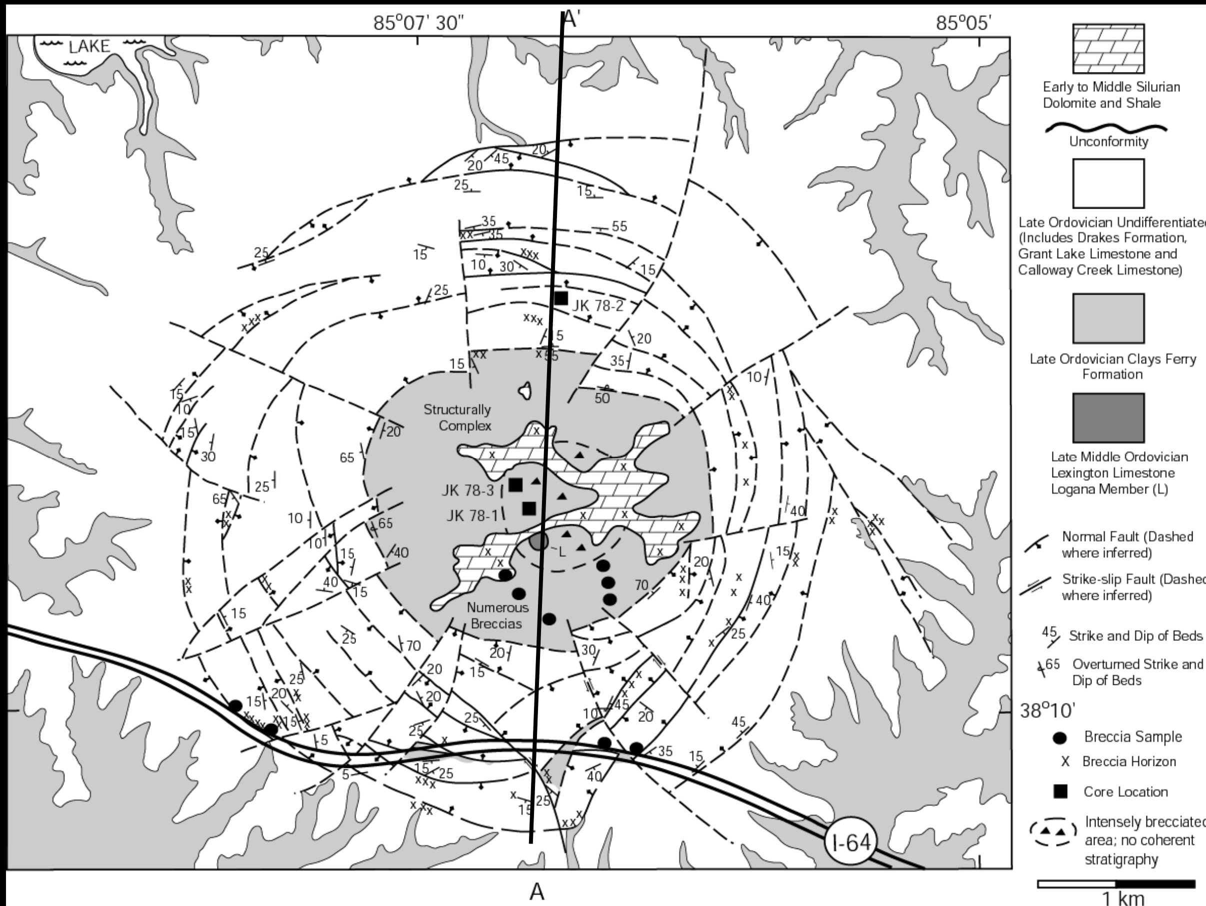


Cap dolomite

In much of NW Ohio (as well as NE IN and much of southern and Western MI, elsewhere)

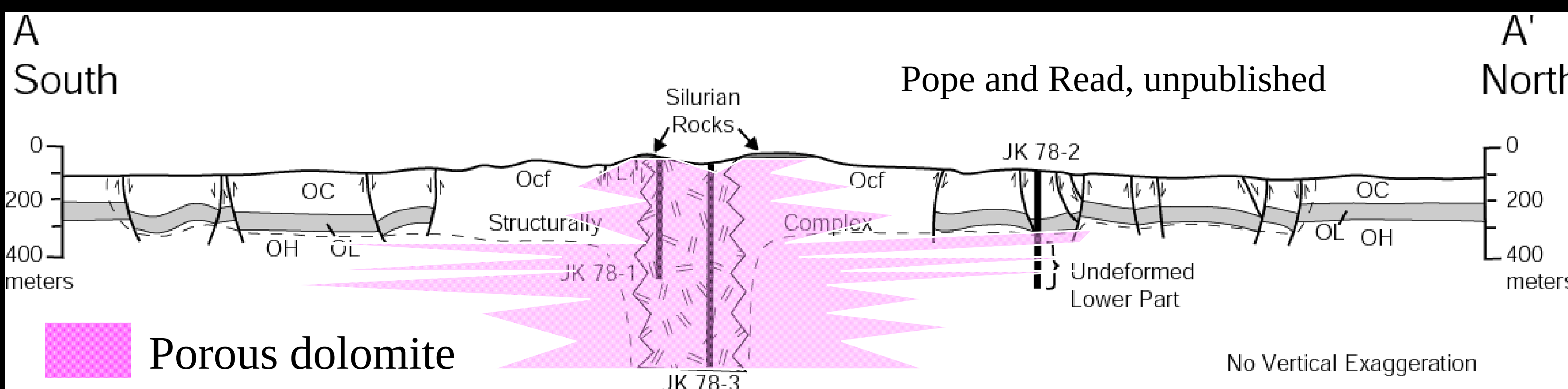
This dolomite is typically tight, iron-rich

Jeptha Knob



The structure is a positive feature that is pervasively dolomitized brecciated, fractured, faulted and very porous

Three cores sampled from core and flank of structure



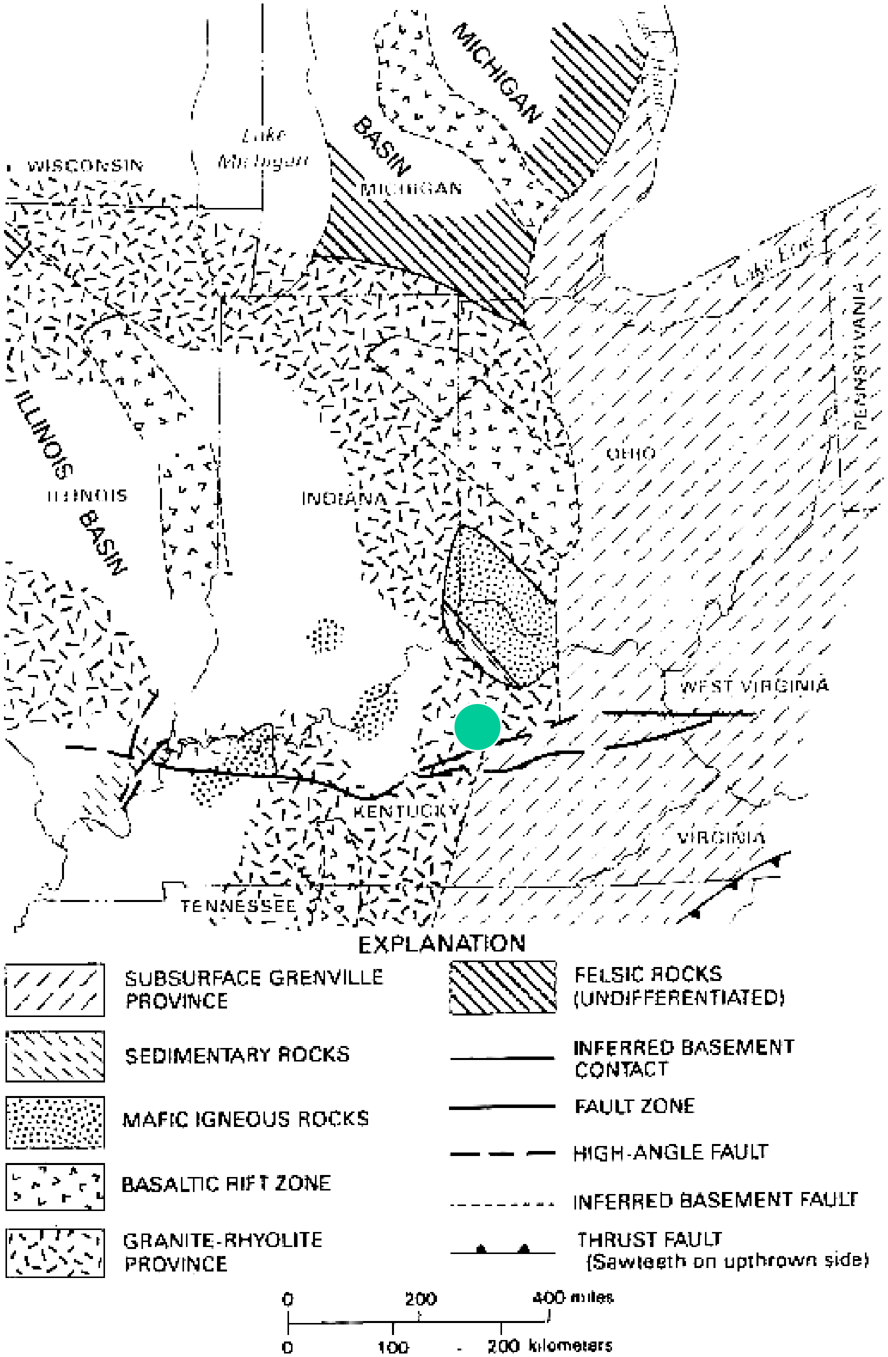
Jeptha Knob

Lexington (Trenton)

High Bridge (Black River)

Pope and Read, unpublished

Jeptha Knob has been interpreted by some to be an impact structure by others to be a tectonic feature– it is here interpreted to be a positive flower structure – The Trenton and Black River are pervasively dolomitized, porous and permeable



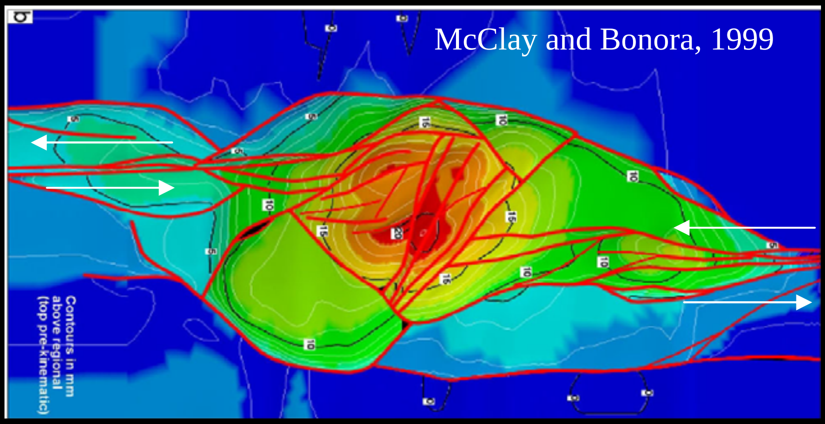
Wickstrom et al. 1992

Basement Map of Eastern US

Looks like major right lateral movement as occurred on 38th parallel lineament

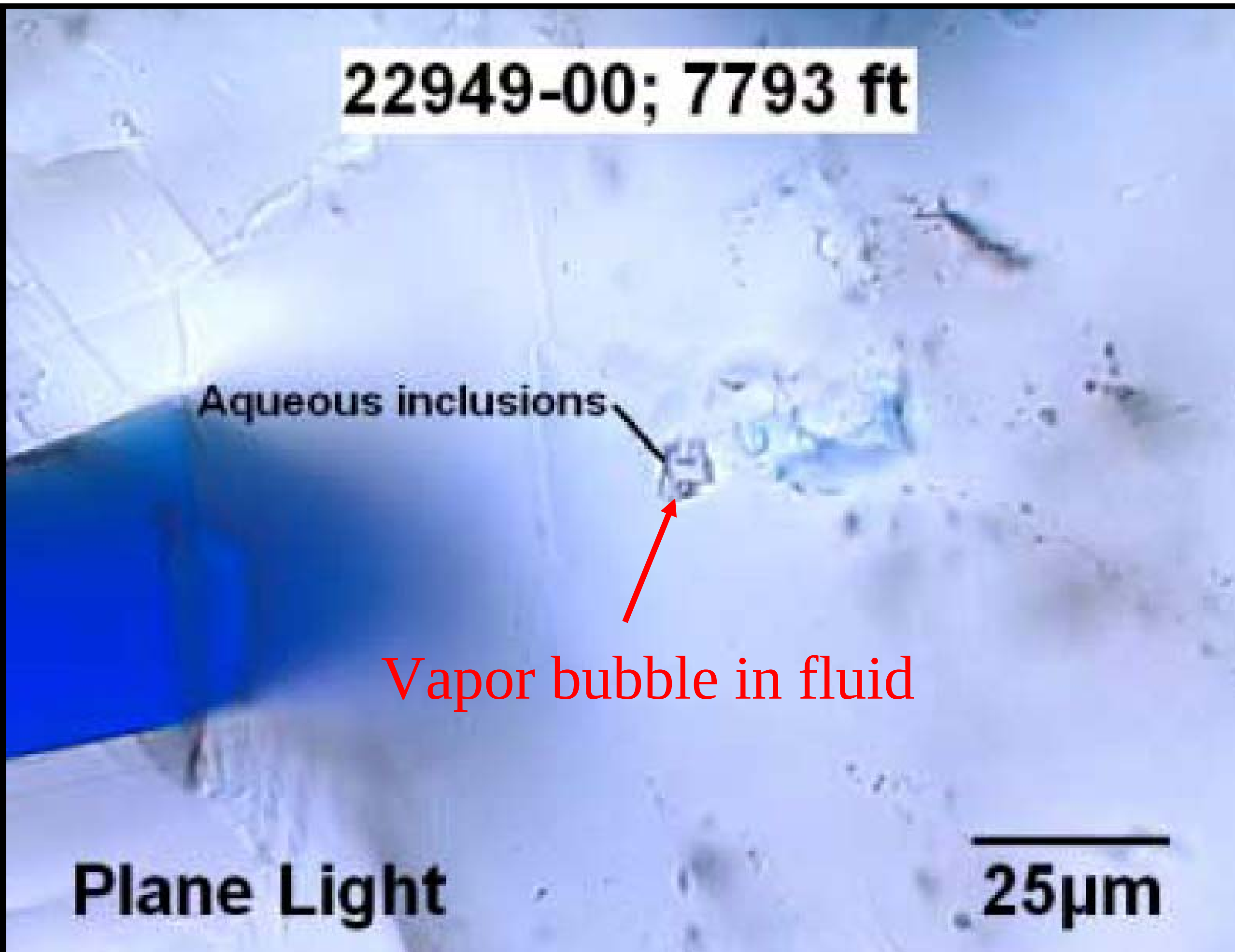
Not sure, but it looks like Jeptha Knob occurs near the lineament (Black, USGS, thought it was related)

If this is a compressional part of the fault zone, a positive flower structure could have formed



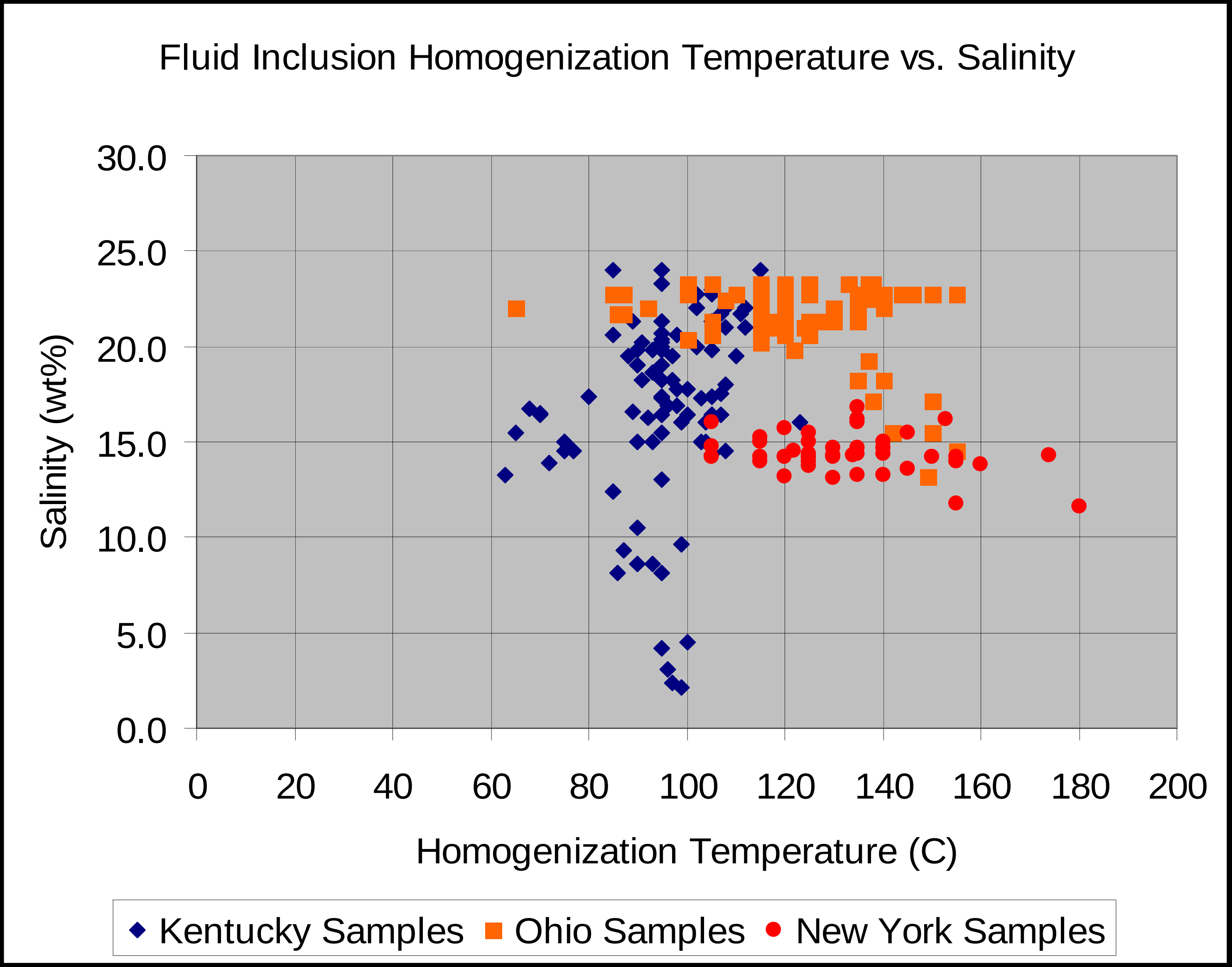
Dolomite Geochemistry

- Did a combination of fluid inclusions, stable isotopes, Strontium Isotopes and trace element analysis to learn origin of dolomites from all different types of structures in NY, OH, KY and WV
- Bottom-line: All reservoir-quality dolomite in study area is of a fault-related hydrothermal origin

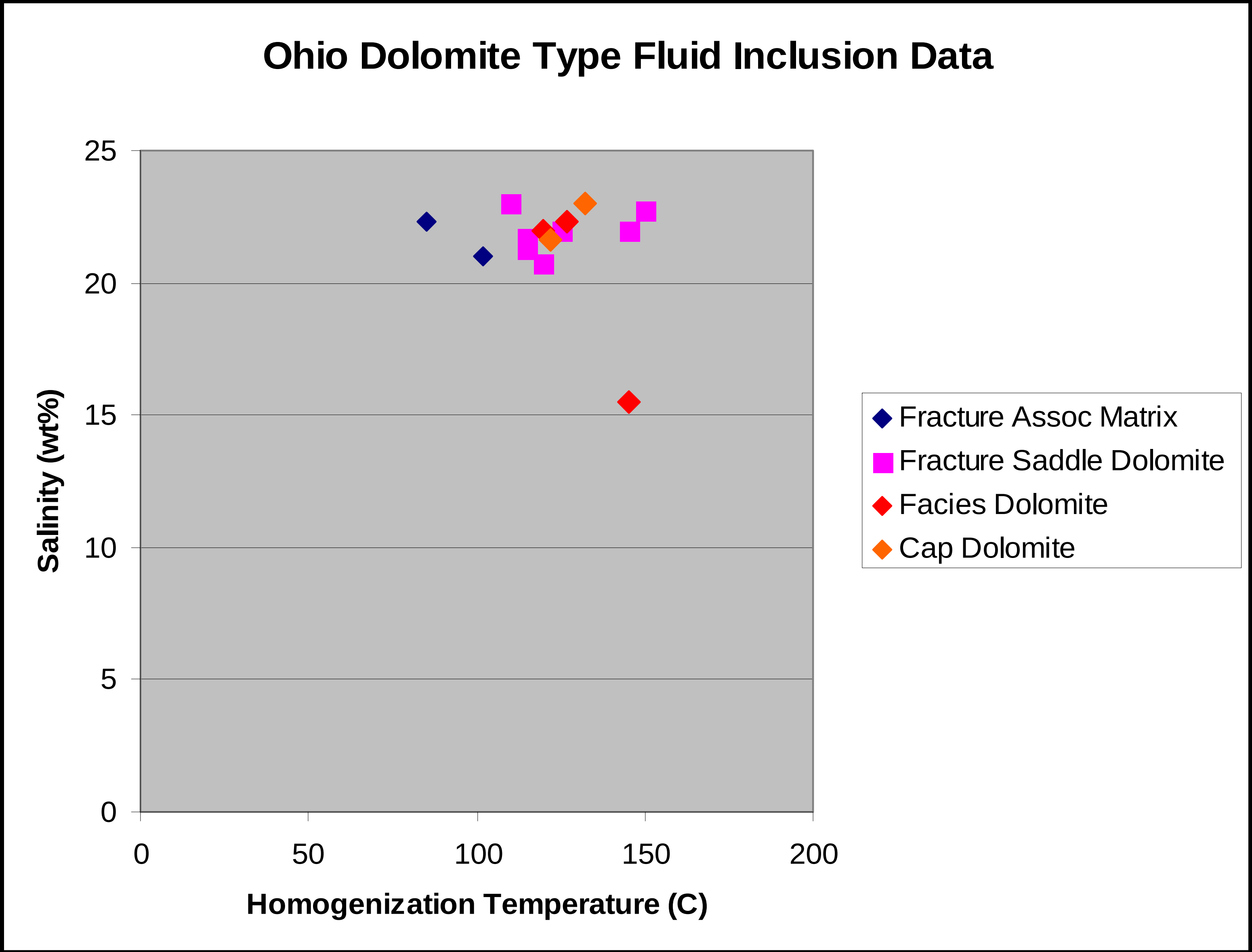


Homogenization temperature determined by heating sample until vapor bubble in two-phase inclusion disappears

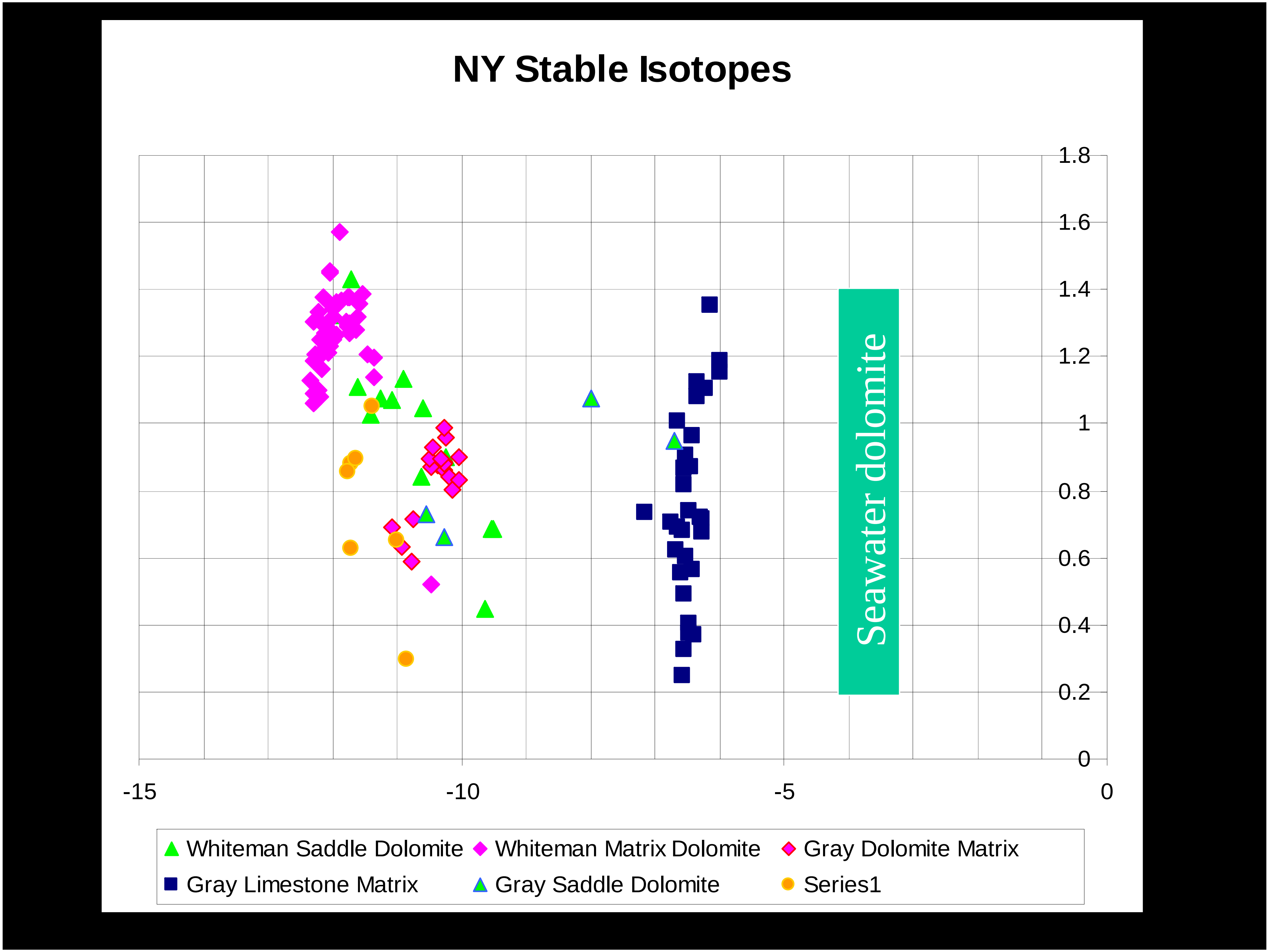
Salinity determined by cooling inclusion until it freezes, then slowly warming it until it melts - higher salinity fluids freeze at progressively lower temperatures

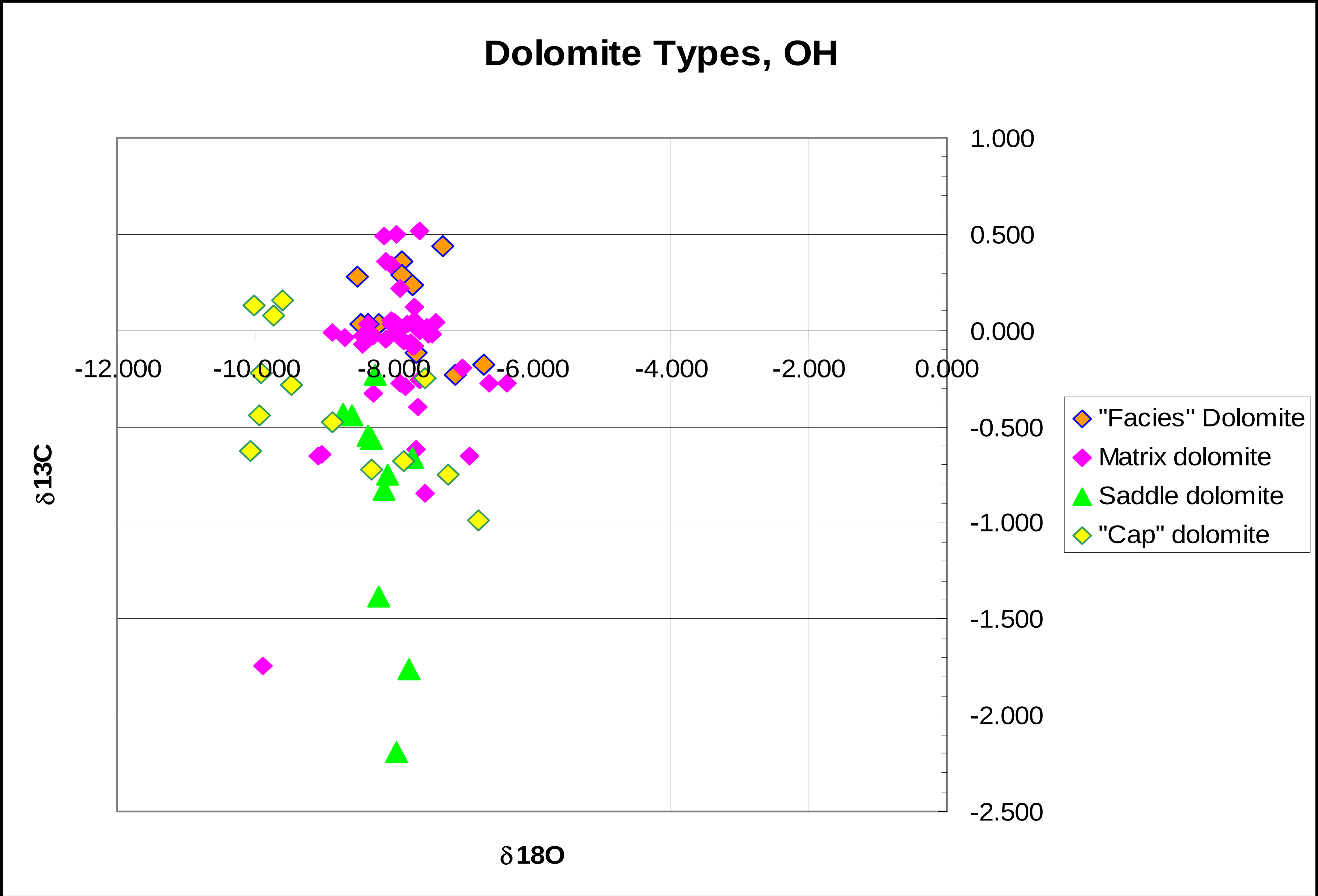


Most of the dolomite formed between 85-160C and all of it formed above surface temperatures – most salinities between 13 and 24 wt%

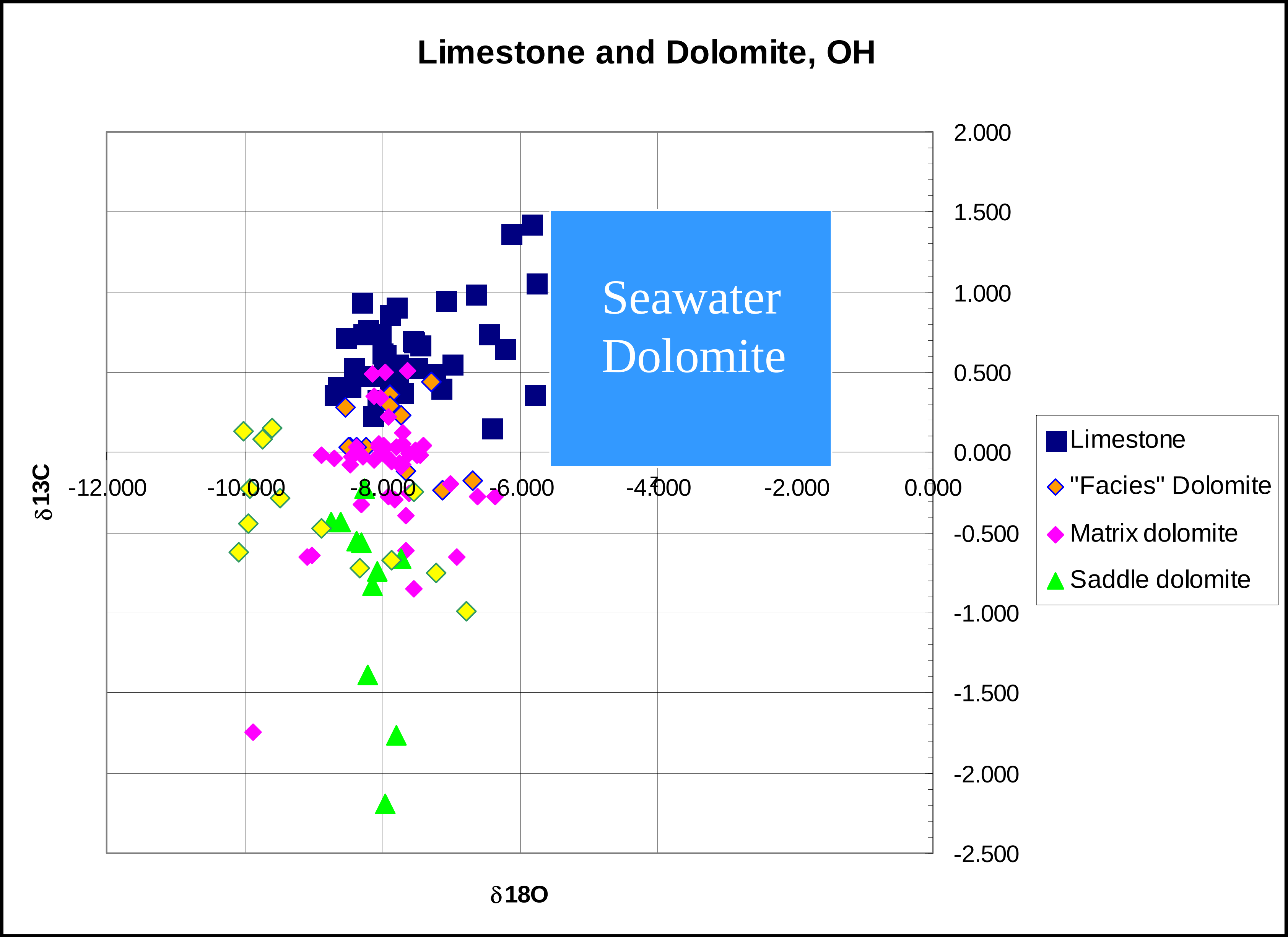


Ohio Fluid Inclusion Data shows that “facies,” “cap” and fracture related saddle and matrix dolomites all formed from hydrothermal brines


NY Stable Isotopes
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
-15
-10
-5
0
Seawater dolomite
Whiteman Saddle Dolomite
Whiteman Matrix Dolomite
Gray Dolomite Matrix
Gray Limestone Matrix
Gray Saddle Dolomite
Series1



All dolomite types in Ohio have similar values suggesting same origin

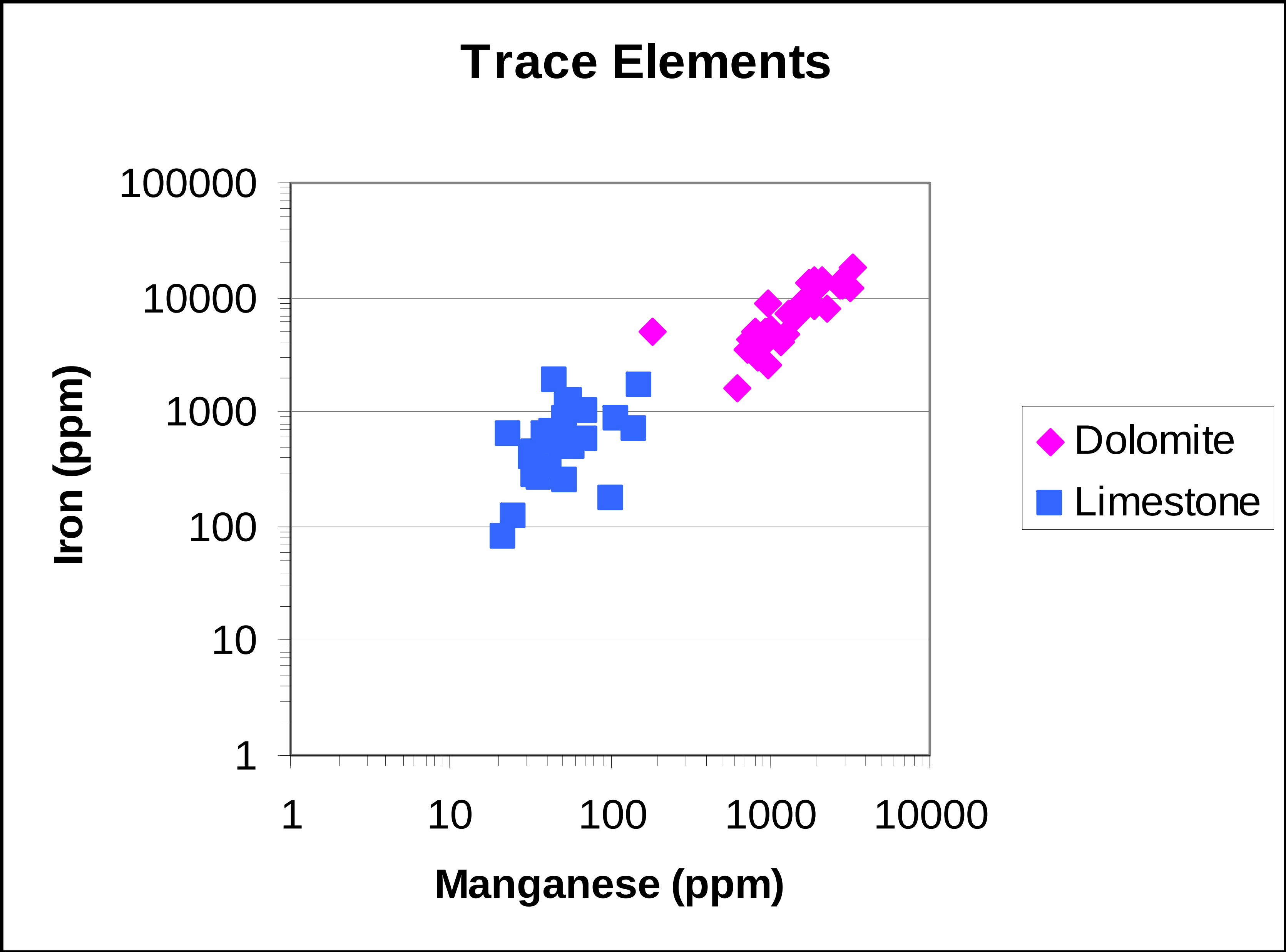


All dolomite types in Ohio have similar values suggesting same origin

Trace Elements

Element	Seawater	Oil Field Brine
Ca	411 ppm	1,000-20,000
Fe	.002	.01-500
Mn	.0002	.1-100
Fe/Ca	10^{-6}	10^{-3}
Mn/Ca	10^{-7}	10^{-4} or 10^{-3}

From Allan and Wiggins, 1993



Dolomites are Fe and Mn-rich which supports a subsurface origin

Summary

- Fluid inclusions, stable isotopes, strontium isotopes and trace elements all support a hot, subsurface origin for all the dolomite in the TBR
- The fluid that made the dolomite was hot, saline, +2 to +4 d18O, Fe- and Mn-rich and passed through basement rocks or immature siliciclastics prior to making the dolomite
- The link to faults strongly suggests a fault-related hydrothermal origin for the dolomites

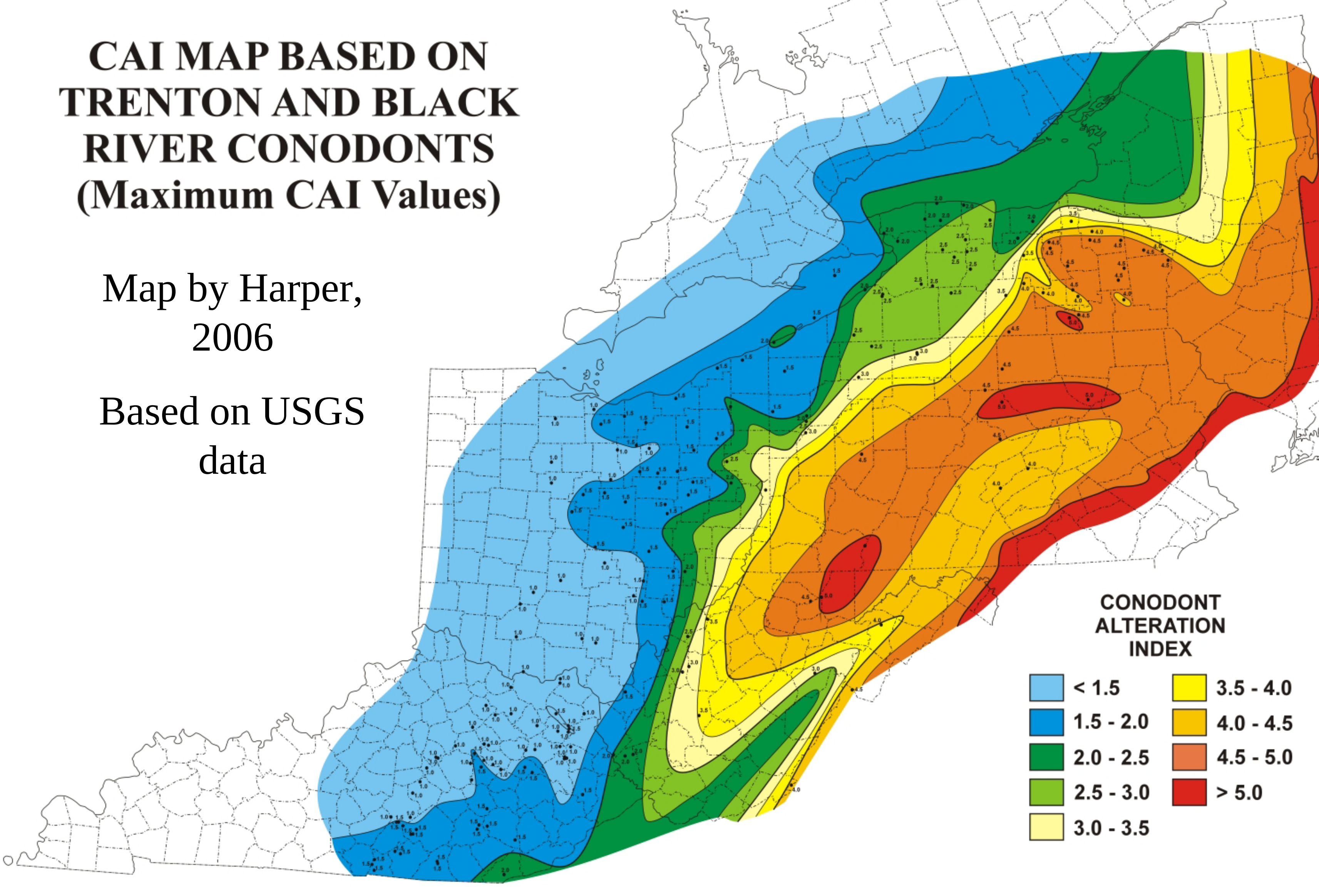
Are the TBR Dolomites Unequivocally Hydrothermal?

- A good way to demonstrate an unequivocally hydrothermal origin for dolomite is to show that the dolomites formed at a higher temperature than the ambient temperature ever was or was at the time of dolomitization
- This can be done using fluid inclusions and burial history plots

CAI MAP BASED ON TRENTON AND BLACK RIVER CONODONTS (Maximum CAI Values)

Map by Harper, 2006

Based on USGS data

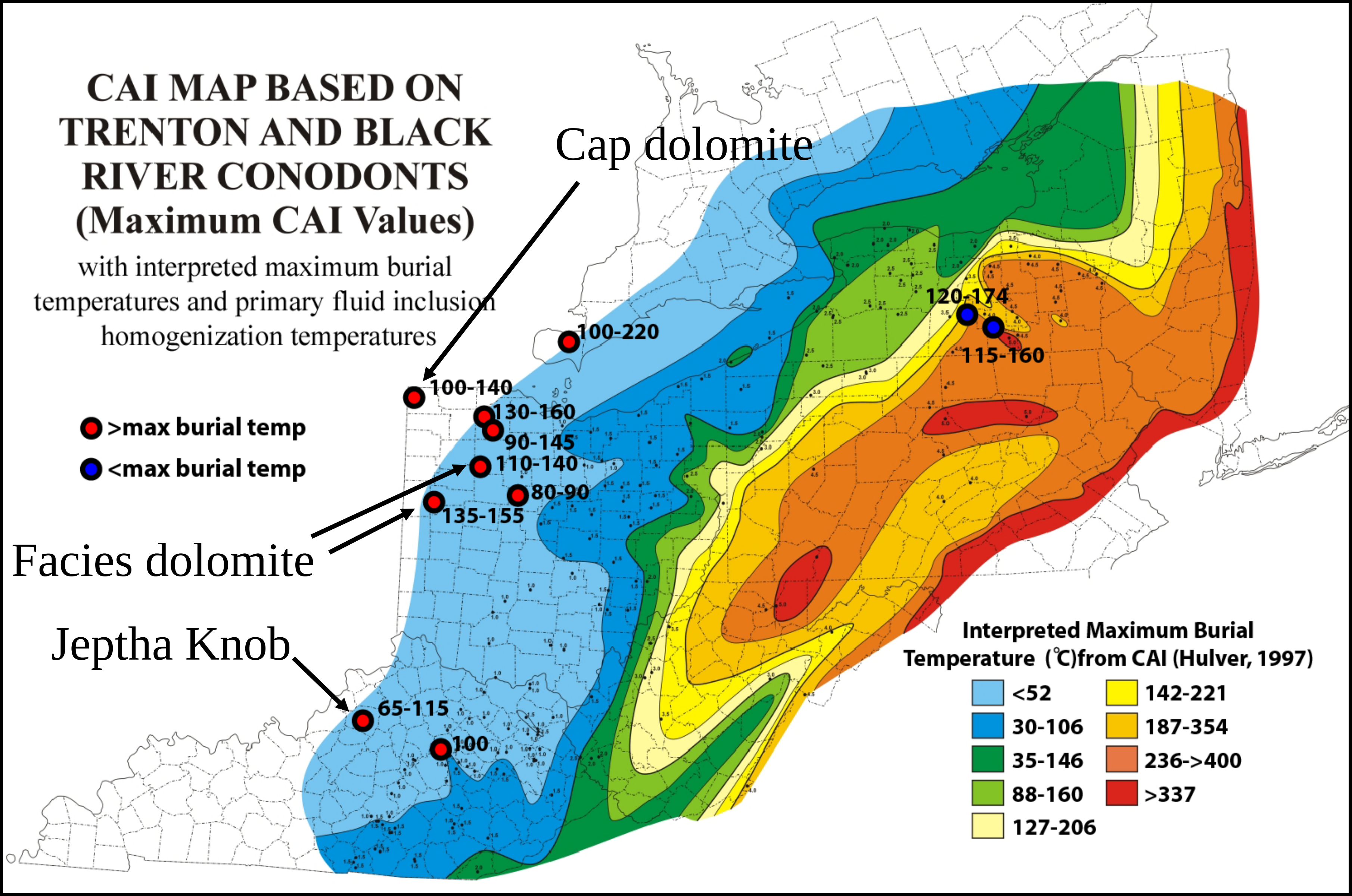


Can use CAI (conodont alteration index) values and temperature ranges calculated by Hulver, 1997 to determine maximum ambient burial temperatures

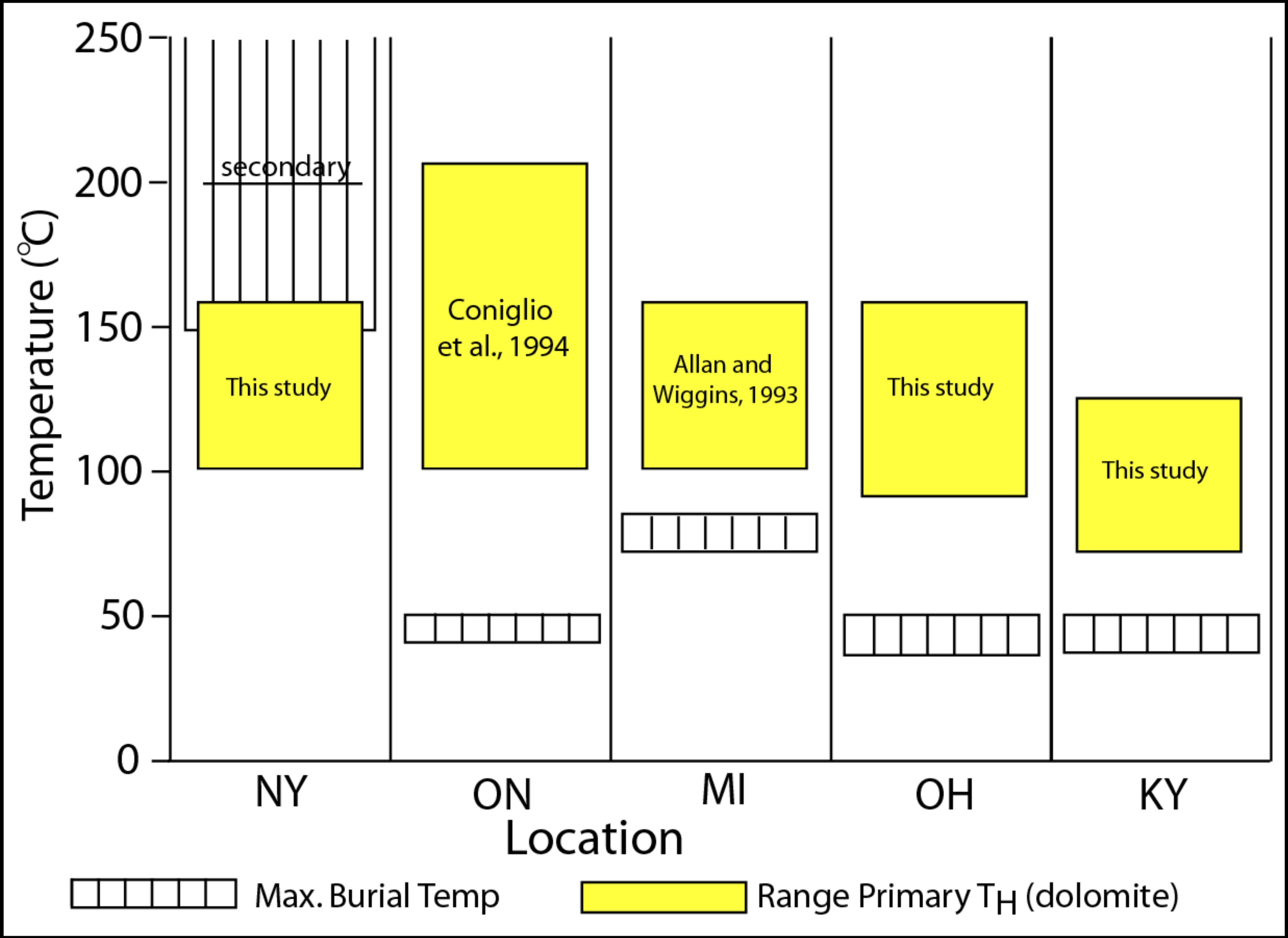
Conodont Color Alteration Index Temperatures for Geological Heating Durations of 10-100 m.y.

CAI	Minimum Temperature (°C)†	Maximum Temperature (°C)‡	Temperature Range (°C)™	Calculated Depth of Burial (km)®
1	20±5©	20±5©	20±5	0.00±0.20
1.5	30±5	52±7	37±22	0.68±0.88
2	35±7	106±10	72±44	2.00±1.76
2-2.5*	35±7	146±6	90±62	2.80±2.48
2.5	88±9	146±6	116±36	3.82±1.46
3	127±6	160±6	144±22	4.94±0.90
3-3.5*	127±6	206±8	168±56	5.92±2.24
3.5	142±6	206±8	175±39	6.20±1.56
4	187±8	254±9	221±42	8.04±1.68
4-4.5*	187±8	354±1	267±88	9.88±3.52
4.5	236±9	354±1	291±64	10.84±2.56
5	337±1	>400	368±32	13.92±1.28

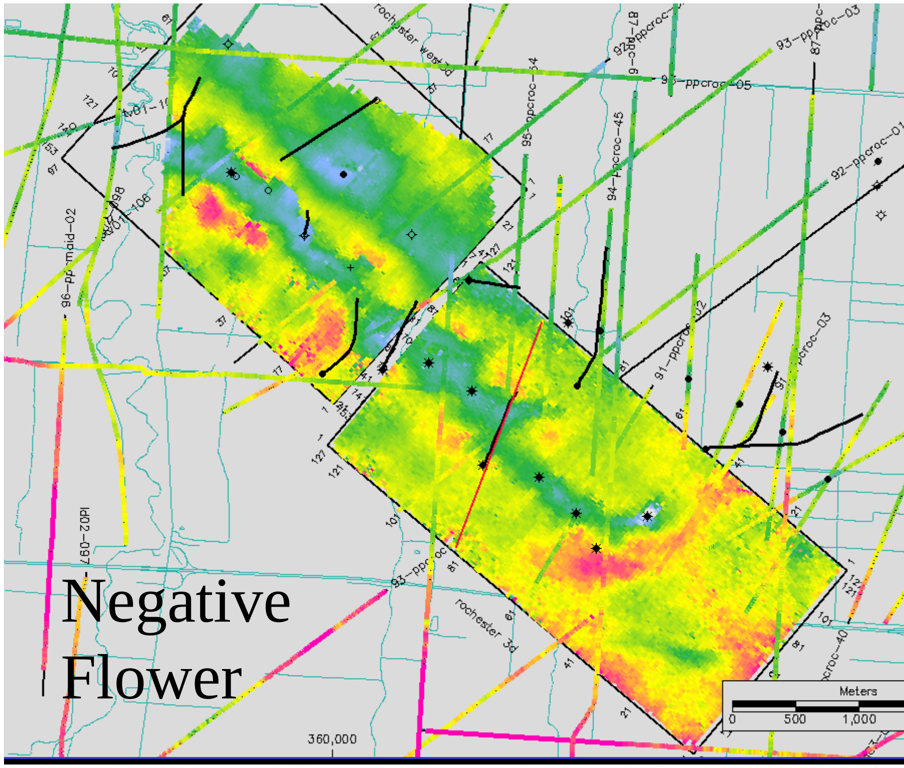
Conversion of CAI values to minimum and maximum temperatures (from Hulver, 1997)– minimum correct if strata stay at or near maximum burial for>100 m.y., maximum temperature correct if strata near maximum burial temp for 10 m.y. - minimum temperatures most likely to be correct in Appalachian Basin

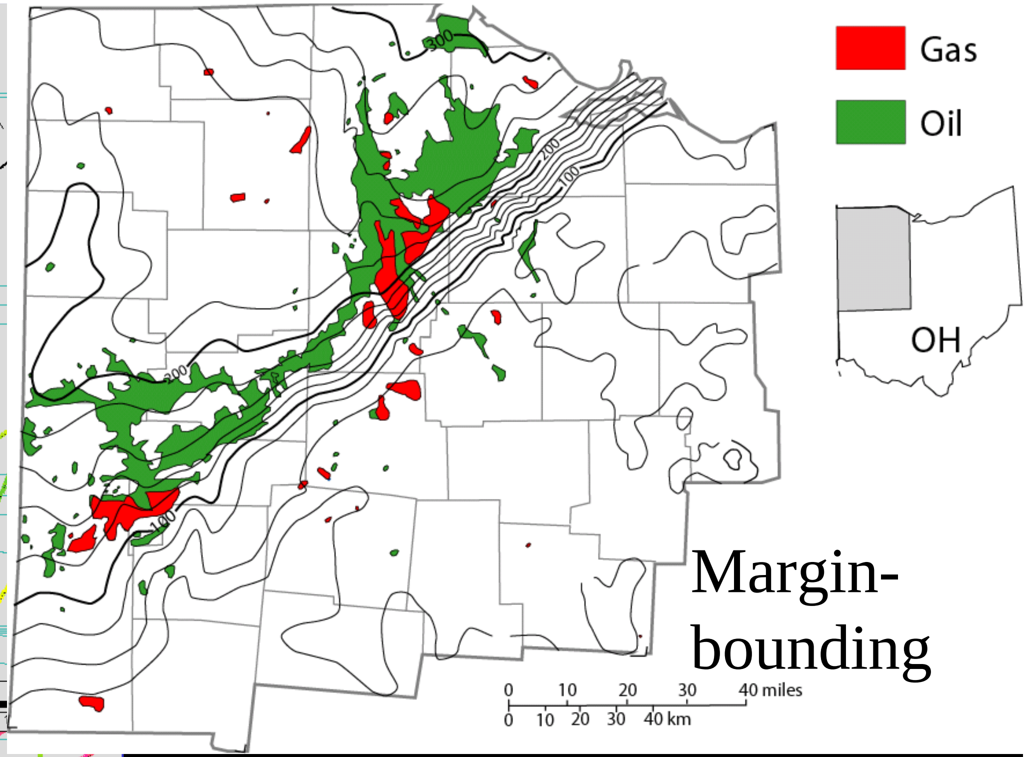


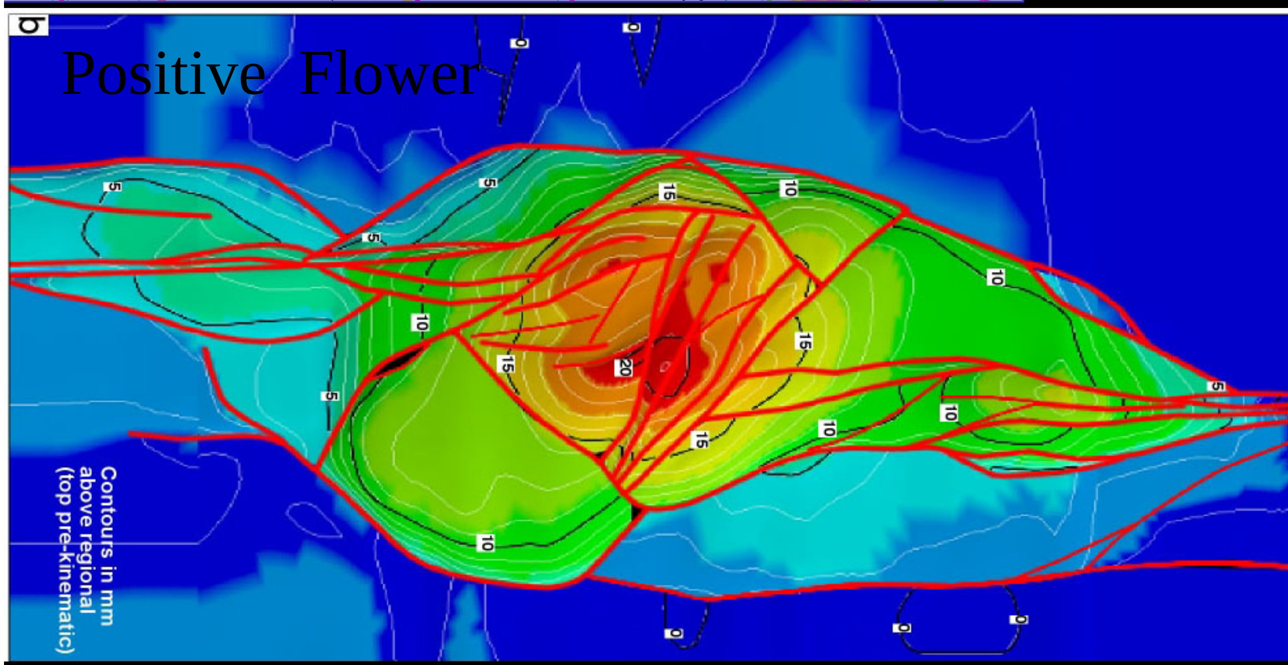
Fluid inclusion homogenization temps vs. maximum burial temperatures - unequivocally hydrothermal at red dot locations



In all locations except NY, fluid inclusion homogenization temperatures exceed maximum ambient burial temperatures



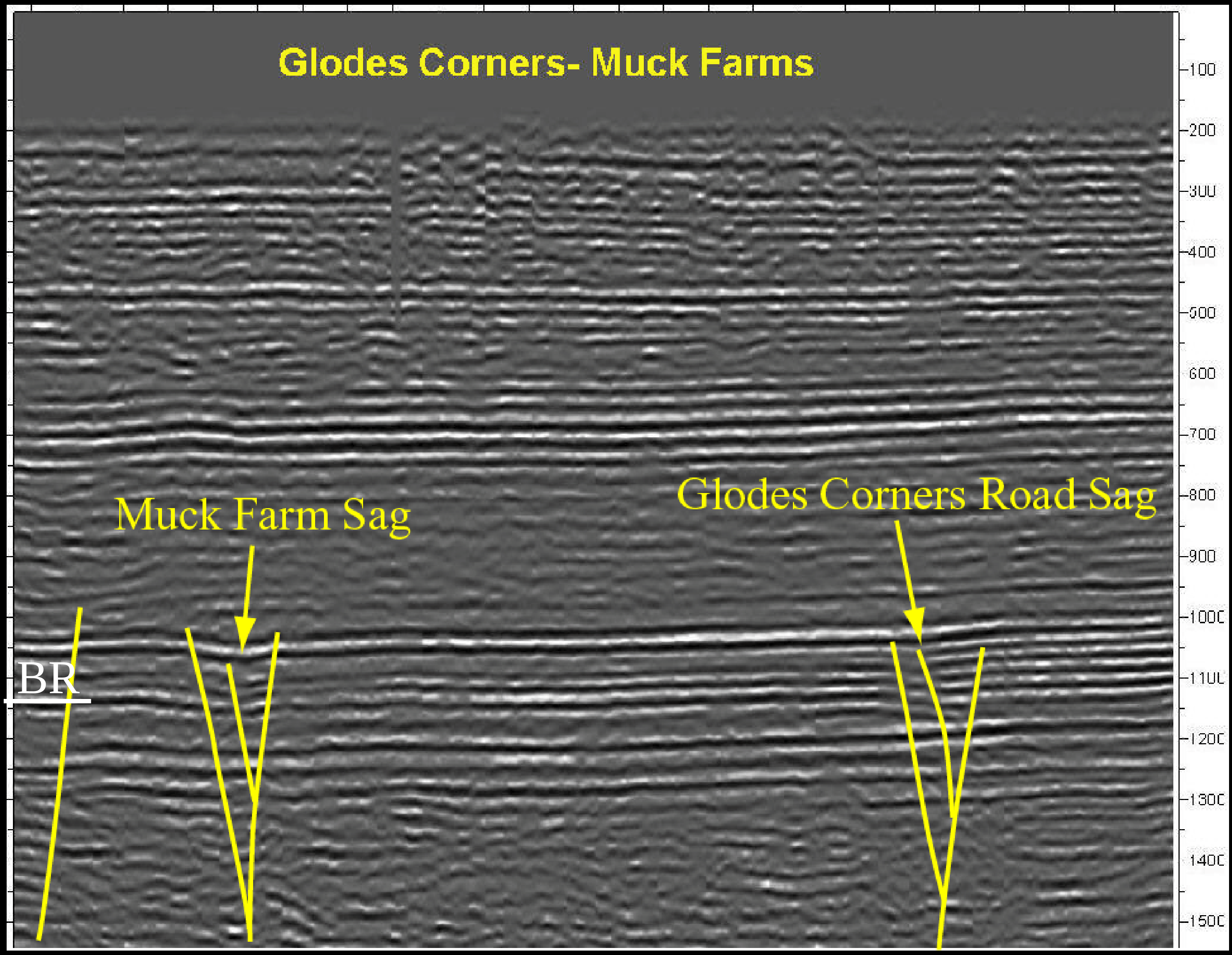




There are multiple dolomitized play types that are all of a hydrothermal origin – Sags might not the only indicator

Timing of dolomitization

- Sibson (1990) and Knipe (1993) suggest that most fluid flow up faults occurs when the faults are active
- In almost all cases in the TBR, it looks like there is dolomitization around faults that were active during Trenton and Utica time when the formation was buried to a depth of less than 1 km
- These faults were in some cases reactivated in Devonian or Pennsylvanian (but more commonly not)
- There is some other evidence that supports a Late Ordovician age for the dolomitization

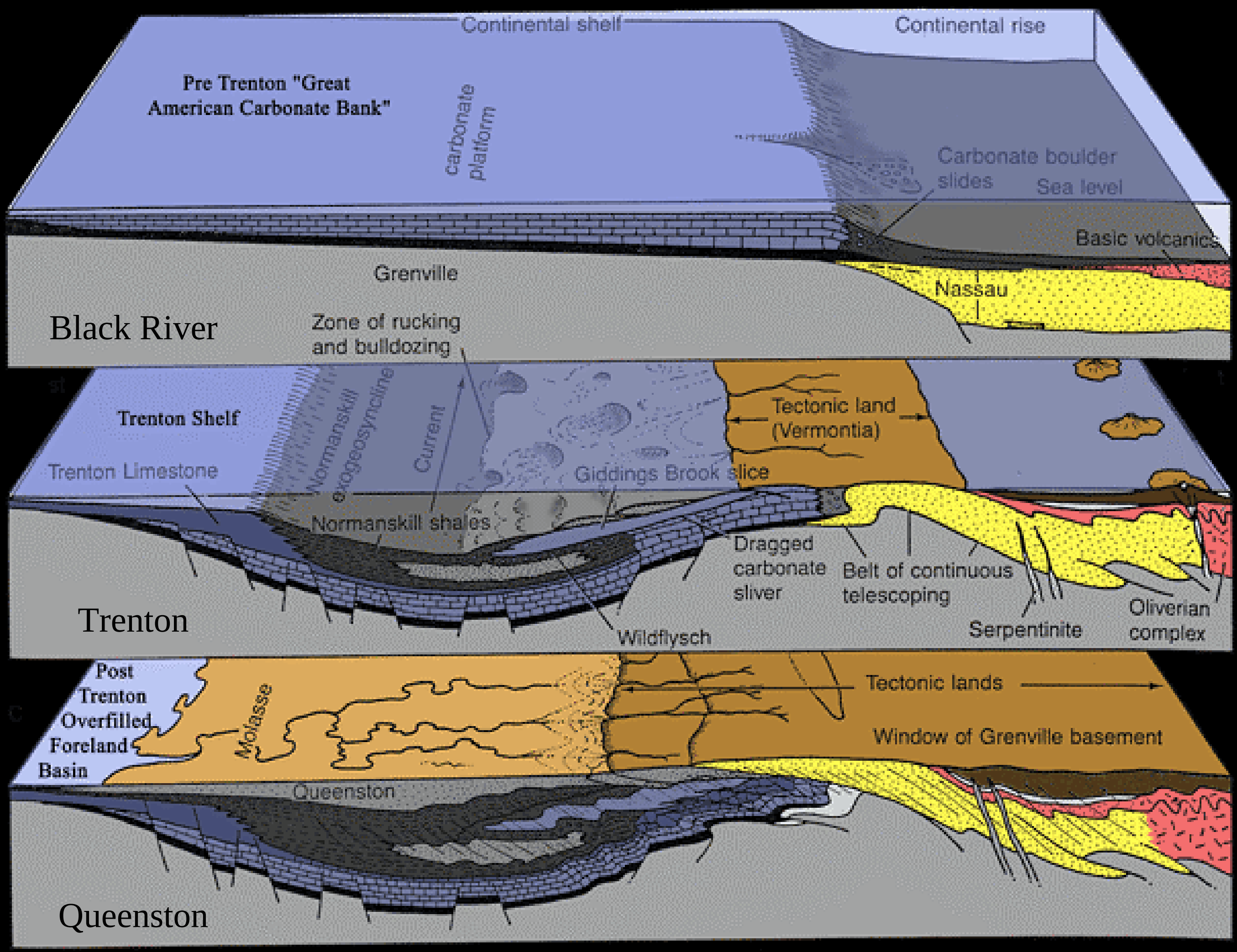


Sags over two Black River fields accommodated within 300 meters

Horizontal cemented fractures are very common – at shallow depths of <1km, least compressive stress is vertical and horizontal fractures form

Piper well, margin southwest of BG fault, Black River, looks like fracture propagating through soft sediment in shallow marine facies

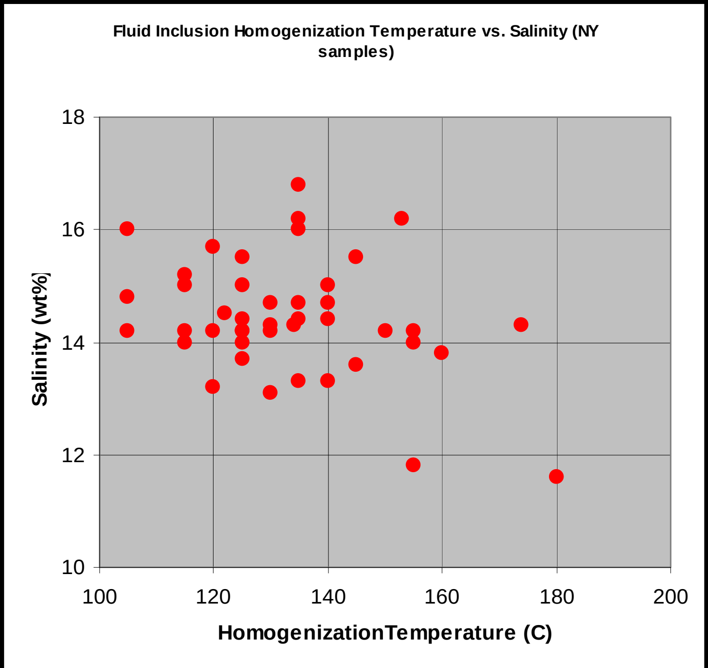
This suggests that the rock was not entirely lithified and therefore pretty shallowly buried at the time of fracturing and dolomitization



Faulting known to occur during Trenton and Utica times in NY; Common seismites (seismically disturbed bedding) in Trenton of KY indicate major widespread faulting during Trenton time

Further evidence for Late Ordovician age of dolomitization

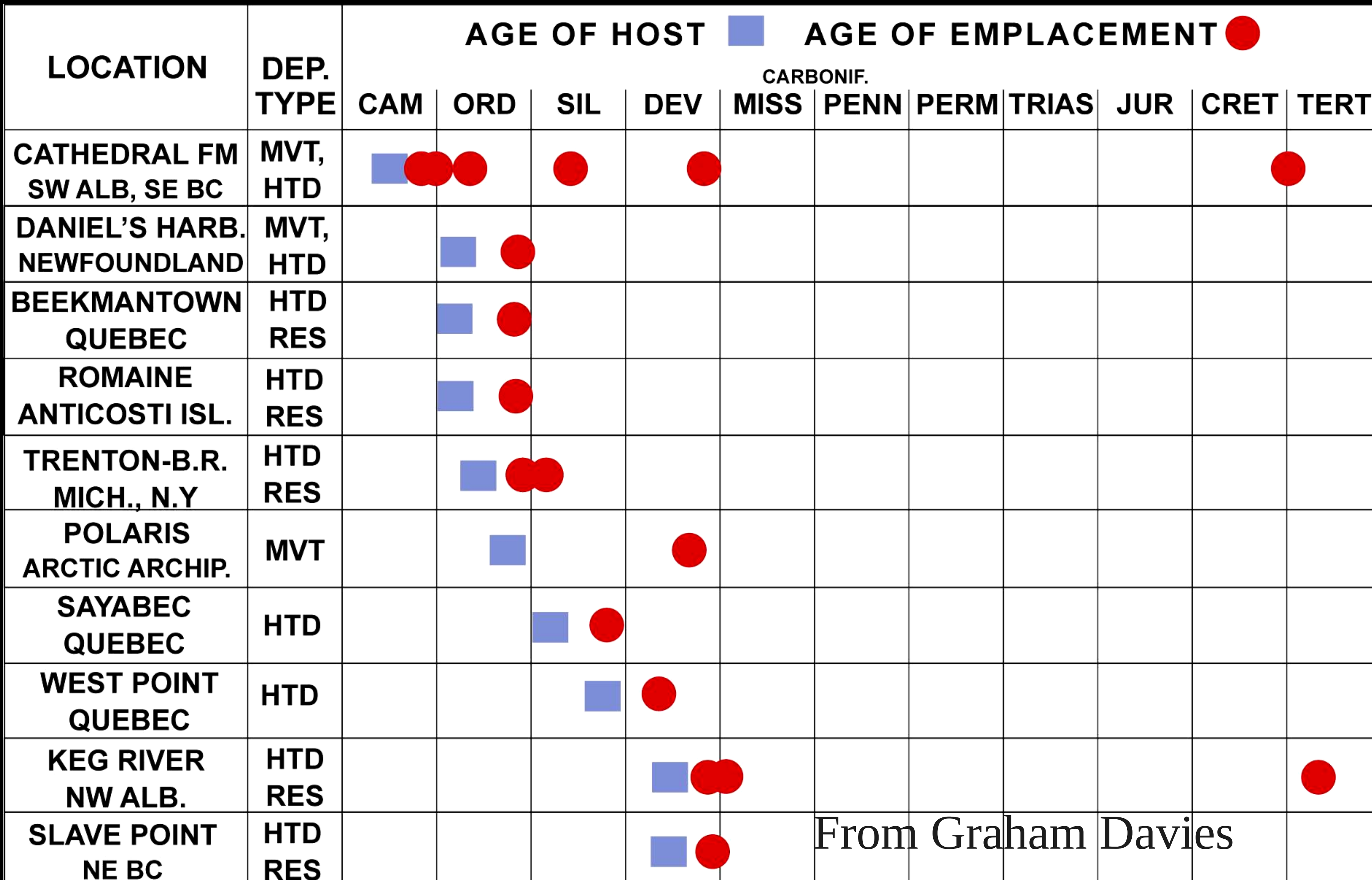
	Modified from Matsumoto et al, 1992, All Values are for New York State					
	Potsdam/ Theresa	Queenston	Medina	Oriskany	Bass Island	Upper Devonian Oil Zones
Measured TDS (mg/L)	300,763	298,358	292,121	231,836	232,500	156,267
Calculated TDS (mg/L)	299,187	302,869	292,727	232,743	232,558	149,582



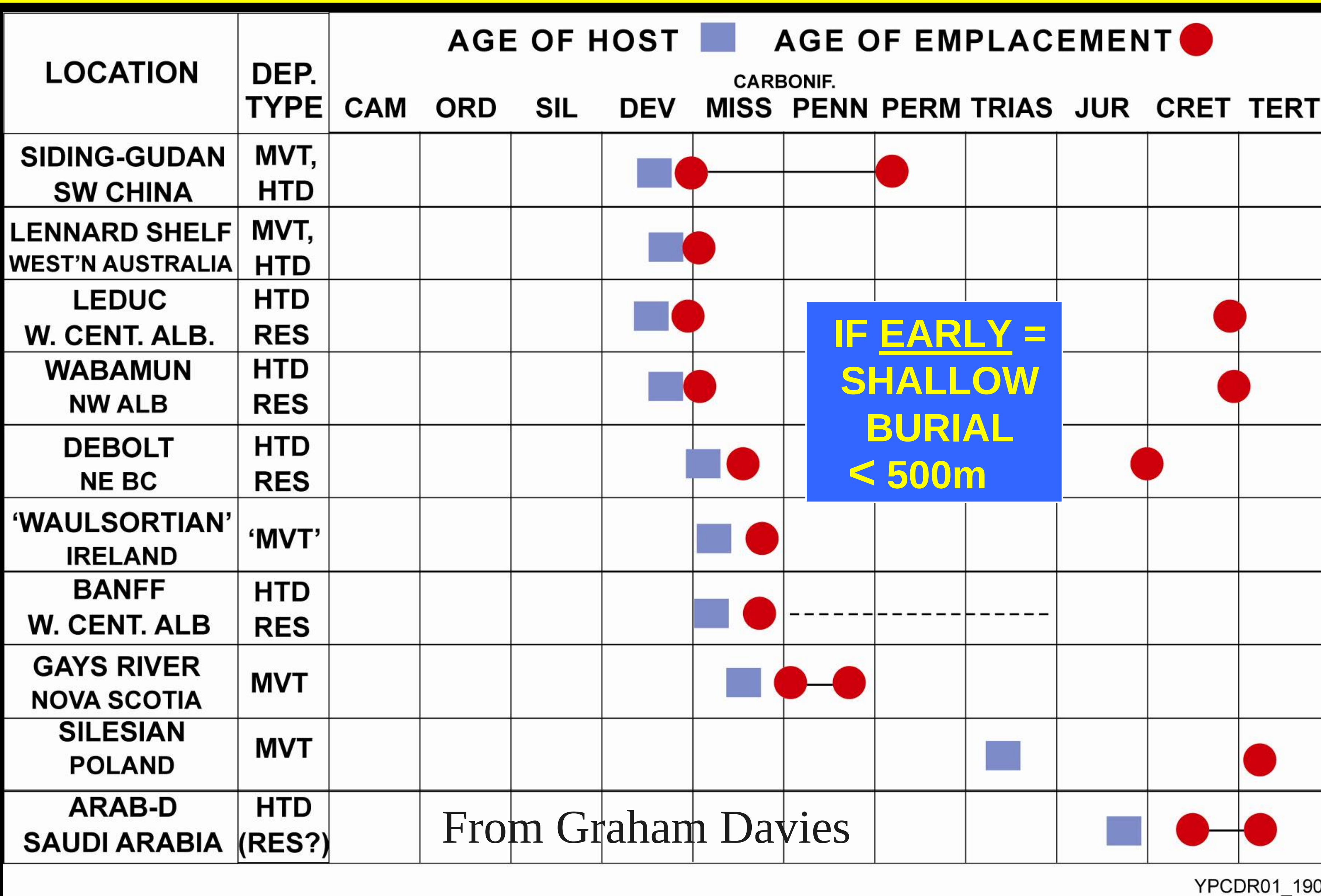
Current formation water salinities from New York State – all formations below the Silurian salt are at or near halite saturation (around 300,000 ppm or 30 wt%)

The New York dolomites formed from a fluid that had about 150,000 ppm or 15 wt% salinity. This suggests that the dolomitization probably predates the deposition of the salt (at which point all formations underlying it were charged with higher salinity brines closer to present day values)

TIMING OF EMPLACEMENT: 1



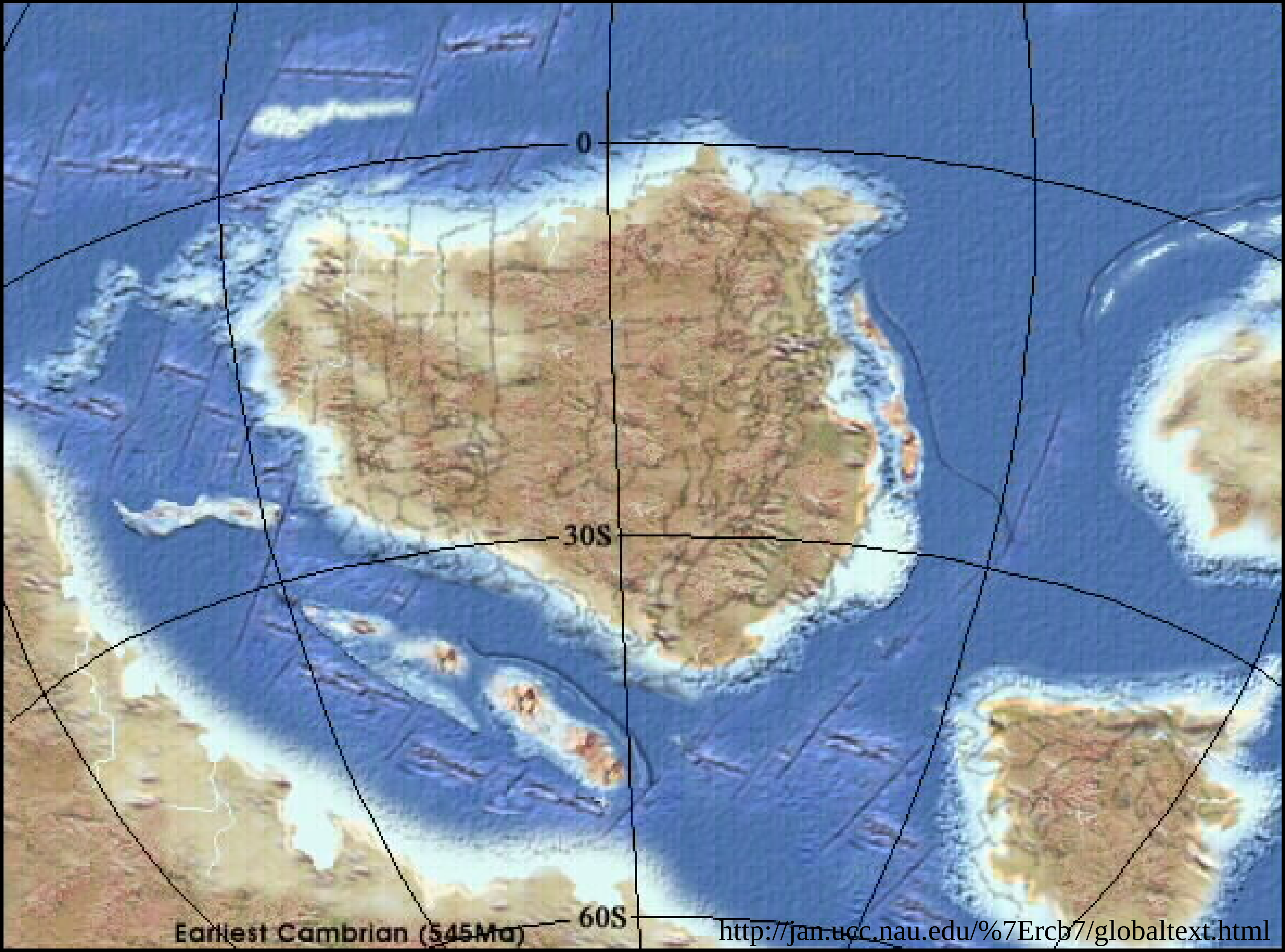
TIMING OF EMPLACEMENT: 2



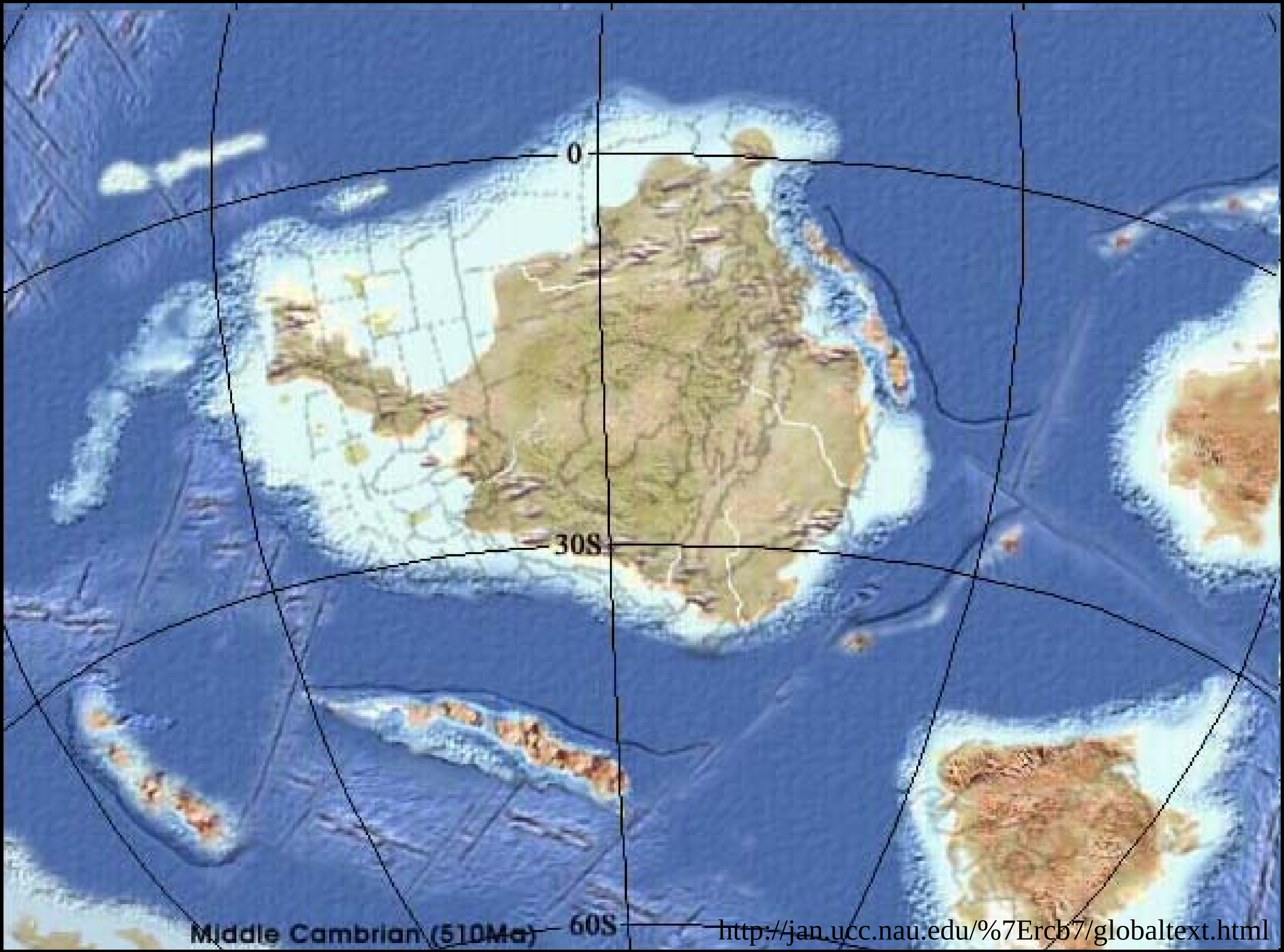
From Graham Davies

So What?

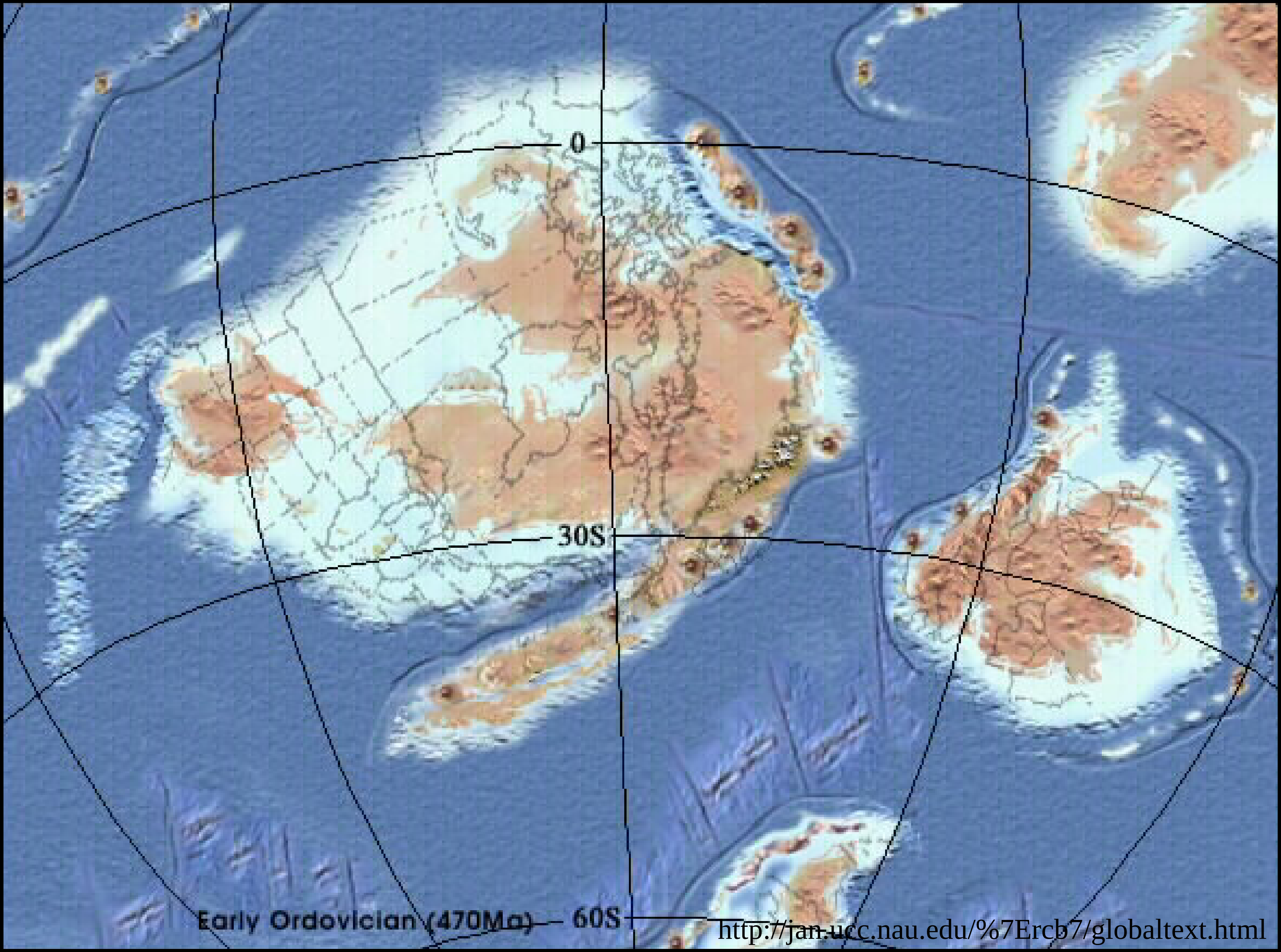
- Prospects in which the faults die out within the Trenton or Utica should be high-graded
- If faults were clearly active during Acadian or Alleghenian, younger formations like the Devonian Dundee Limestone in Michigan may be hydrothermally altered
- That being said, the most prolific field in the trend occurs around the Bowling Green Fault (375 MMBO) which cuts all the way through the Silurian
- Strike-slip faulting may be most common during earliest stages of mountain building events



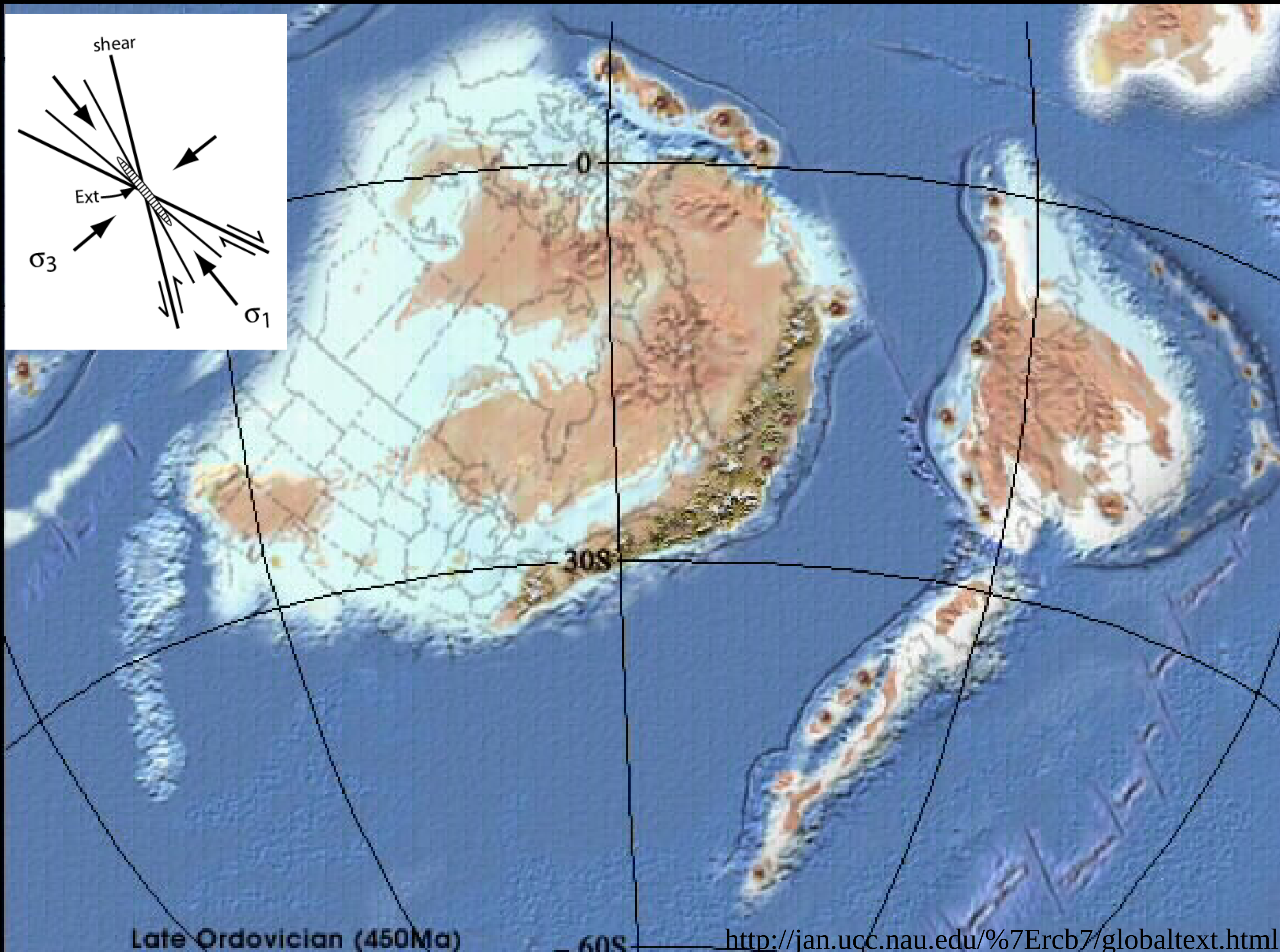
Trenton Black River deposited in Middle Ordovician, altered in Late Ordovician



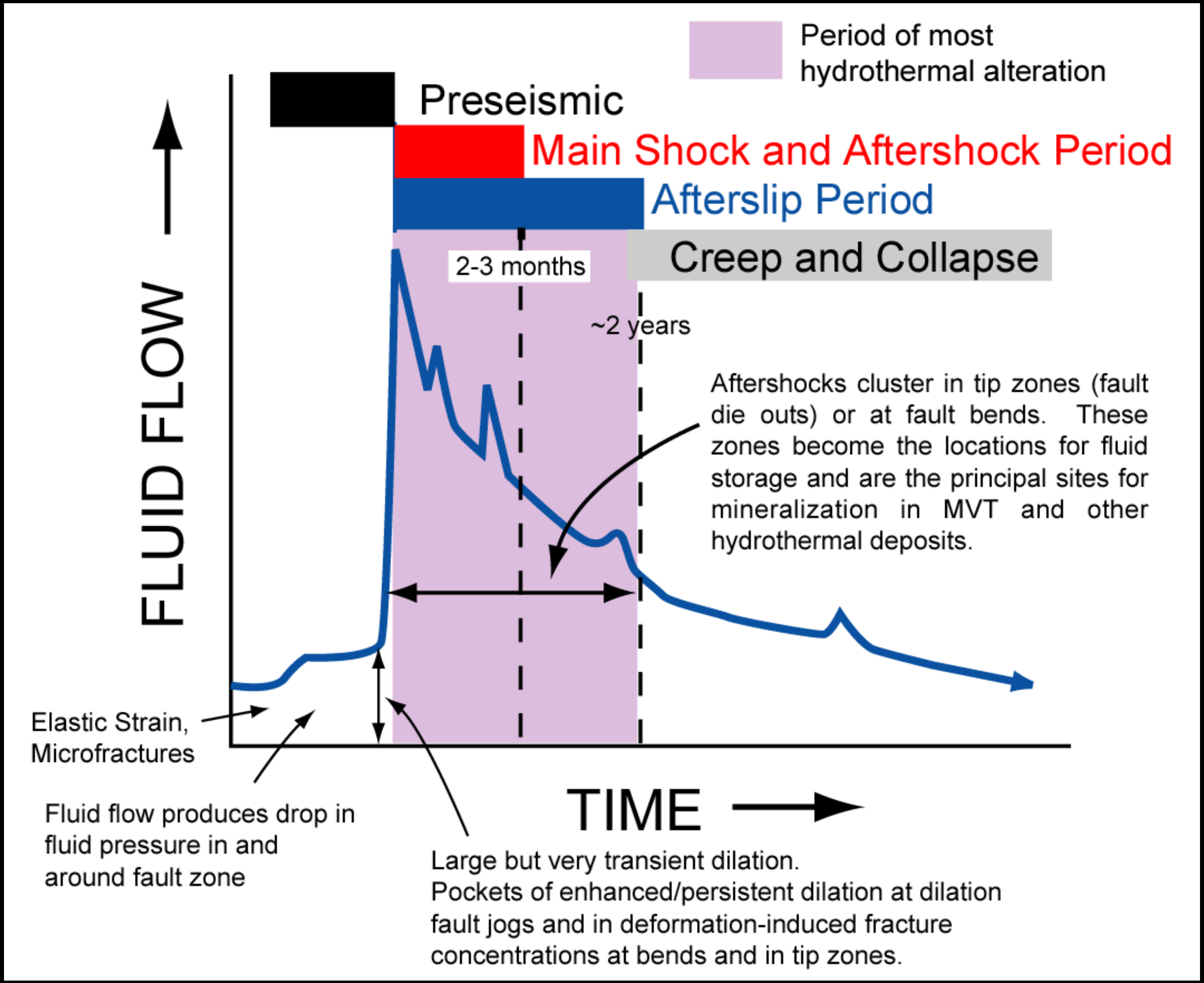
Trenton Black River deposited in Middle Ordovician, altered in Late Ordovician



Trenton Black River deposited in Middle Ordovician, altered in Late Ordovician



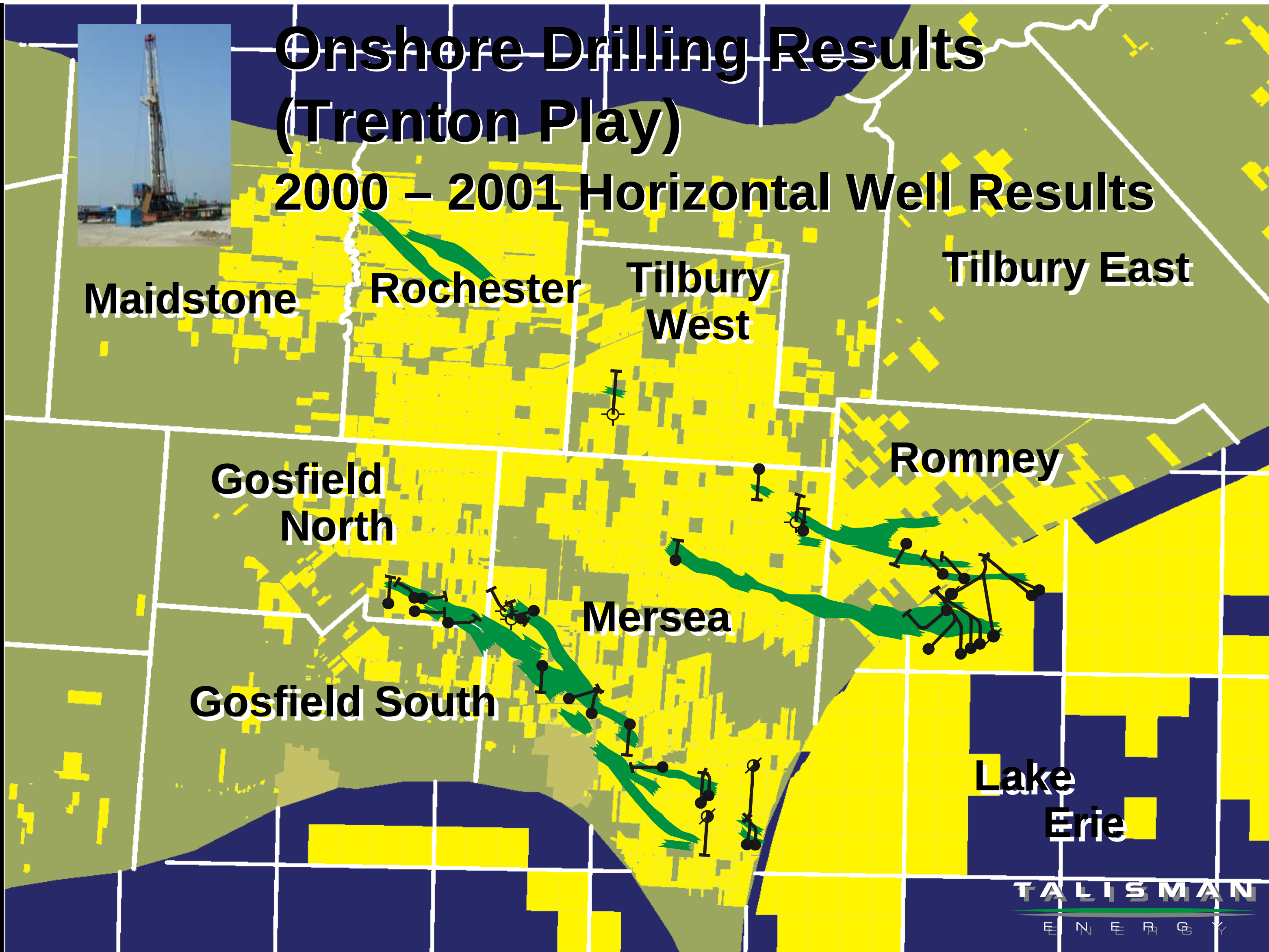
Trenton Black River deposited in Middle Ordovician, altered in Late Ordovician



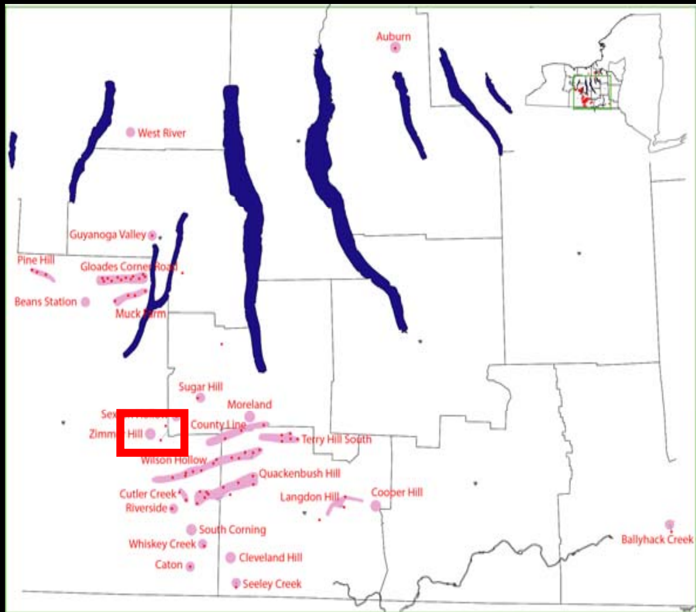
Idealized Permeability Evolution of a Fault Zone
Modified from Knipe, 1993 and Davies, 2001

Onshore Drilling Results (Trenton Play)

2000 – 2001 Horizontal Well Results

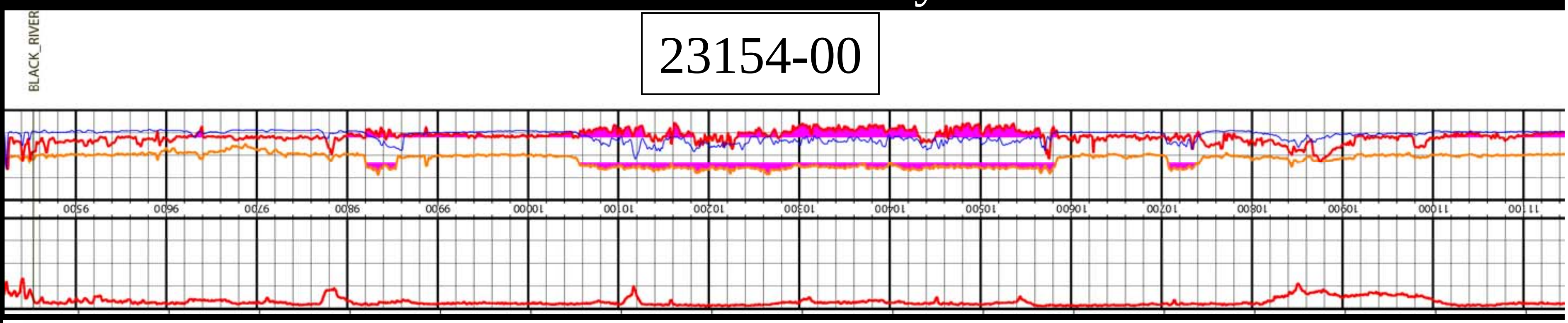


Horizontal drilling helps to penetrate open faults and fractures and mitigate heterogeneity issues – this is a good approach to many hydrothermally altered reservoirs



Zimmer Hill

- Horizontal well
- 675 feet of dolomite
- 150 feet of porosity > 5%
- 525 feet of tight dolomite
- Over 300 feet of limestone at the top of the Black River
- Feature is similar to our quarry analog in Mohawk Valley



Trench #4 - East Side

Trenton/Black River Regional Cross Section

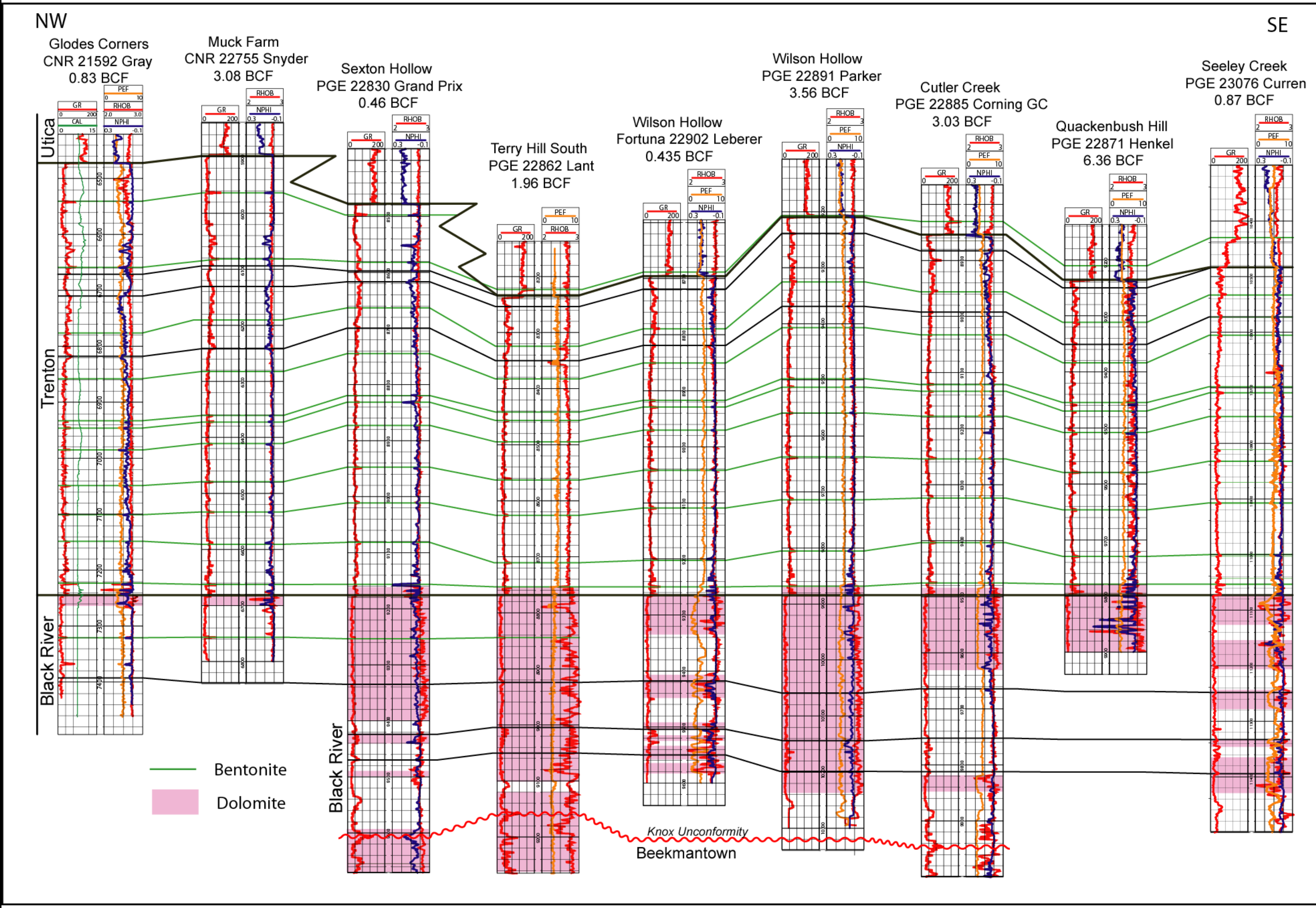
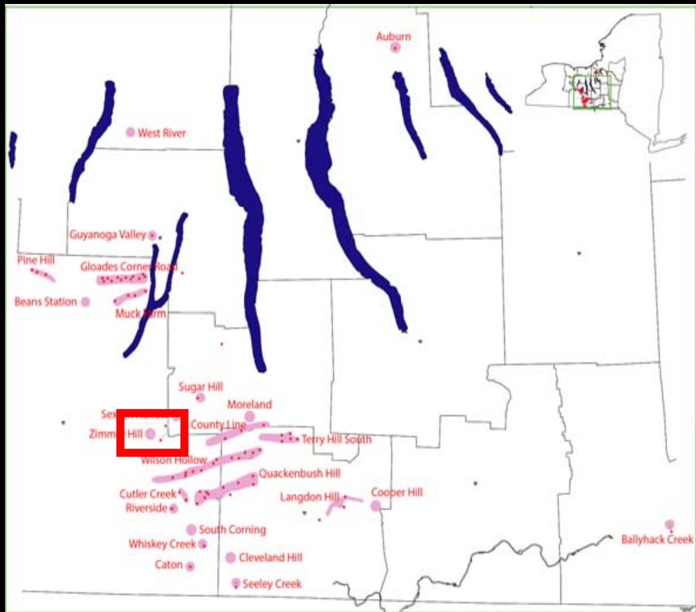


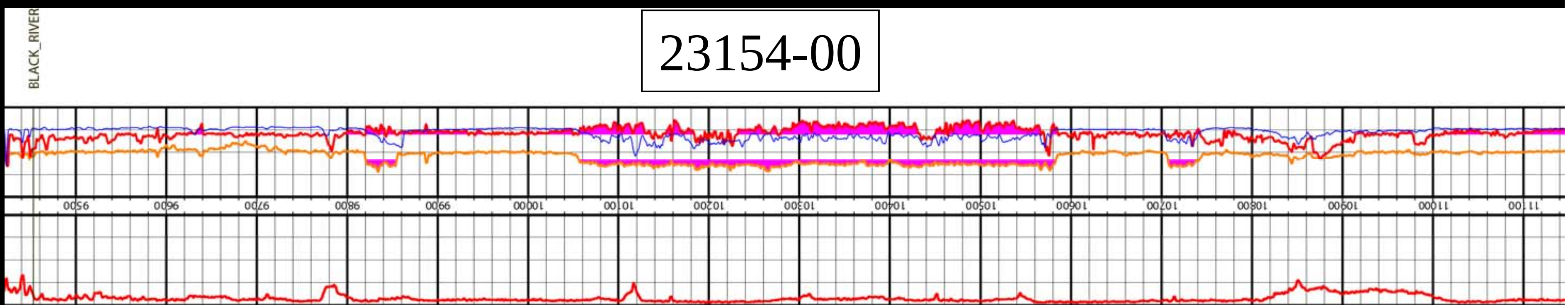
Figure 5-2 Trenton/Black River Regional Cross Section.

For all fields we have prepared similar style of cross section



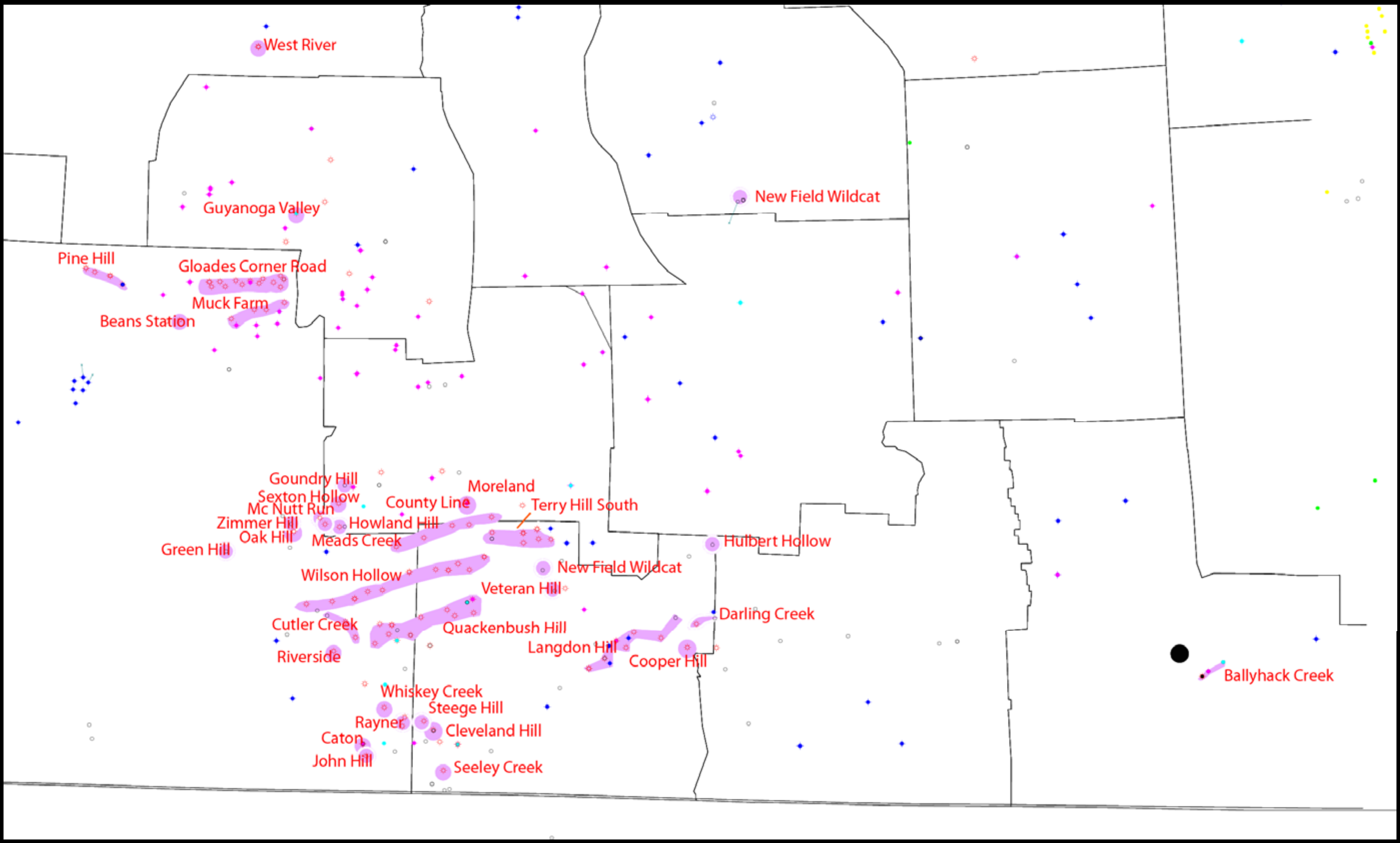
Zimmer Hill Field

- Fields in NY are being drilled with horizontal wells
- This shows heterogeneity across the sags that is very similar to what we encountered in outcrop analog when we cut a trench through the feature

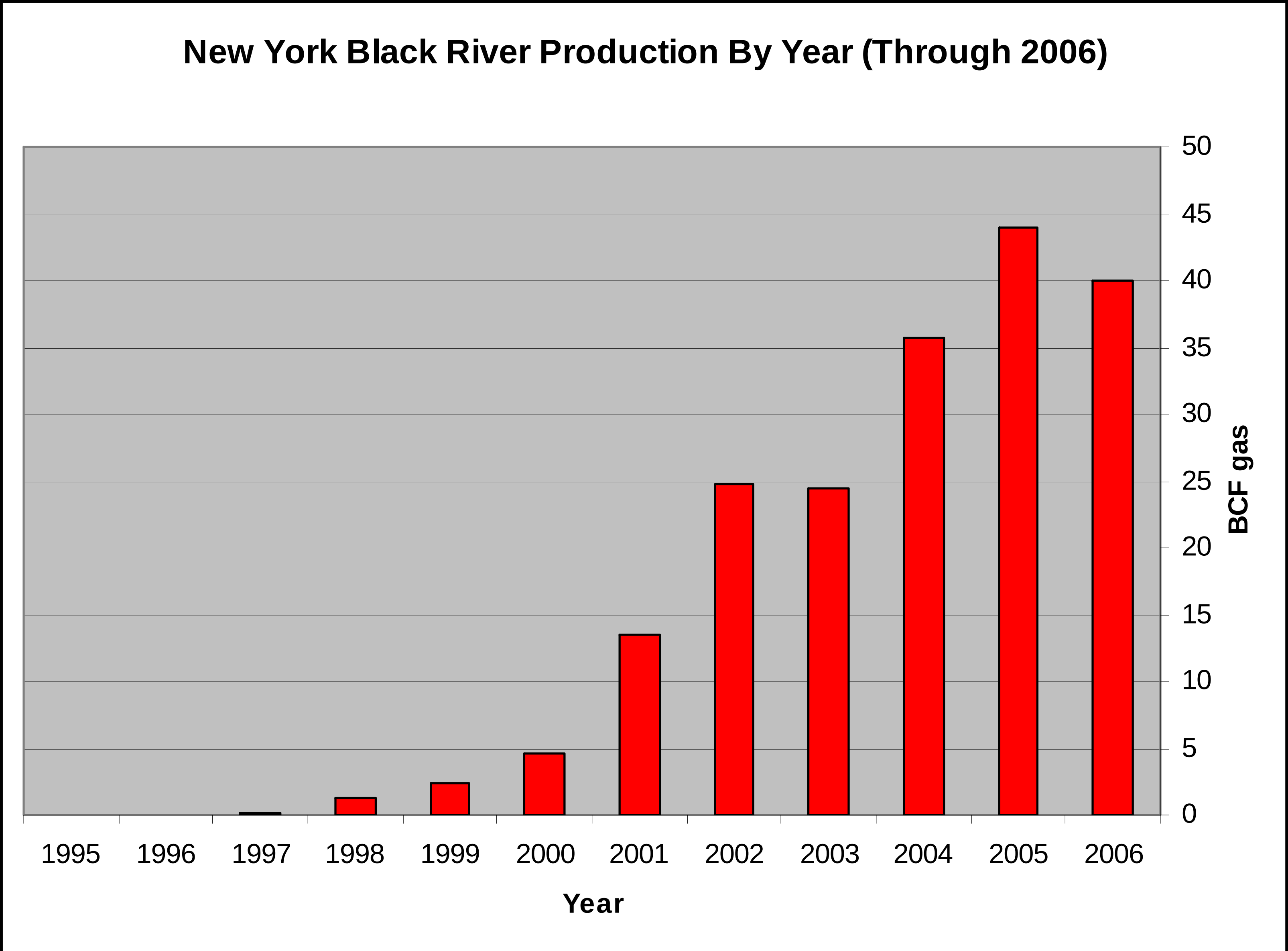


Horizontal versus Vertical

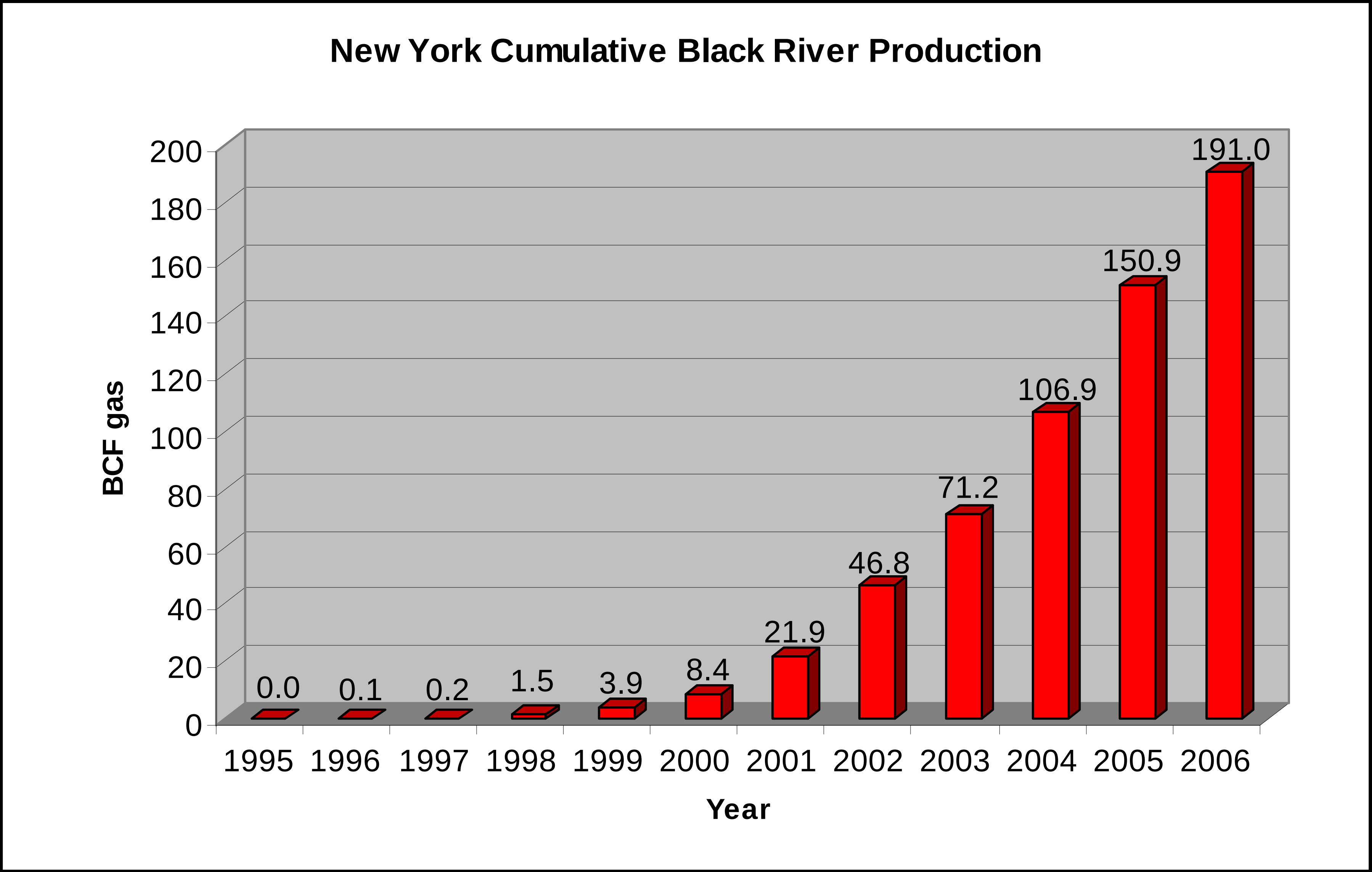
- Generally, when a well is a good producer in NY, it is dolomitized and has good porosity at the top of the Black River – this makes it a good candidate for horizontal drilling
- When the porosity zones occur at many different intervals as they do at York Field in Ohio – verticals may be best
- In a new exploration area where it is not yet known where the porous dolomite occurs, verticals are probably the best approach



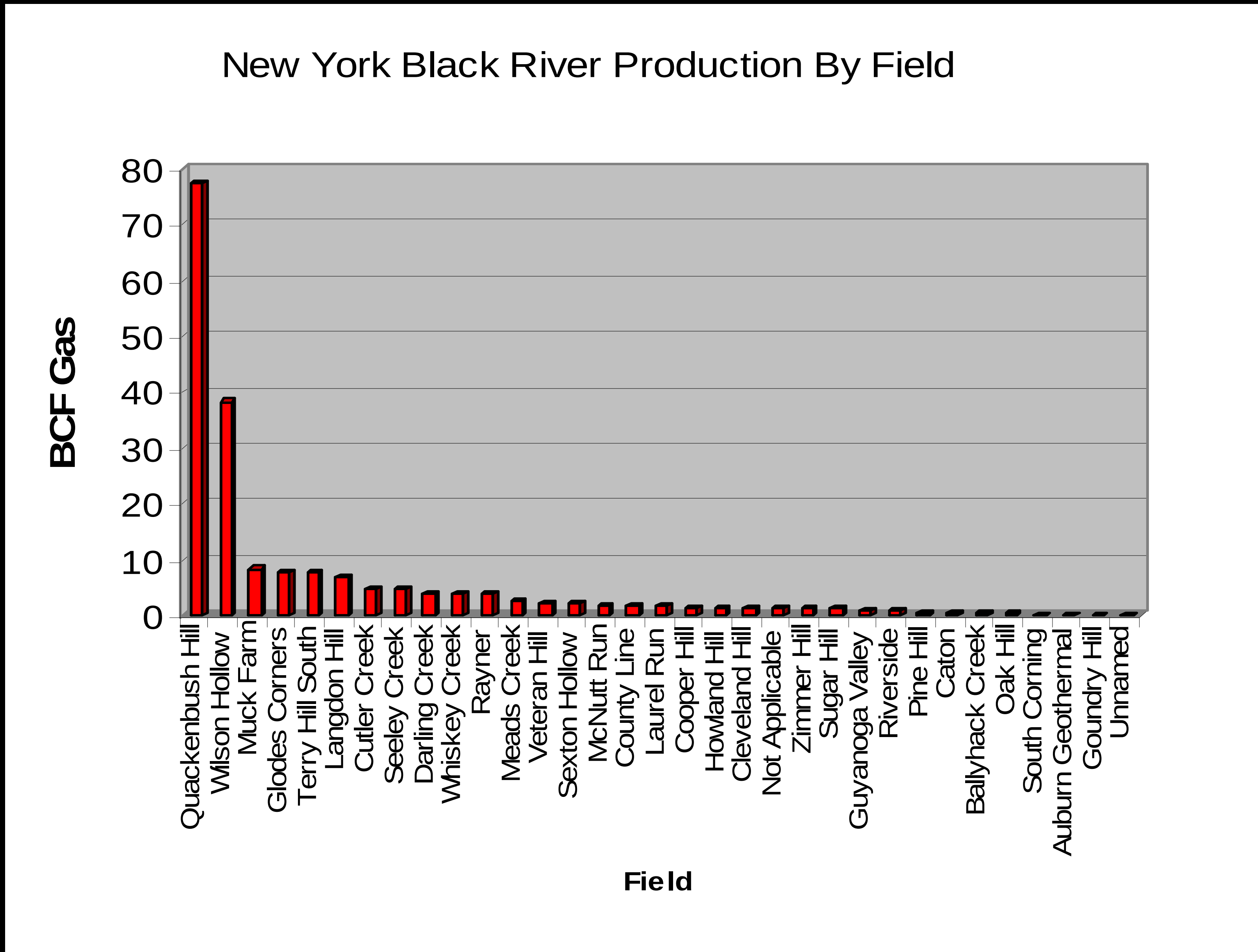
New York now has 34 named fields and 31 with production – some new wells to northeast of the producing area have been wet



Best Year so far was in 2005 at 43BCF, slight decline in 2006



Cumulative production from Black River Play in New York – probably looking at 500BCF total for the play



There are 31 fields that made some gas but two of them produced 61%

Conclusions

- Hydrothermal dolomitization can take place in multiple structural settings including negative and positive flower structures and along margin-bounding extensional faults and at intersections of basement-rooted fault trends
- TBR hydrothermal dolomitization likely took place during Late Ordovician Taconic Orogeny when T-BR was only buried to a depth of a few hundred meters
- Hydrothermal processes are capable of producing large quantities of dolomite and should be considered with other models when interpreting the origin of dolomites