

Update on Trenton Black River Playbook Study-New York State Museum

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New York State Museum



Task IV: Geochemistry

- The New York State Museum has taken the lead on geochemical analyses of the dolomites and other minerals found in the TBR reservoirs
- Knowledge gained from these studies will help to build realistic fluid flow and diagenetic models for the formation of these reservoirs (like the animation that you just saw) which in turn will help better understand and predict their distribution

Geochemical Attributes of Hydrothermal Carbonate Cements

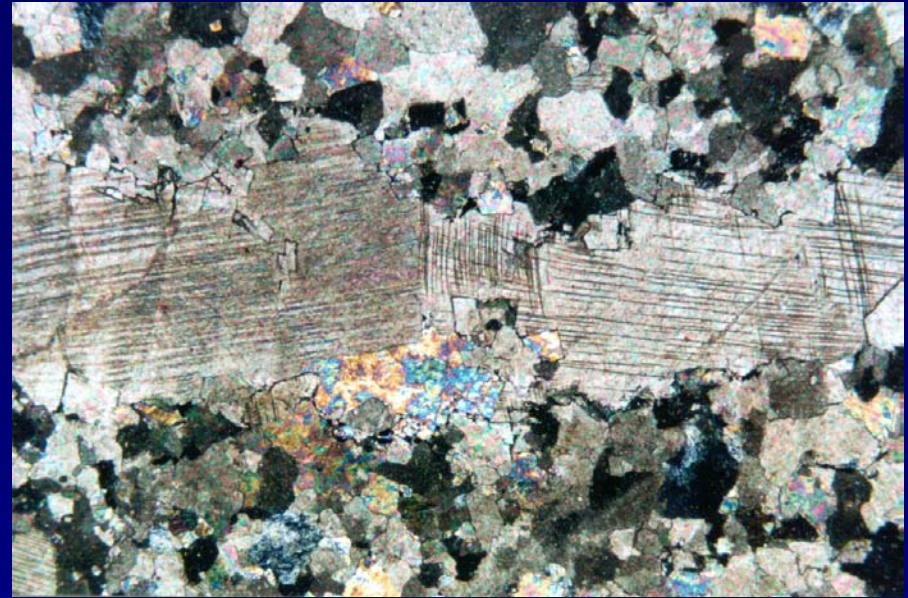
- Hydrothermal carbonate cements *generally (but not always)* have:
 - Fluid inclusions homogenization temperatures between 75° and 250°C and salinities between 6 and 30 wt%
 - Negative oxygen isotope values (PDB) that are lighter than the marine signature
 - Radiogenic $^{87}\text{Sr}/^{86}\text{Sr}$ ratios relative to seawater for the time of deposition
 - Commonly have relatively high Fe and Mn contents
- There are important exceptions to all of these (one analysis is never enough) so we are doing all of these analyses on cores from dolomitized reservoirs

Sampling for Geochemistry

- Ohio: 428 samples from a range of dolomite types and limestone
- West Virginia: 133 samples from primarily limestone Sand Hill Core (no evidence for hydrothermal)
- Kentucky: 273 samples (from Jephtha Knob and Perry County cores)
- New York: 140 samples (from three dolomitized cores)
- All samples will be analyzed for stable isotopes
- Several hundred trace elements total
- ~75 Sr isotopes and fluid inclusions total



2.5 cm

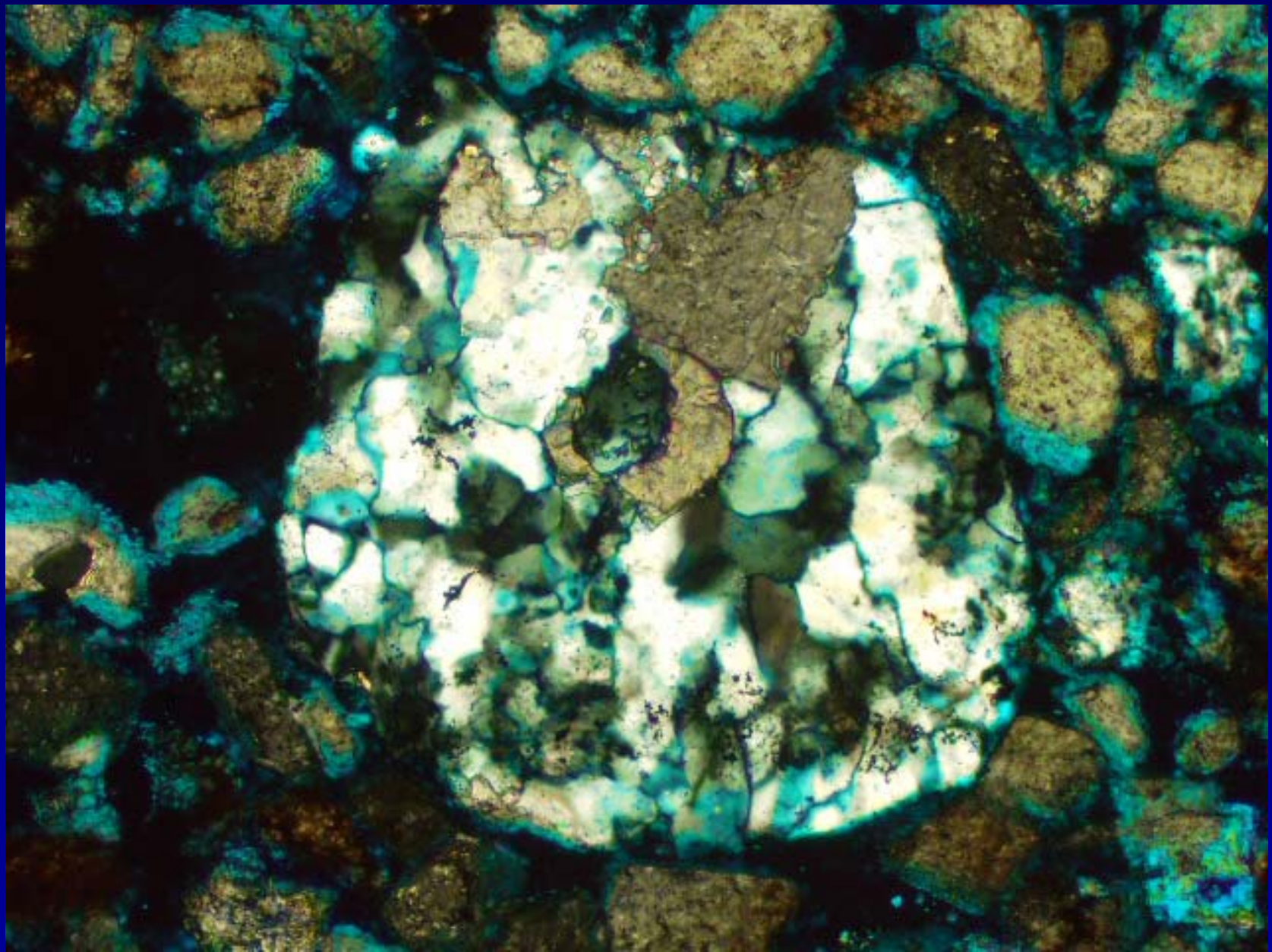


0.5mm

Have been sampling and
analyzing both dark matrix
dolomite and coarse white
saddle dolomite



Post saddle
dolomite blocky ,
calcite



19682-
7860'

Quartz and chert cement plugging
porosity in dolomite

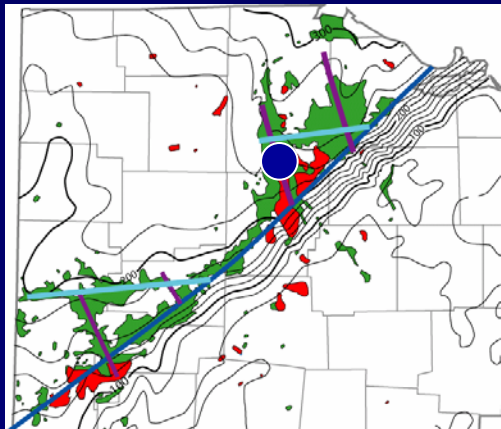
0.25 mm

Fluid Inclusions

- Fluid inclusions can tell us the temperature of formation and the salinity of the fluid that made the various minerals
- Should be able to get fluid inclusion data for matrix dolomite, saddle dolomite, calcite and quartz
- Hydrothermal dolomites typically have homogenization temperatures between 75 and 250C and salinities between 6 and 30 wt%
- All new analyses done by Fluid Inclusion Technologies

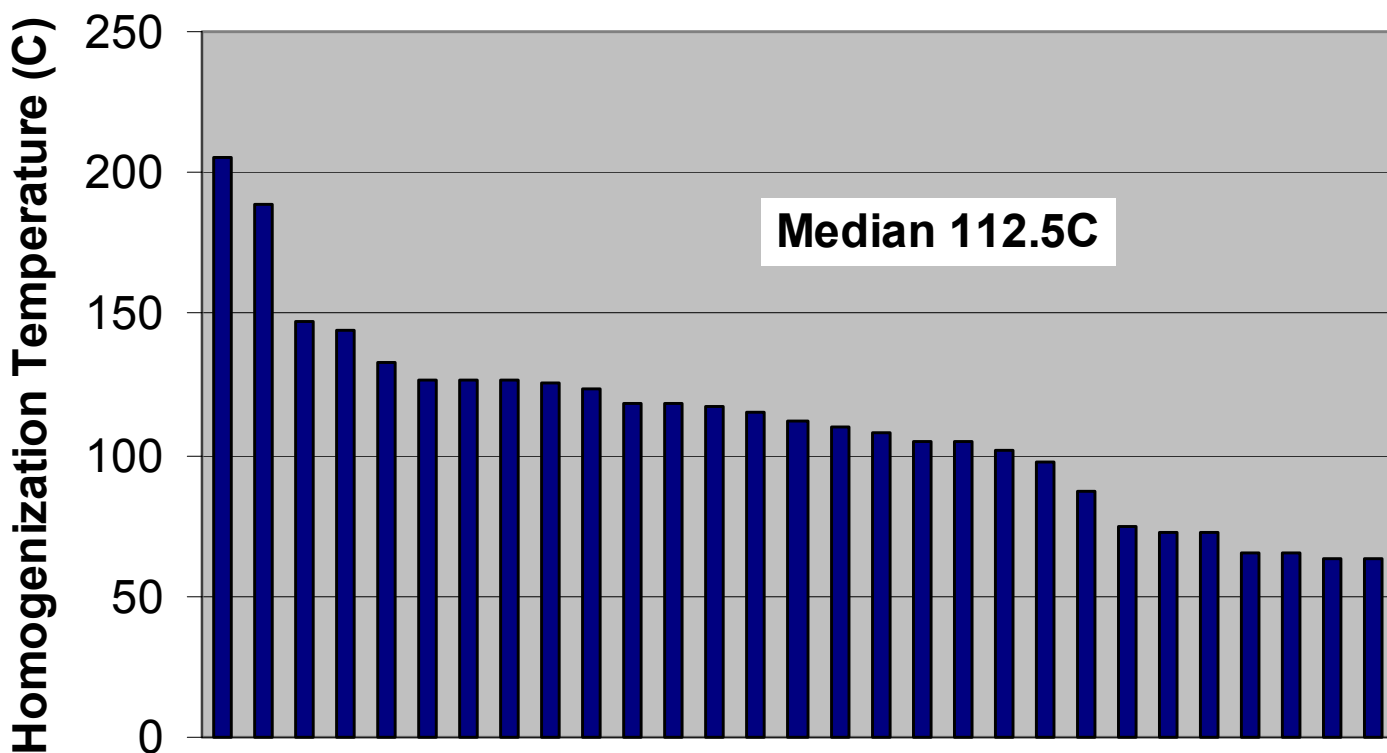
Preliminary Data: Homogenization Temperatures

- Homogenization temps from NY range from 100-180°C; in Ohio they range from 65 to >200 ° C; In Michigan they range from 110-160 ° C.
- These are comparable to those found in hydrothermal dolomite reservoirs in other parts of the world
- None of the formations were ever subjected to normal burial temperatures equal to the higher values for homogenization temperatures



Homogenization Temperatures, Saddle Dolomite, Bowling Green Fault Zone (around 350 meters, probably never buried more than 1Km)

Trenton
(currently at
1200 ft)
probably
never buried
more than 1
km on
Findlay Arch
(50°C) – truly
hydrothermal



These temperatures suggest that TBR is truly hydrothermal,
Homogenization temps > ambient temperature ever was

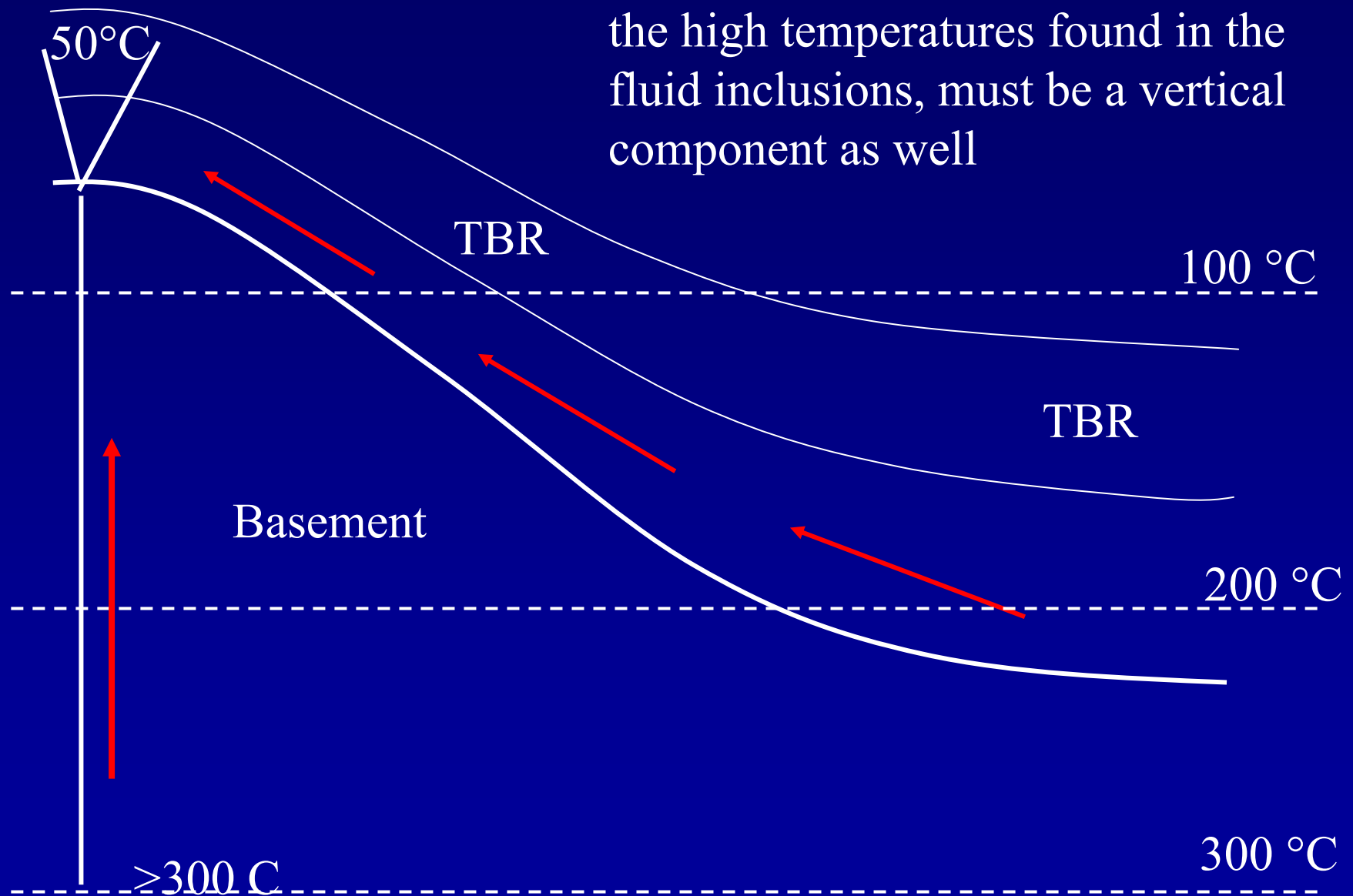
Implications of Preliminary OH Fluid Inclusion data

- The high homogenization temperatures but low burial depths (<1 km) through time support a hydrothermal origin for these dolomites
- That is, very hot fluids ascended from great depth along faults and fractures
- These temperatures and burial history probably rule out any kind of lateral flow from deeper in the basin as well – The high temps probably come from fluids that have flowed through the deep crust

Arch

Basin

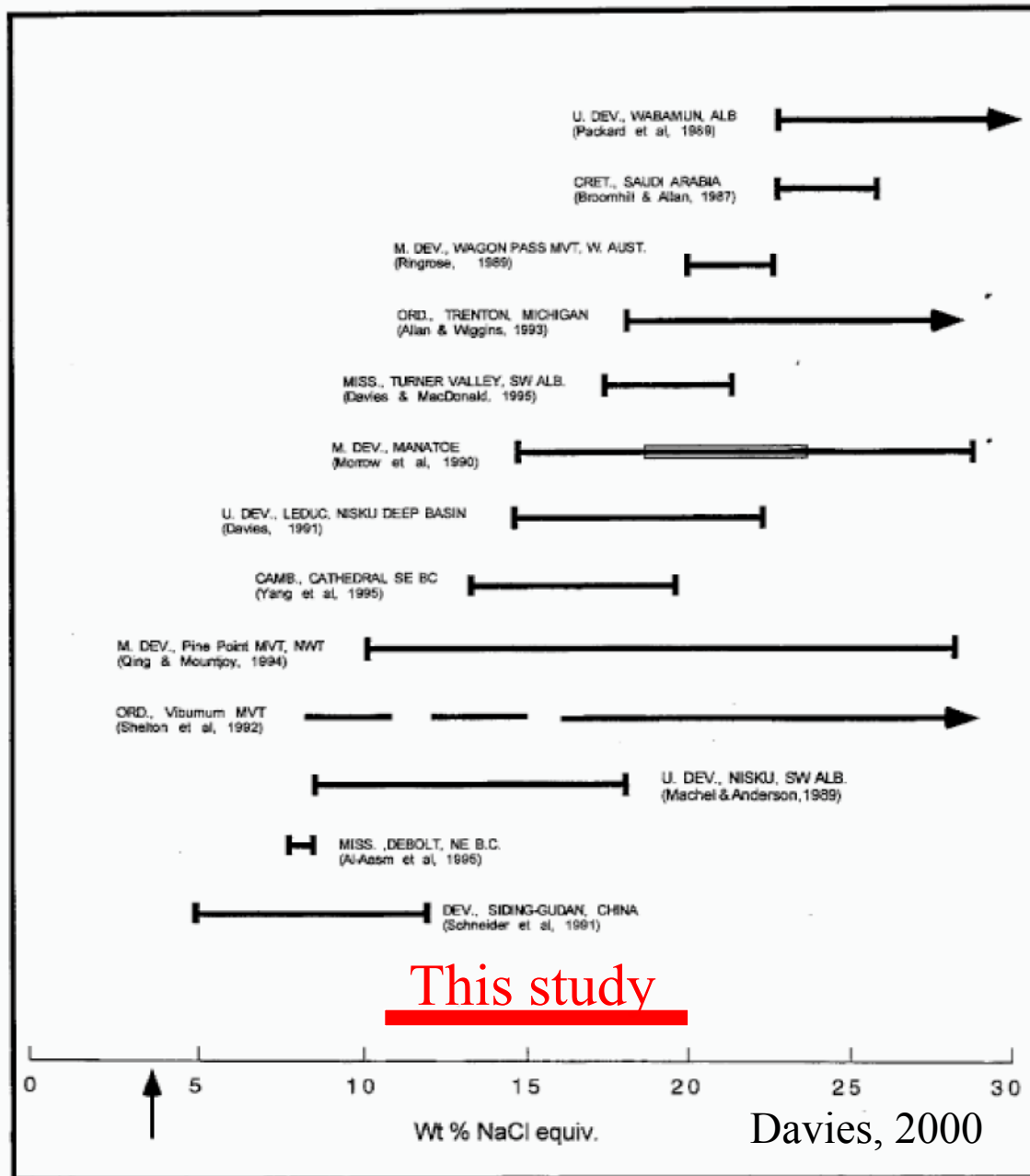
Lateral flow alone cannot produce the high temperatures found in the fluid inclusions, must be a vertical component as well



Salinity

- The fluid inclusions from the saddle dolomites in NY have salinities ranging from 11 to 20 wt% with an average of around 15 wt %. The Ohio samples clustered around 20 wt%.
- Normal seawater has salinity of 3.5 wt %
- The dolomite therefore formed from saline brines
- Again, this is consistent with other TBR reservoirs and hydrothermal dolomite reservoirs from around the world

Table 2 Salinity of Fluid Inclusions from Melting Temperature (T_m) for Saddle Dolomite: Selected Sources



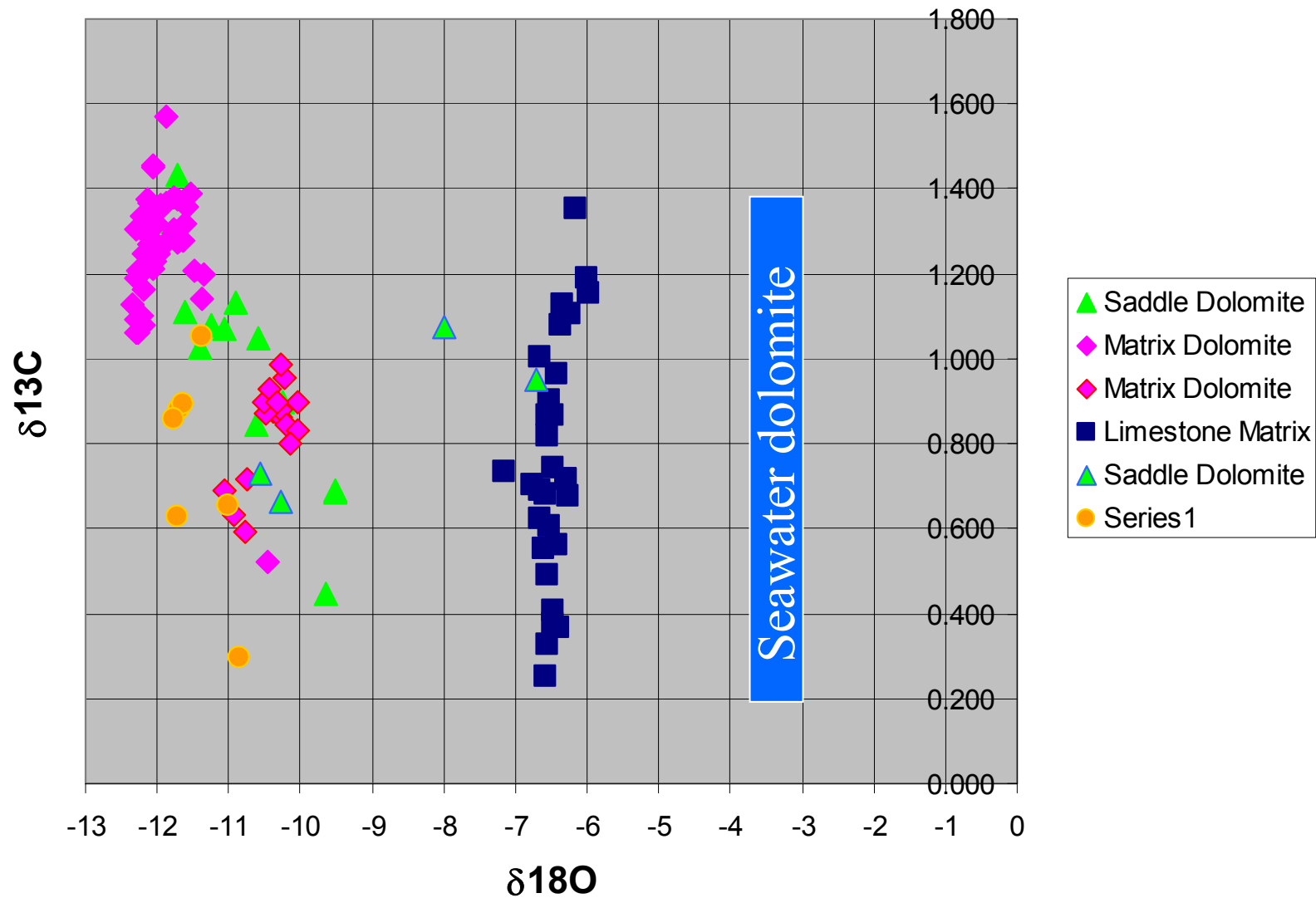
Salinity of the fluid that made the dolomite can be determined from fluid inclusions

TBR dolomite averages around 20 wt% (6 times normal seawater)

Stable Isotopes

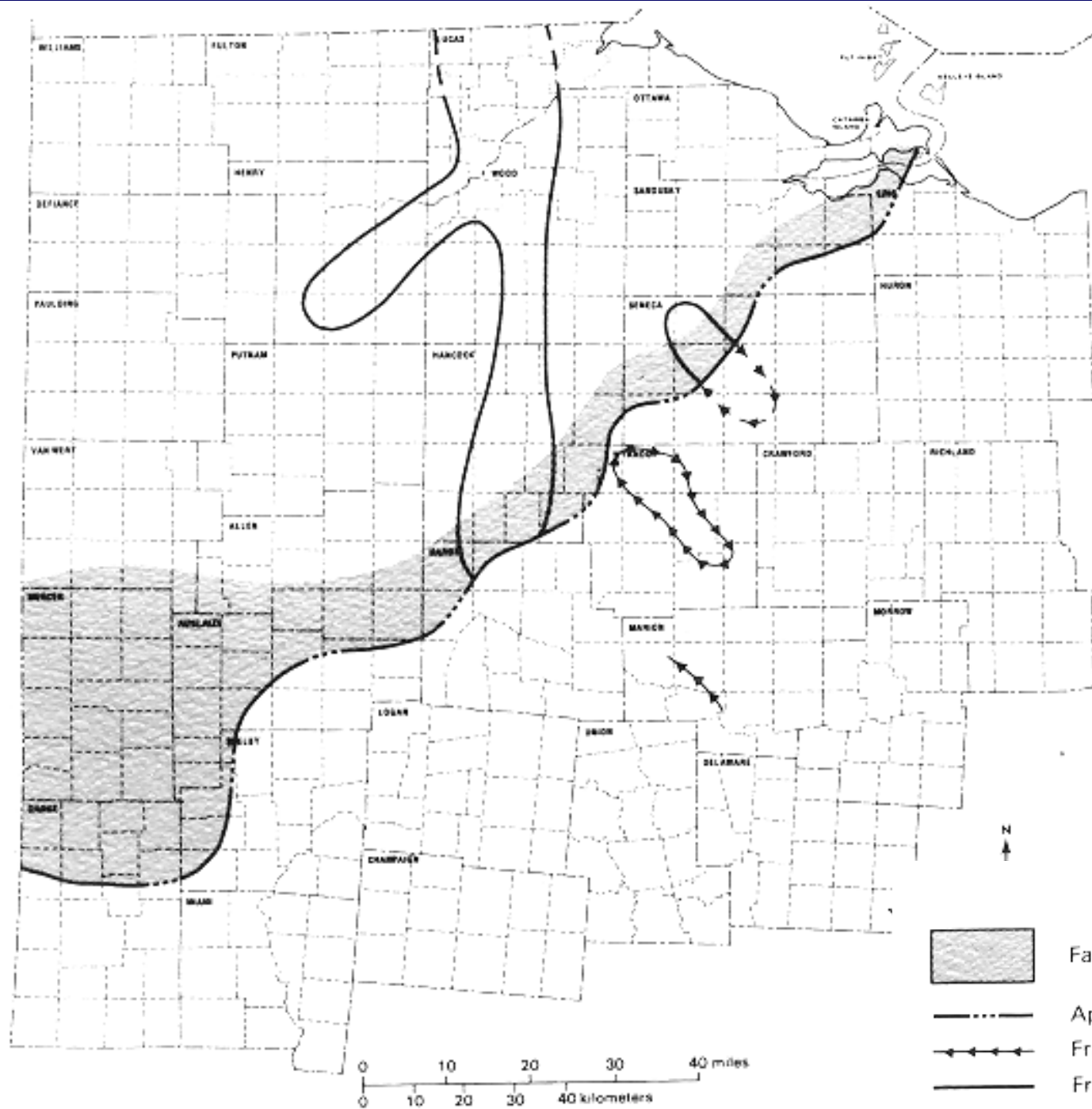
- Stable isotopes are measured in parts per thousand (‰) of ^{18}O vs. ^{16}O and ^{13}C vs. ^{12}C
- Oxygen isotopes in hydrothermally altered reservoirs are commonly more negative than values that come from unaltered limestones
- Due to the fractionation of dolomite vs. calcite, dolomite will have a $\delta^{18}\text{O}$ value that is 3 per mil heavier than calcite formed from the same water
- In other words, if a limestone has a value of around -6 ‰, dolomites formed from the same seawater should therefore have a value of around -3 ‰.

Stable Isotopes



New York Stable Isotopes

“Facies dolomite” occurs along fault-controlled margin, fracture-related dolomite along major fault zones



EXPLANATION



Facies dolomite



Approximate eastern limit of cap dolomite



Fracture dolomite



Fracture and cap dolomite

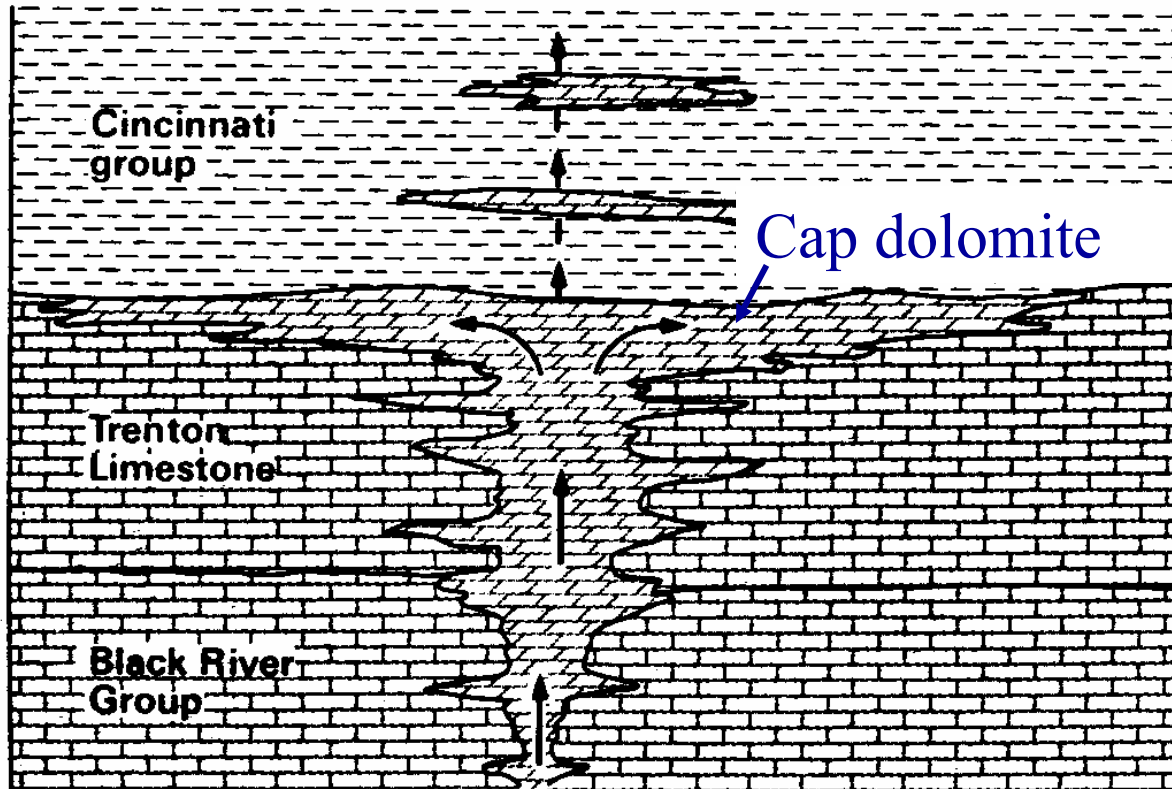
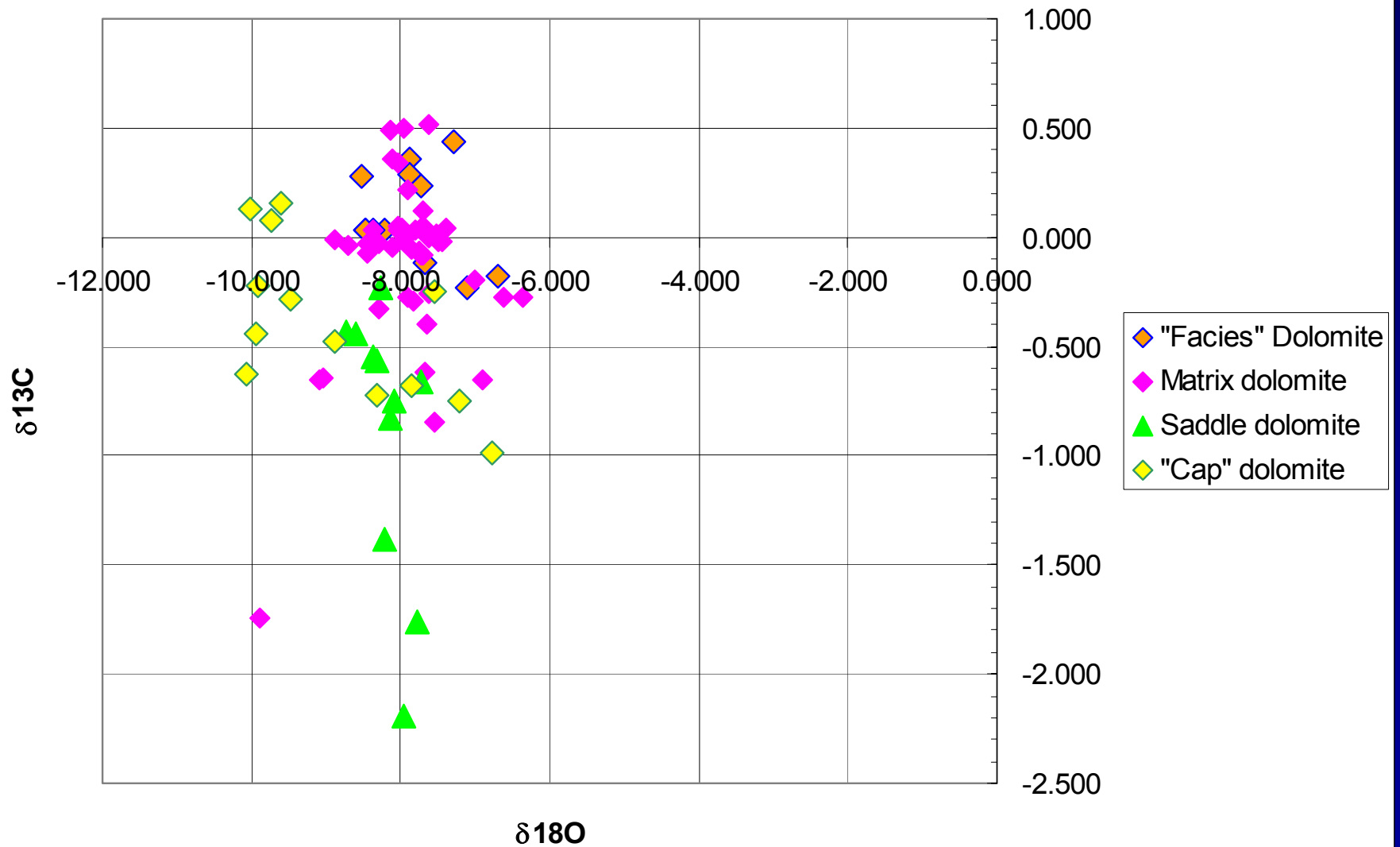


FIGURE 18.—Diagrammatic model of dolomitization along fracture trends in the Black River Group and Trenton Limestone of northwestern Ohio. Fractures and faults act as conduits of migration for ascending fluids. As the fluids cool and react with the host rock, dolomite and other secondary minerals precipitate.

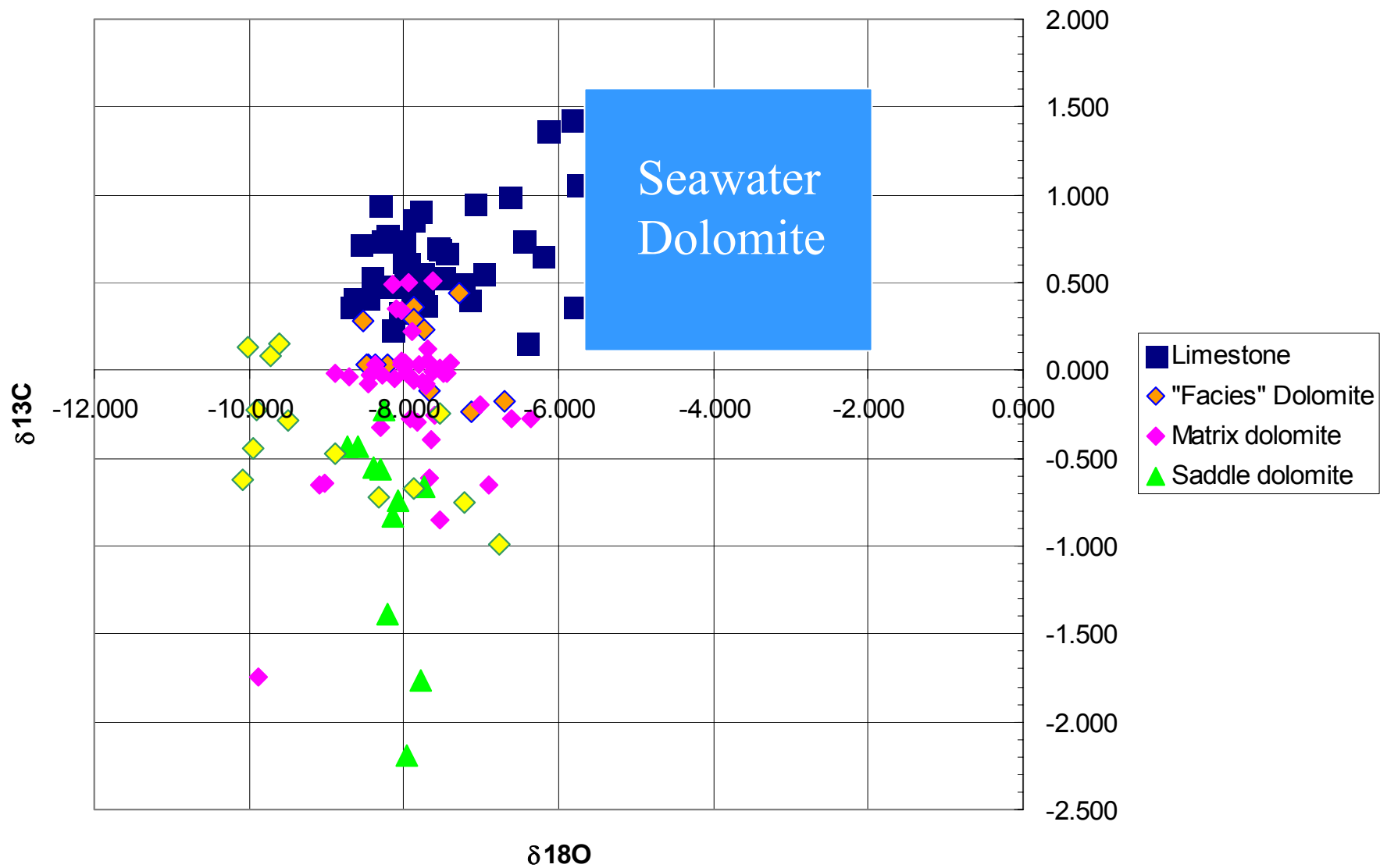
Wickstrom et al. (1992) model for fracture controlled dolomitization

- Cap dolomite at top of Trenton either fracture sourced or formed from shale compaction

Dolomite Types, OH

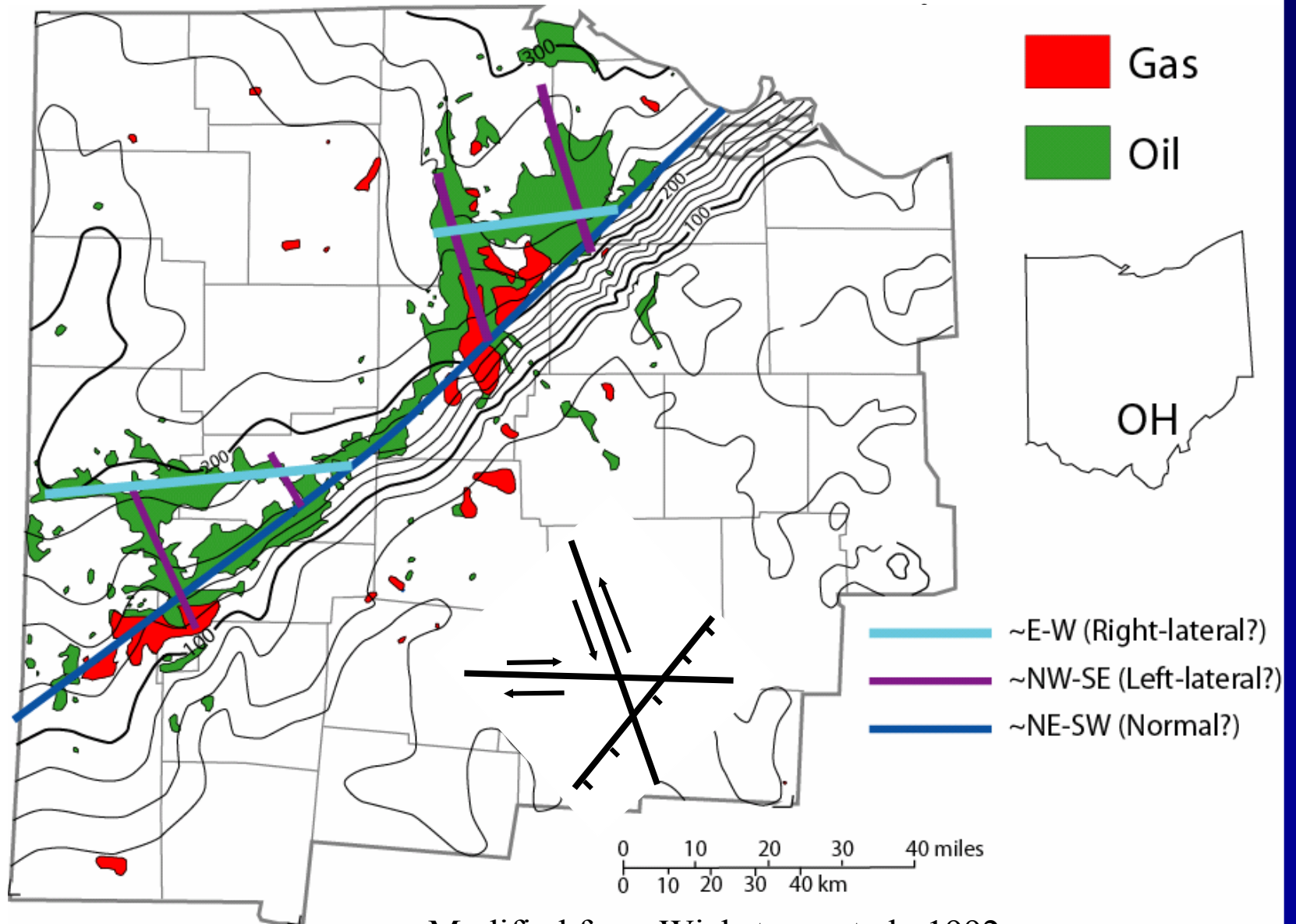


Limestone and Dolomite, OH



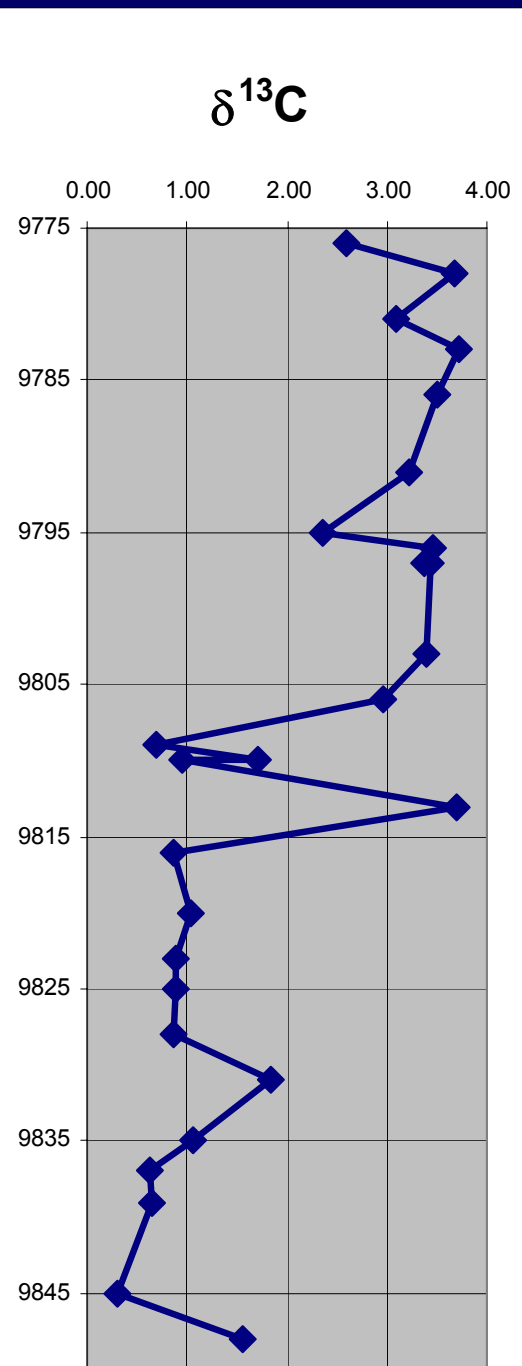
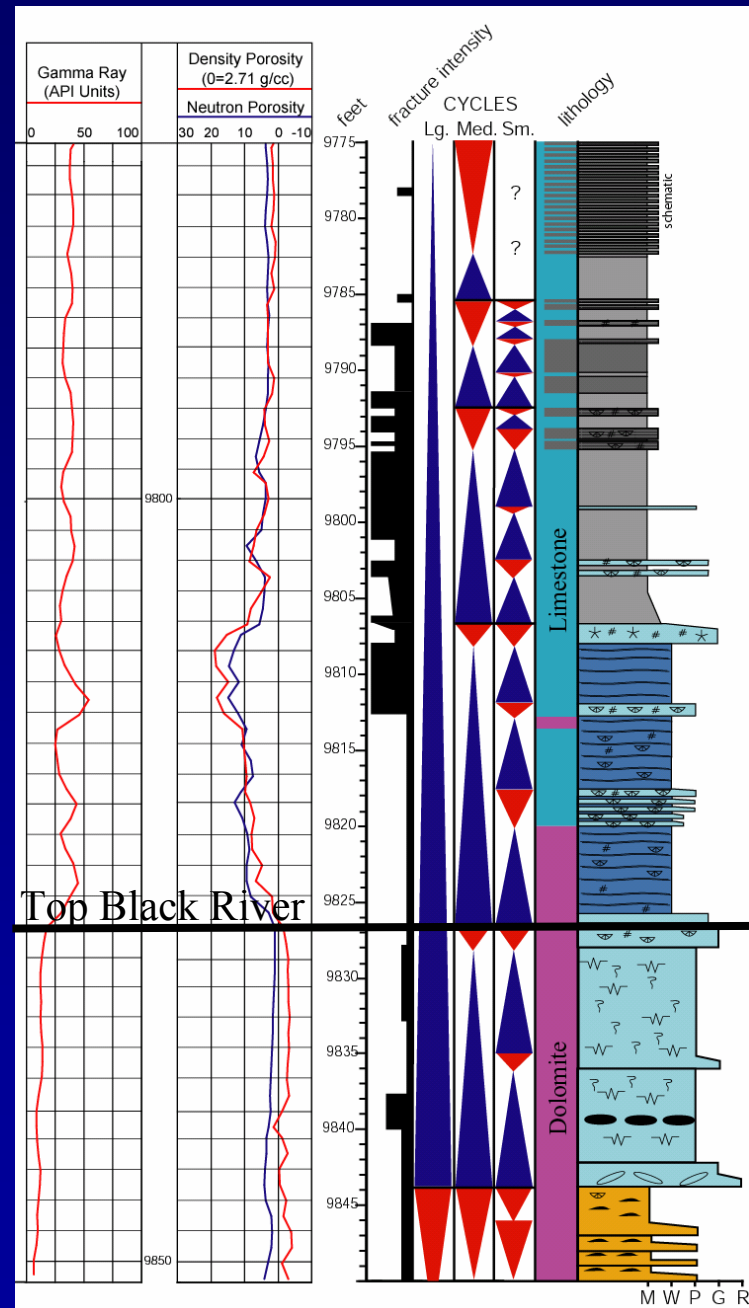
Dolomite Types

- The Facies dolomite, cap dolomite, saddle dolomite and matrix dolomite around the Bowling Green Fault Zone all appear to have roughly the same stable isotope values
- This suggests that the dolomite may all be of a similar origin – fault-related hydrothermal
- Shale compaction dolomites should be heavier or more positive than the values that we have obtained



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

Matejka # 1 Core



There appears to be a significant shift in $\delta^{13}\text{C}$ just above the Trenton Black River boundary in New York – remains to be seen if it is local or secular variation in seawater

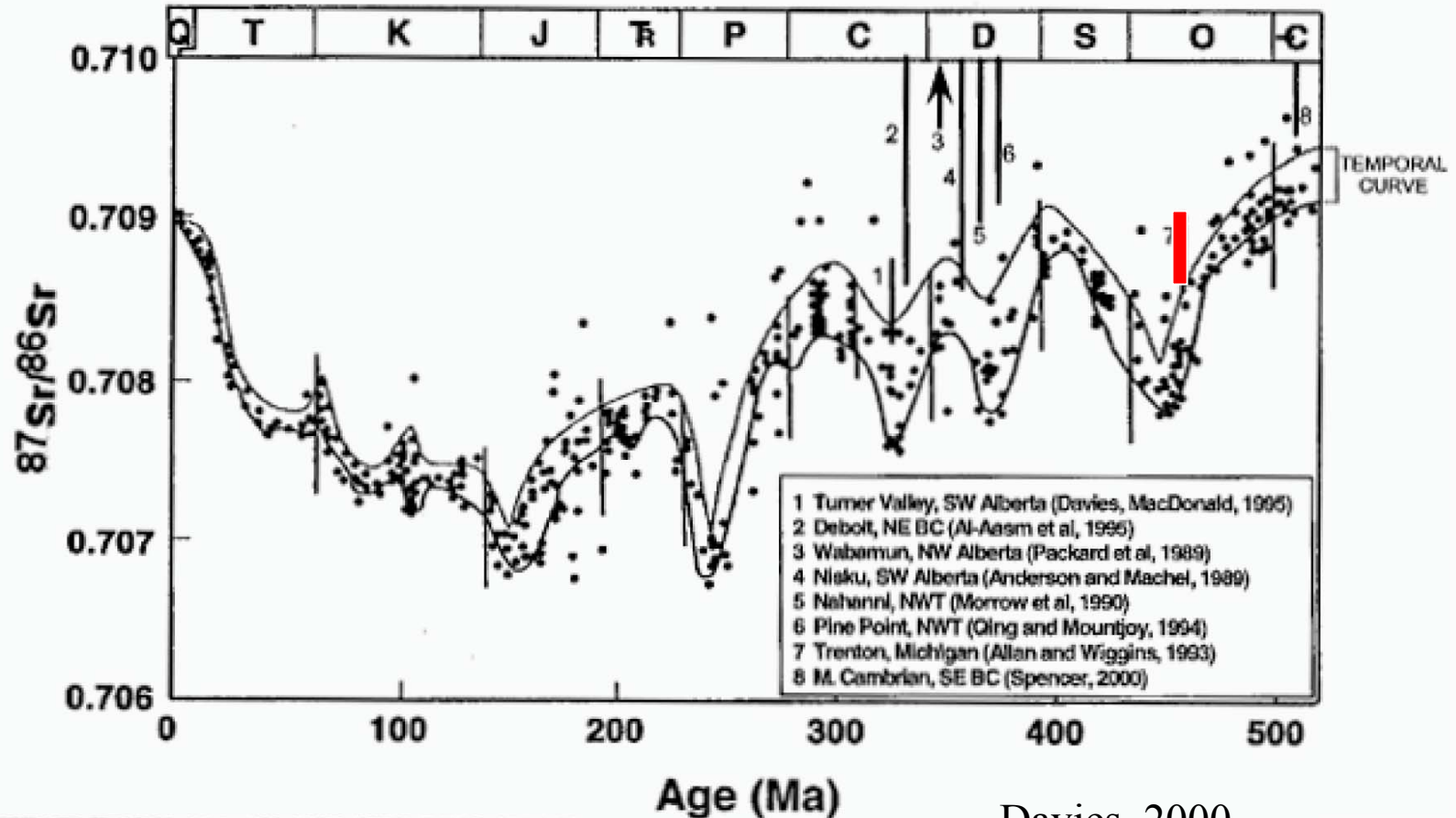
This could be a powerful correlation tool across the five states (and then some)

There could be other shifts in the Trenton and Black River

Chemostratigraphy

- Have sampled 3-5 key sections every 5 feet to see if trend can be correlated
- This could really help correlate and work out sequence stratigraphy in different areas and in different rock types, particularly where the top of the Black River is not obvious
- Could use cuttings, core and/or outcrops

STRONTIUM ISOTOPE COMPOSITION OF SADDLE DOLOMITE



Sr CURVE FROM ALLAN AND WIGGINS (1993)

Davies, 2000

GDGC96

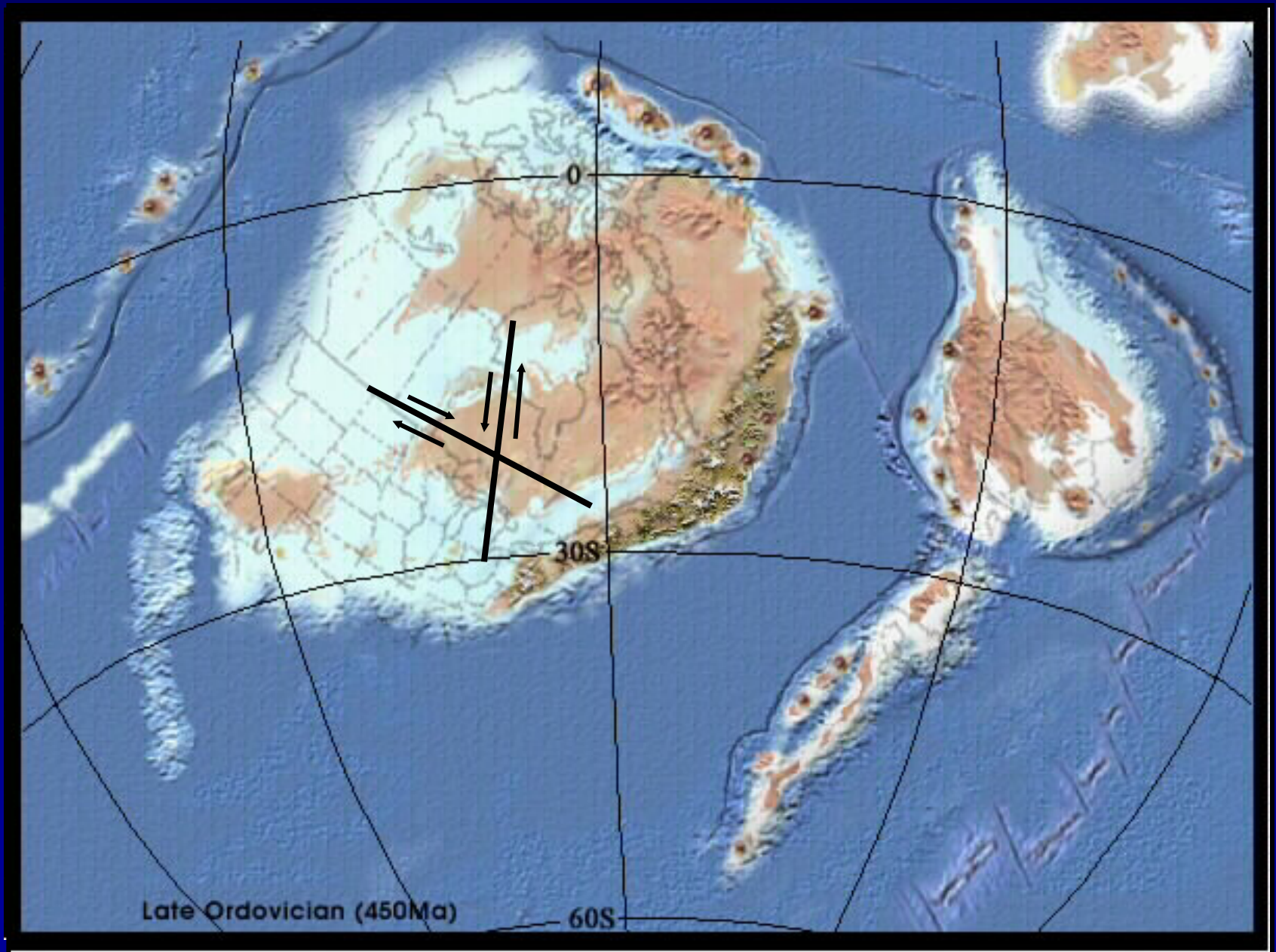
Hydrothermal dolomites typically plot as more radiogenic than seawater for the time the rocks were deposited – True for TBR (barely)

Trace Elements

- Based on only a few measurements so far, TBR dolomites have a High Iron (avg. 3500 ppm) and Manganese (1000 ppm)
- High iron and manganese are consistent with a subsurface origin (seawater has virtually no iron or manganese in it)
- They are also depleted with respect to total Sr (average of about 300 ppm for limestones and 30 ppm for dolomites in one core)

Preliminary Conclusions

- The fluids that made the matrix and saddle dolomites in the Trenton and Black River were hot (up to $>200^{\circ}\text{C}$), iron and manganese-rich saline brines (15 to 20 wt% salinity), that passed through continental basement rocks or immature siliciclastics prior to making the dolomite
- Occurrence of these dolomites on Findlay Arch which was never buried more than 1km show that these dolomites were truly hydrothermal



Theory: Hydrothermal dolomitization occurred during Late Ordovician Taconic Orogeny when TBR was only a few hundred meters deep

Evidence for Shallow Burial at the Time of Alteration

- Seismic shows faults dying out in Trenton or Utica in many cases
- Horizontal fractures common in cores - Horizontal fractures common from surface down to about 1500 feet, then vertical fractures take over
- Seismites abundant in Trenton outcrops
- Soft sediment deformation around fractures and faults
- Findlay Arch area probably never buried more than 0.75 km yet everything looks the same there as it does elsewhere (alteration definitely did occur at shallow depths in this instance so it is possible)

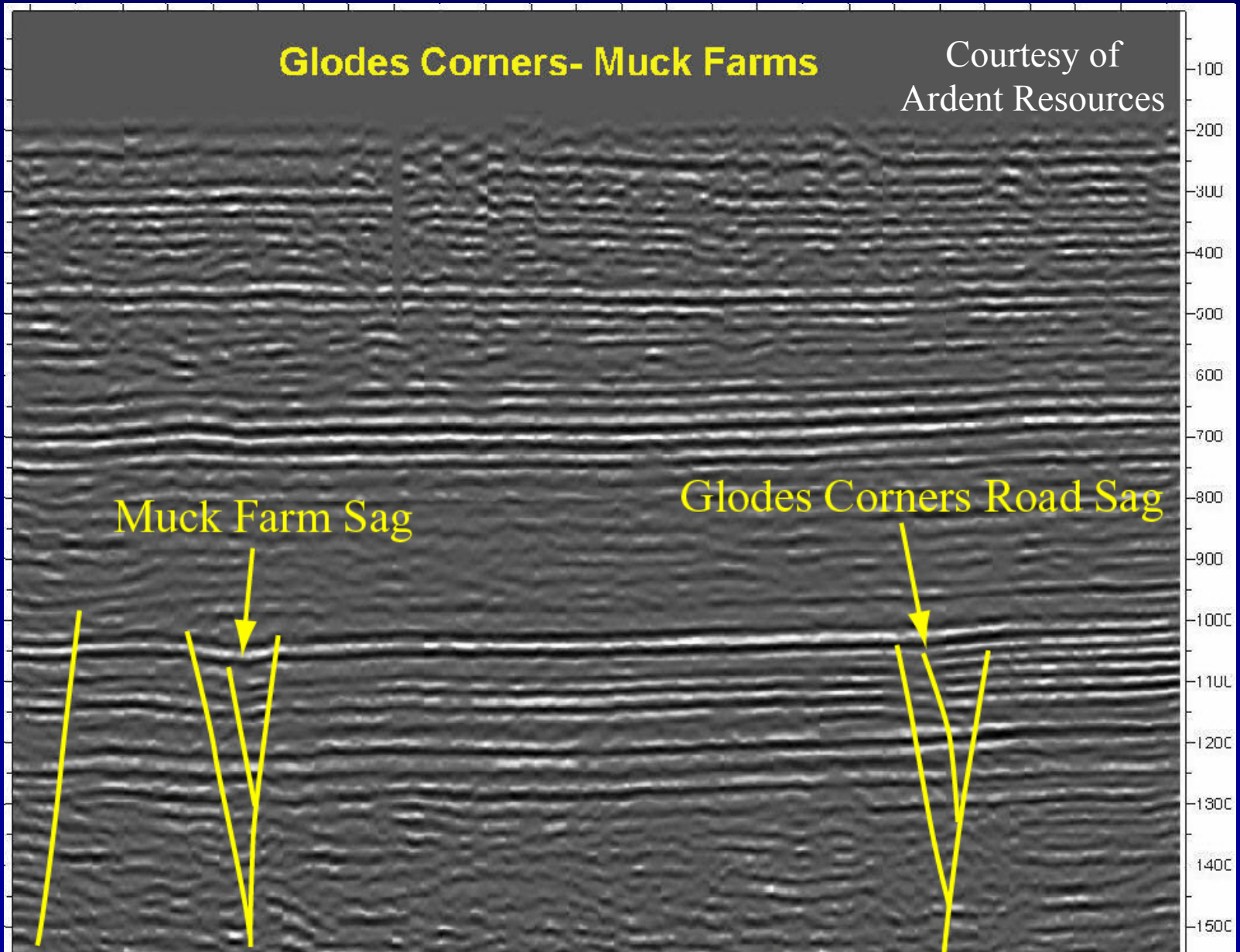
Glodes Corners- Muck Farms

Courtesy of
Ardent Resources

Muck Farm Sag

Glodes Corners Road Sag

Seismic over New York HTD reservoirs



Saddle dolomite in horizontal clay seam; horizontal vugs also very common





Seismites (seismically disturbed bedding) In Trenton of KY

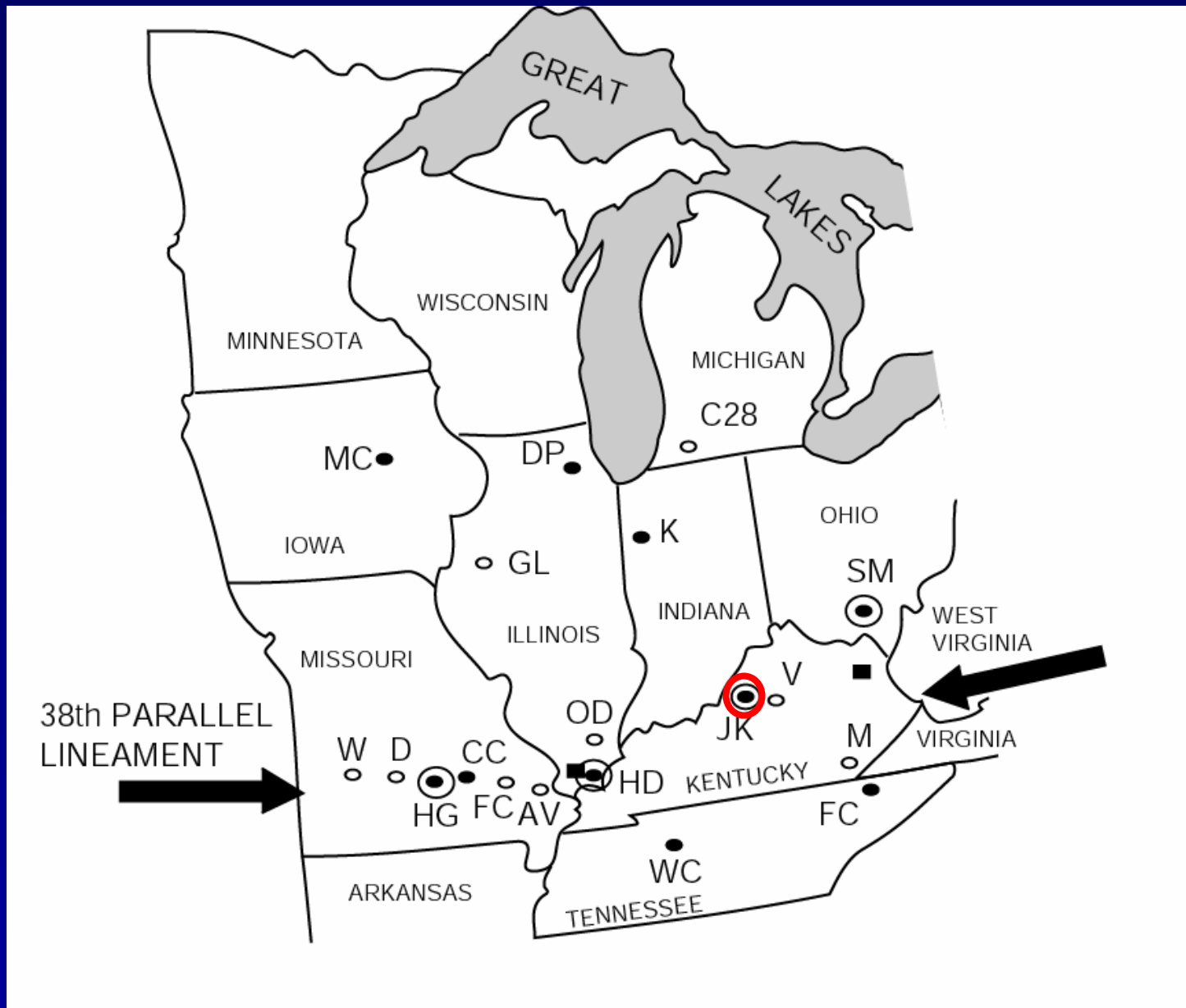


Piper, margin southwest of
BG fault, Black River,
looks like fracture
propagating through soft
sediment in shallow marine
facies

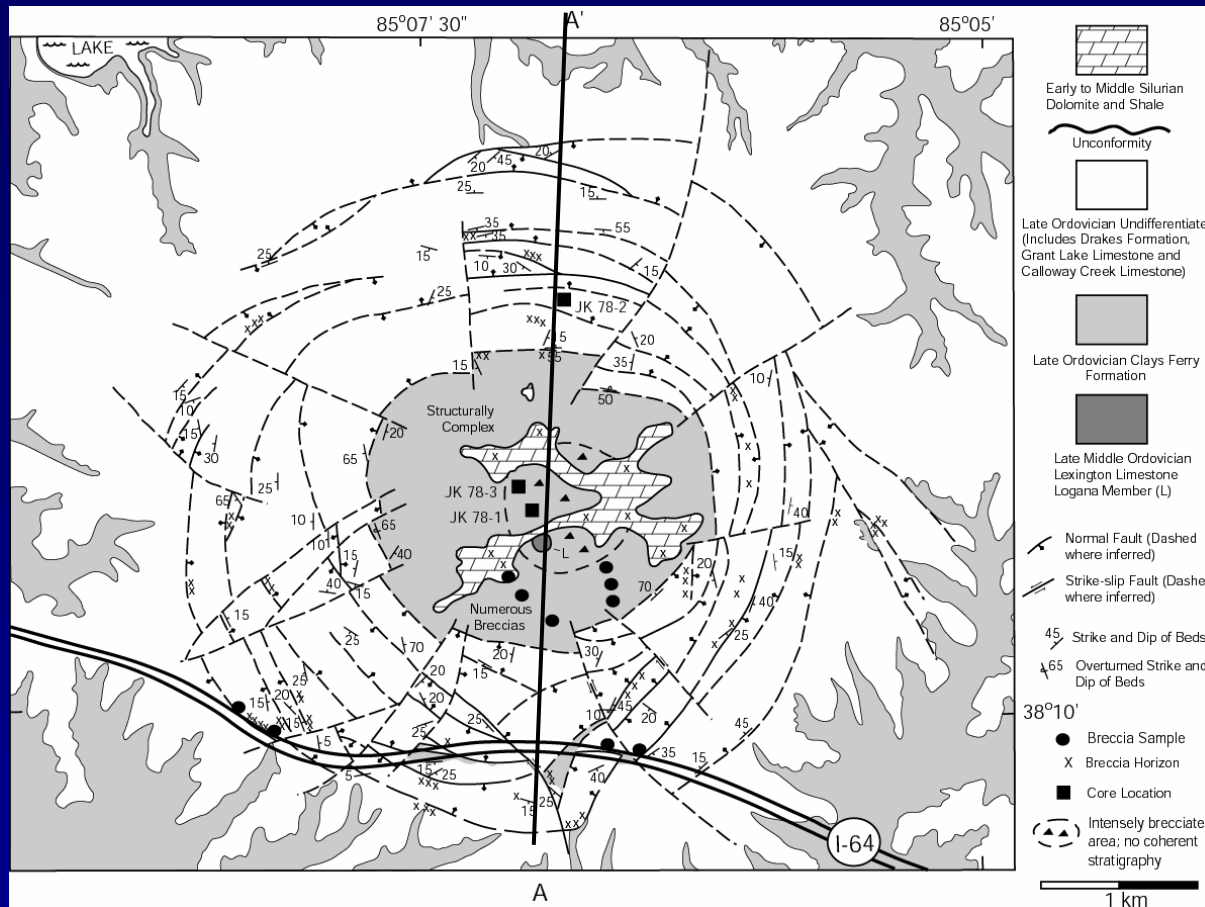
This suggests that the rock
was not lithified and
therefore pretty shallowly
buried at the time of
fracturing

Jeptha Knob, KY – Positive Dolomitized Feature

- Round feature in outcrop
- Pervasively dolomitized in many Middle Ordovician formations that are normally limestone
- Extremely porous – would be a great reservoir
- Heavily faulted and chaotic
- All deformation occurred prior to Silurian
 - Interpreted as Late Ordovician Impact structure by many authors
 - Interpreted as middle to late Ordovician fault-related structure by Black (1990) and Smith (2002)



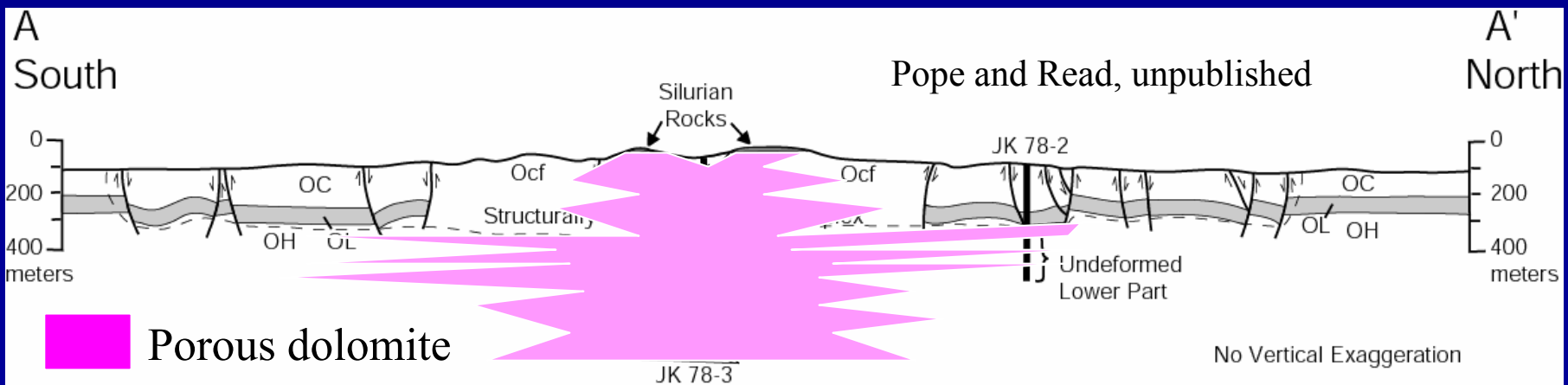
In a trend with many similar features



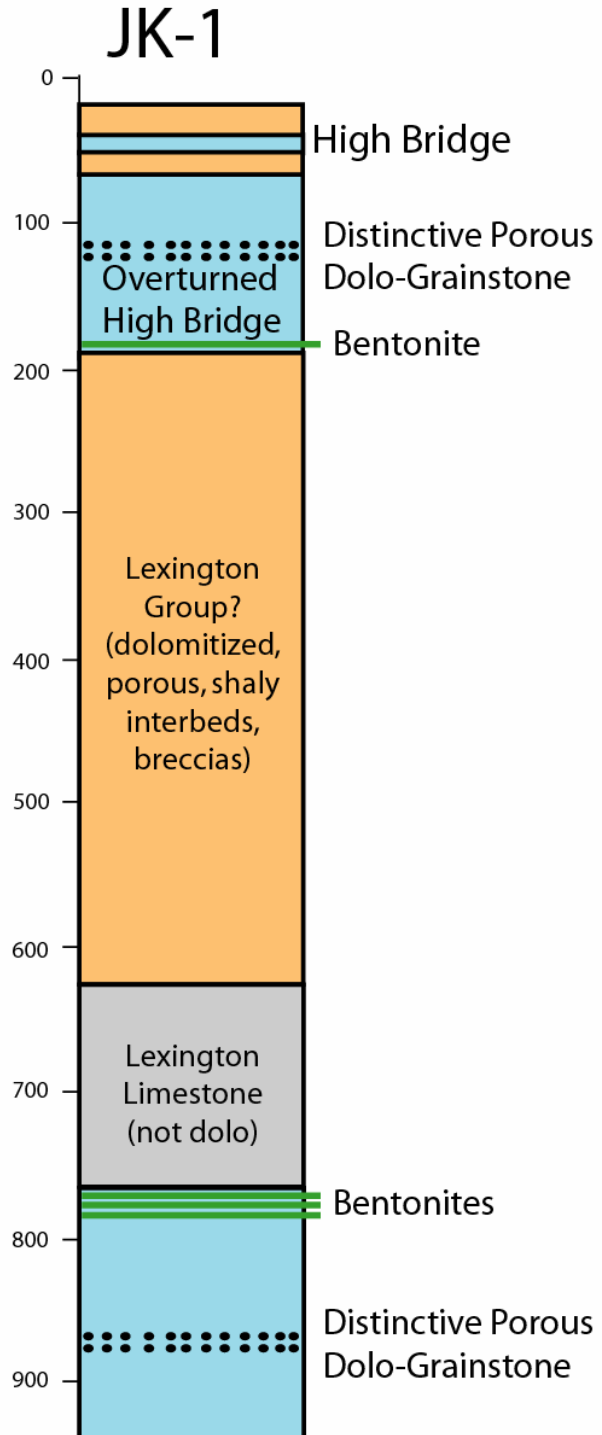
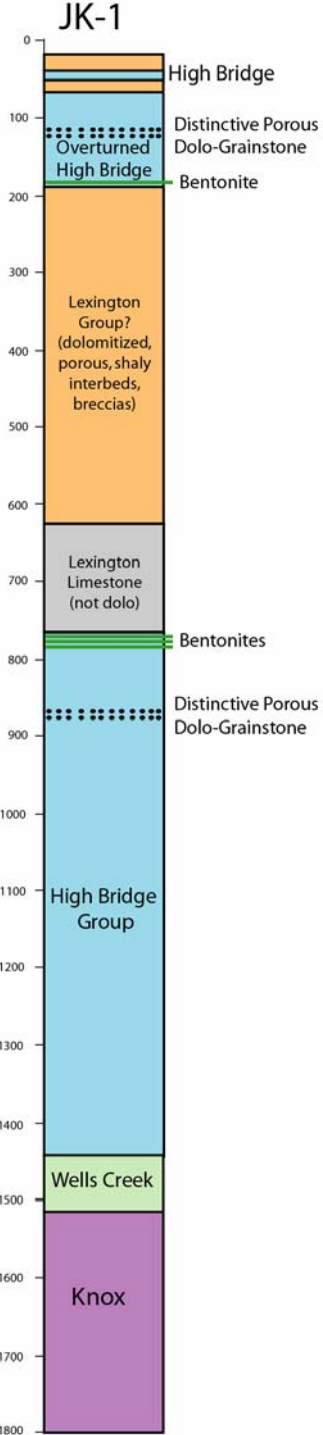
Jephtha Knob

The structure is pervasively dolomitized brecciated, fractured, faulted and very porous

Three cores drilled looking for minerals in KY survey collection

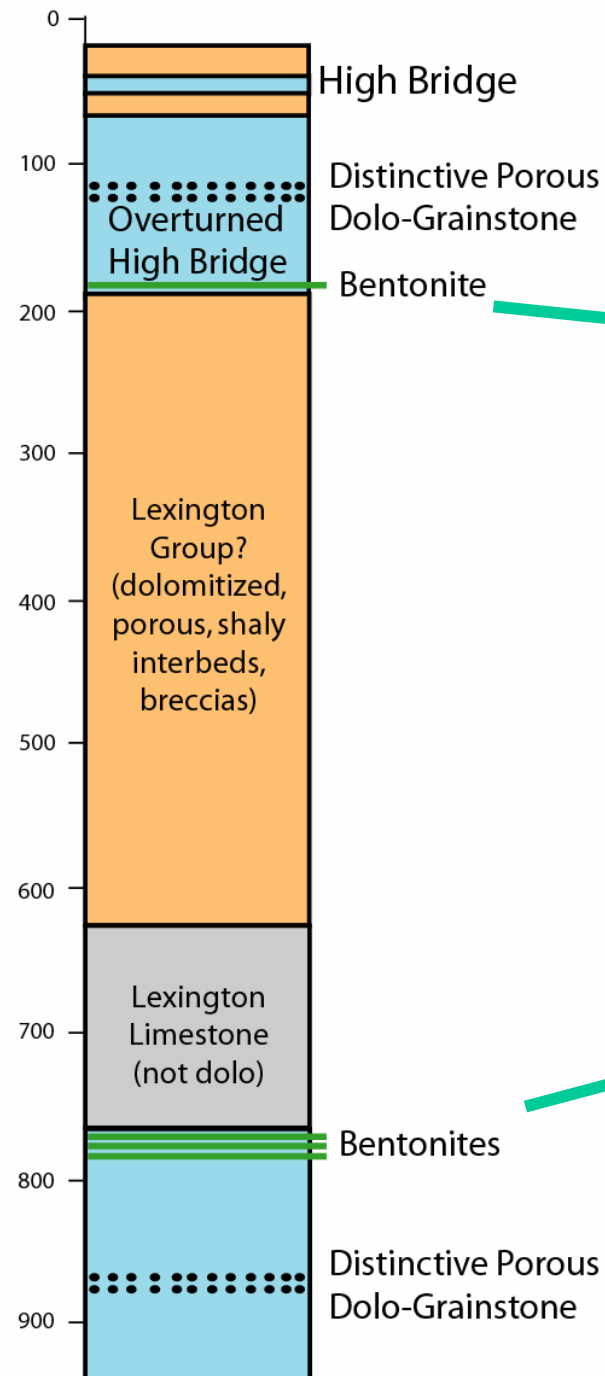






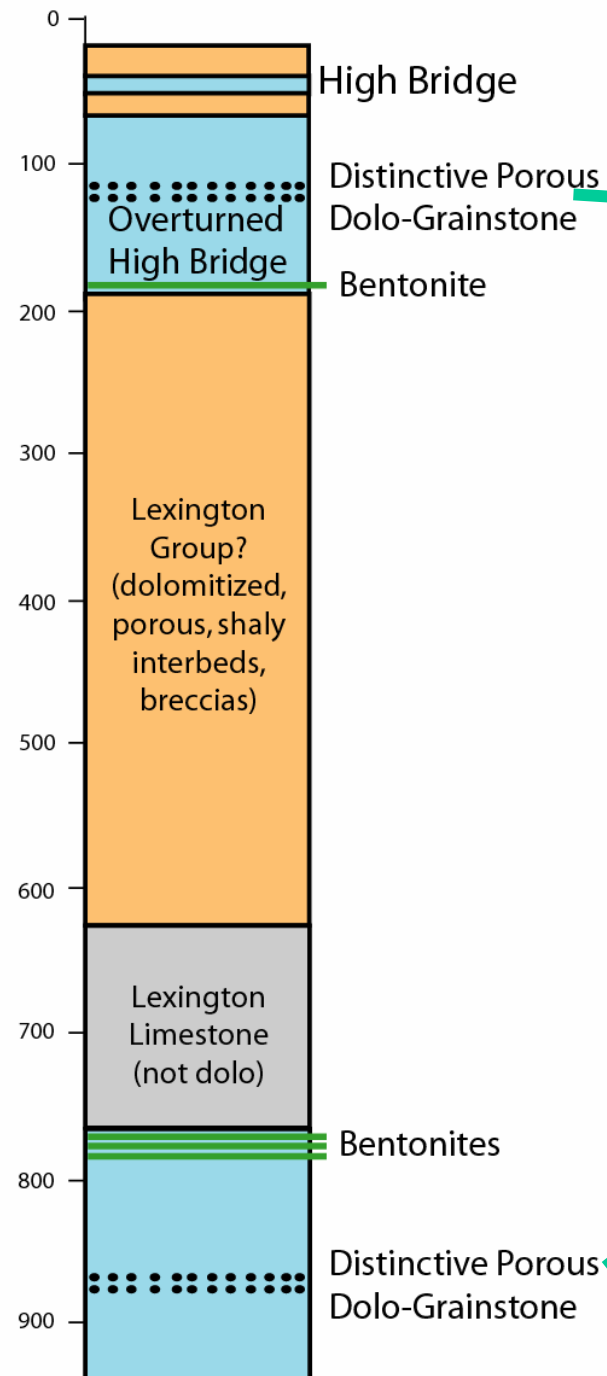
- At top of JK-1, a 127 foot-thick continuous section of overturned High Bridge Group (sits on an overthickened section of dolomitized Lexington Group Carbonates)
- It is clear that the upper occurrence of High Bridge is overturned – there is a bentonite at the base that is found at the top of the High Bridge, and a distinctive porous dolomitized grainstone about 90 feet above the bentonite that occurs 90 feet below the bentonite in the lower right-side-up section

JK-1



Bentonite

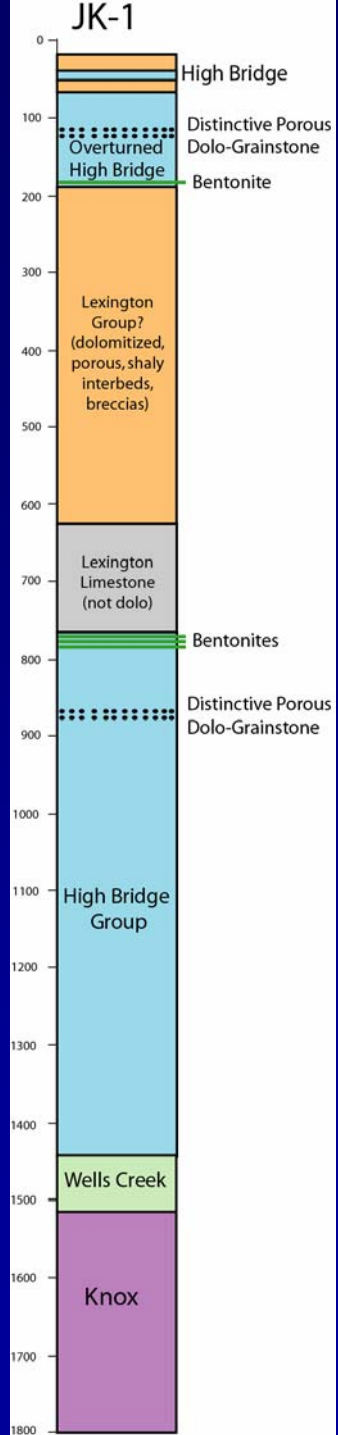
JK-1



Distinctive
Grainstone



Porous High Bridge (Black River) dolomite from overturned block at top of JK1



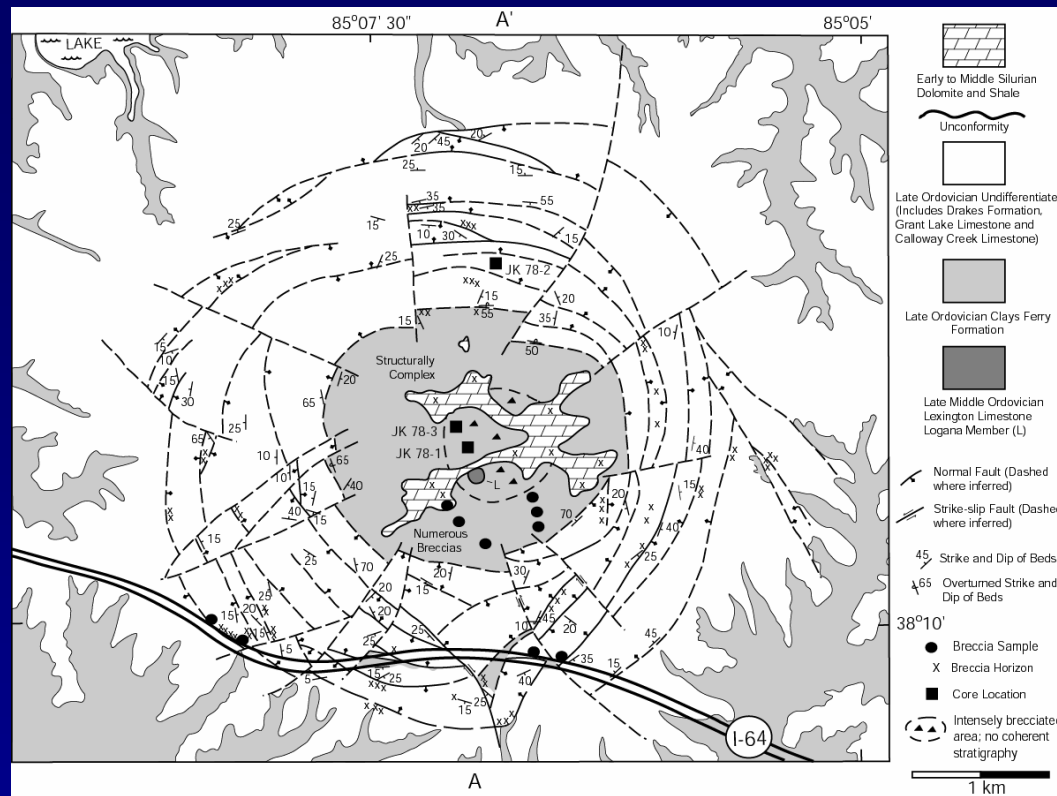
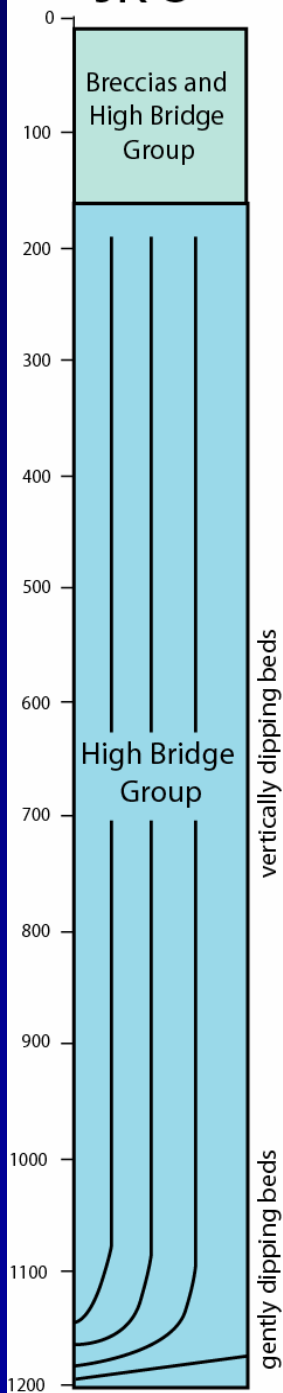
Dip of Beds changes throughout the core

Beds range from horizontal to vertical to overturned

Steeply dipping beds occur all the way down in the Knox more than 1500 feet below the surface

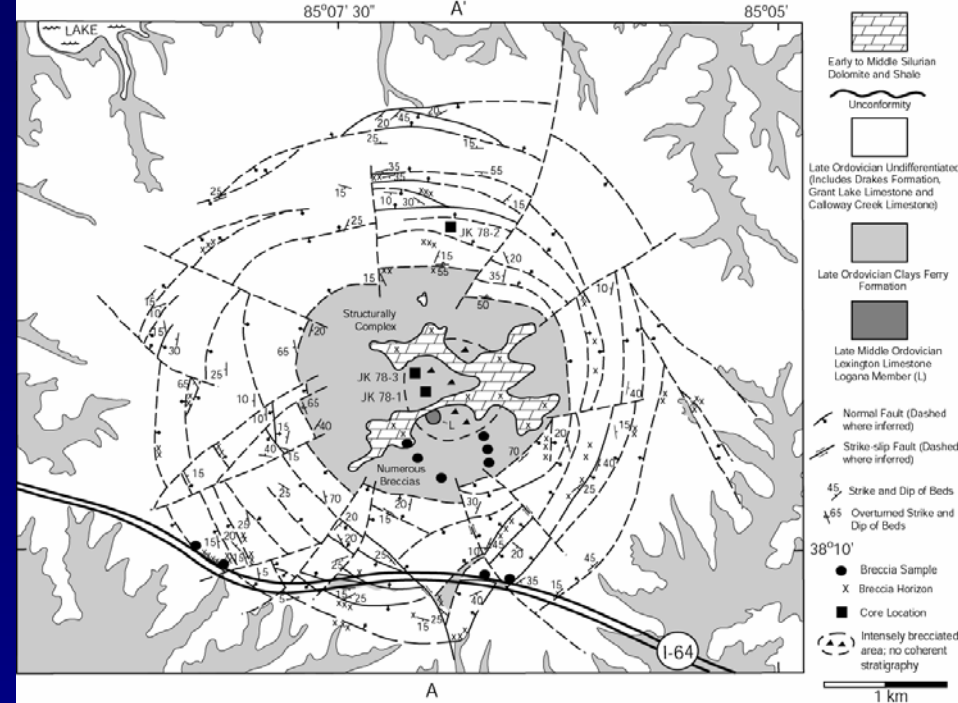
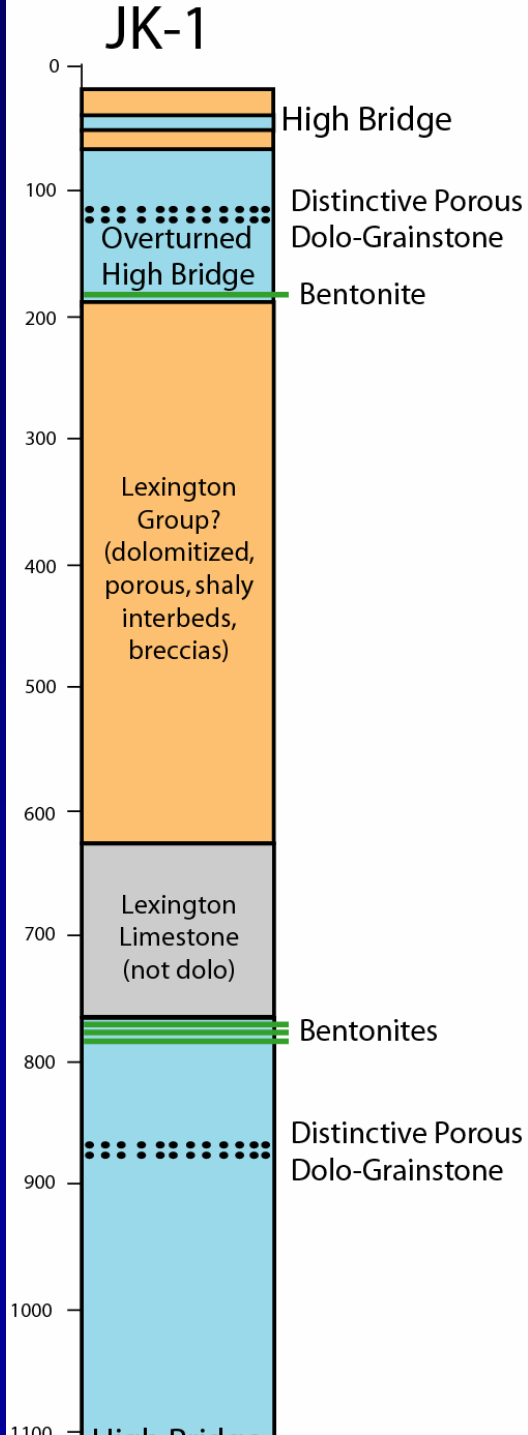
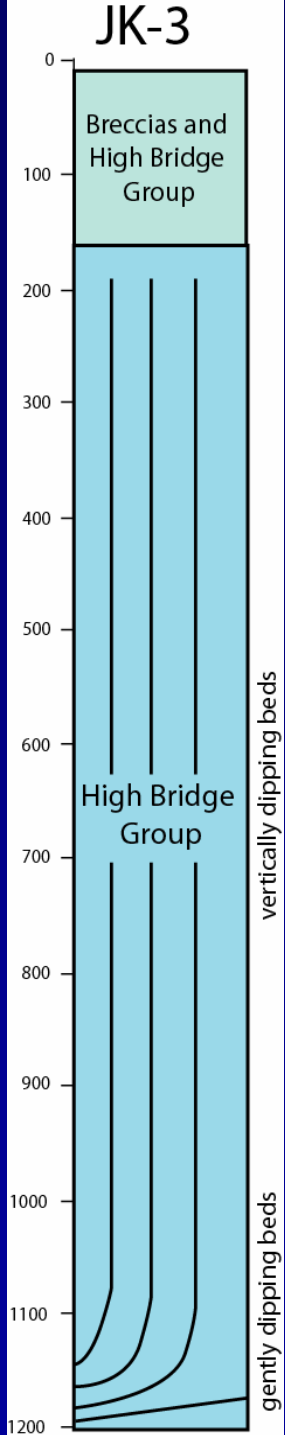
Many intervals of horizontal bedding occur between dipping beds

JK-3



Jephtha Knob 3 core is composed of ~150 feet of breccias and High Bridge, then ~950 feet of vertically dipping High Bridge grading down to slightly dipping high Bridge in the basal 100 feet

The vertical section seems to be the same interval that was overturned in JK1



Vertically dipping beds, repeated sections and overturned beds suggest compressional tectonics of some kind



JK 2 Very top of Core

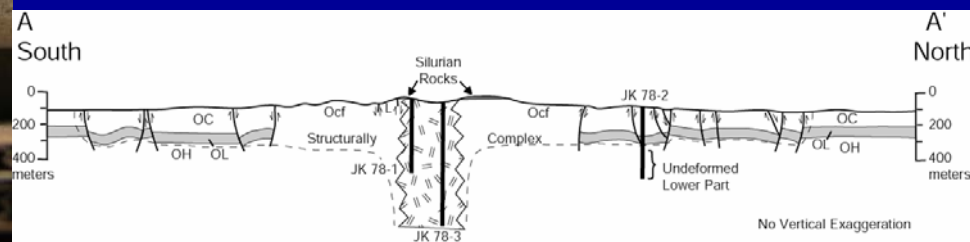


JK 2 Lexington Group



JK 2 Very top of Core

Conglomerates/breccias occur at up to 8 stratigraphic intervals in off structure core (JK-2) and outcrops – they are bound by flat lying, undeformed strata – these breccias do not normally occur in these formations elsewhere



Implications

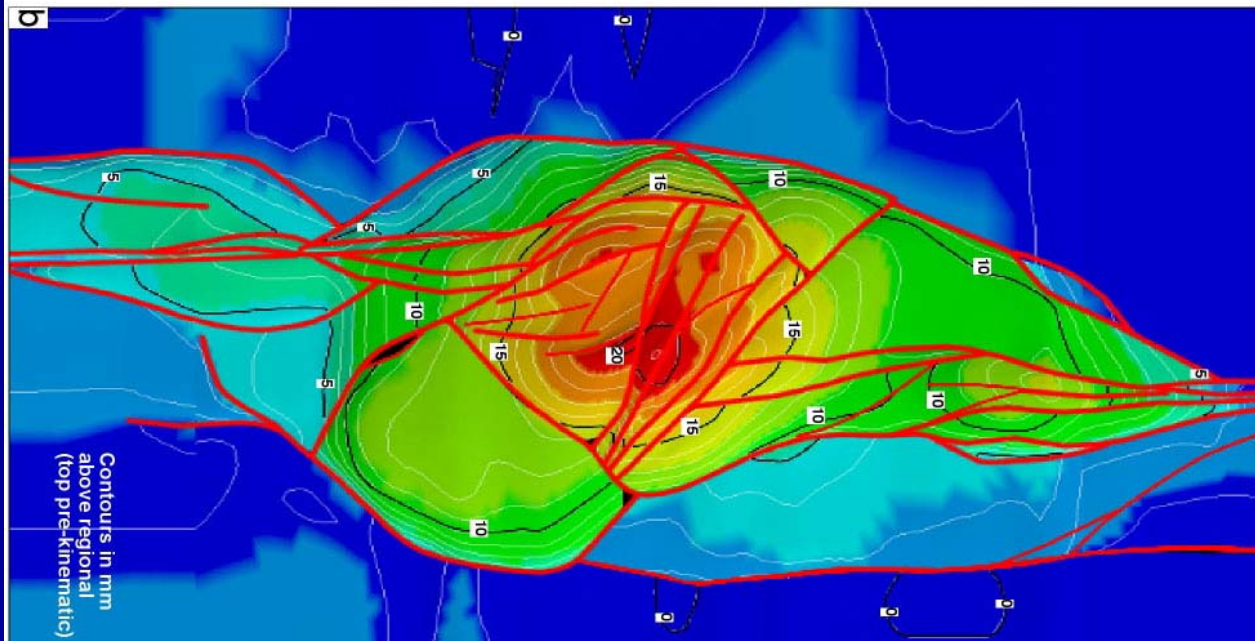
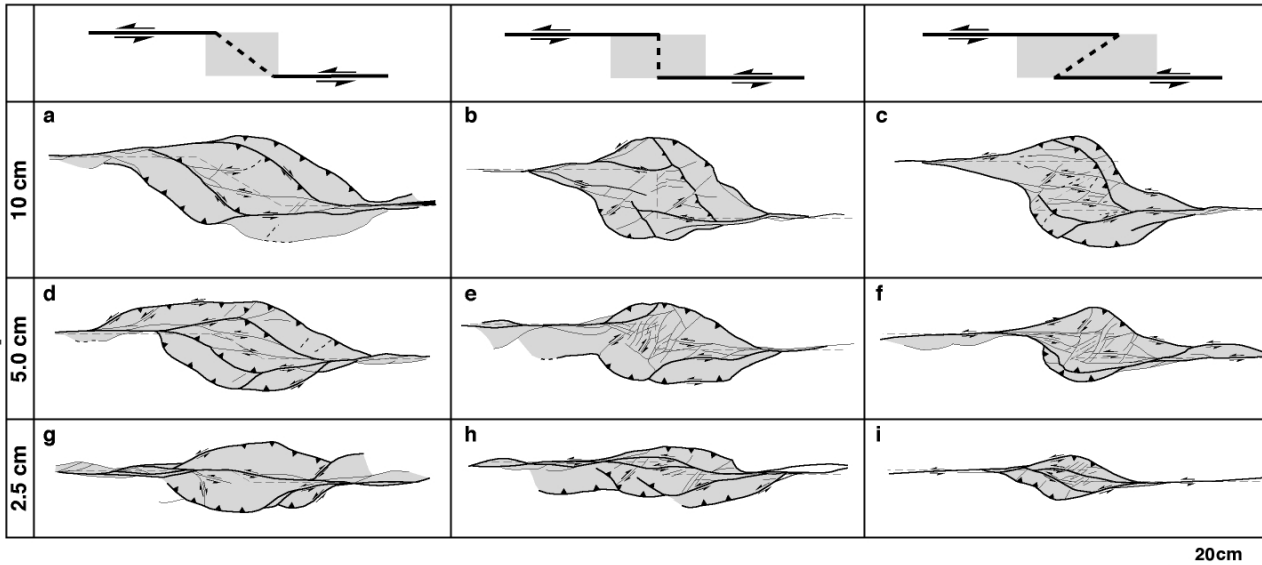
- It is difficult to explain the 127 foot thick overturned bed of High Bridge 800 feet above in place High Bridge with some intervals of flat-lying strata in between with an impact model
- Also hard to explain multiple breccia beds that occur in outcrop and off-structure core bounded by flat lying in place strata – impact is one event, not many in same place

So What is it?

- It looks like a thrust fault or transpressional fault has repeated the High Bridge and Lexington section
- Black River overturned as thrust propagated upward?
- Round shape suggests possible positive flower structure formed at offset between two strike slip faults

Basement Fault Geometry

Stepover Width

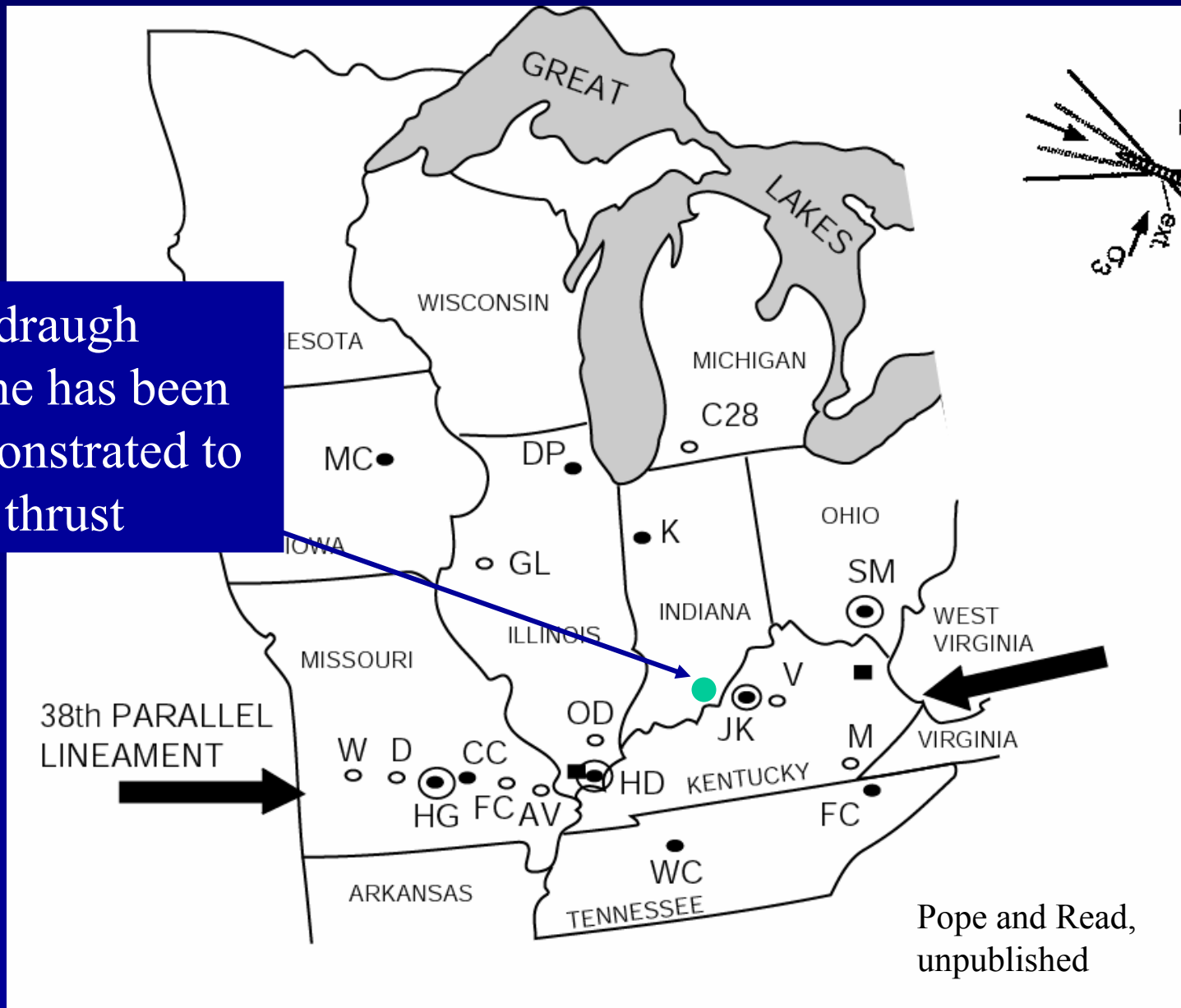


From McClay and Bonora

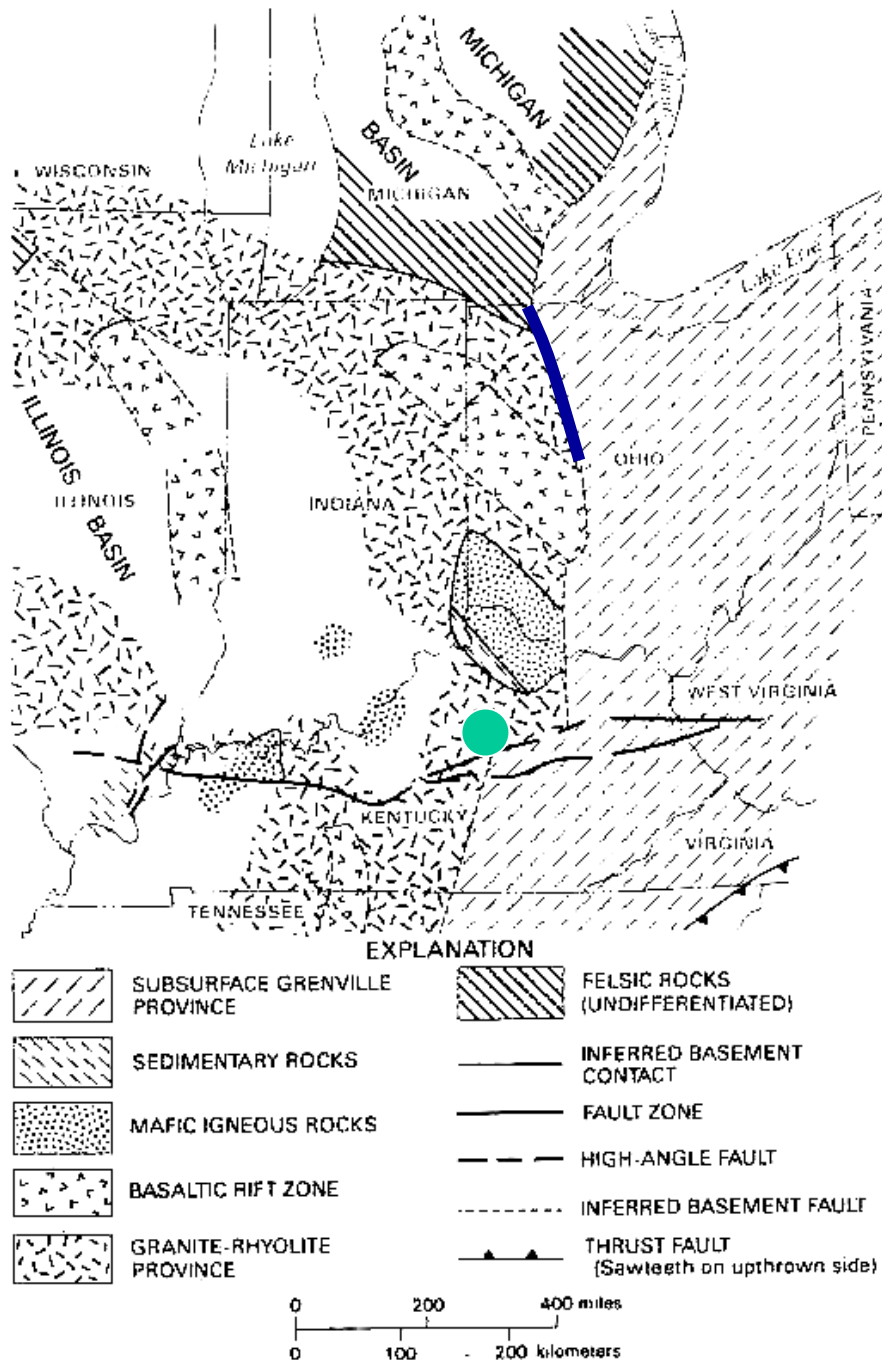
Positive features should also form as a result of strike-slip faulting during the Ordovician and they too may be dolomitized and porous

Some pop-up structures may occur in Kentucky where some of them have been interpreted as impact structures

Muldraugh
Dome has been
demonstrated to
be a thrust



Many “crypto-explosive” dome structures all line up along E-W
38th parallel lineament



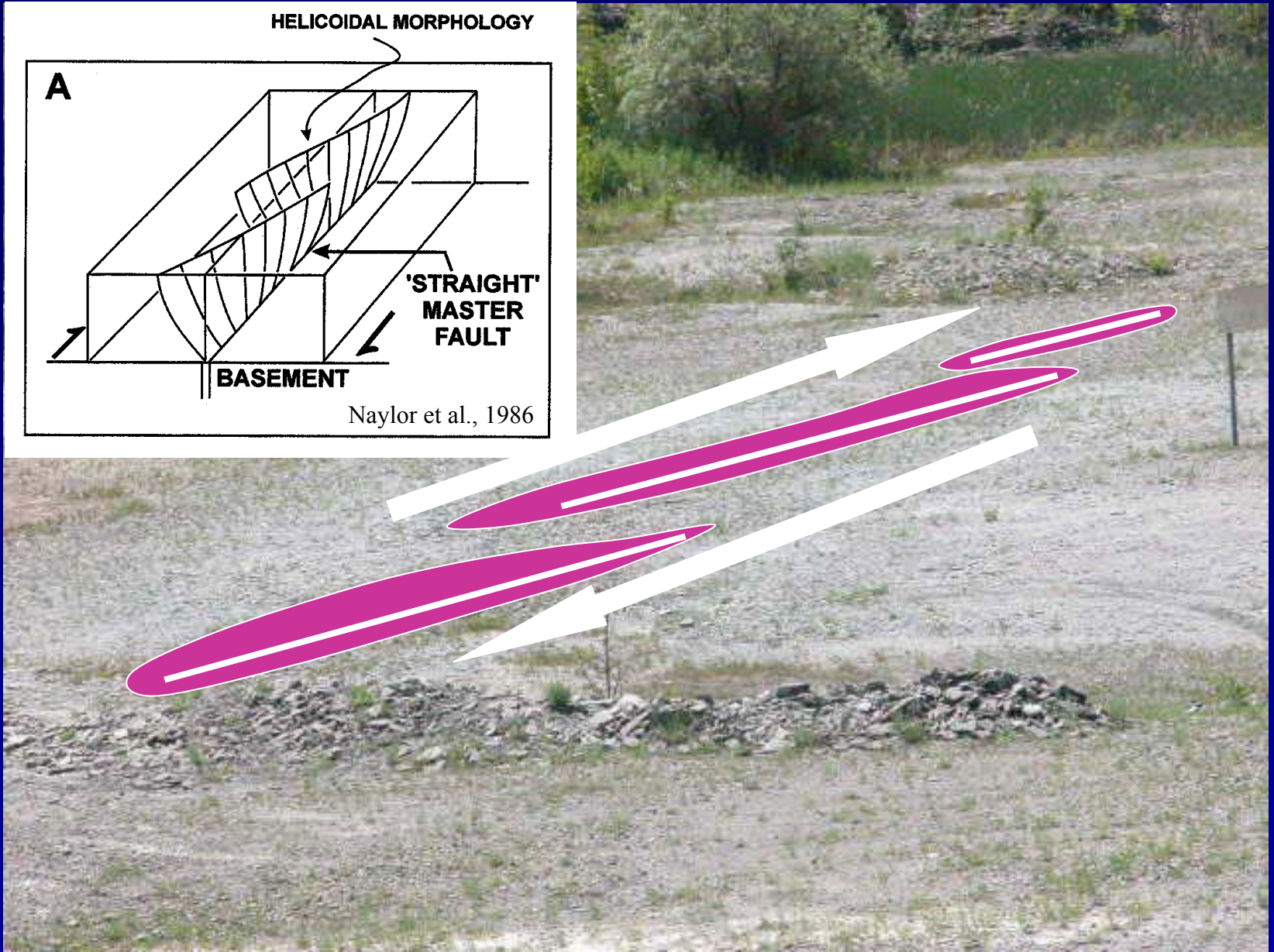
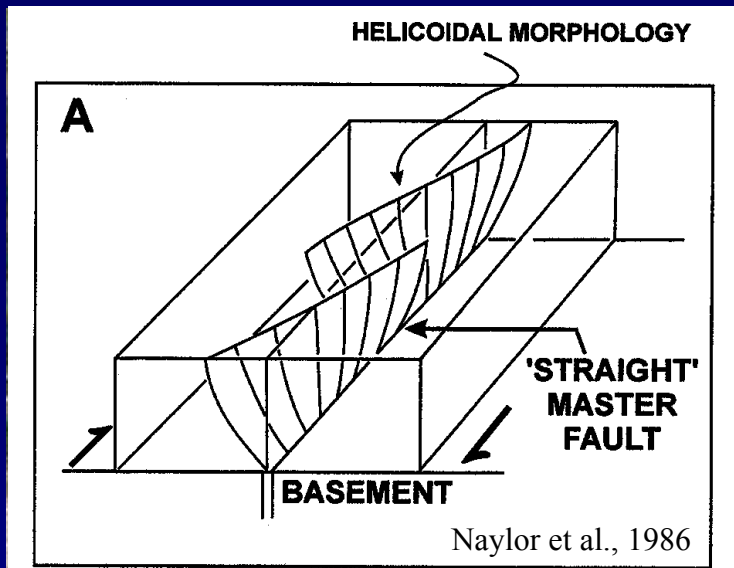
Basement Map of Eastern US

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

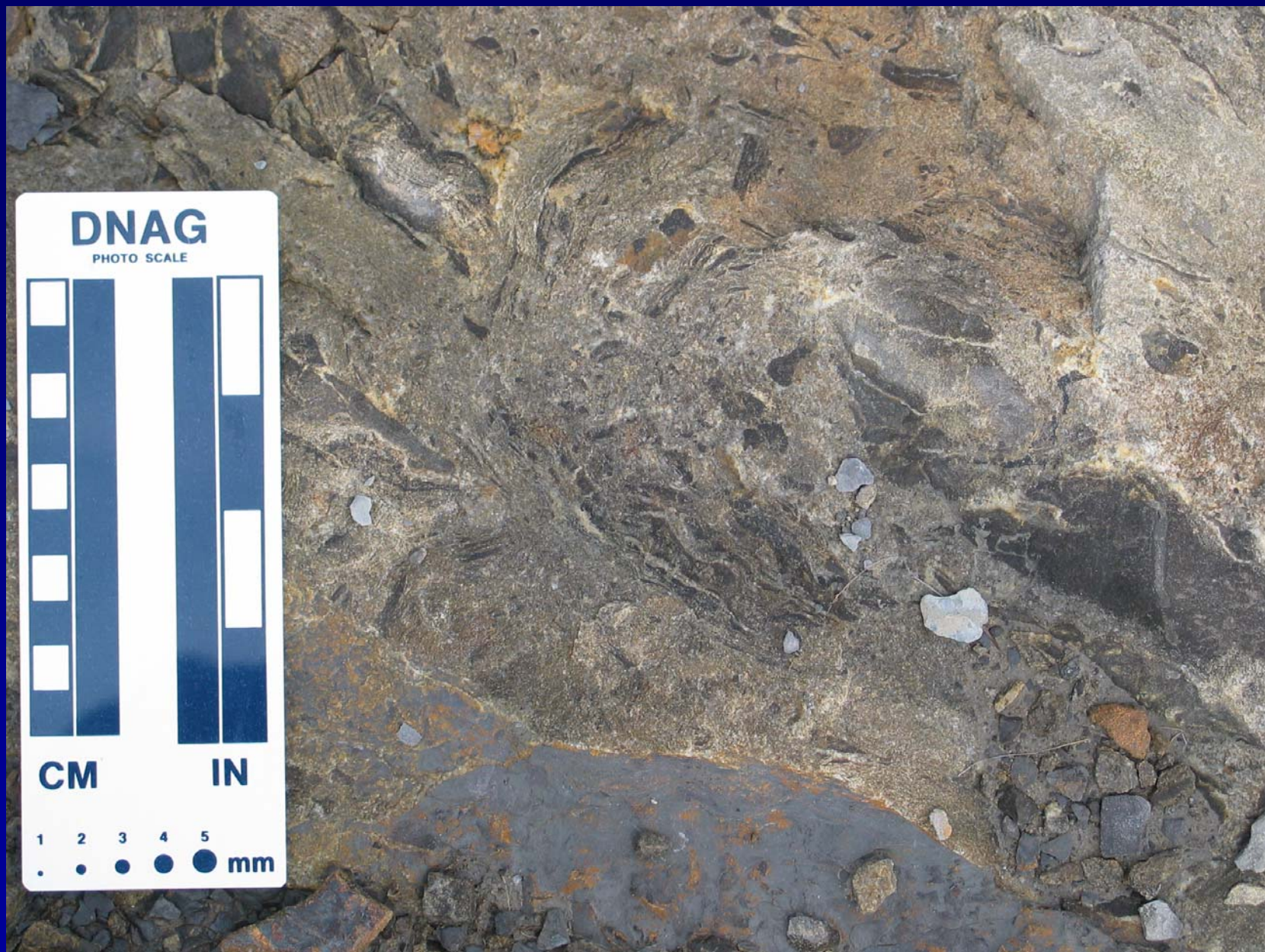
Not sure, but it looks like Jephtha Knob occurs on or very near the lineament

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

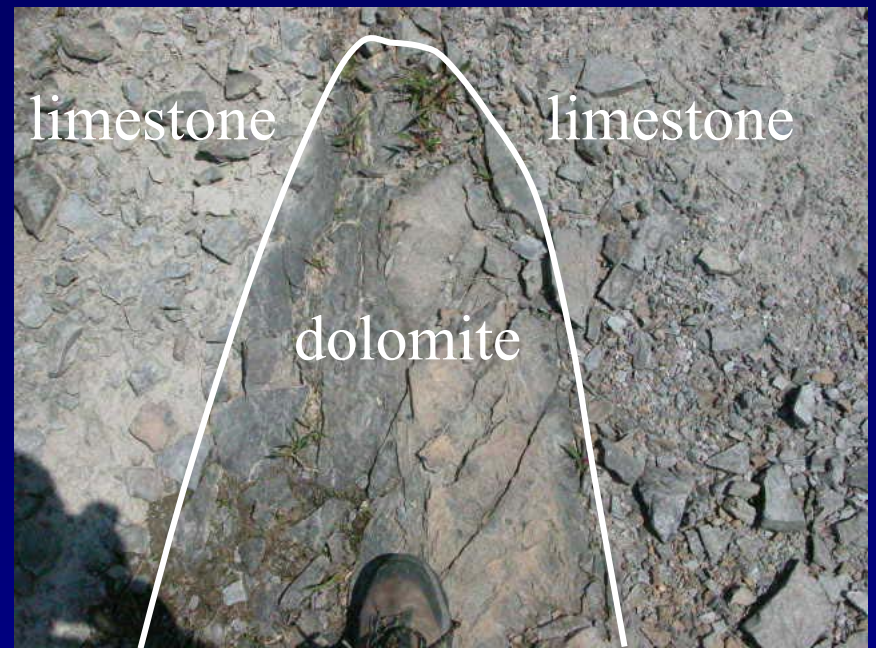
The point is that we should probably be looking for some positive features as well



Dolomitization around Reidel Shears over right lateral strike-slip fault in Ordovician of New York – Will lead field trip here next year



Saddle dolomite cemented breccia



Ordovician Tribes Hill Formation outcrop, Mohawk Valley, New York