Prospect of Additional Gas Shales in the Appalachian Basin

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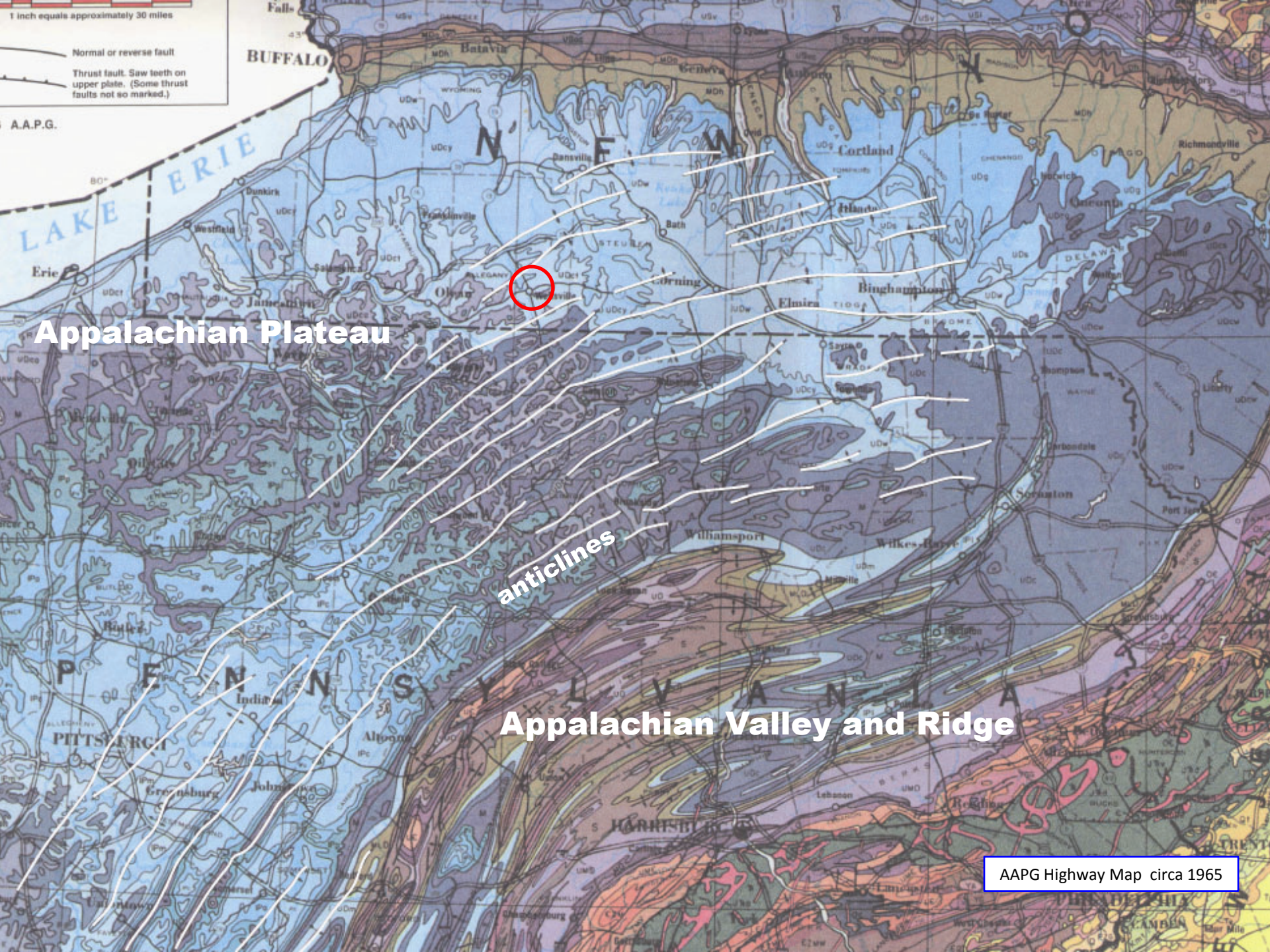
University Park, PA 16802

AAPG
March 2008
EXPLORER
10/07-10/10
37 months
Marcellus
Talk #163
Cumulative
Attendance
9641
Appalachian Spring
A new shale play
emerges in the East

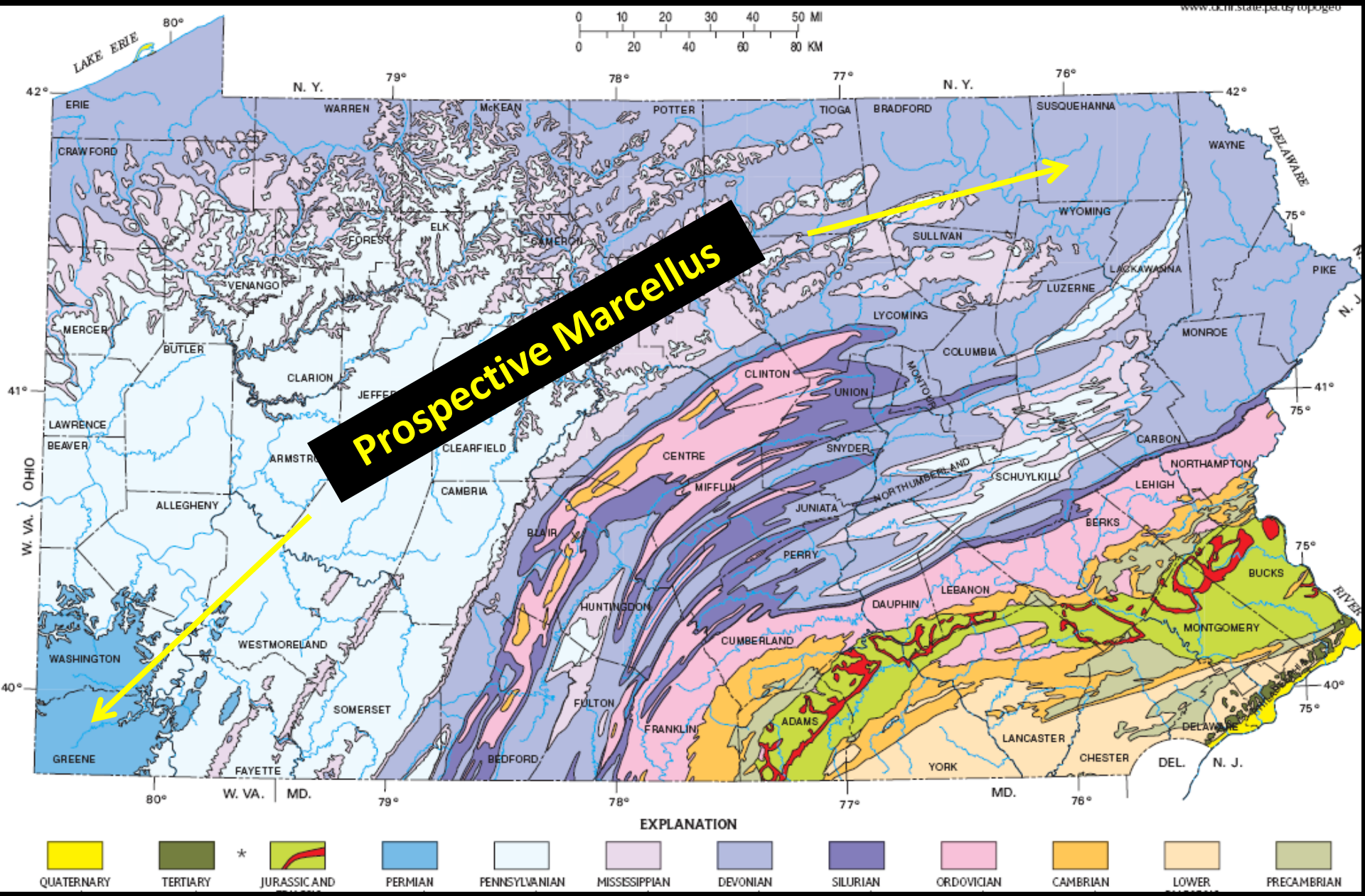
What is the connection between Nittany Mountain and prospective gas shales?

- Objectives of talk:
- Introduce the Nittany Mountain and Utica Shale
  - Called the Antis Shale here in Central PA
- Explain structural geology of Nittany Mountain and Utica Shale.
- Explain how gas generation in Utica shale helped in development of morphology of Valley and Ridge around the PSU campus……

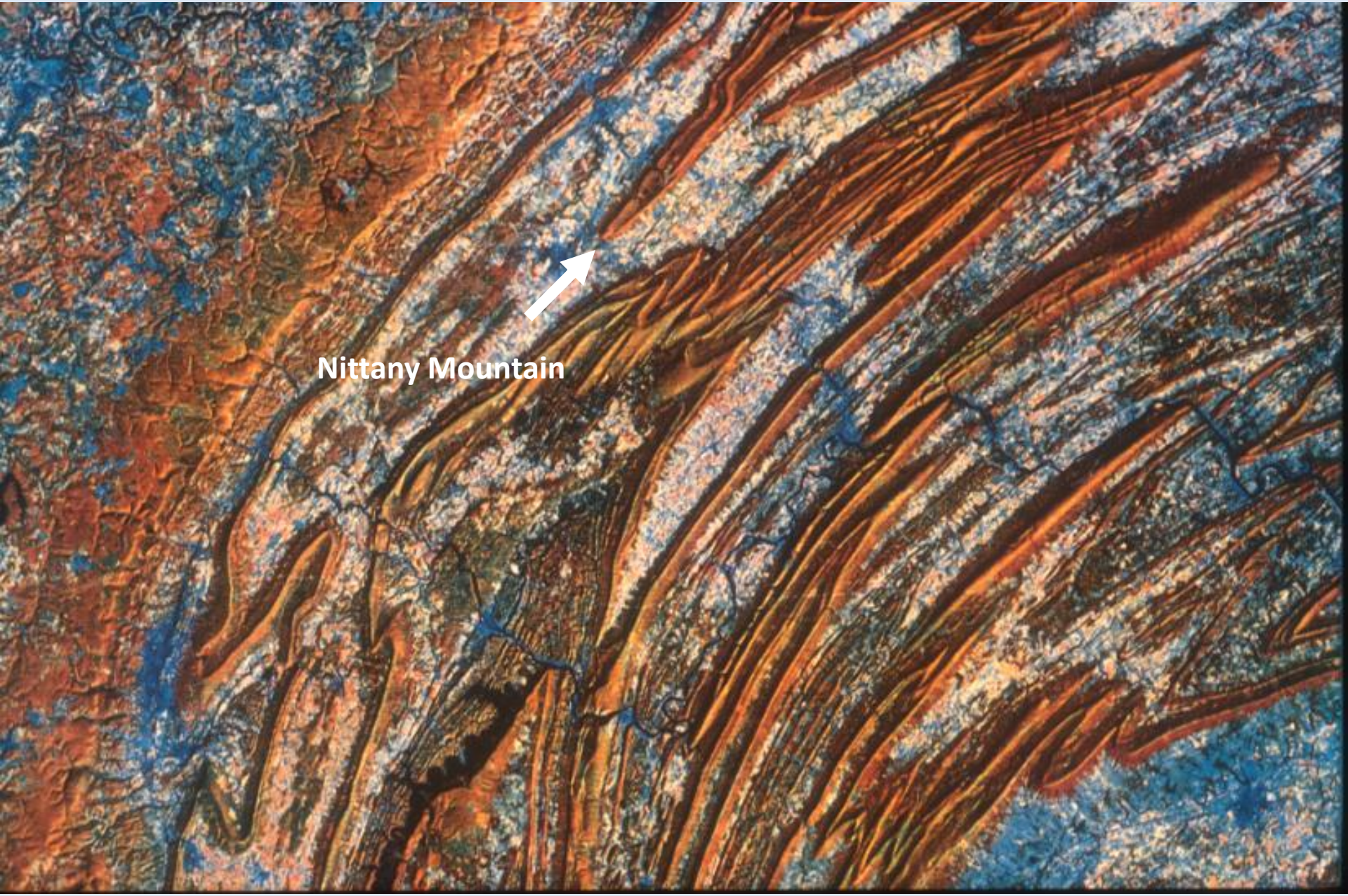
The rug on Prof. and Mrs. Engelder's bedroom floor!
Wellsville
New York
Pennsylvania
Beech Hill – Independence Anticline


1 inch equals approximately 30 miles
Normal or reverse fault
Thrust fault. Saw teeth on upper plate. (Some thrust faults not so marked.)
A.A.P.G.
BUFFALO
LAKE ERIE
Erie
Appalachian Plateau
anticlines
Appalachian Valley and Ridge
Williamsport
Scranton
Binghamton
Elmira
Corning
Cortland
Batavia
Geneva
Dansville
Franklinville
Bath
Olean
Jamestown
Westfield
Dunkirk
Salamanca
Wellsville
Mendville
Oil City
Butler
Indiana
Altoona
Greensburg
Johnstown
PITTSBURGH
HARRISBURG
Lebanon
Reading
Lancaster
Chambersburg
Carbondale
Port Jervis
Richmondville
Norwich
Oneonta
Liberty
Thompson
Wayne
Sayre
Towanda
Milville
Lock Haven
Bradford
Hamilton
Lewisburg
Sunbury
Wilkes-Barre
Hazleton
Pottsville
Lancaster
Chambersburg
Uniontown
Somerset
Bedford
Cambridge
Ithaca
Syracuse
Auburn
Geneva
Rochester
Dunkirk
Falls
Richmondville
Norwich
Oneonta
Delaware
Tioga
Bradford
Wayne
Pennsylvania
New York
Ohio
Maryland
Wyoming
Allegany
Steuben
Chenango
Tompkins
Cayuga
Seneca
Yates
Ontario
Wyoming
Lake Erie
Pennsylvania
Appalachian Valley and Ridge
AAPG Highway Map circa 1965

Appalachian Plateau = 2 km from Allegheny Front



Allegheny Front marked by outcrops of nearly vertical to slightly overturned Tuscarora

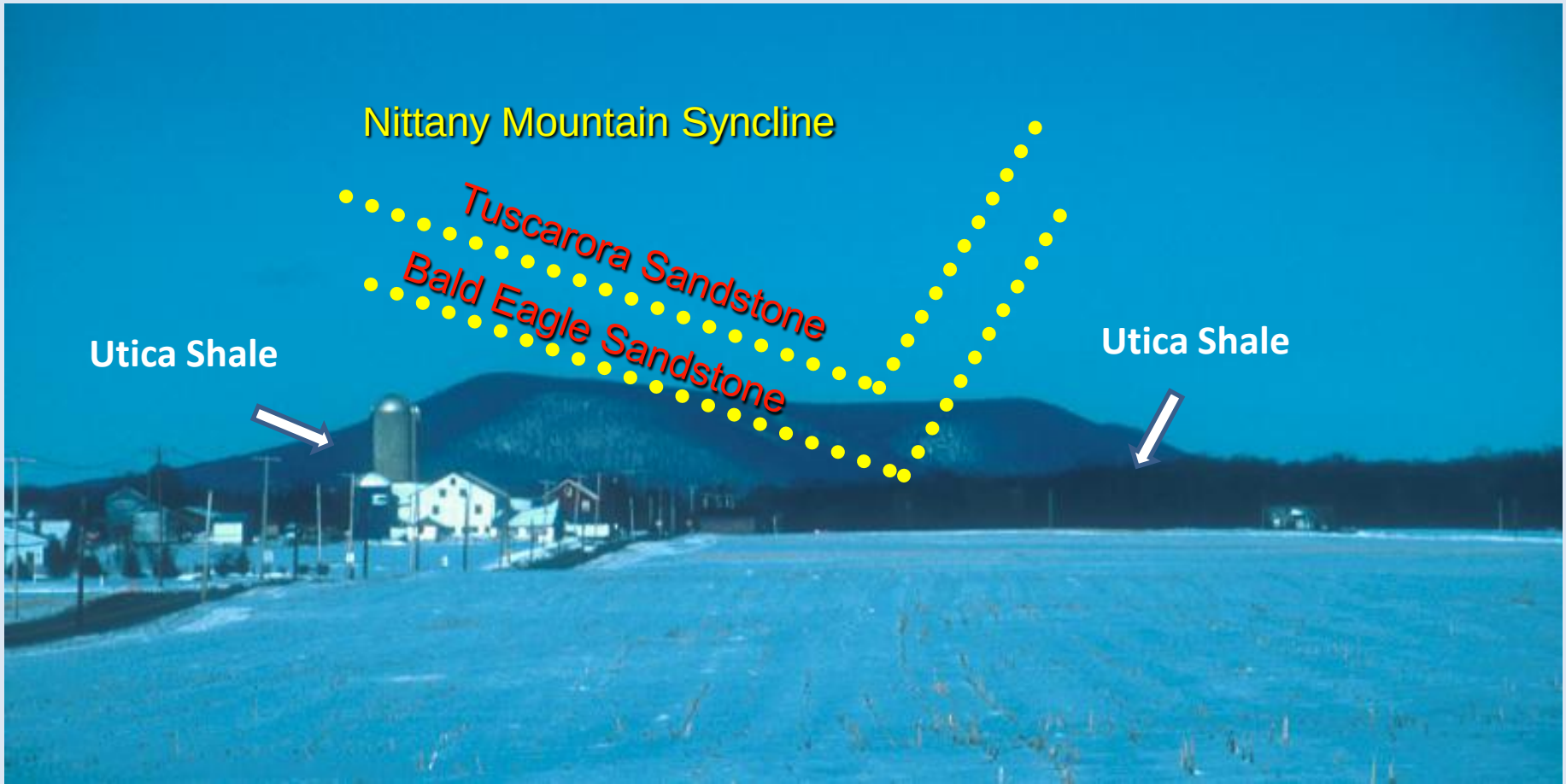

Nittany Mountain

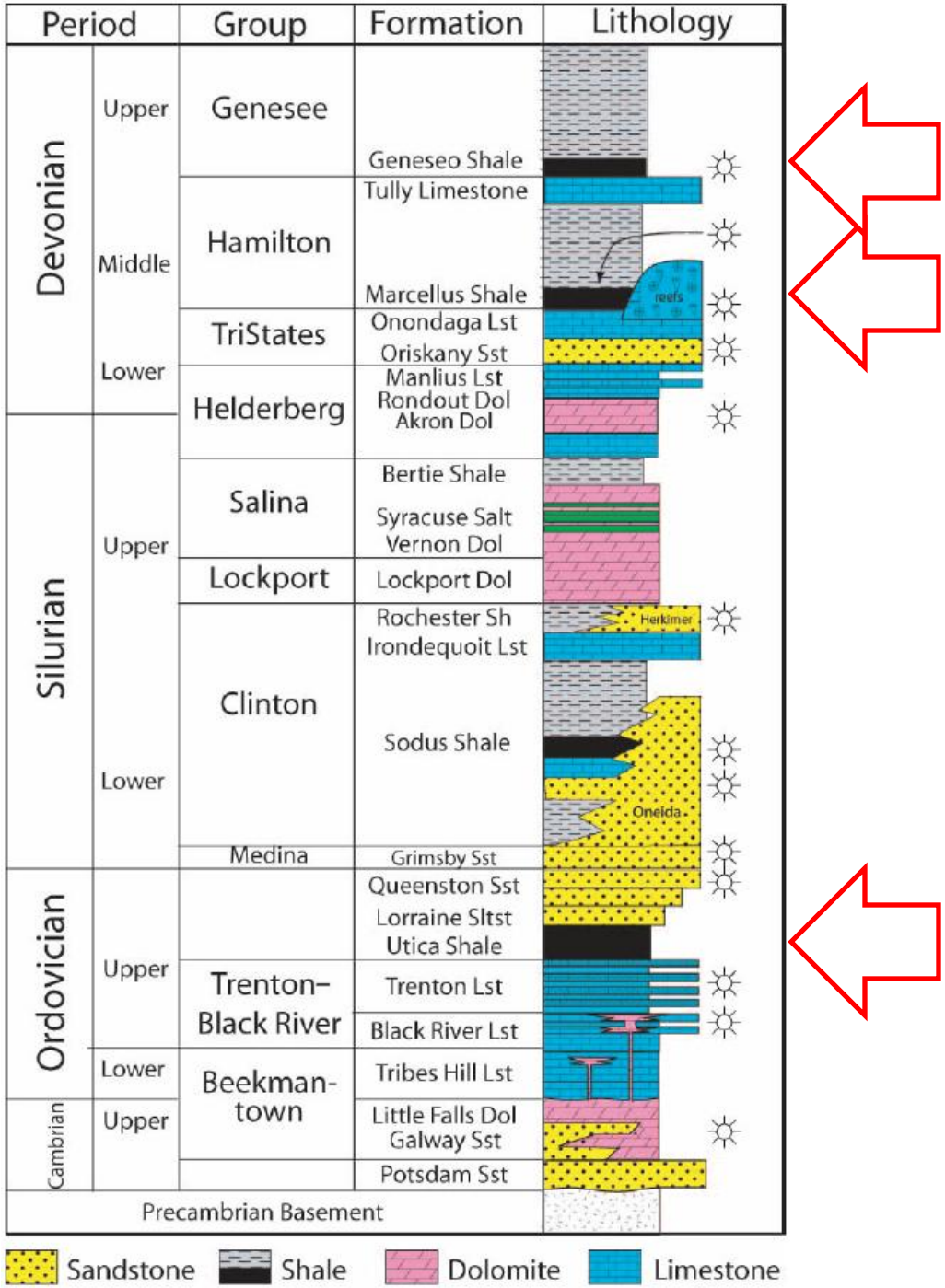
Strike of Nittany Mountain
Nittany Valley

Nittany Mountain

(looking east)

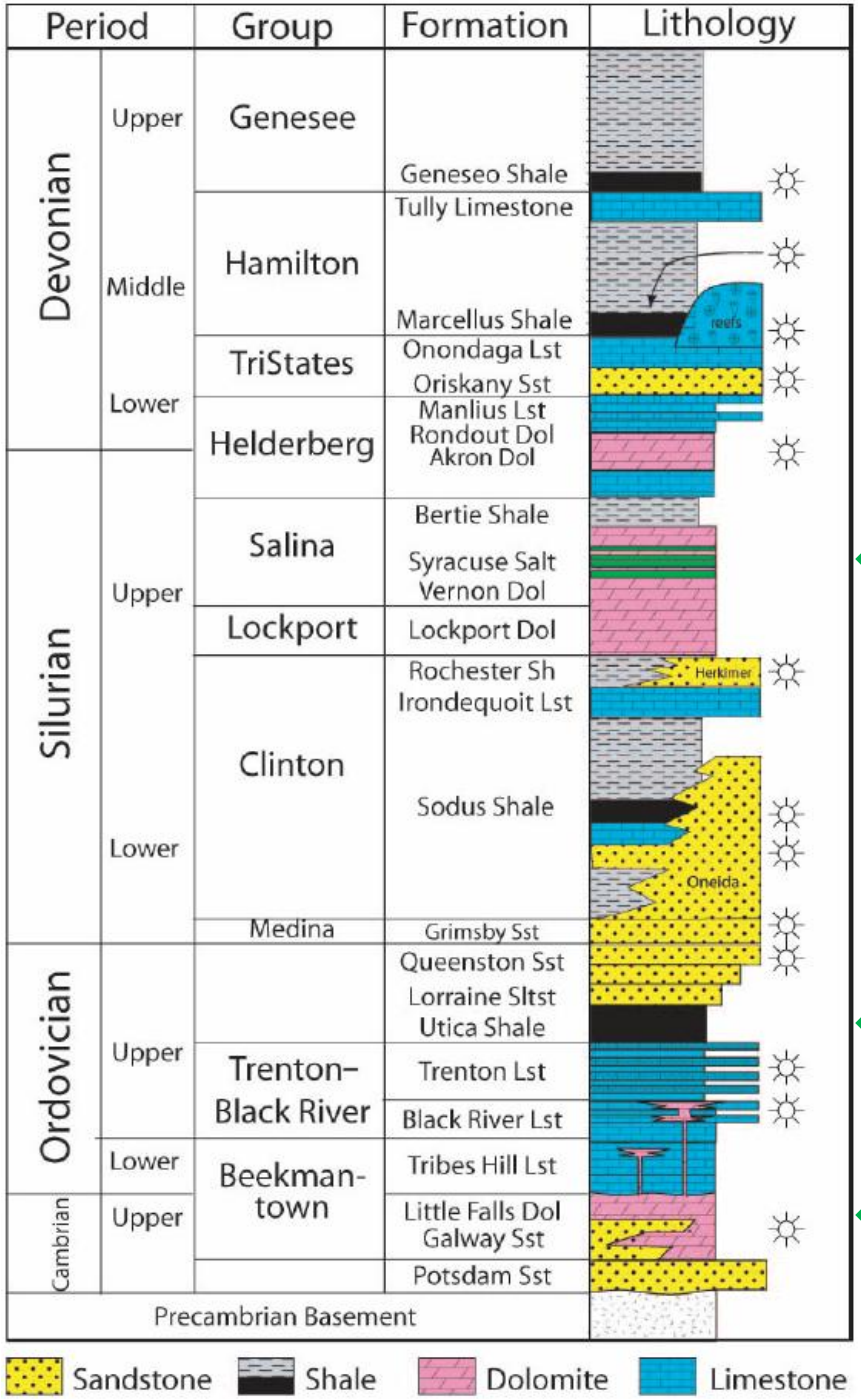
- Rocks of Nittany Mountain form a syncline





Stratigraphic Column: Targets for gas drilling in Western PA

Smith (2006) AAPG Bull



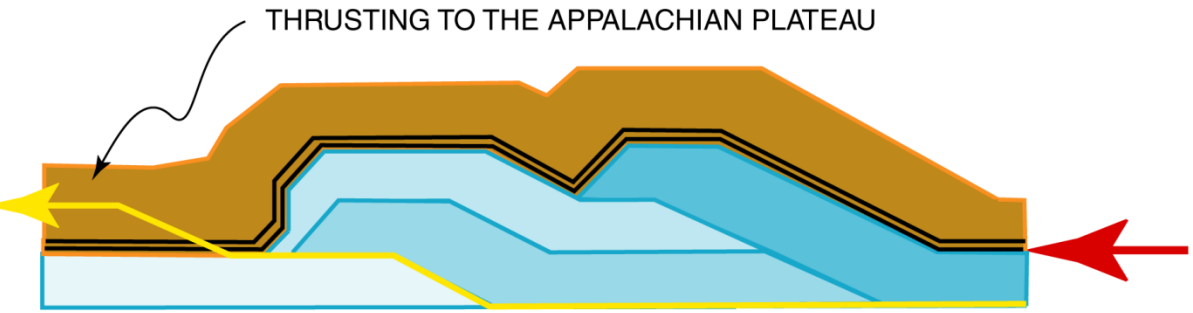
Stratigraphic Column: Surfaces of low friction for large scale sliding

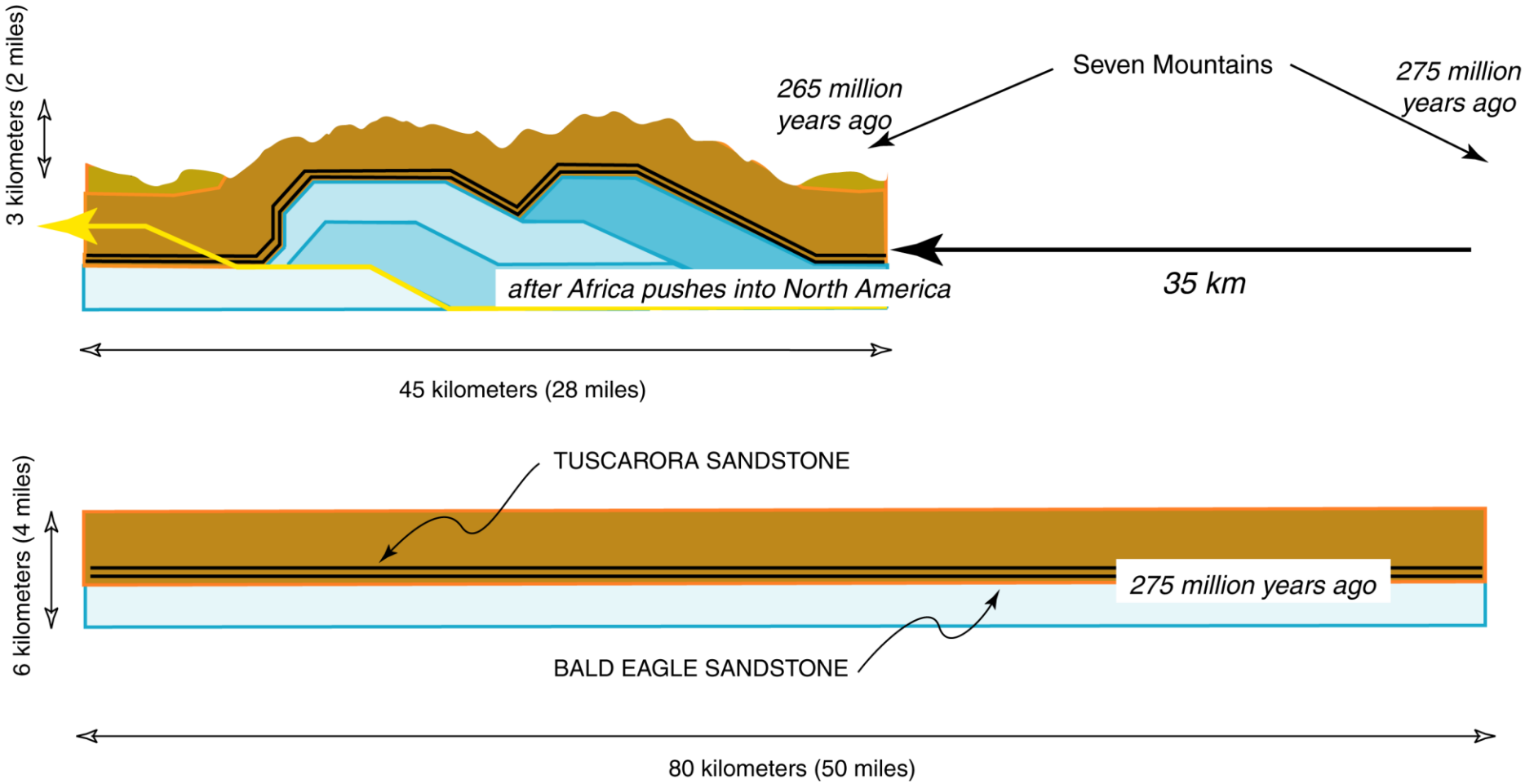
Appalachian Plateau floor

Valley and Ridge roof

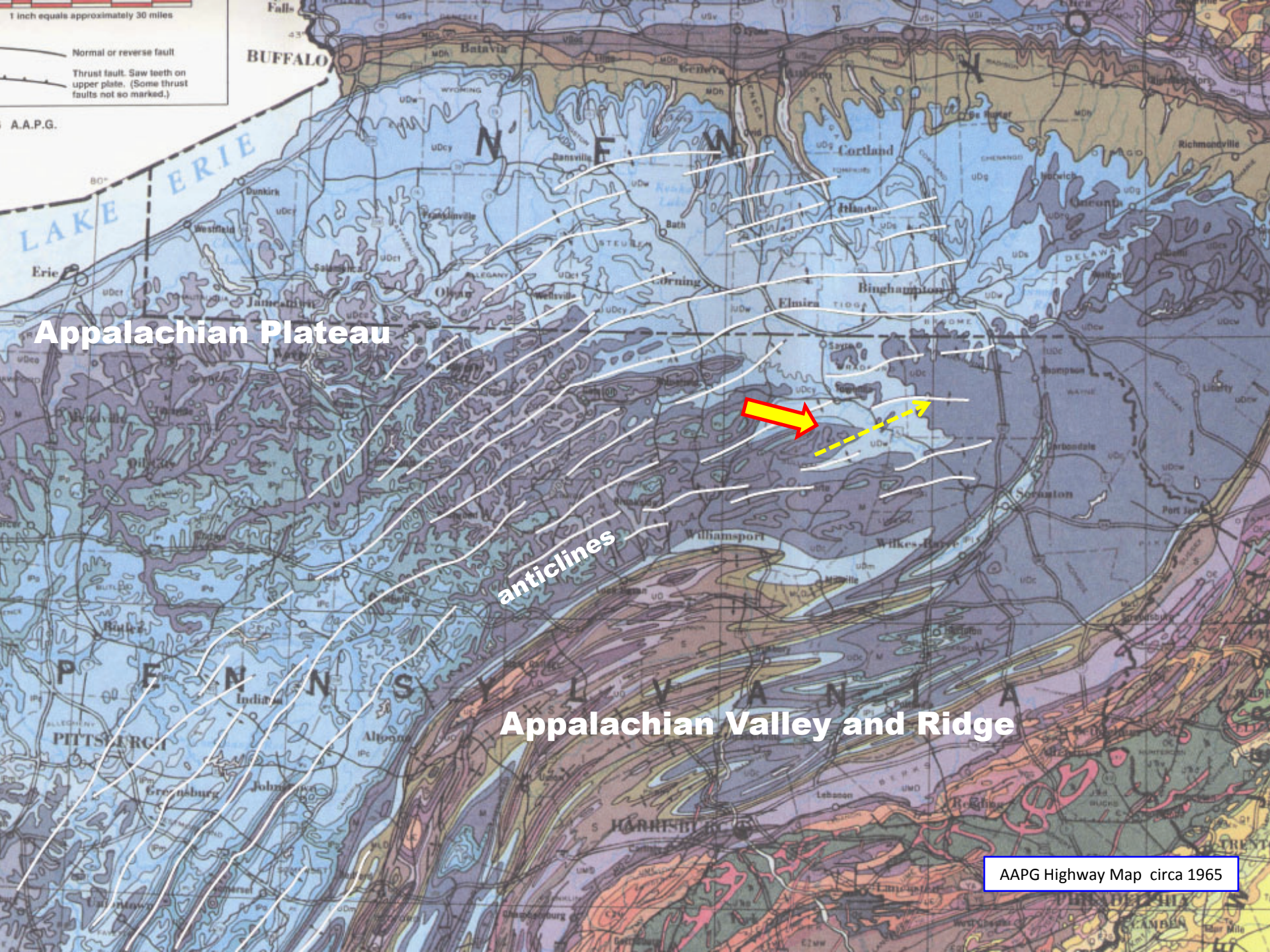
Valley and Ridge floor

Smith (2006) AAPG Bull


THRUSTING TO THE APPALACHIAN PLATEAU



- approximately 10 million years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Normal or reverse fault
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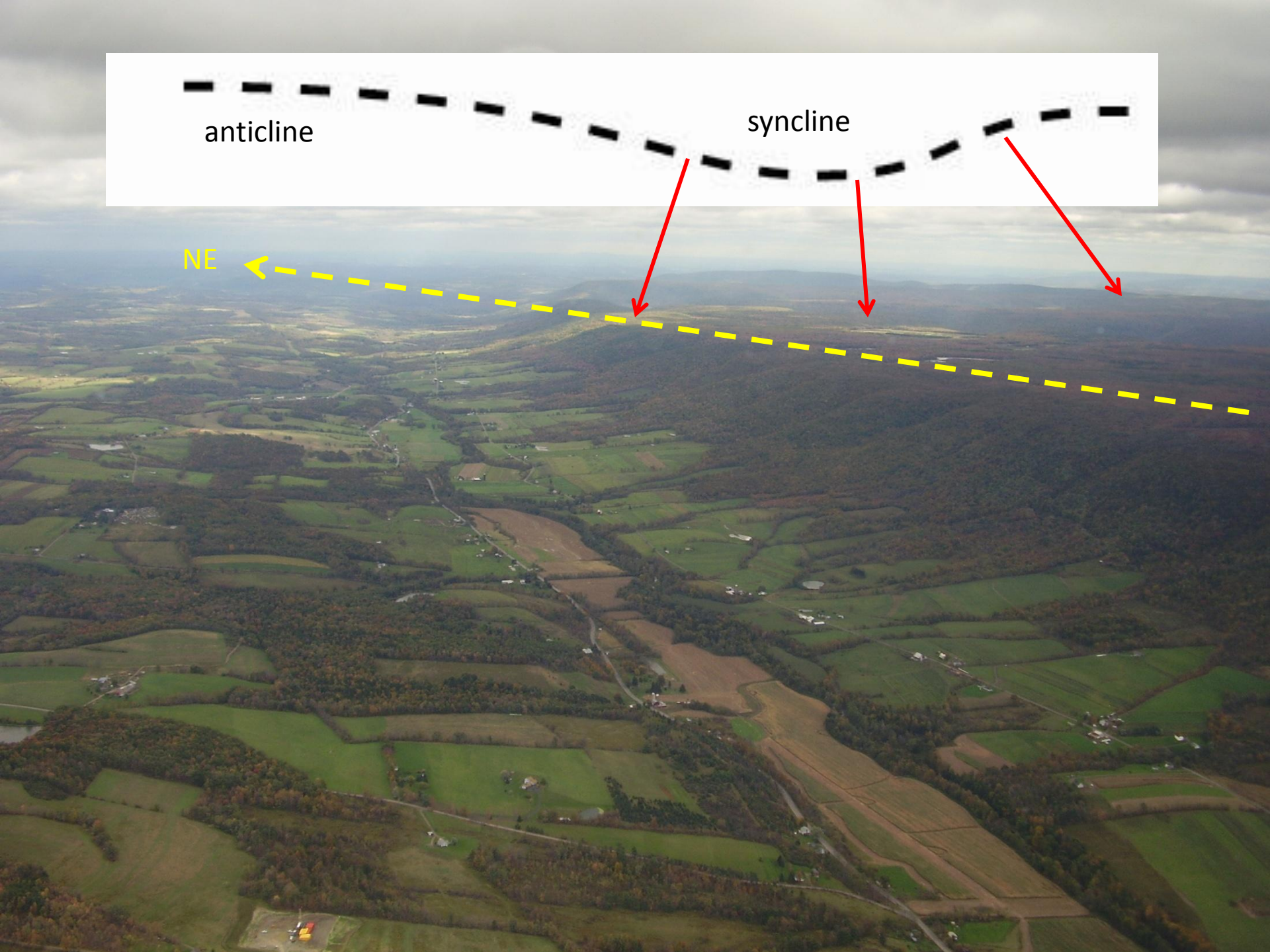
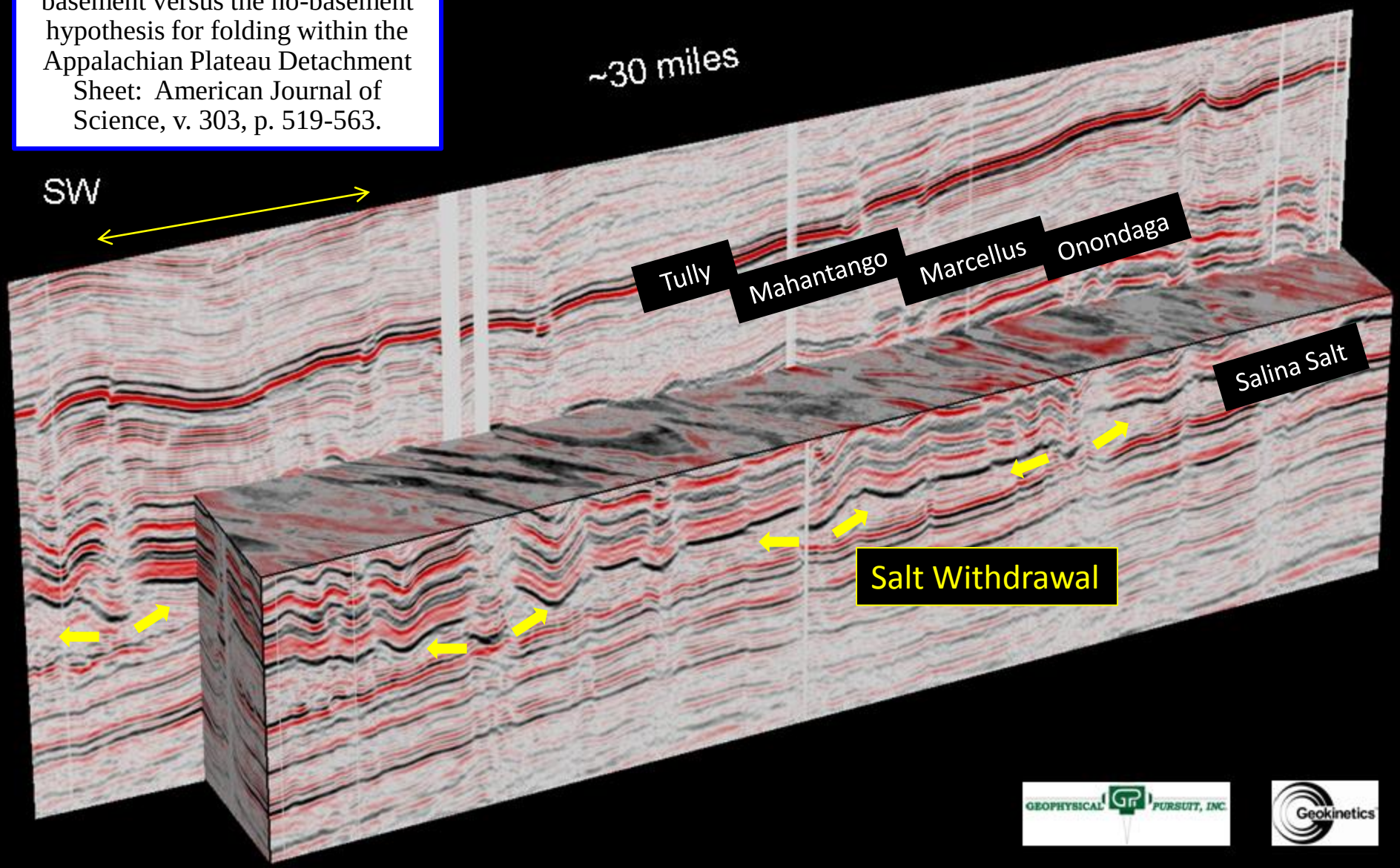
A.A.P.G.
BUFFALO
LAKE ERIE
Appalachian Plateau
anticlines
Appalachian Valley and Ridge
PENNSYLVANIA
Erie
Dunkirk
Westfield
Jamestown
Olean
Corning
Elmira
Binghamton
Cortland
Ithaca
Batavia
Geneva
Bath
Williamsport
Scranton
Wilkes-Barre
Indiana
Altoona
Johnstown
Greensburg
PITTSBURGH
HARRISBURG
Lebanon
Reading
Richmondville
AAPG Highway Map circa 1965


anticline
syncline
NE

Seismic time profile from Bradford & Mehoopany 3D

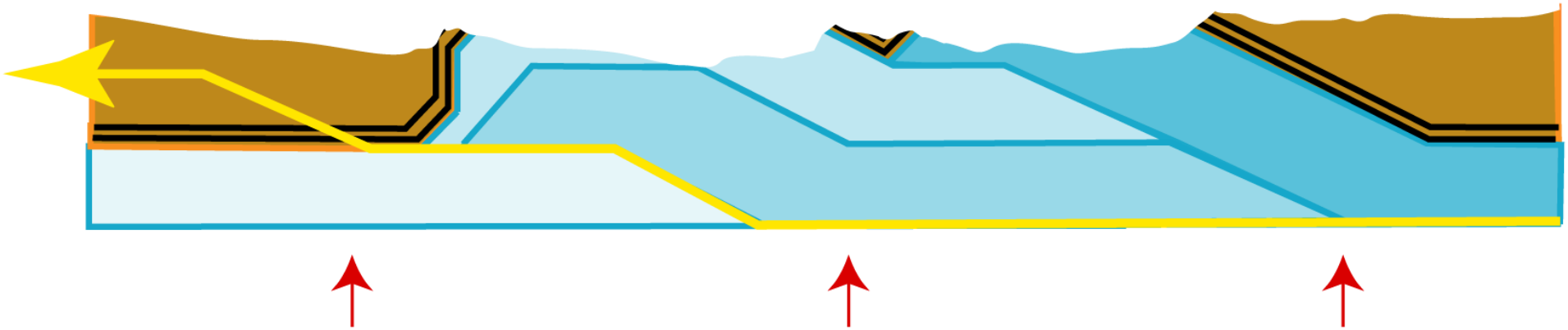
Scanlin & Engelder, 2003, The basement versus the no-basement hypothesis for folding within the Appalachian Plateau Detachment Sheet: American Journal of Science, v. 303, p. 519-563.

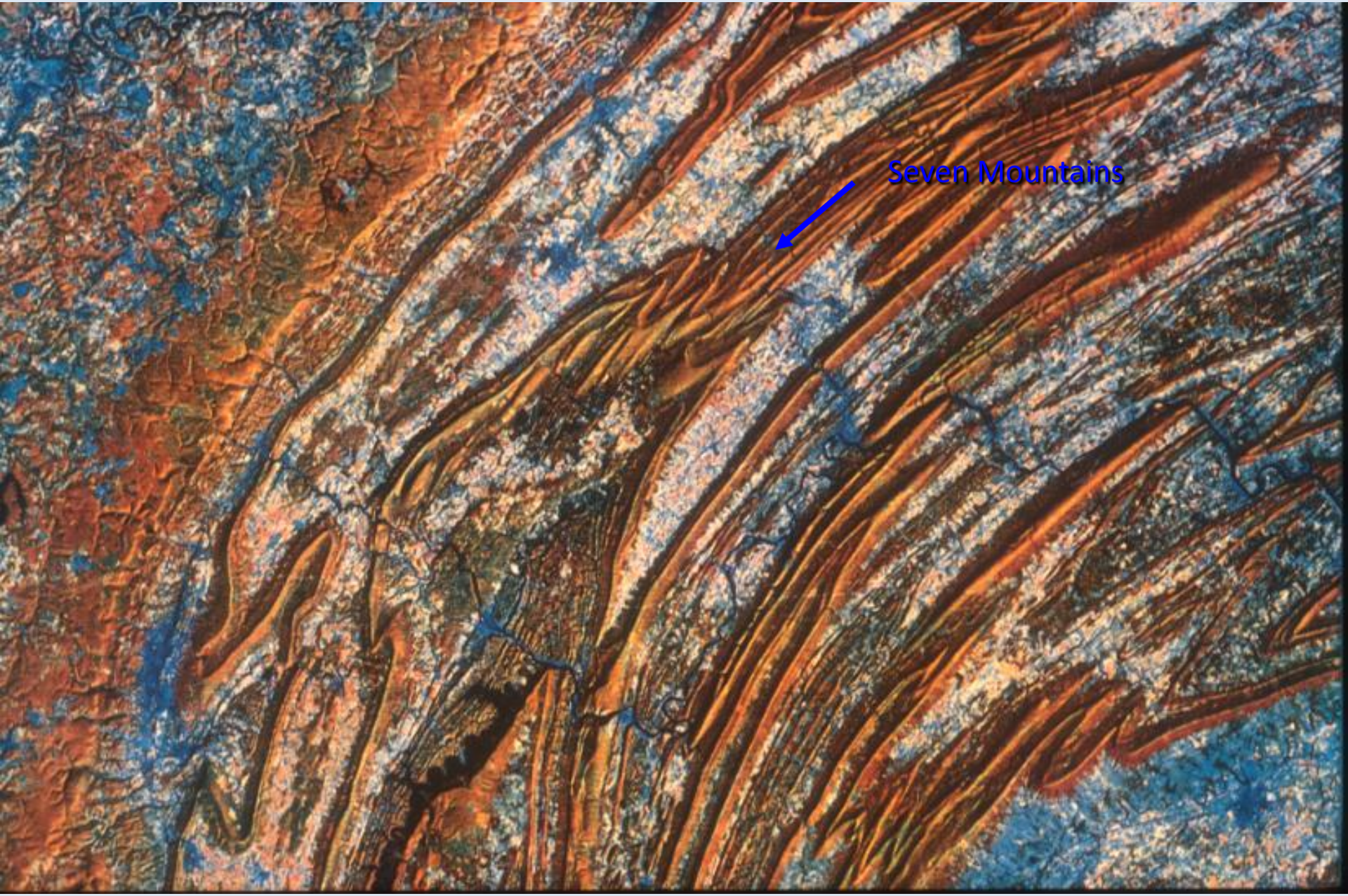


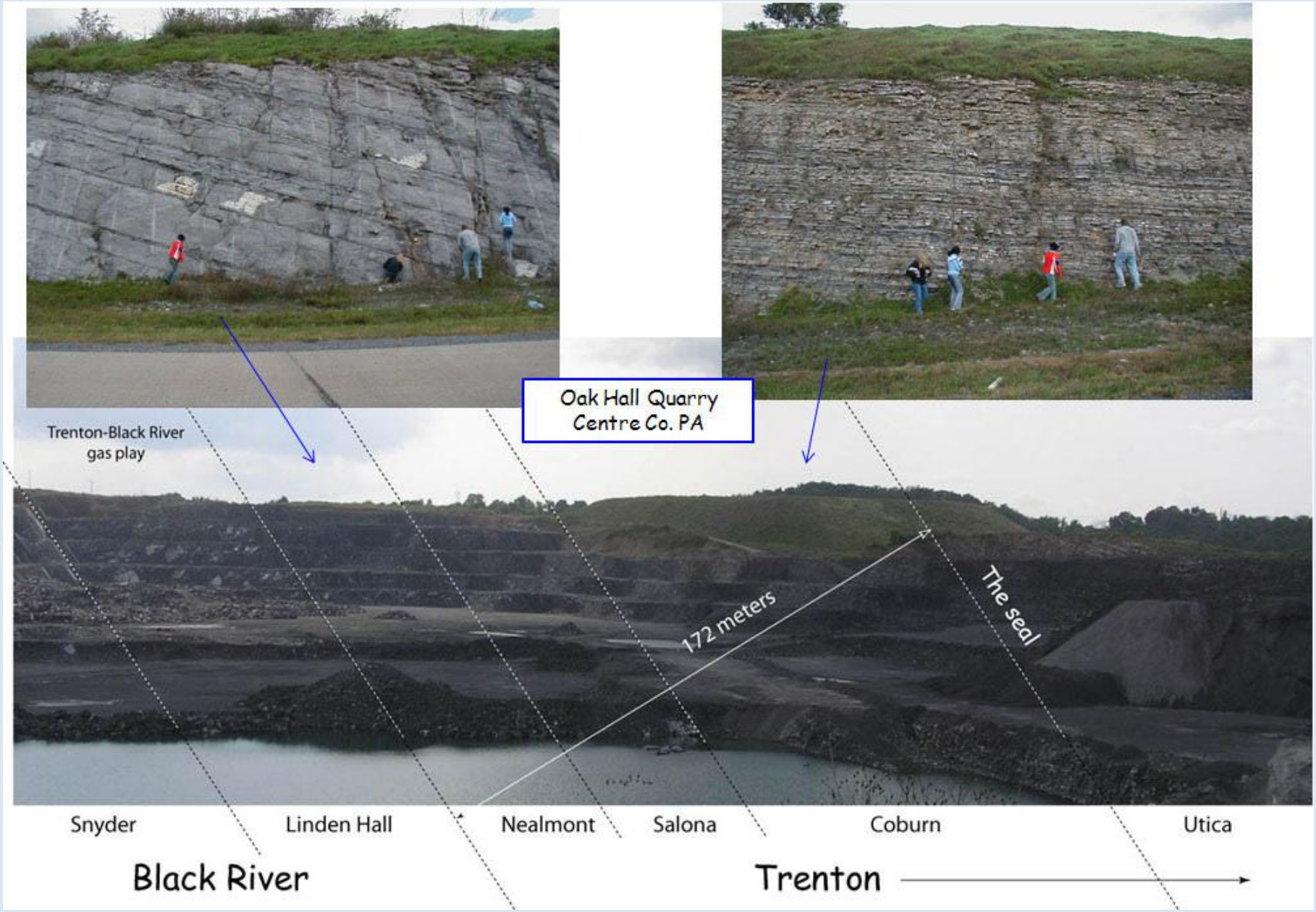
Development of Topography
(one interpretation)

- High Mountains form with Nittany Mtn. Syncline
  - 275 Ma (million years ago).
- Erosion of high mountains
  - 275 Ma to 10 Ma
- Uplift of 300 m
  - About 10 Ma
- Erosion of Nittany Valley and Penns Valley
  - 10 Ma to present.

Erosion downward of 300 meters to present topography.



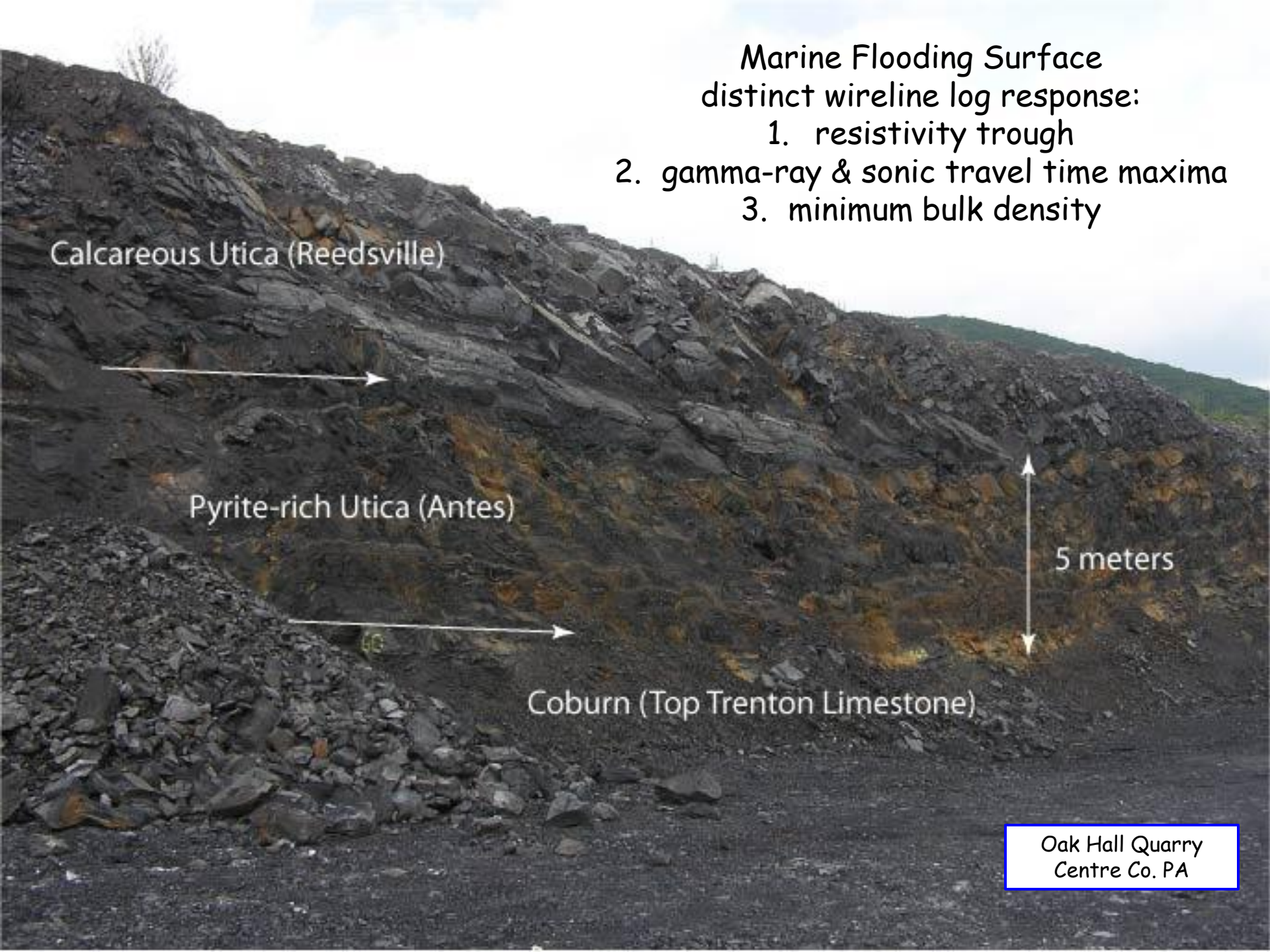

Seven Mountains


Oak Hall Quarry
Centre Co. PA
Trenton-Black River
gas play
172 meters
The seal
Snyder
Linden Hall
Nealmont
Salona
Coburn
Utica
Black River
Trenton

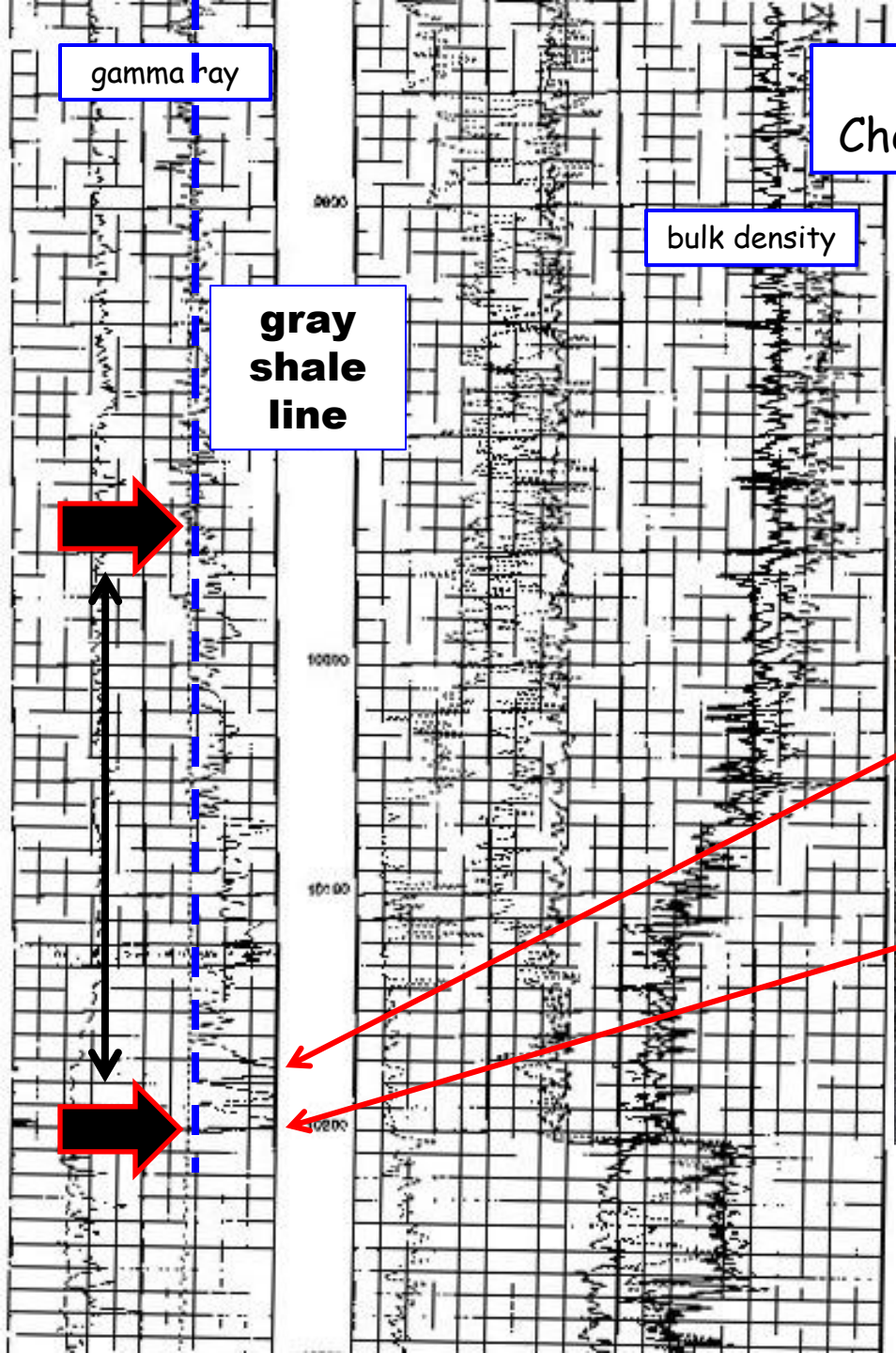
Calcareous Utica (Reedsville)
Pyrite-rich Utica (Antes)
Coburn (Trenton) Limestone
Oak Hall Quarry
Centre Co. PA

Marine Flooding Surface
distinct wireline log response:

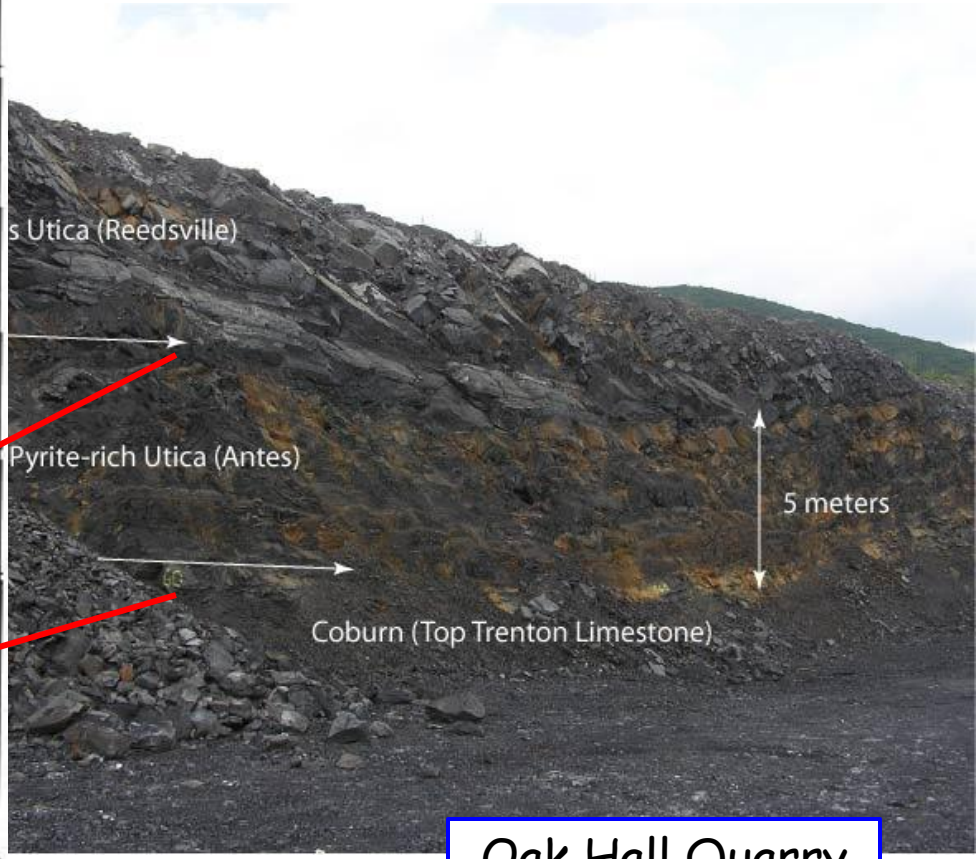
1. resistivity trough
2. gamma-ray & sonic travel time maxima
3. minimum bulk density



Oak Hall Quarry
Centre Co. PA

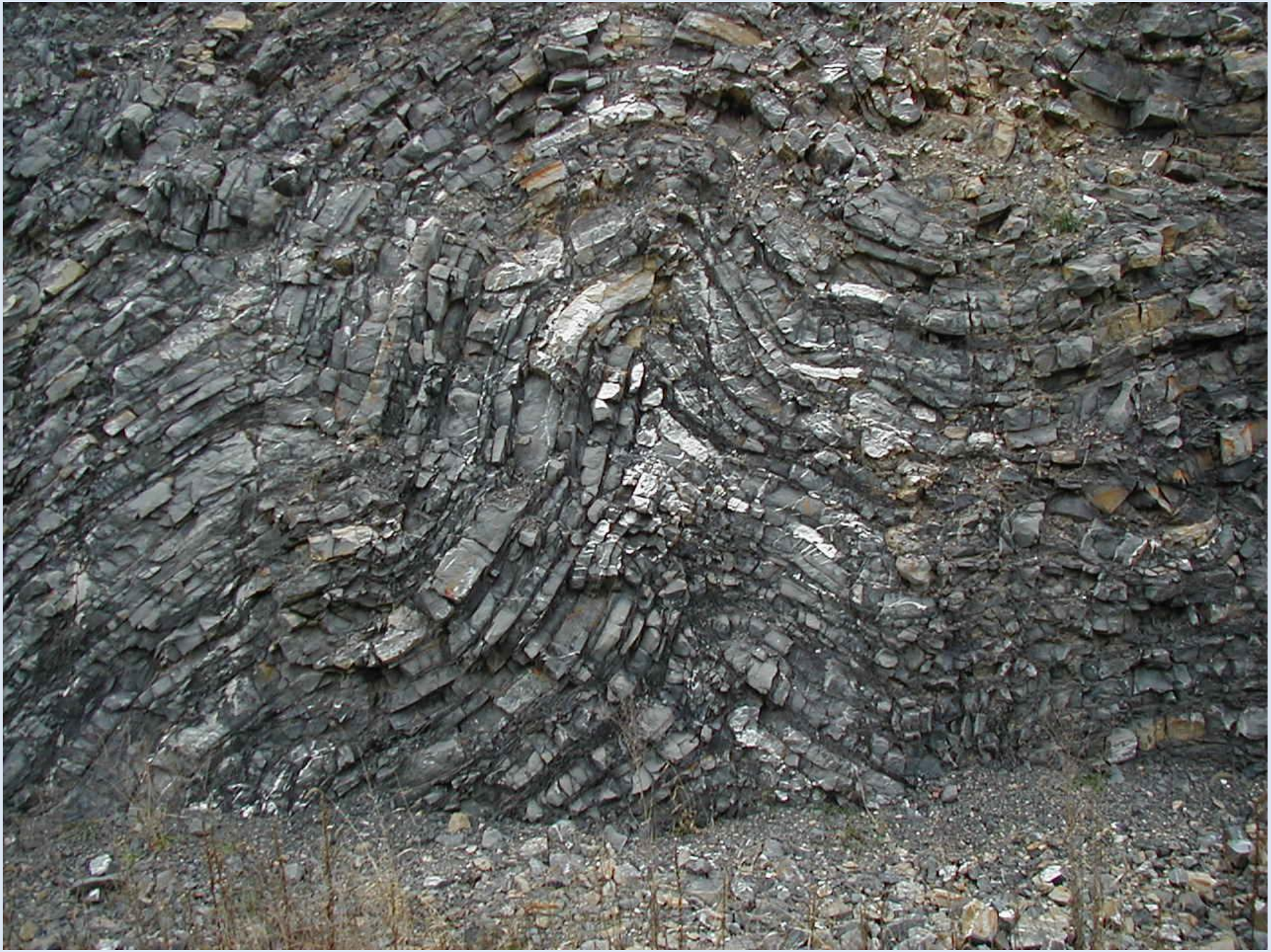


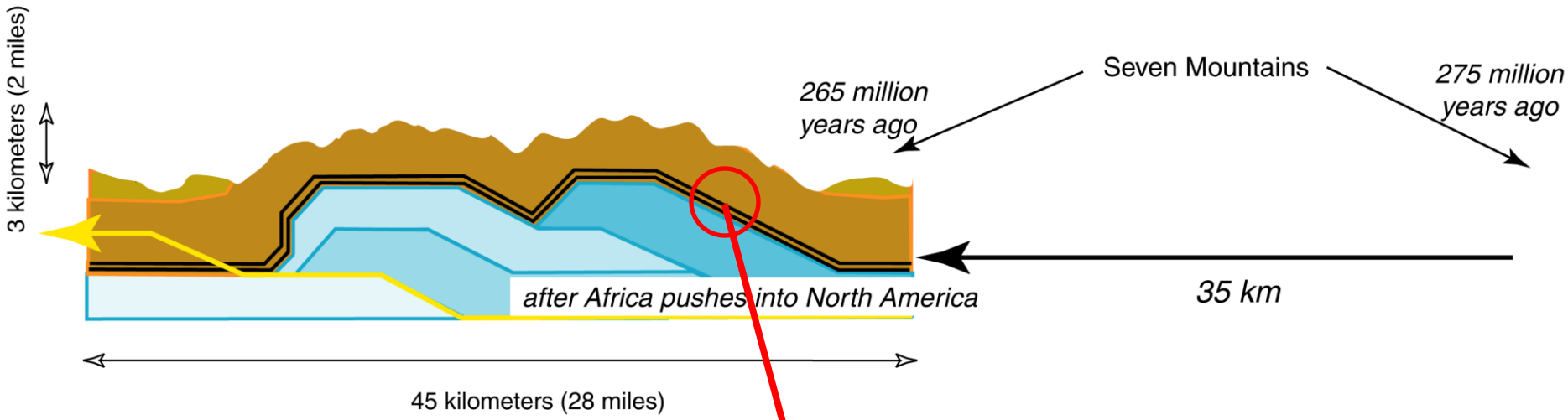
Giles #1
Chemung Co. NY



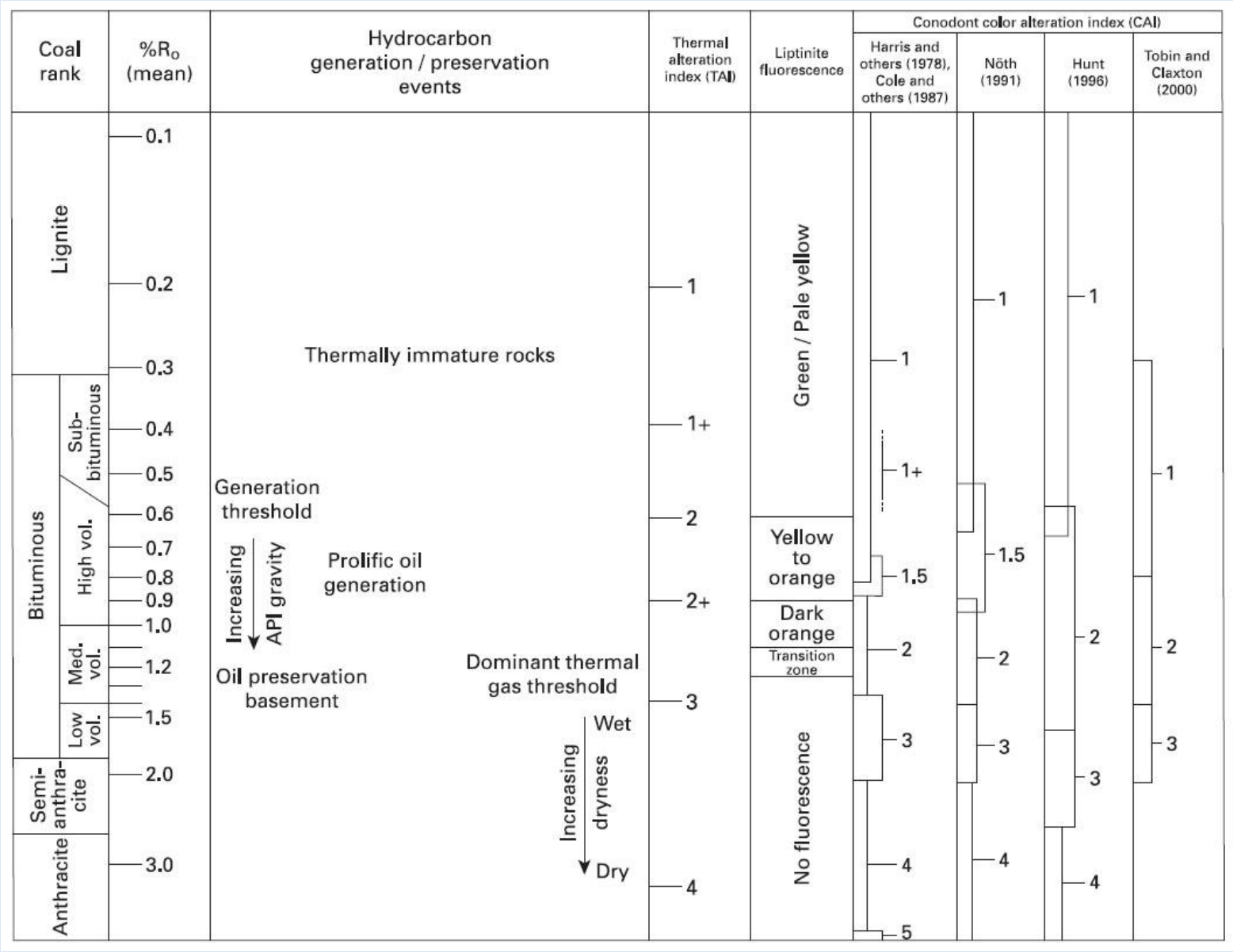
Oak Hall Quarry
Centre Co. PA

EXIT
30
M.P.H.




3 kilometers (2 miles)
Seven Mountains
265 million years ago
275 million years ago
after Africa pushes into North America
35 km
45 kilometers (28 miles)

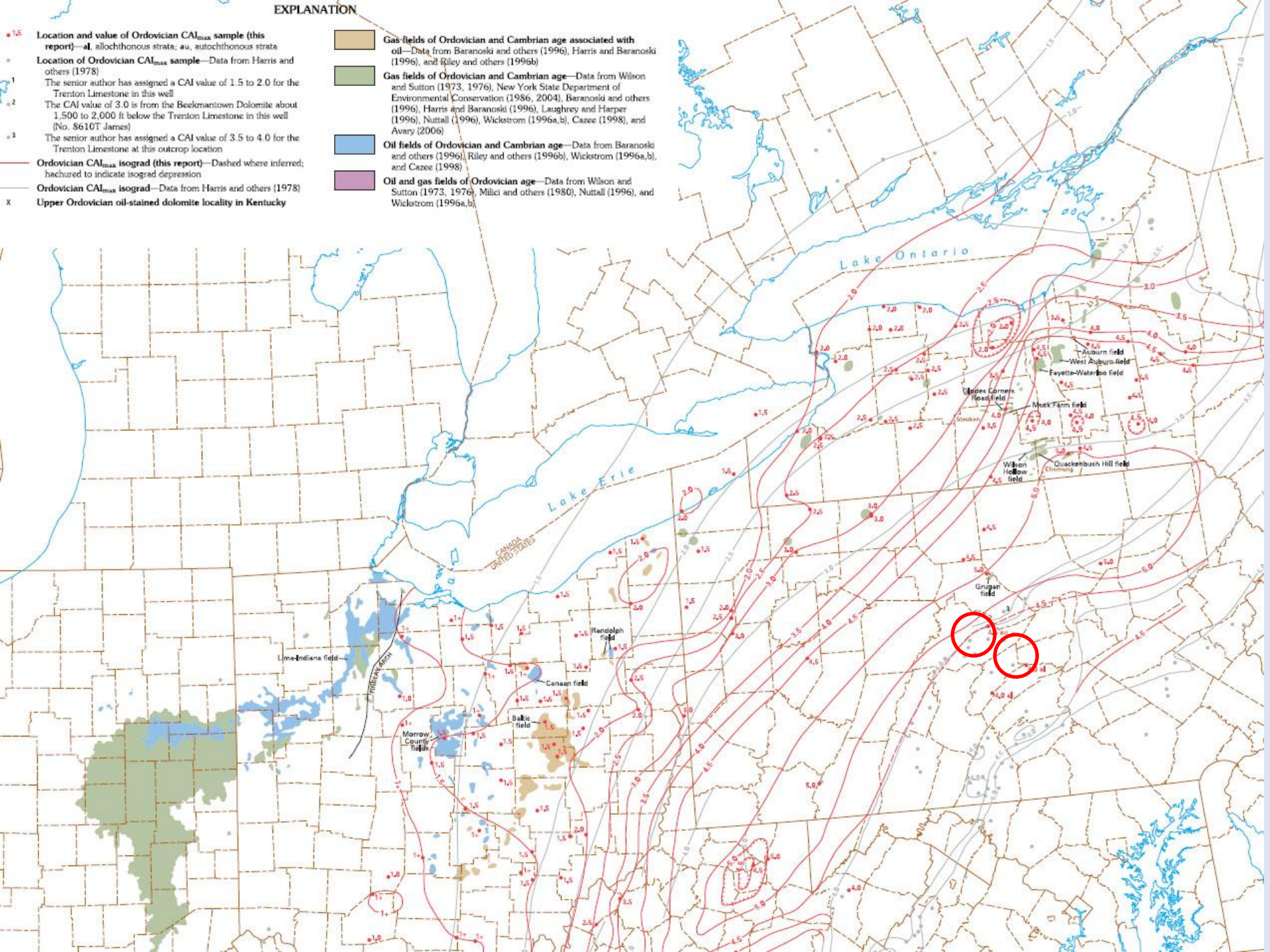
Thermal Maturation

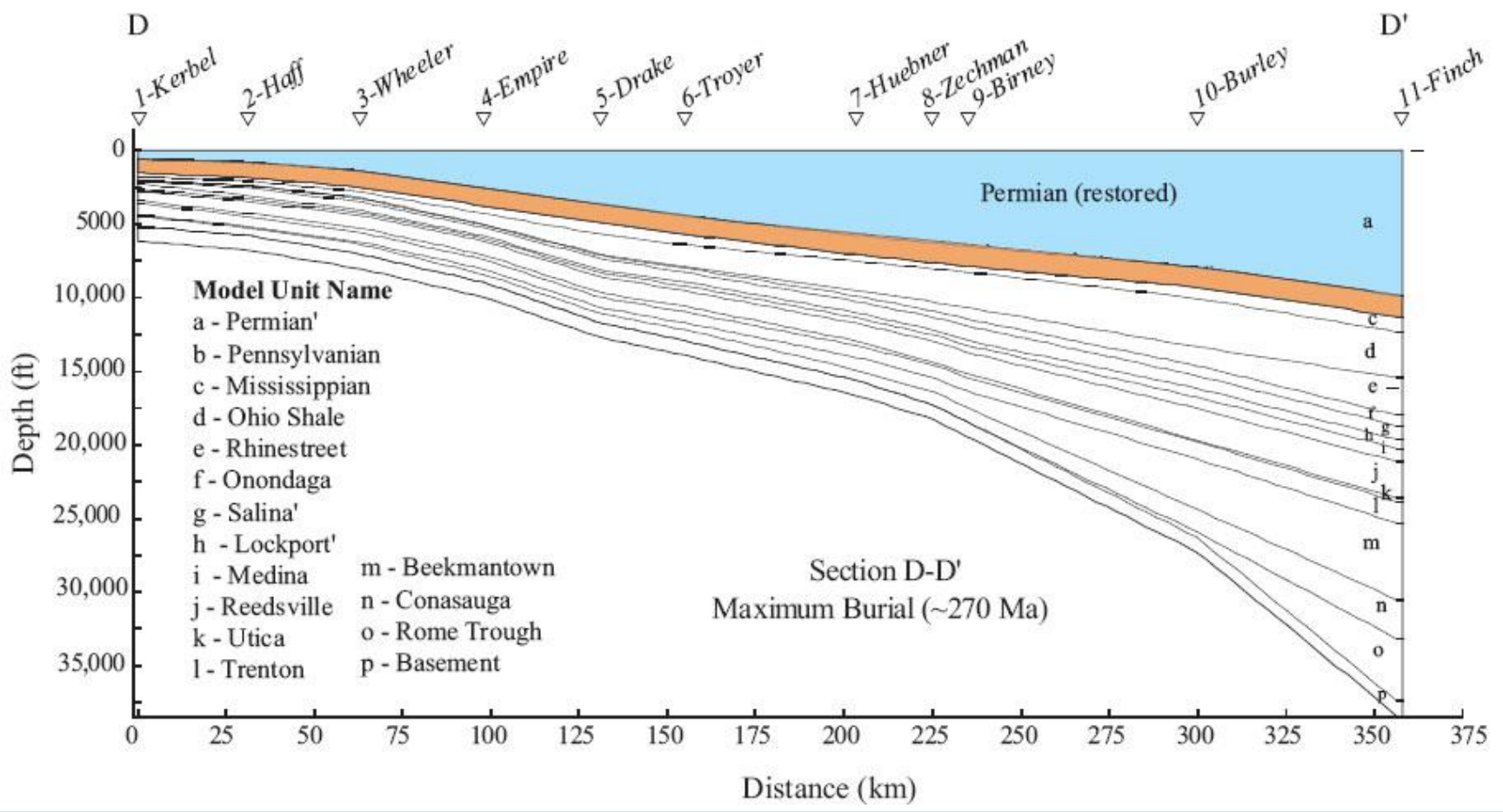


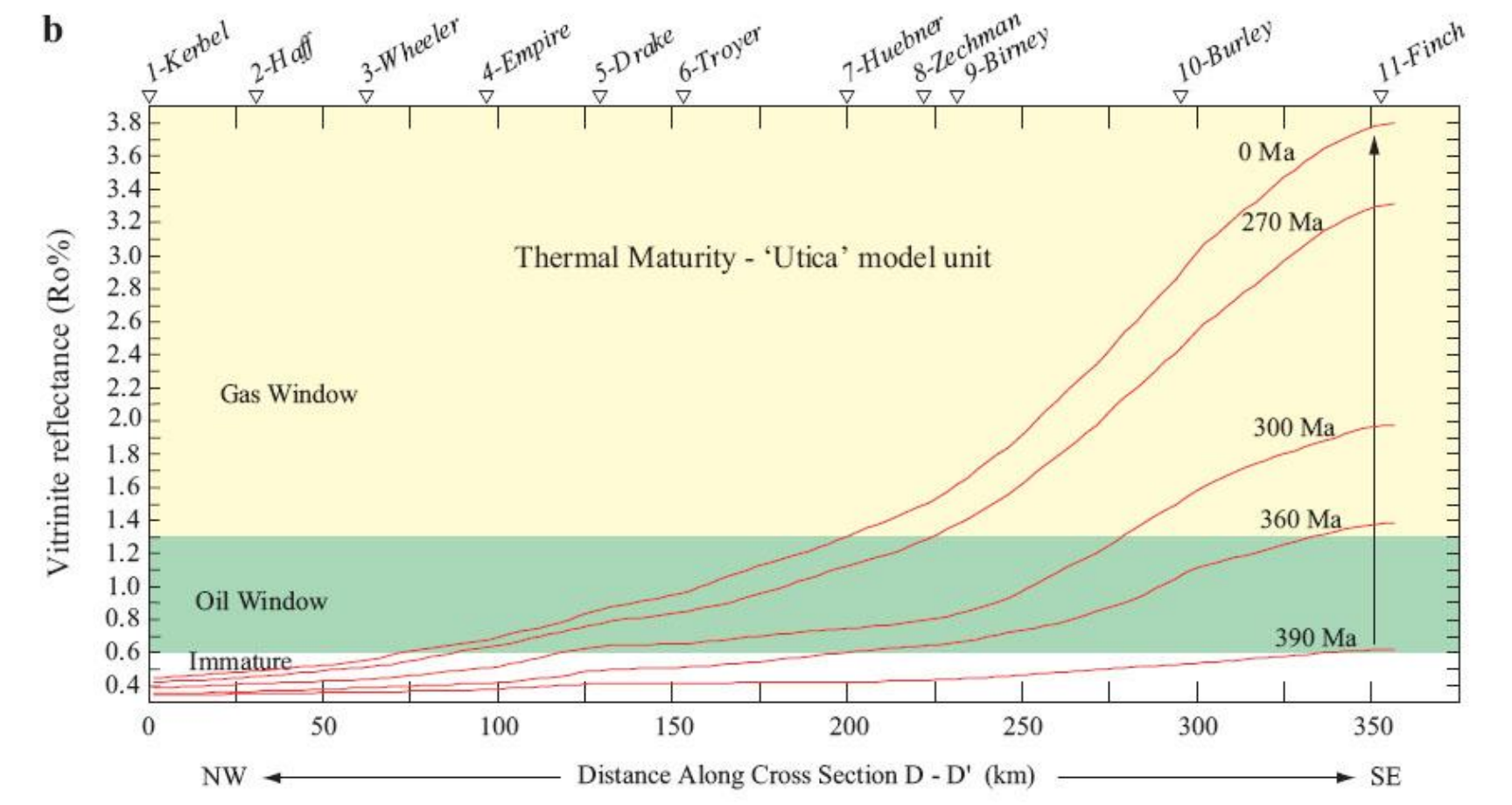
EXPLANATION

- **Location and value of Ordovician CAI_{max} sample (this report)**—**al**, allochthonous strata; **au**, autochthonous strata
- **Location of Ordovician CAI_{max} sample**—Data from Harris and others (1978)
  - [1] The senior author has assigned a CAI value of 1.5 to 2.0 for the Trenton Limestone in this well
  - [2] The CAI value of 3.0 is from the Beekmantown Dolomite about 1,500 to 2,000 ft below the Trenton Limestone in this well (No. 8610T James)
  - [3] The senior author has assigned a CAI value of 3.5 to 4.0 for the Trenton Limestone at this outcrop location
- **Ordovician CAI_{max} isograd (this report)**—Dashed where inferred; hachured to indicate isograd depression
- **Ordovician CAI_{max} isograd**—Data from Harris and others (1978)
- x **Upper Ordovician oil-stained dolomite locality in Kentucky**

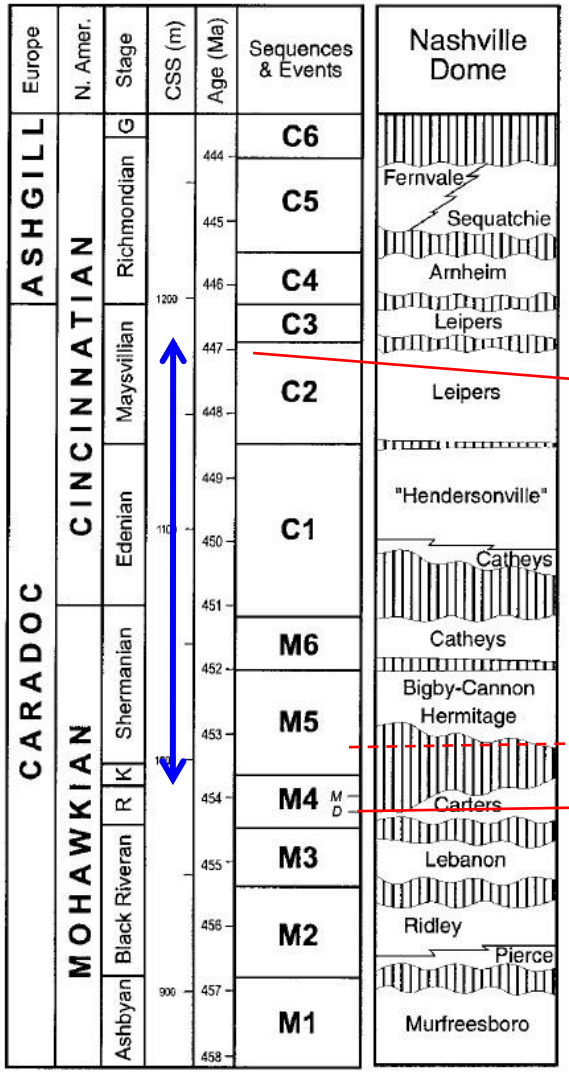
- **Gas fields of Ordovician and Cambrian age associated with oil**—Data from Baranoski and others (1996), Harris and Baranoski (1996), and Riley and others (1996b)
- **Gas fields of Ordovician and Cambrian age**—Data from Wilson and Sutton (1973, 1976), New York State Department of Environmental Conservation (1986, 2004), Baranoski and others (1996), Harris and Baranoski (1996), Laughrey and Harper (1996), Nuttall (1996), Wickstrom (1996a,b), Cazee (1998), and Avary (2006)
- **Oil fields of Ordovician and Cambrian age**—Data from Baranoski and others (1996), Riley and others (1996b), Wickstrom (1996a,b), and Cazee (1998)
- **Oil and gas fields of Ordovician age**—Data from Wilson and Sutton (1973, 1976), Milici and others (1980), Nuttall (1996), and Wickstrom (1996a,b)

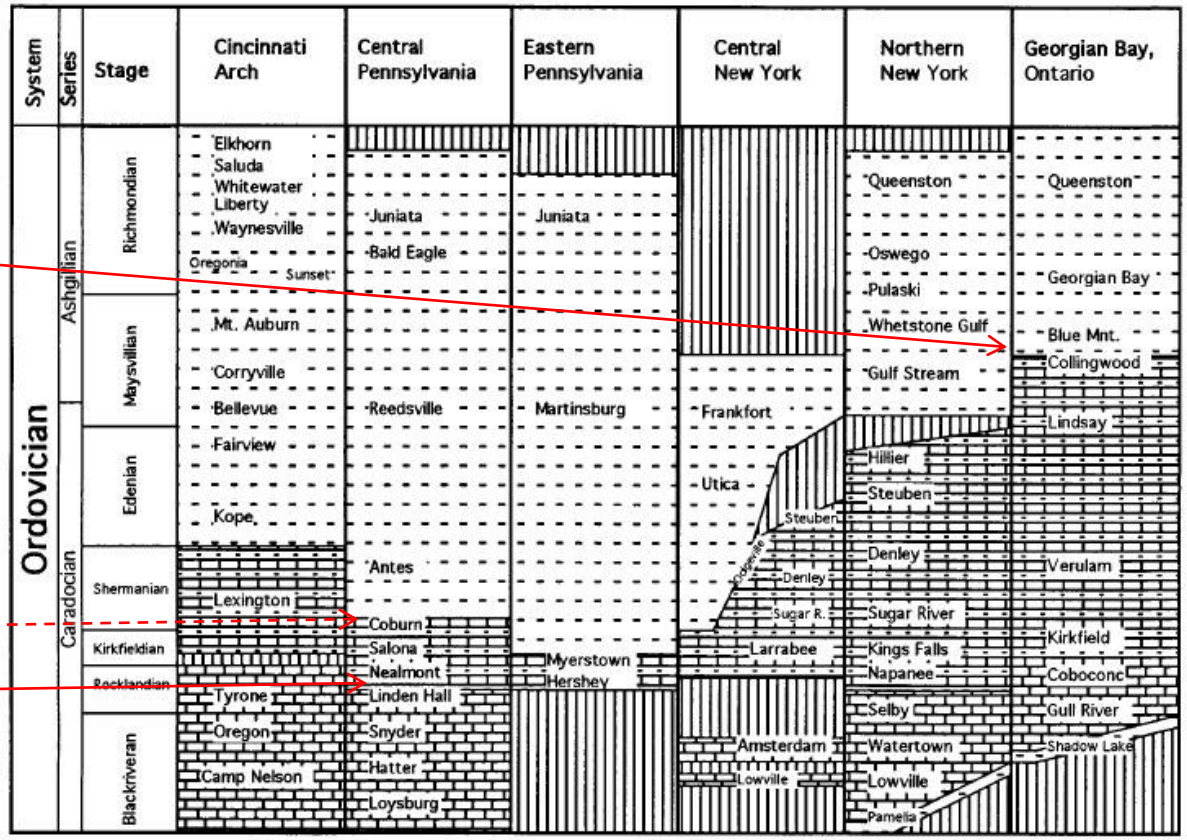



D
D'
1-Kerbel
2-Haff
3-Wheeler
4-Empire
5-Drake
6-Troyer
7-Huebner
8-Zechman
9-Birney
10-Burley
11-Finch
Permian (restored)
Model Unit Name
a - Permian'
b - Pennsylvanian
c - Mississippian
d - Ohio Shale
e - Rhinestreet
f - Onondaga
g - Salina'
h - Lockport'
i - Medina
j - Reedsville
k - Utica
l - Trenton
m - Beekmantown
n - Conasauga
o - Rome Trough
p - Basement
Section D-D'
Maximum Burial (~270 Ma)
Depth (ft)
0
5000
10,000
15,000
20,000
25,000
30,000
35,000
0
25
50
75
100
125
150
175
200
225
250
275
300
325
350
375
Distance (km)


b
1-Kerbel
2-Haff
3-Wheeler
4-Empire
5-Drake
6-Troyer
7-Huebner
8-Zechman
9-Birney
10-Burley
11-Finch
Thermal Maturity - 'Utica' model unit
Vitrinite reflectance (Ro%)
3.8
3.6
3.4
3.2
3.0
2.8
2.6
2.4
2.2
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
Gas Window
Oil Window
Immature
0 Ma
270 Ma
300 Ma
360 Ma
390 Ma
0
50
100
150
200
250
300
350
NW
Distance Along Cross Section D - D' (km)
SE

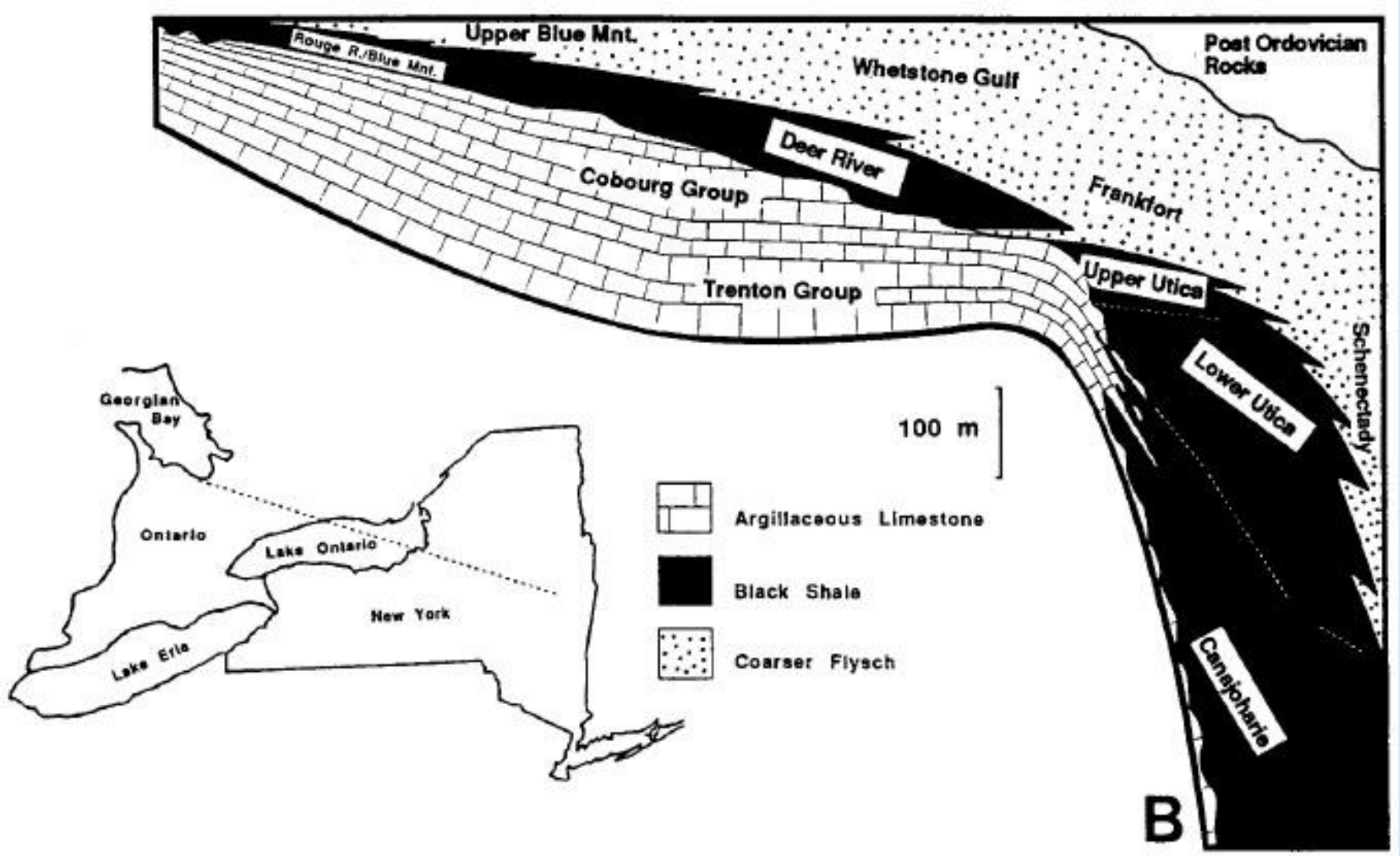
7 million year amalgamation

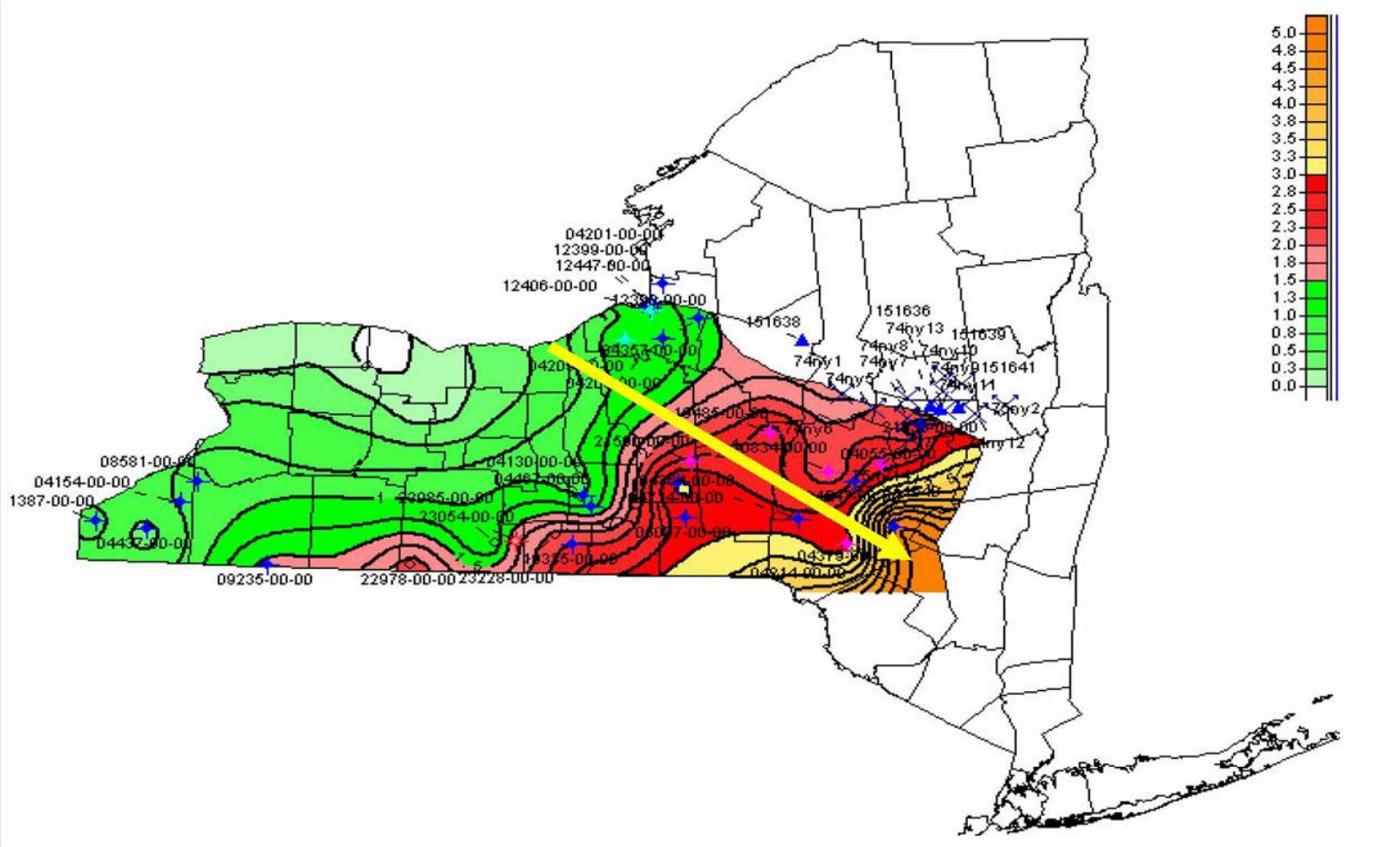




(Holland and Patzkowsky, 1997)

(Lehmann et al., 1995)


Upper Blue Mnt.
Rouge R./Blue Mnt.
Whetstone Gulf
Post Ordovician Rocks
Deer River
Cobourg Group
Frankfort
Upper Utica
Trenton Group
Schenectady
Lower Utica
Canajoharie
100 m
Argillaceous Limestone
Black Shale
Coarser Flysch
Georgian Bay
Ontario
Lake Ontario
New York
Lake Erie
B


5.0
4.8
4.5
4.3
4.0
3.8
3.5
3.3
3.0
2.8
2.5
2.3
2.0
1.8
1.5
1.3
1.0
0.8
0.5
0.3
0.0
04201-00-00
12399-00-00
12447-00-00
12406-00-00
151638
151636
74ny13
151639
74ny8
74ny10
74ny1
74ny7
74ny9
151641
74ny5
74ny11
74ny2
74ny12
08581-00-00
04154-00-00
1387-00-00
04130-00-00
22085-00-00
23054-00-00
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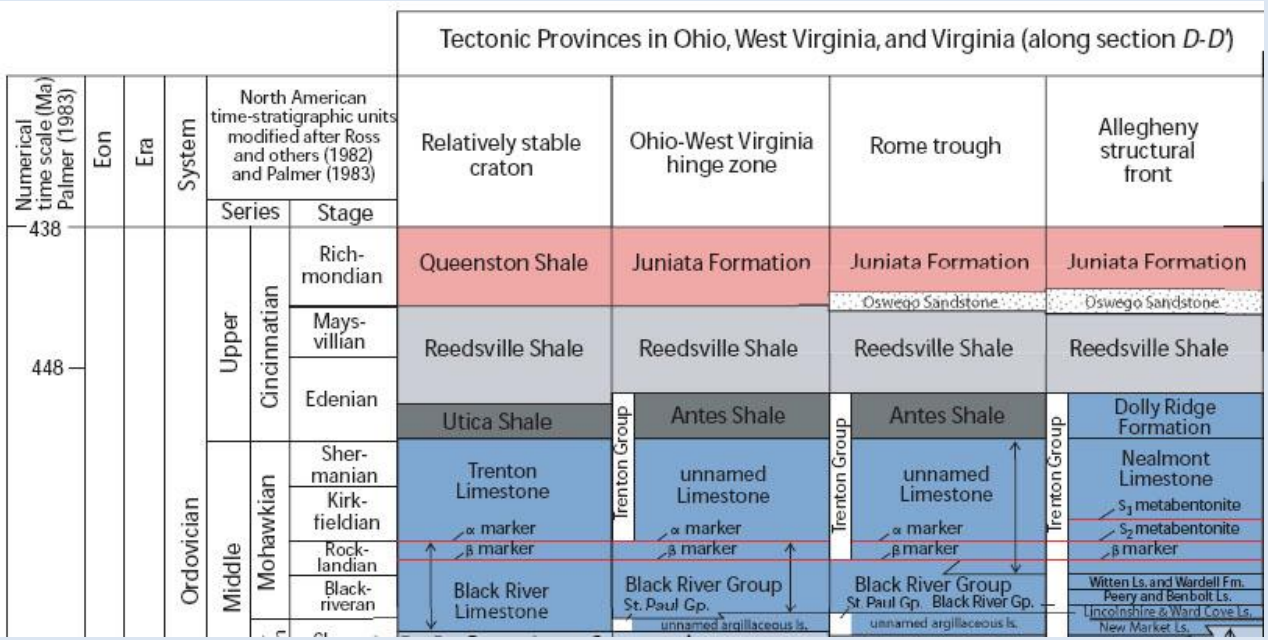
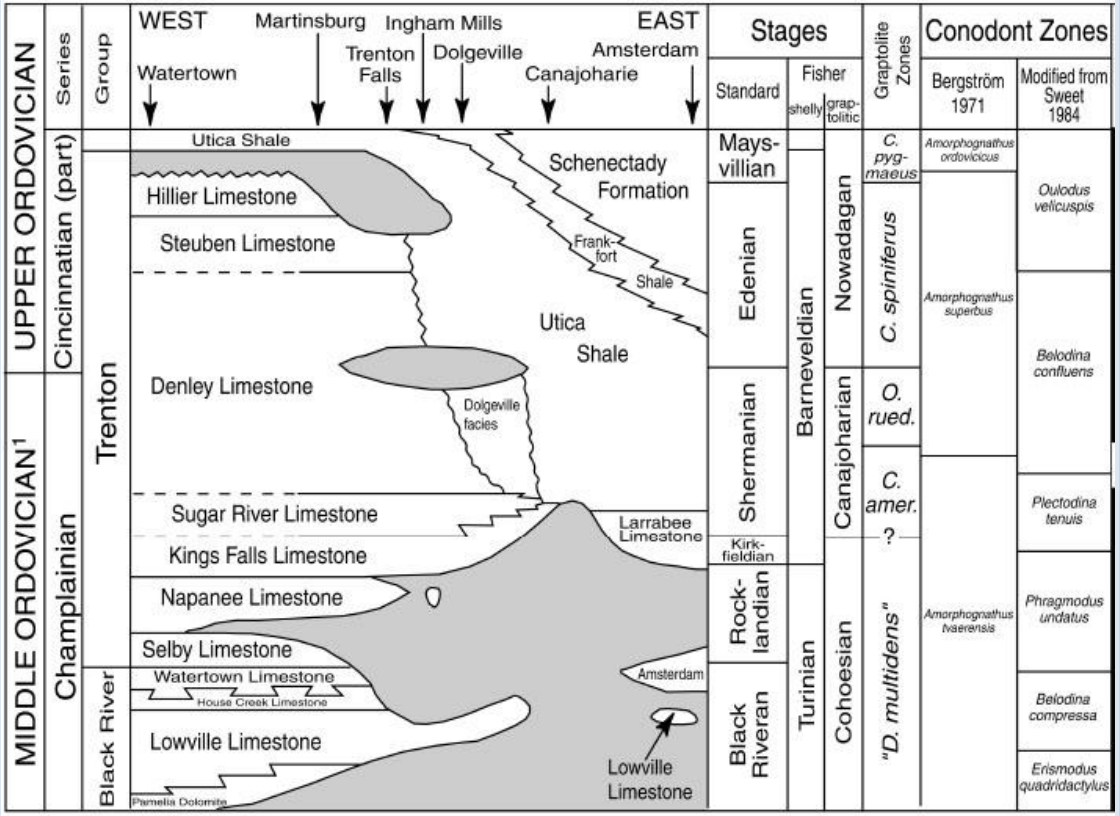
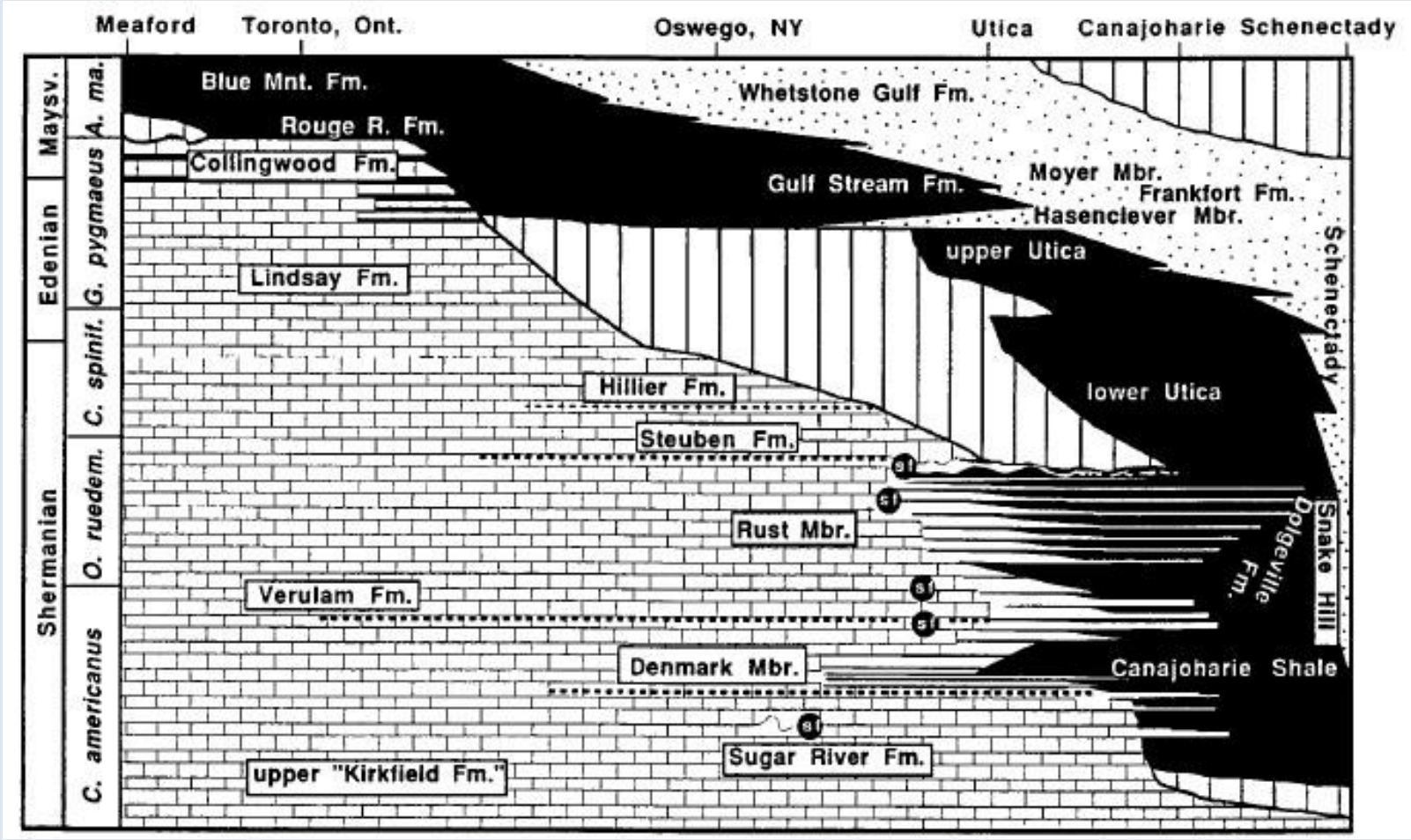
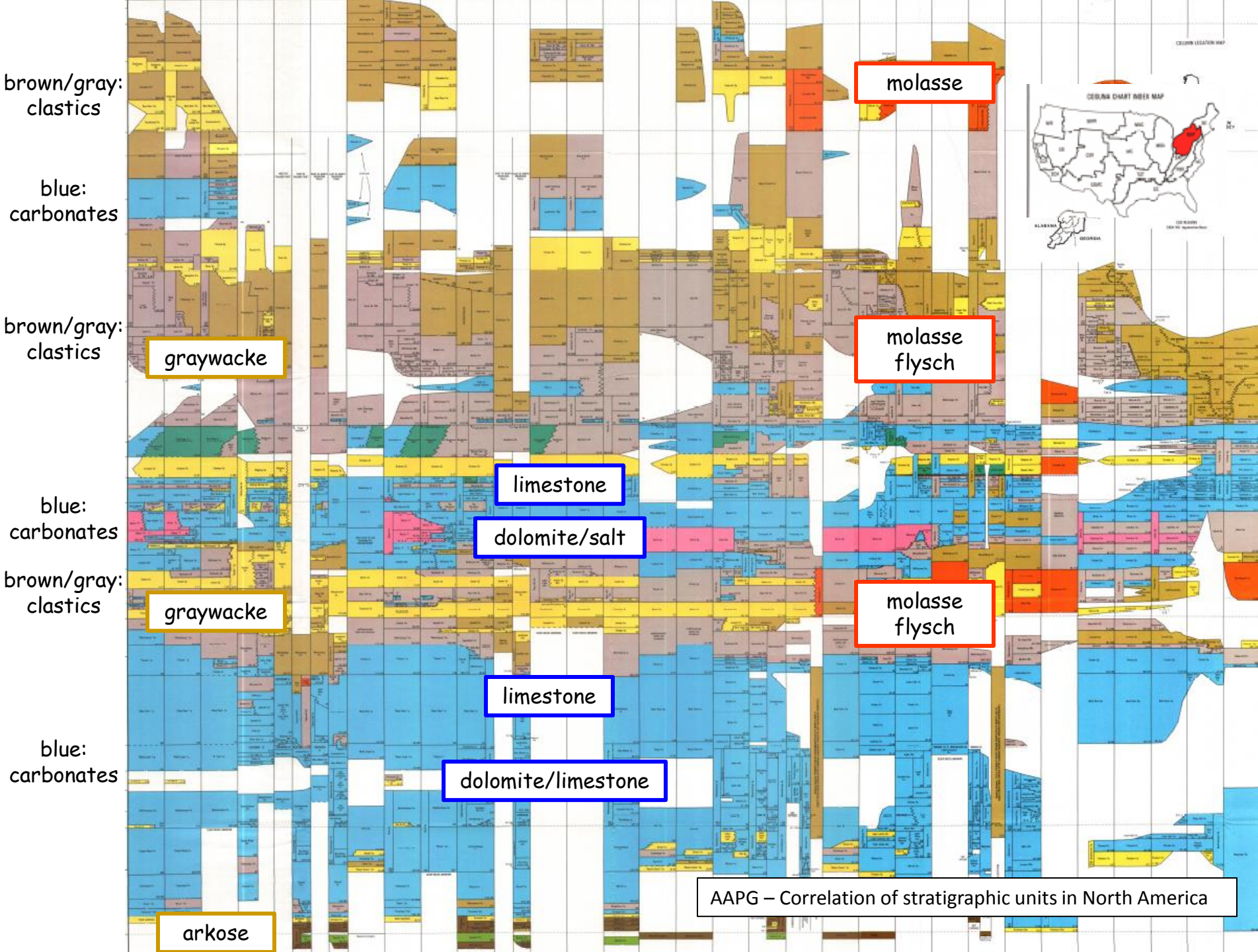
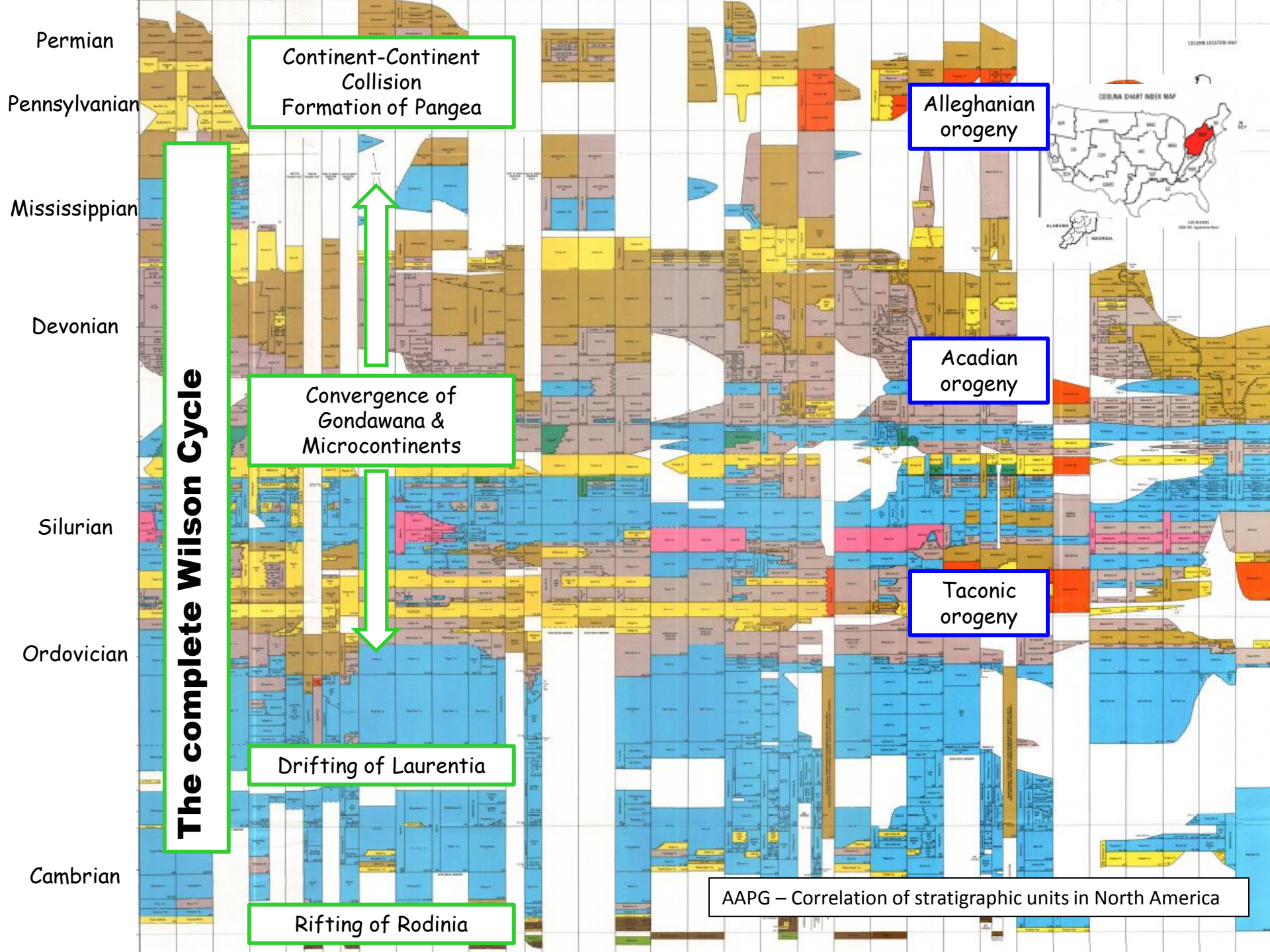
22978-00-00
23228-00-00

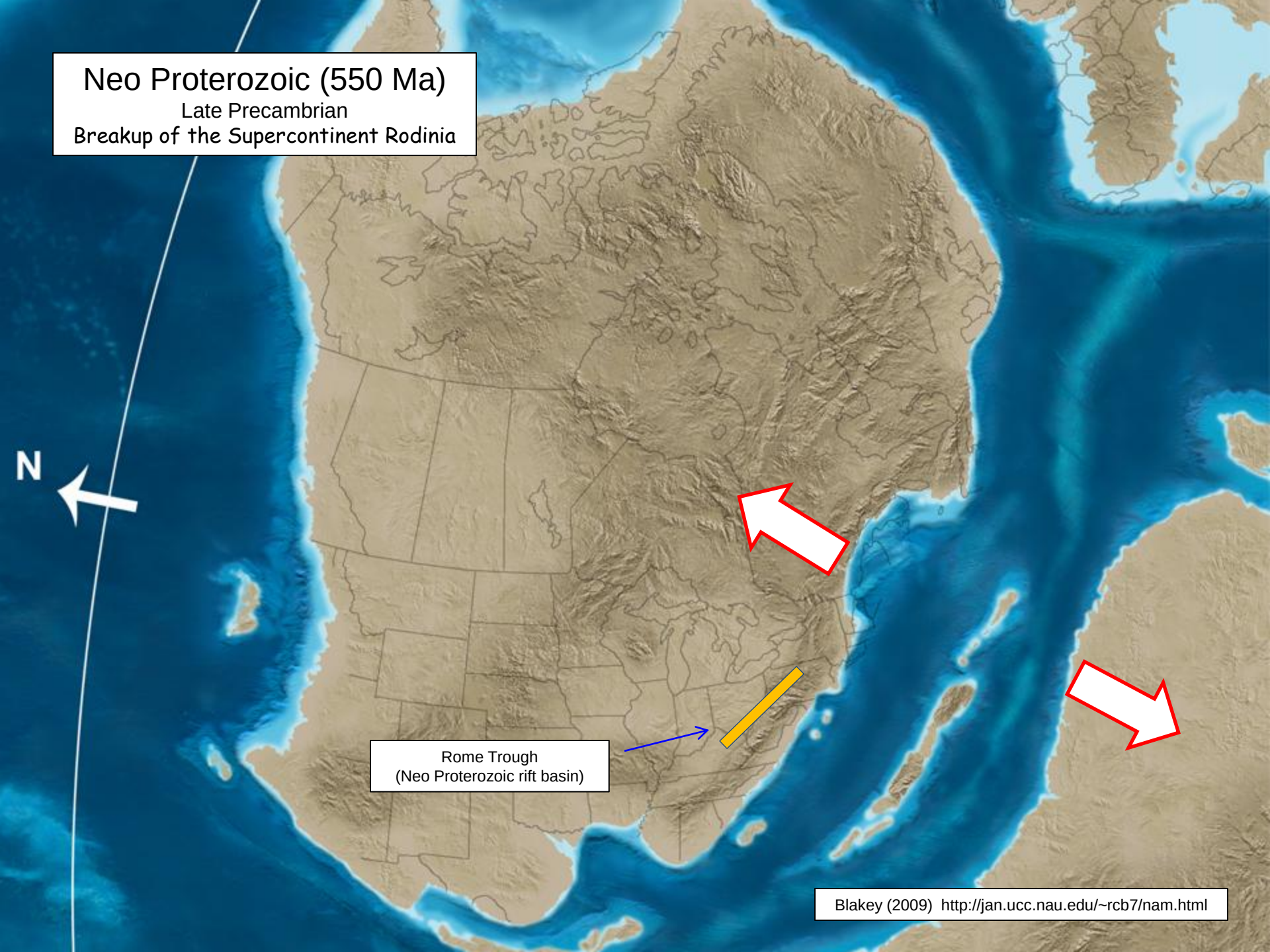

Tectonic Provinces in Ohio, West Virginia, and Virginia (along section D-D')
Numerical time scale (Ma) Palmer (1983)
Eon
Era
System
North American time-stratigraphic units modified after Ross and others (1982) and Palmer (1983)
Series
Stage
Relatively stable craton
Ohio-West Virginia hinge zone
Rome trough
Allegheny structural front
438
448
Ordovician
Upper
Middle
Cincinnatian
Mohawkian
Rich-mondian
Mays-villian
Edenian
Sher-manian
Kirk-fieldian
Rock-landian
Black-riveran
Queenston Shale
Juniata Formation
Oswego Sandstone
Reedsville Shale
Utica Shale
Antes Shale
Dolly Ridge Formation
Trenton Limestone
unnamed Limestone
Nealmont Limestone
Trenton Group
α marker
β marker
S1 metabentonite
S2 metabentonite
Black River Limestone
Black River Group
St. Paul Gp.
Black River Gp.
unnamed argillaceous ls.
Witten Ls. and Wardell Fm.
Peery and Benbolt Ls.
Lincolnshire & Ward Cove Ls.
New Market Ls.


UPPER ORDOVICIAN
MIDDLE ORDOVICIAN[1]
Series
Group
Cincinnatian (part)
Champlainian
Trenton
Black River
WEST
EAST
Watertown
Martinsburg
Trenton Falls
Ingham Mills
Dolgeville
Canajoharie
Amsterdam
Utica Shale
Hillier Limestone
Steuben Limestone
Denley Limestone
Dolgeville facies
Sugar River Limestone
Kings Falls Limestone
Napanee Limestone
Selby Limestone
Watertown Limestone
House Creek Limestone
Lowville Limestone
Pamelia Dolomite
Schenectady Formation
Frank-fort Shale
Utica Shale
Larrabee Limestone
Amsterdam
Lowville Limestone
Stages
Standard
Fisher
shelly
grap-tolitic
Mays-villian
Edenian
Shermanian
Kirk-fieldian
Rock-landian
Black Riveran
Barneveldian
Turinian
Nowadagan
Canajoharian
Cohoesian
Graptolite Zones
C. pyg-maeus
C. spiniferus
O. rued.
C. amer.
?
"D. multidens"
Conodont Zones
Bergström 1971
Modified from Sweet 1984
Amorphognathus ordovicicus
Amorphognathus superbus
Amorphognathus tvaerensis
Oulodus velicuspis
Belodina confluens
Plectodina tenuis
Phragmodus undatus
Belodina compressa
Erismodus quadridactylus

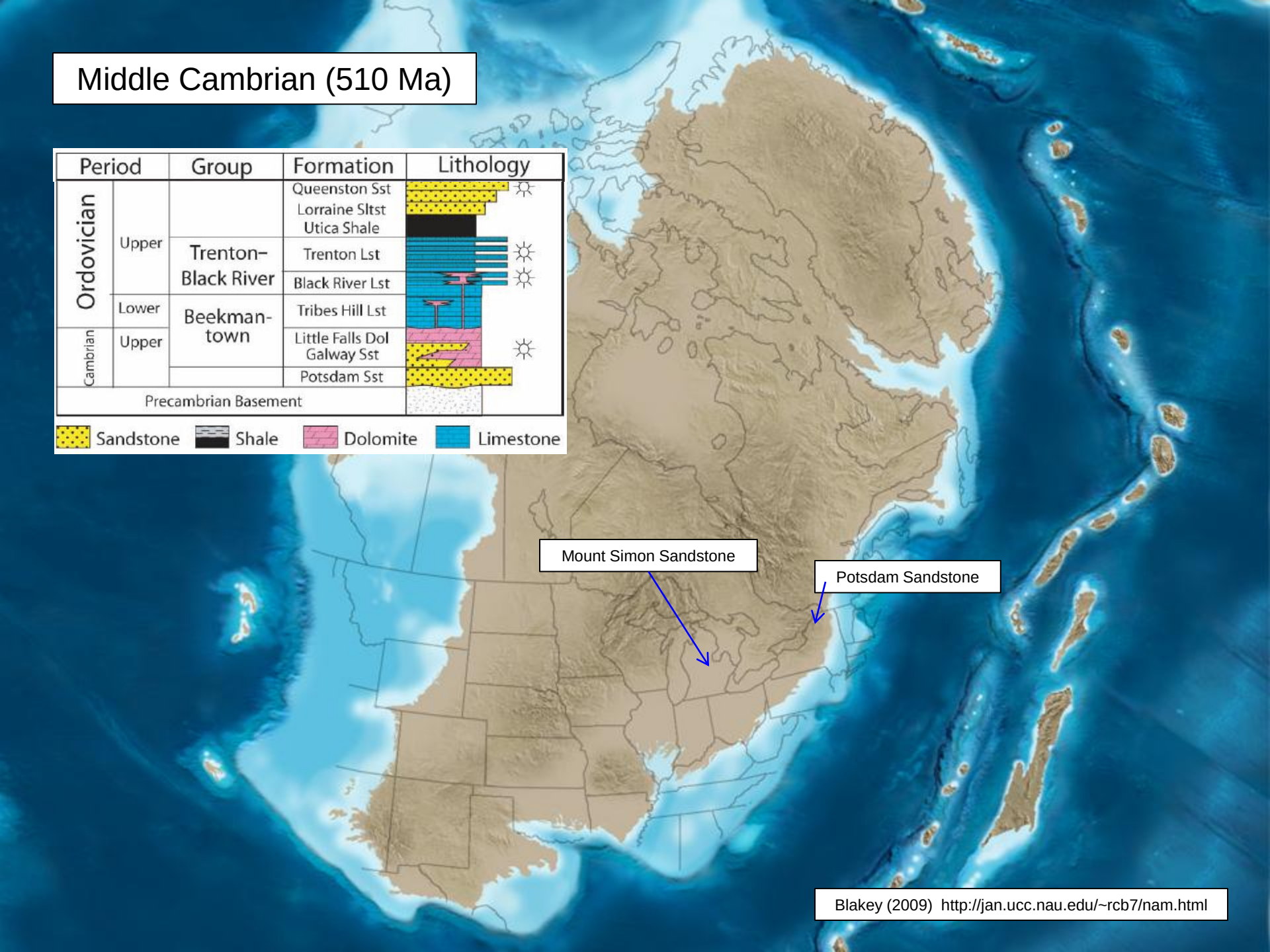

Meaford
Toronto, Ont.
Oswego, NY
Utica
Canajoharie
Schenectady
Maysv.
Edenian
Shermanian
A. ma.
G. pygmaeus
C. spinit.
O. ruedem.
C. americanus
Blue Mnt. Fm.
Rouge R. Fm.
Collingwood Fm.
Lindsay Fm.
Hillier Fm.
Steuben Fm.
Rust Mbr.
Verulam Fm.
Denmark Mbr.
Sugar River Fm.
upper "Kirkfield Fm."
Whetstone Gulf Fm.
Gulf Stream Fm.
Moyer Mbr.
Frankfort Fm.
Hasenclever Mbr.
upper Utica
lower Utica
Schenectady
Snake Hill
Dolgeville Fm.
Canajoharie Shale


brown/gray: clastics
blue: carbonates
brown/gray: clastics
blue: carbonates
brown/gray: clastics
blue: carbonates
molasse
molasse flysch
molasse flysch
graywacke
graywacke
arkose
limestone
dolomite/salt
limestone
dolomite/limestone
AAPG – Correlation of stratigraphic units in North America


Permian
Pennsylvanian
Mississippian
Devonian
Silurian
Ordovician
Cambrian
The complete Wilson Cycle
Continent-Continent Collision Formation of Pangea
Convergence of Gondawana & Microcontinents
Drifting of Laurentia
Rifting of Rodinia
Alleghanian orogeny
Acadian orogeny
Taconic orogeny
AAPG – Correlation of stratigraphic units in North America

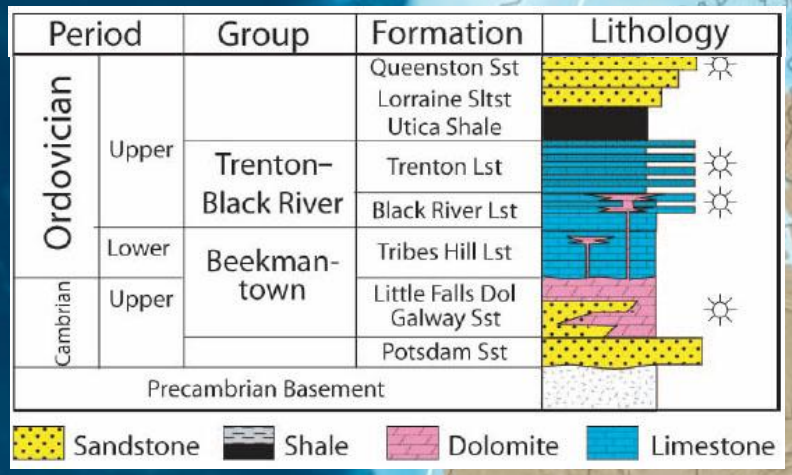

Neo Proterozoic (550 Ma)
Late Precambrian
Breakup of the Supercontinent Rodinia
N
Rome Trough
(Neo Proterozoic rift basin)
Blakey (2009) http://jan.ucc.nau.edu/~rcb7/nam.html

Middle Cambrian (510 Ma)



Blakey (2009) http://jan.ucc.nau.edu/~rcb7/nam.html

Late Cambrian (500 Ma)



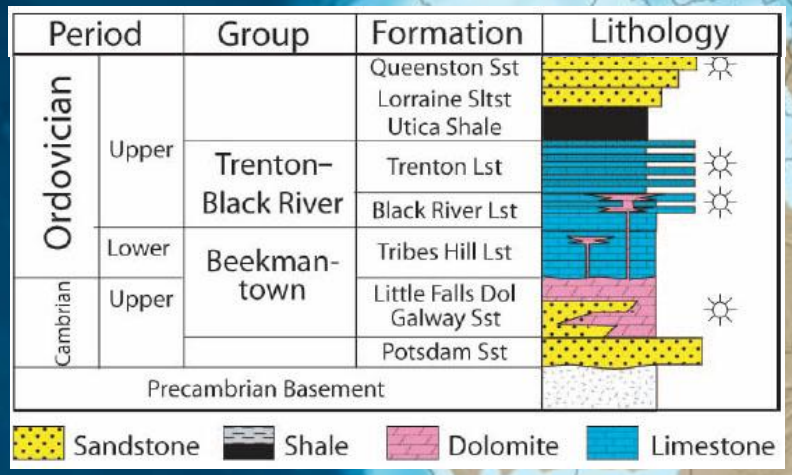
Eu Claire
Dolomite/Sandstone

Theresa
Dolomite/Sandstone

Gatesburg
Dolomite/Sandstone

Blakey (2009) http://jan.ucc.nau.edu/~rcb7/nam.html

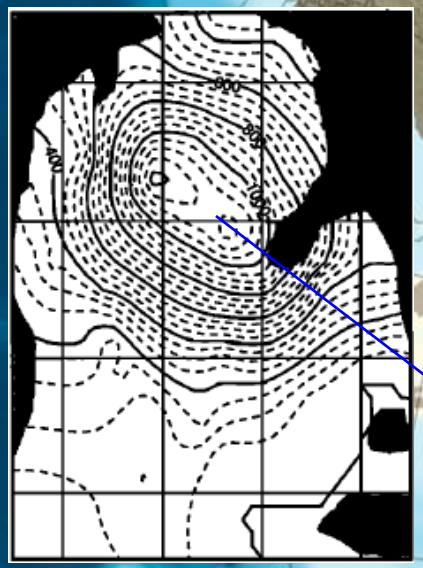
Early Ordovician (485 Ma)



Nittany Dolomite
Stonehenge Limestone

Blakey (2009) http://jan.ucc.nau.edu/~rcb7/nam.html

Middle Ordovician (470 Ma)

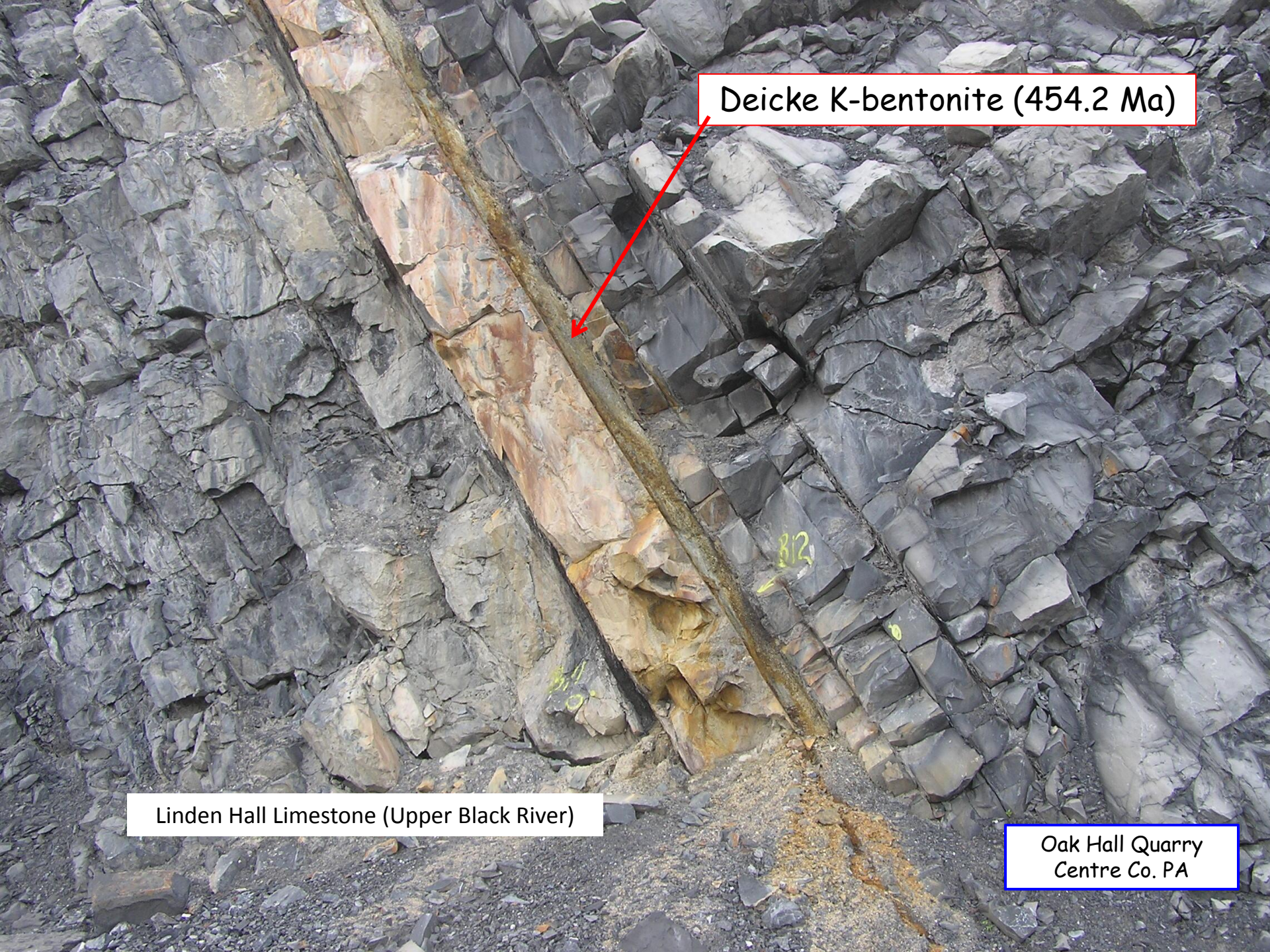


Glenwood Limestone
St. Peters Sandstone
Shapookie Limestone

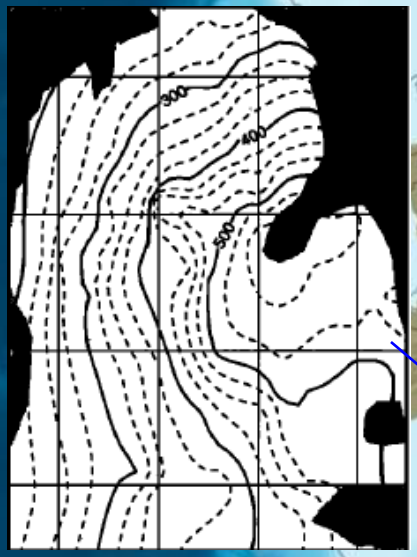
Knox Unconformity

Loysburg Limestone
Bellefonte Dolomite
Axemann Limestone

Blakey (2009) http://jan.ucc.nau.edu/~rcb7/nam.html


Deicke K-bentonite (454.2 Ma)
Linden Hall Limestone (Upper Black River)
Oak Hall Quarry
Centre Co. PA

Late Ordovician (450 Ma)

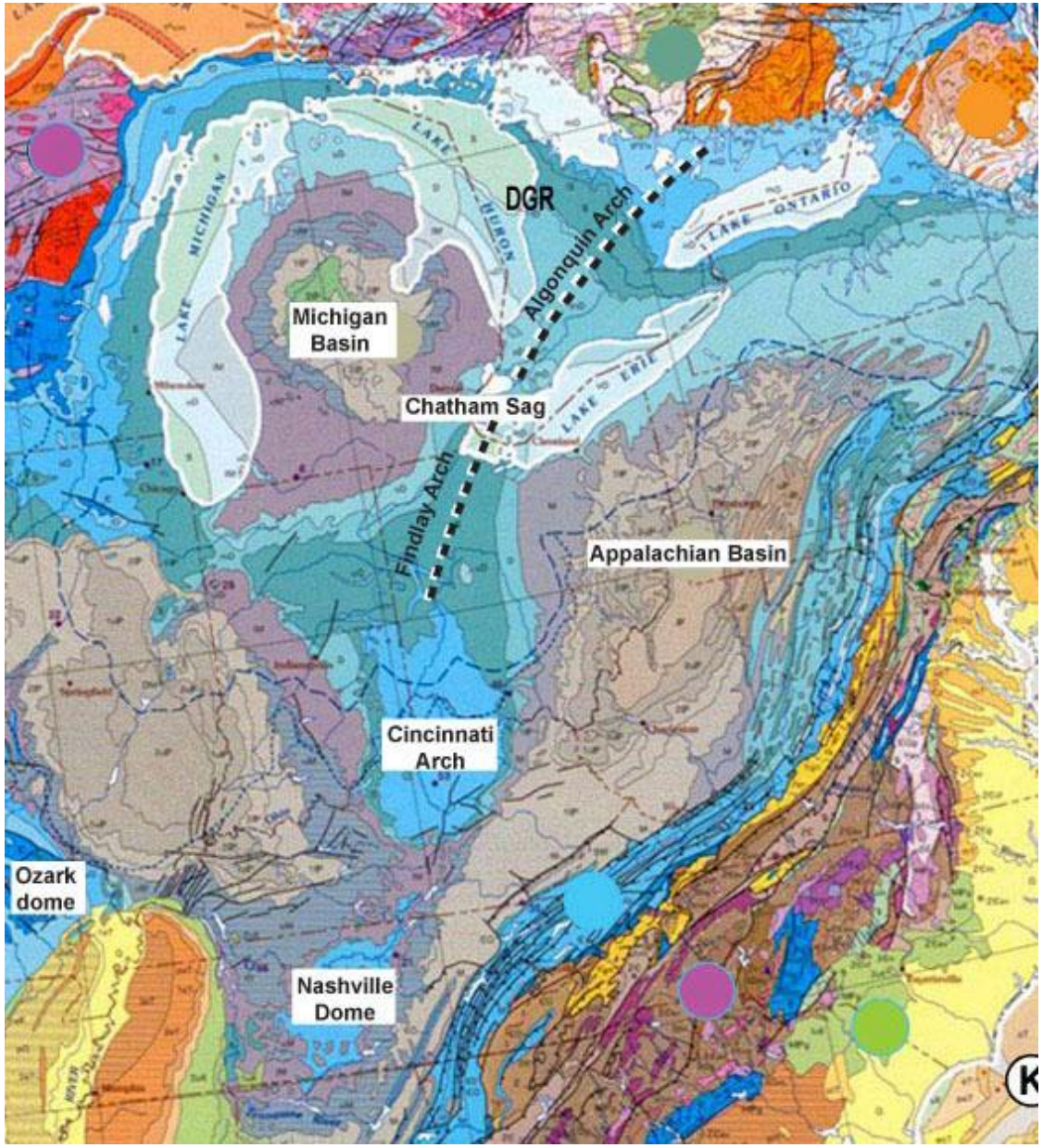


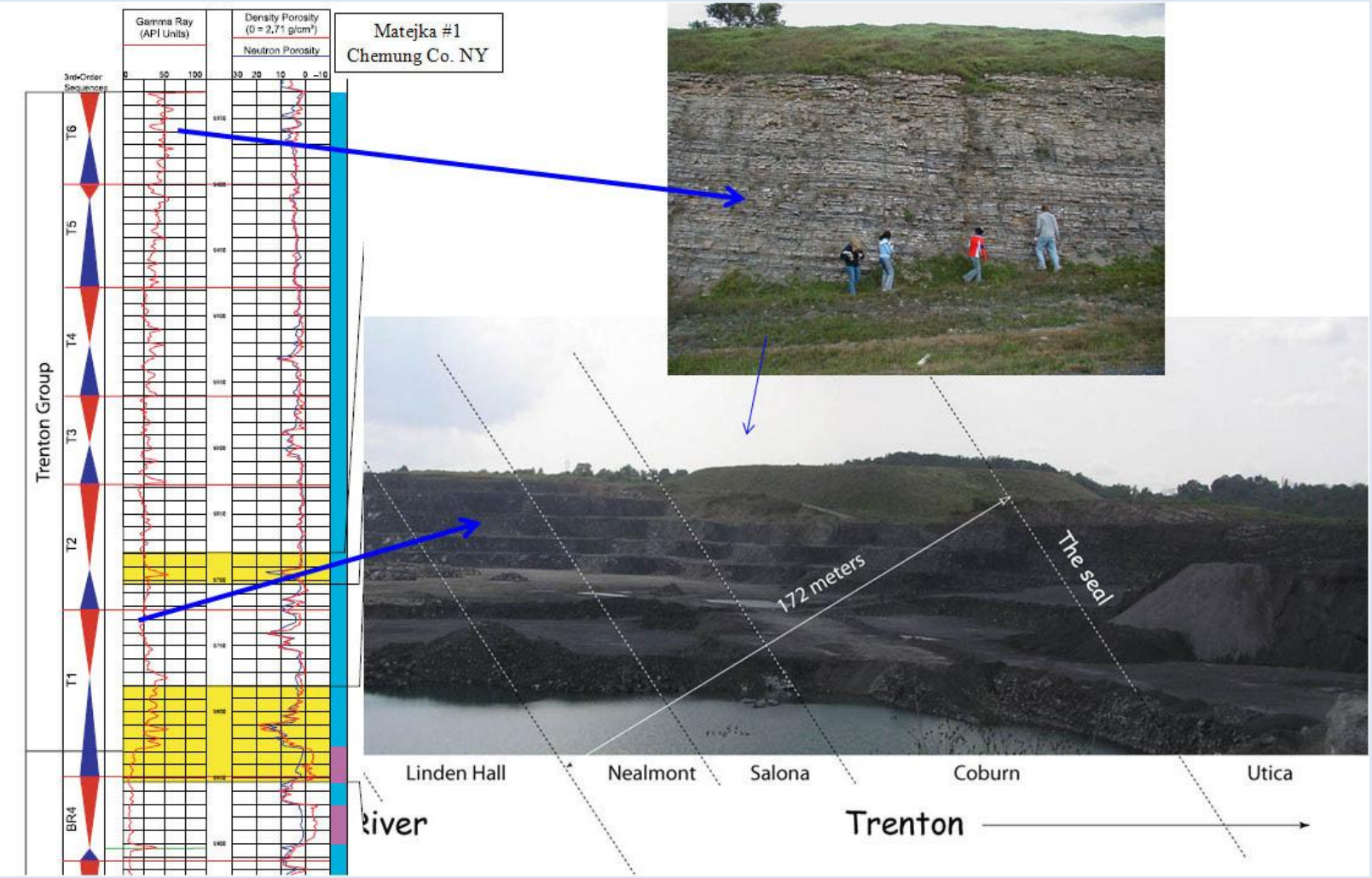
Utica Black Shale
Trenton Limestones
Black River Limestones

Laurentian Platform tilts to south

Utica Black Shale
Trenton Limestones
Black River Limestones

Blakey (2009) http://jan.ucc.nau.edu/~rcb7/nam.html


DGR
Algonquin Arch
LAKE ONTARIO
LAKE HURON
LAKE MICHIGAN
Michigan Basin
Chatham Sag
LAKE ERIE
Findlay Arch
Appalachian Basin
Cincinnati Arch
Ozark dome
Nashville Dome


Gamma Ray
(API Units)
Density Porosity
(0 = 2.71 g/cm³)
Neutron Porosity
Matejka #1
Chemung Co. NY
3rd-Order Sequences
Trenton Group
T6
T5
T4
T3
T2
T1
BR4
172 meters
The seal
Linden Hall
Nealmont
Salona
Coburn
Utica
Trenton

Geochemists talk about gas shales in terms of thermal maturity

A structural geologist's view of gas shale may be in terms of:

1. tectonic maturity.

- immature vs. mature

2. fields of tectonic maturity.

- brittle maturity
- ductile maturity

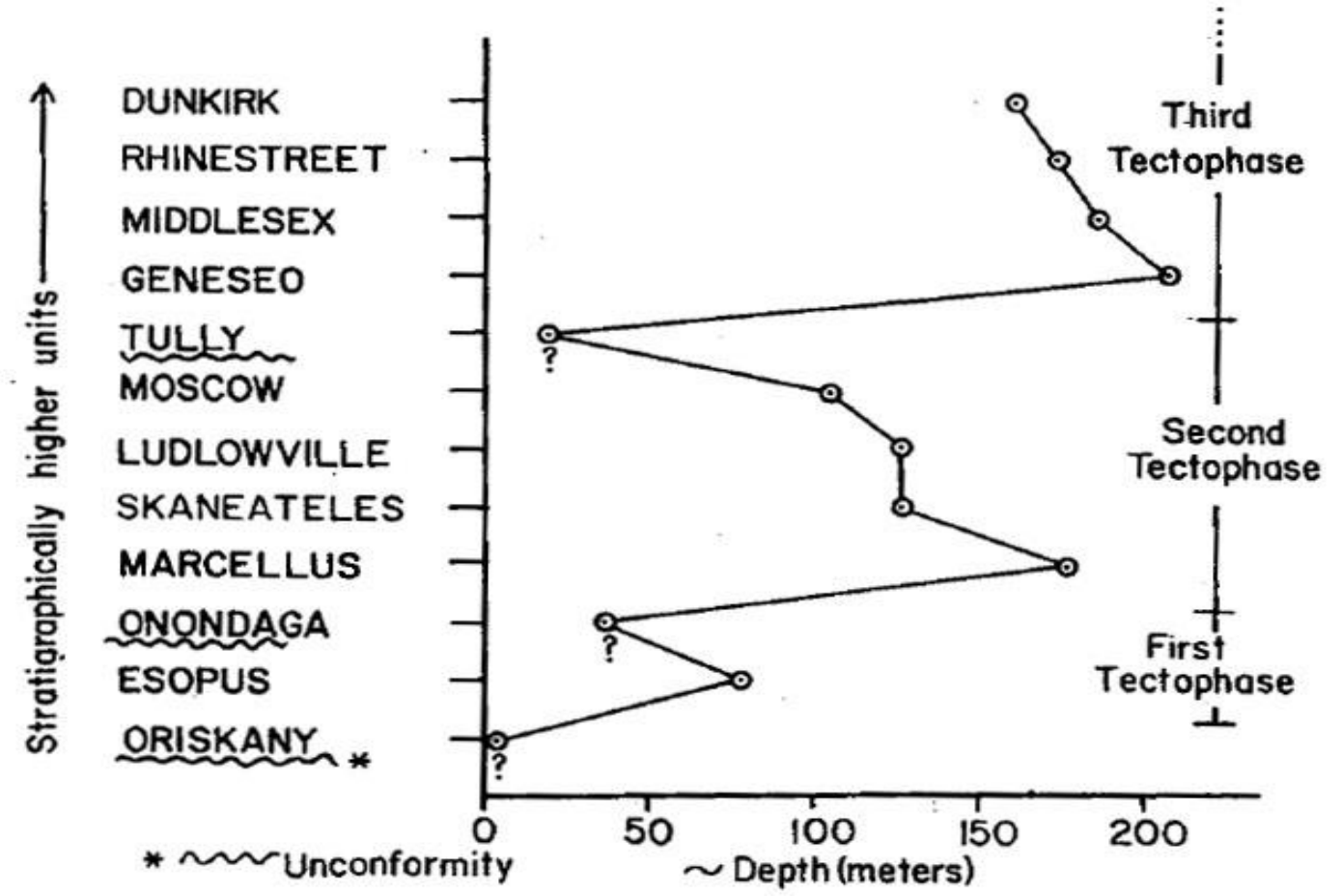
Conclusion by reinforcing the notions:

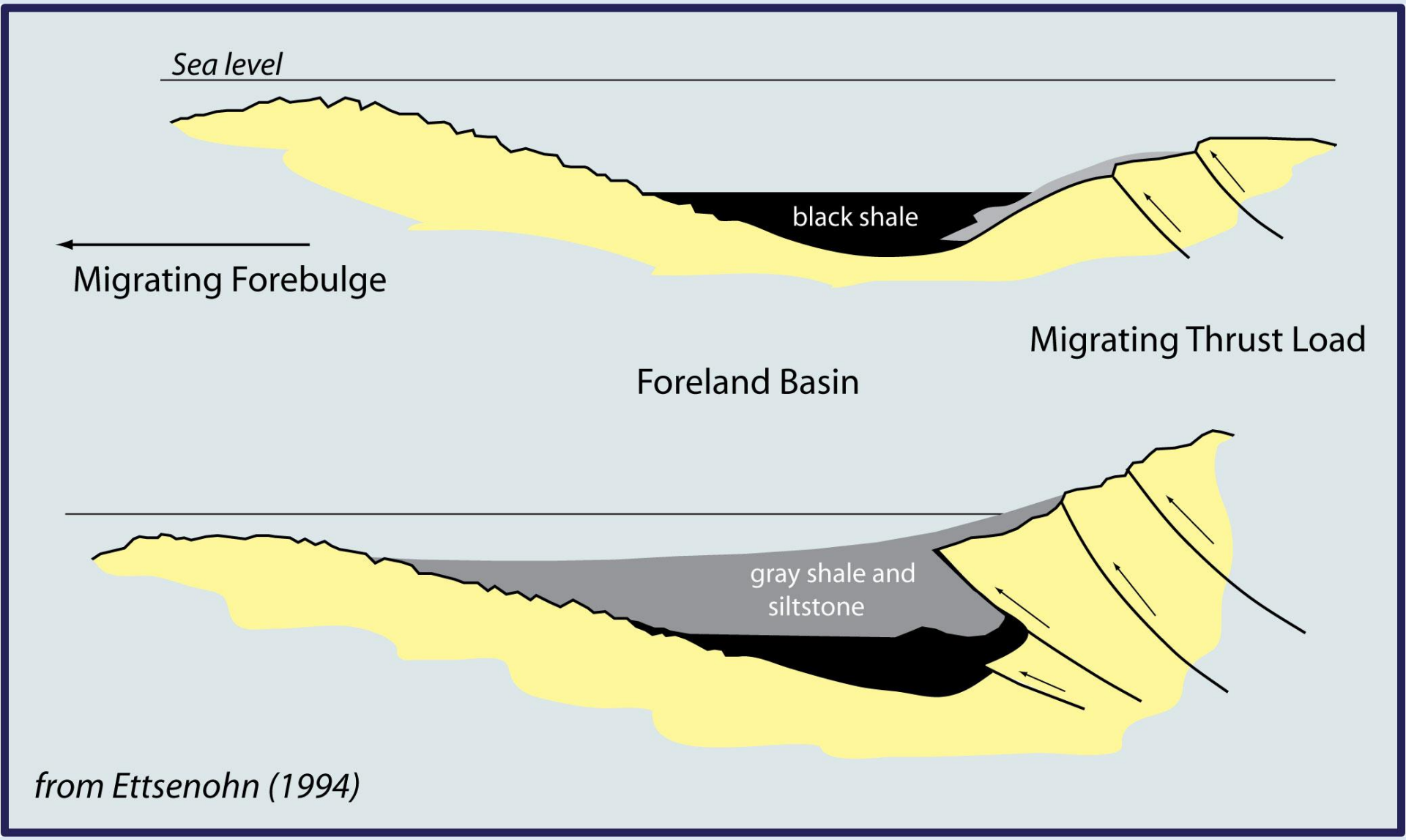
1. that shale plays are distinguished by tectonic materity.
2. that tectonic deformation does not compromise gas shale productivity.
3. that brittle and ductile structures can co-exist during tectonic evolution of a gas shale.

Conclusions

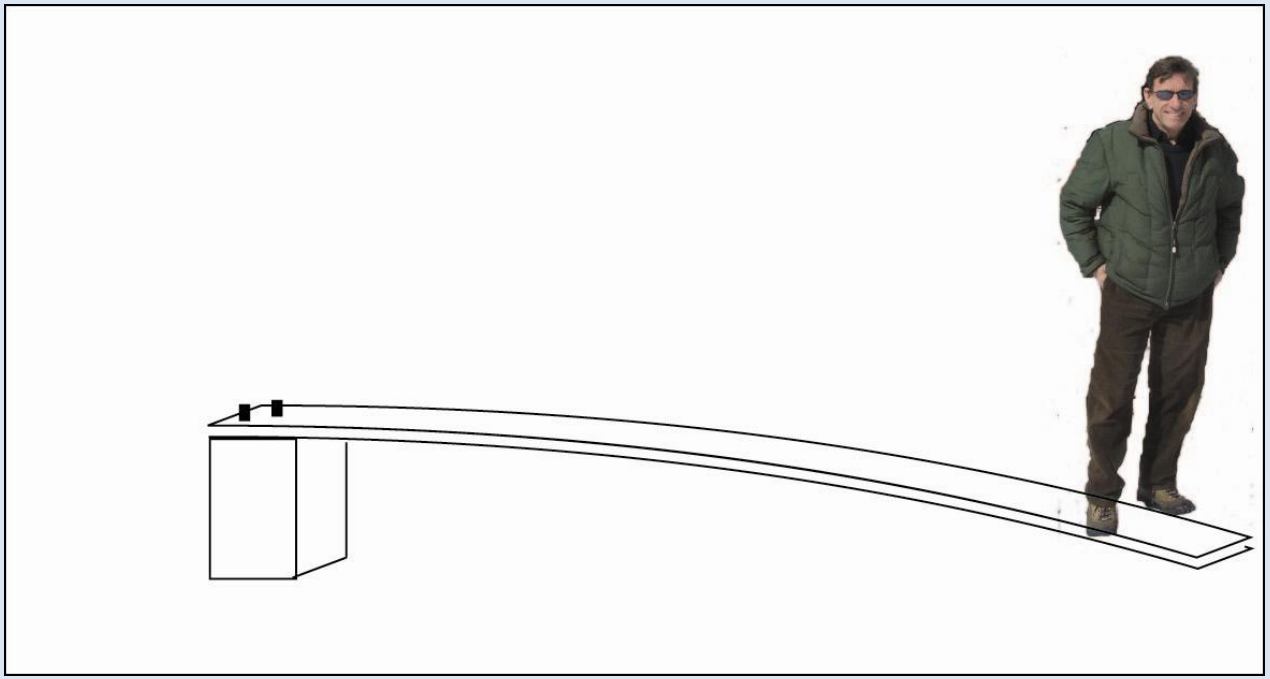
- Marcellus has a strong systematic tectonic fabric that impacts state of stress during fracture growth.
- While vertical extension is apparent in rock fabric and undoubtedly contributes to $S_V > S_{hmin}$, it is believed that $S_V > S_{hmin}$ is achieved largely by axis parallel stretching along an oroclinal bend.

Ettensohn's (1985 Tectophases

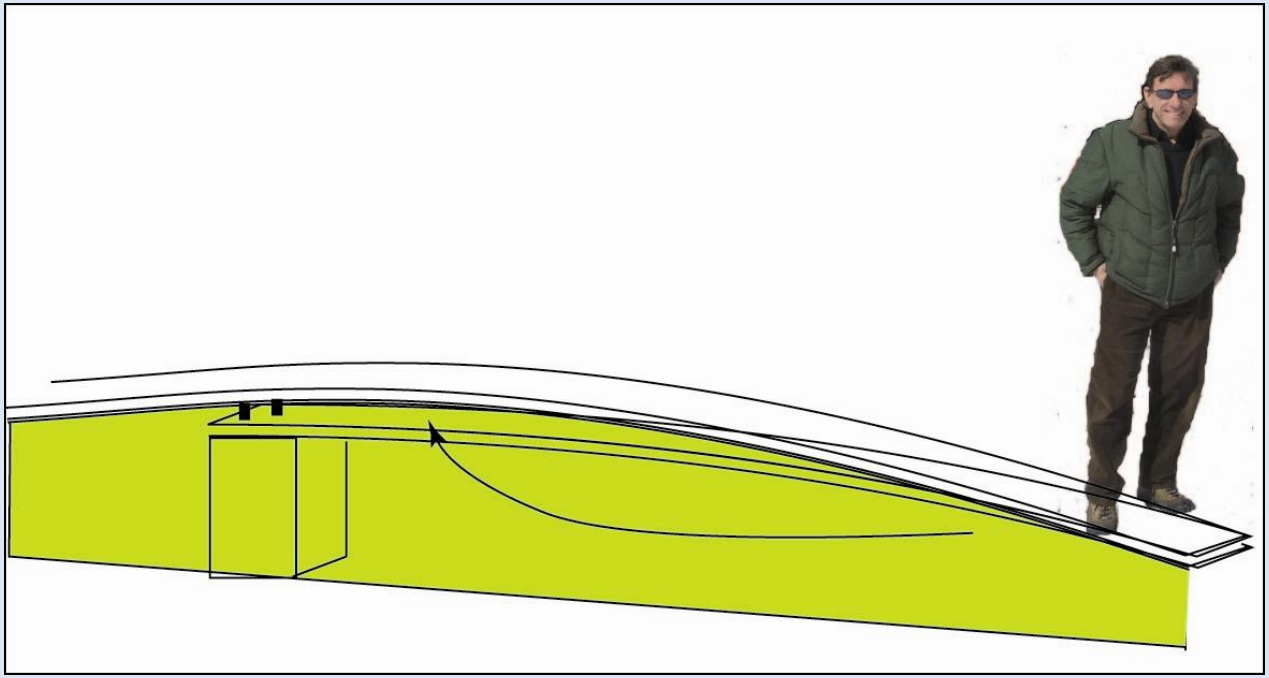


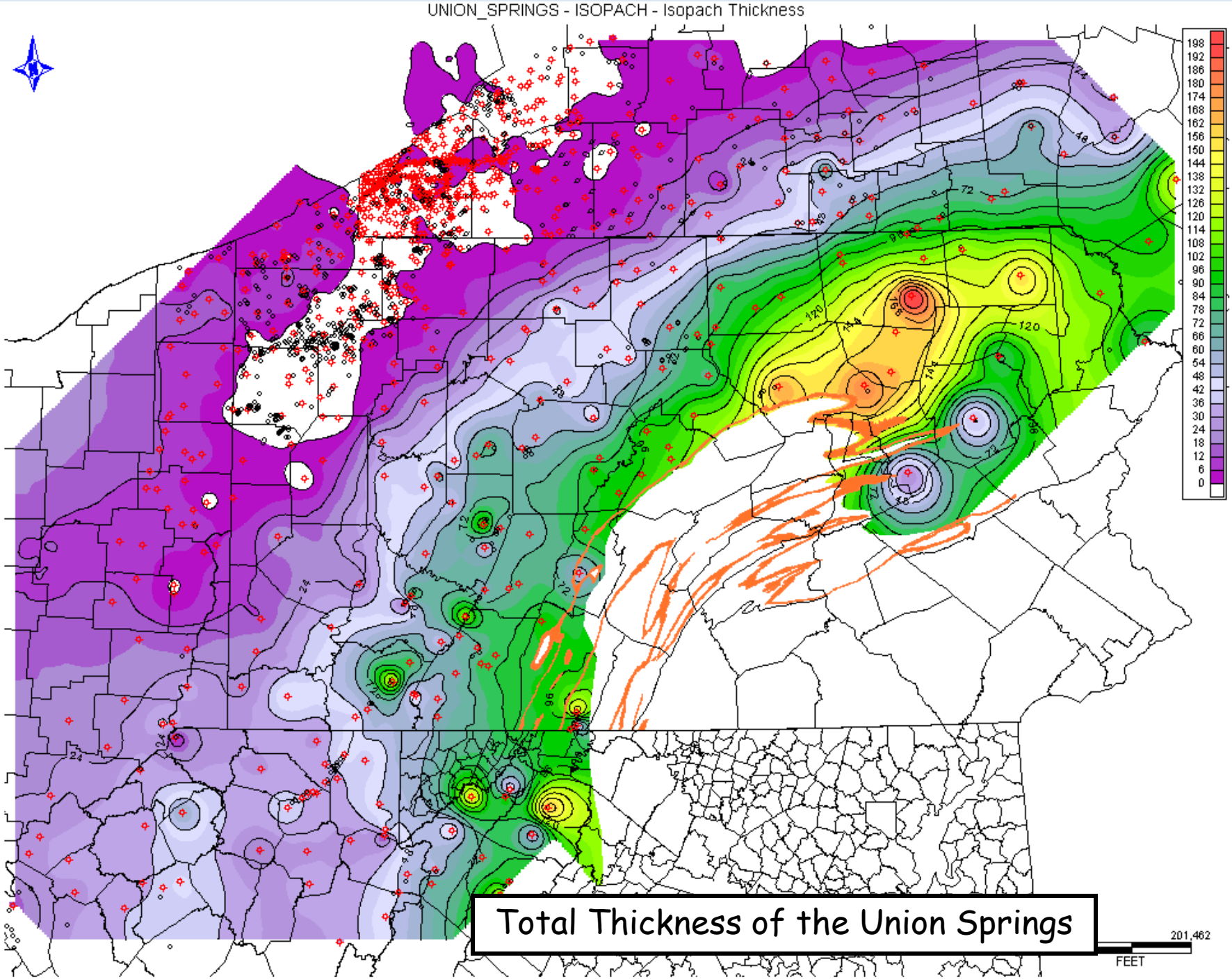


from Ettsenohn (1994)

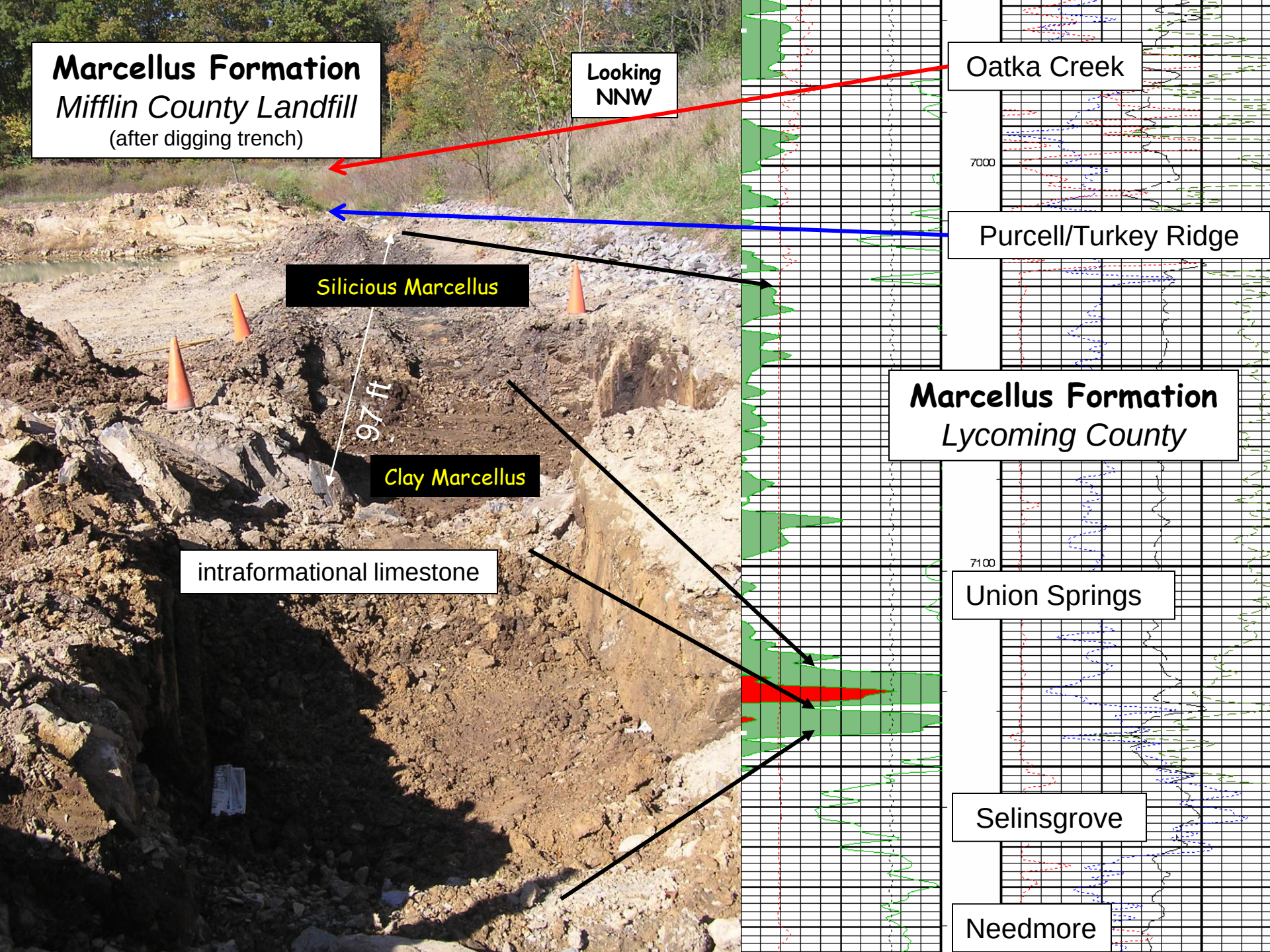


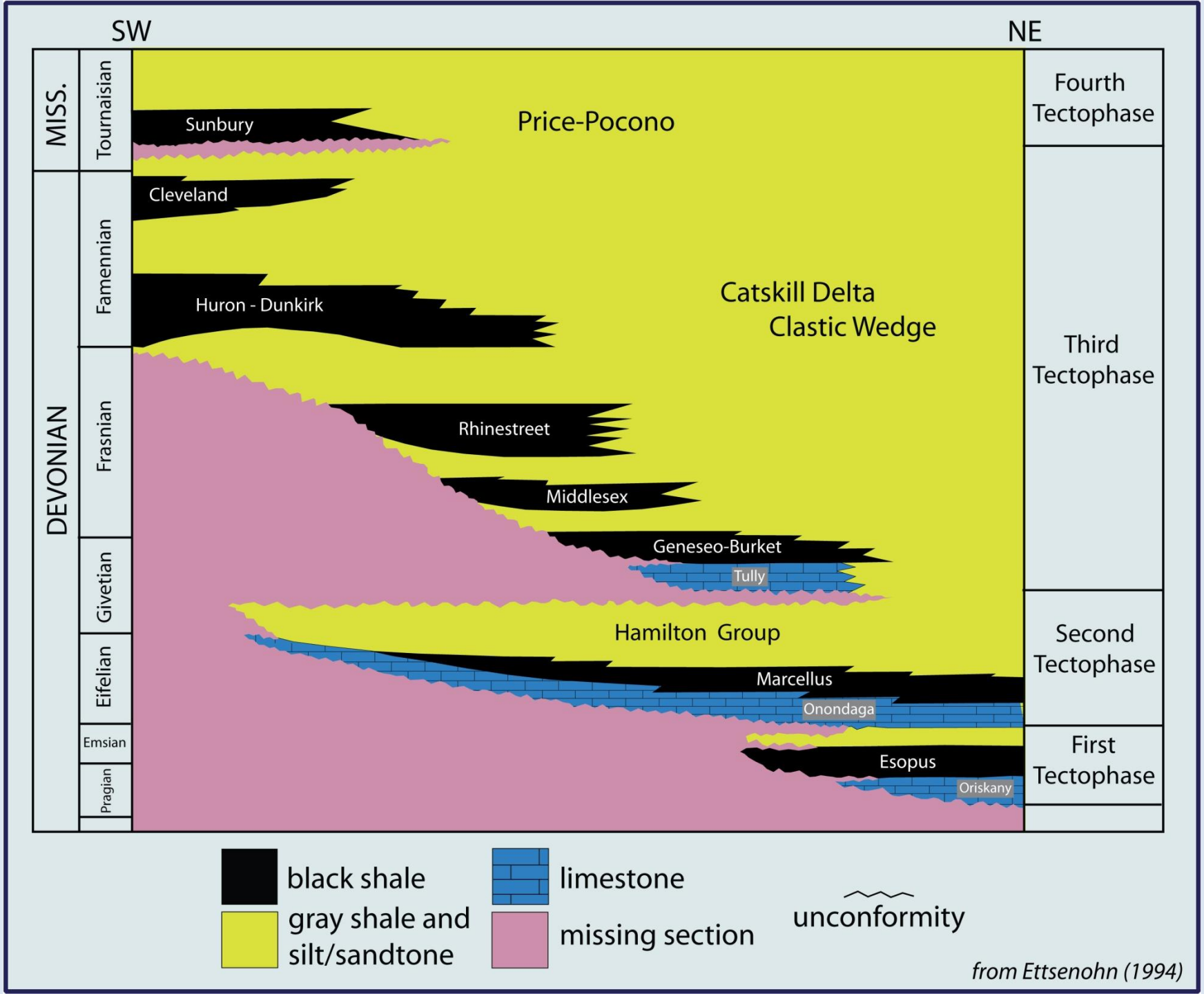
forebulge



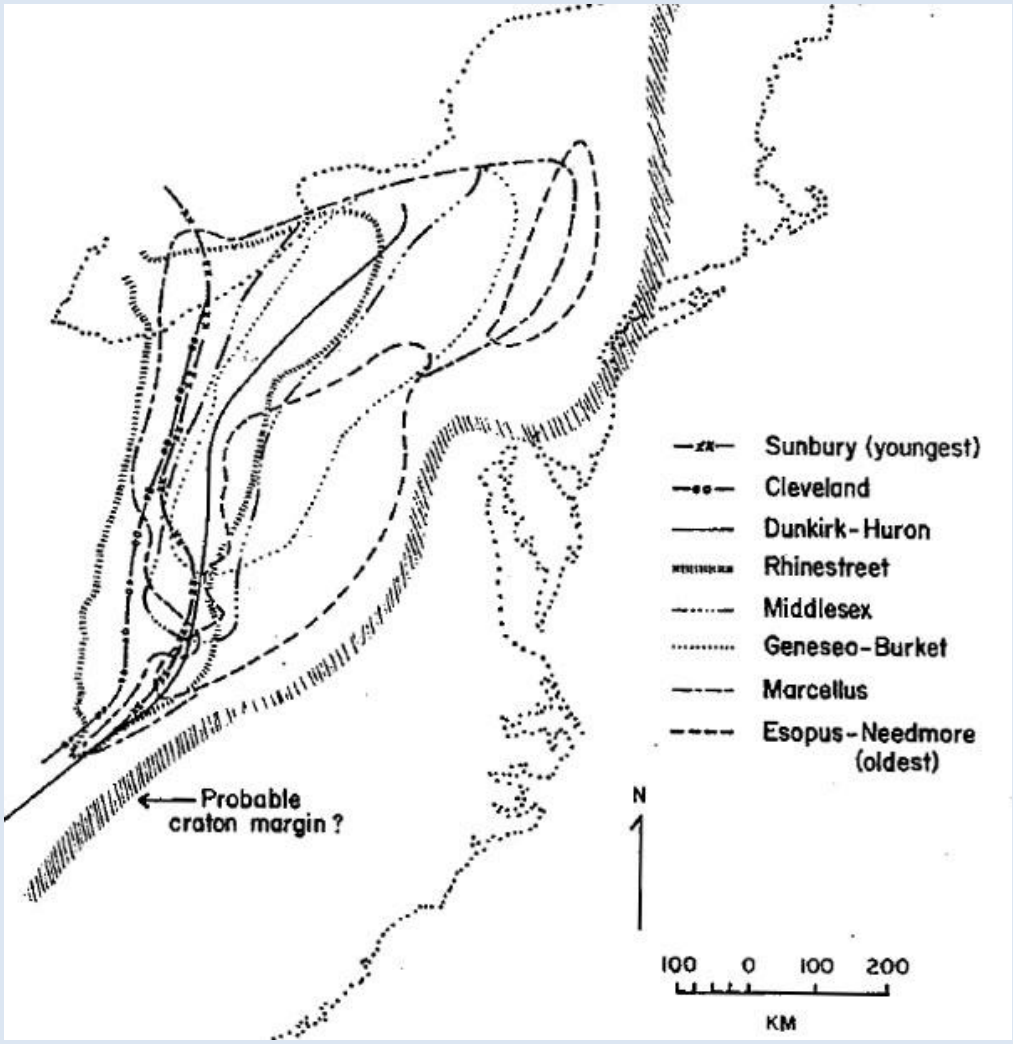


Total Thickness of the Union Springs


Marcellus Formation
Mifflin County Landfill
(after digging trench)
Looking NNW
Oatka Creek
Purcell/Turkey Ridge
Silicious Marcellus
97 ft
Clay Marcellus
intraformational limestone
Marcellus Formation
Lycoming County
7000
7100
Union Springs
Selinsgrove
Needmore

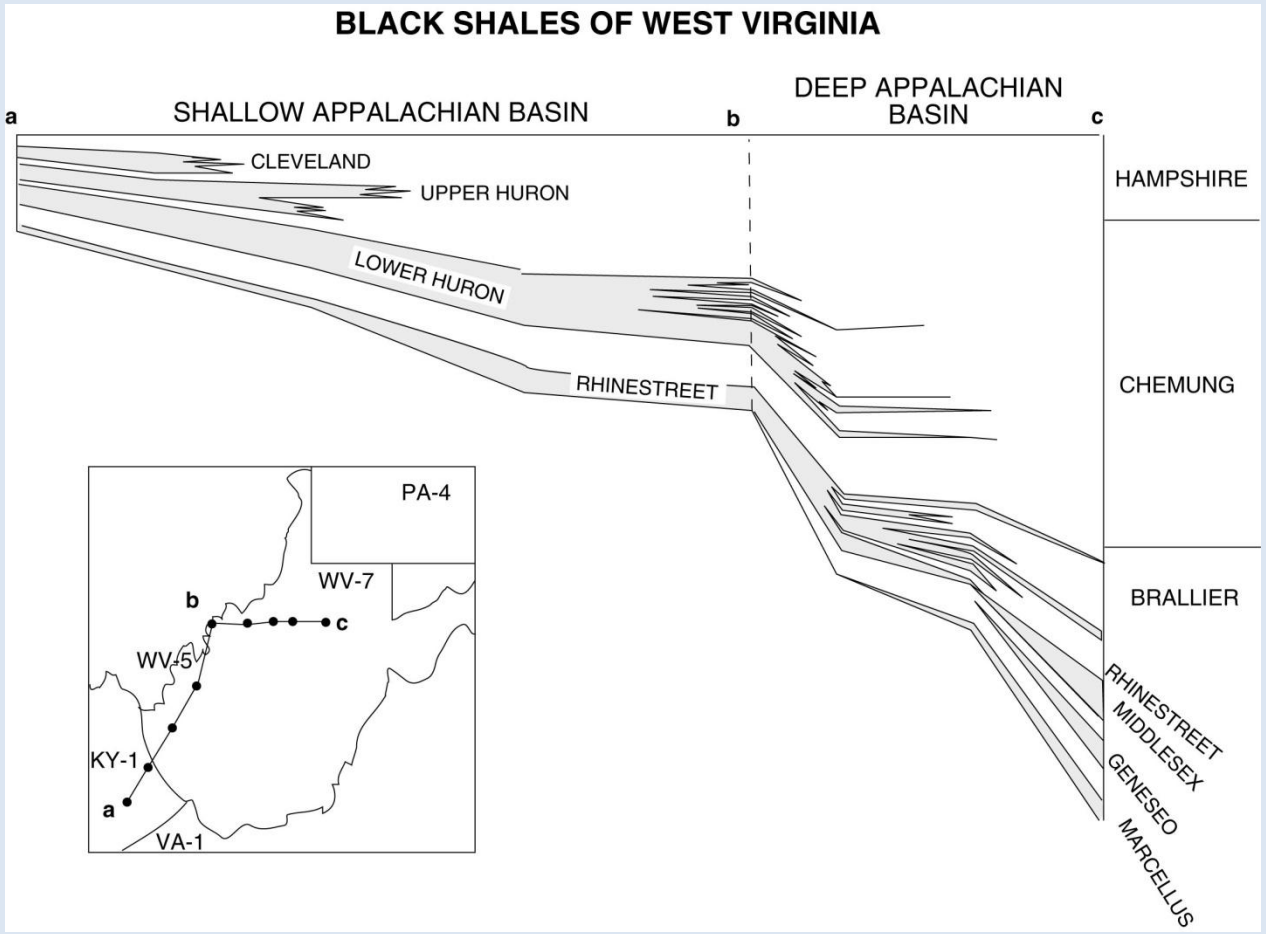

SW
NE
MISS.
DEVONIAN
Tournaisian
Famennian
Frasnian
Givetian
Eifelian
Emsian
Pragian
Sunbury
Cleveland
Huron - Dunkirk
Rhinestreet
Middlesex
Geneseo-Burket
Tully
Hamilton Group
Marcellus
Onondaga
Esopus
Oriskany
Price-Pocono
Catskill Delta
Clastic Wedge
Fourth
Tectophase
Third
Tectophase
Second
Tectophase
First
Tectophase
black shale
gray shale and
silt/sandtone
limestone
missing section
unconformity
from Ettsenohn (1994)

Approximate aerial distribution of the successive black-shale units

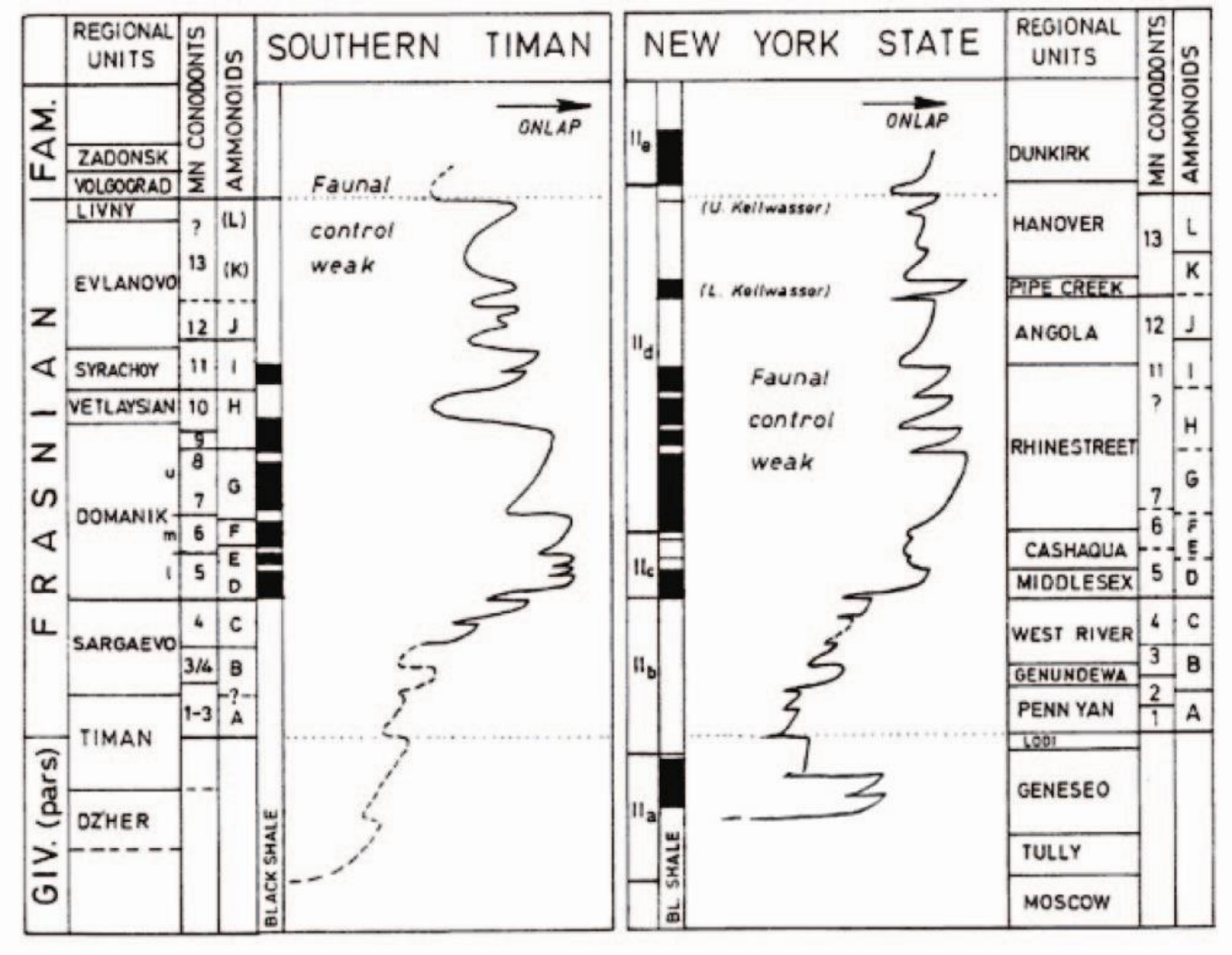


westward and southward migration as a consequence of the dextral transpressive nature of the boundary between Laurentia and Avalon

Cross section of Devonian stratigraphy through West Virginia

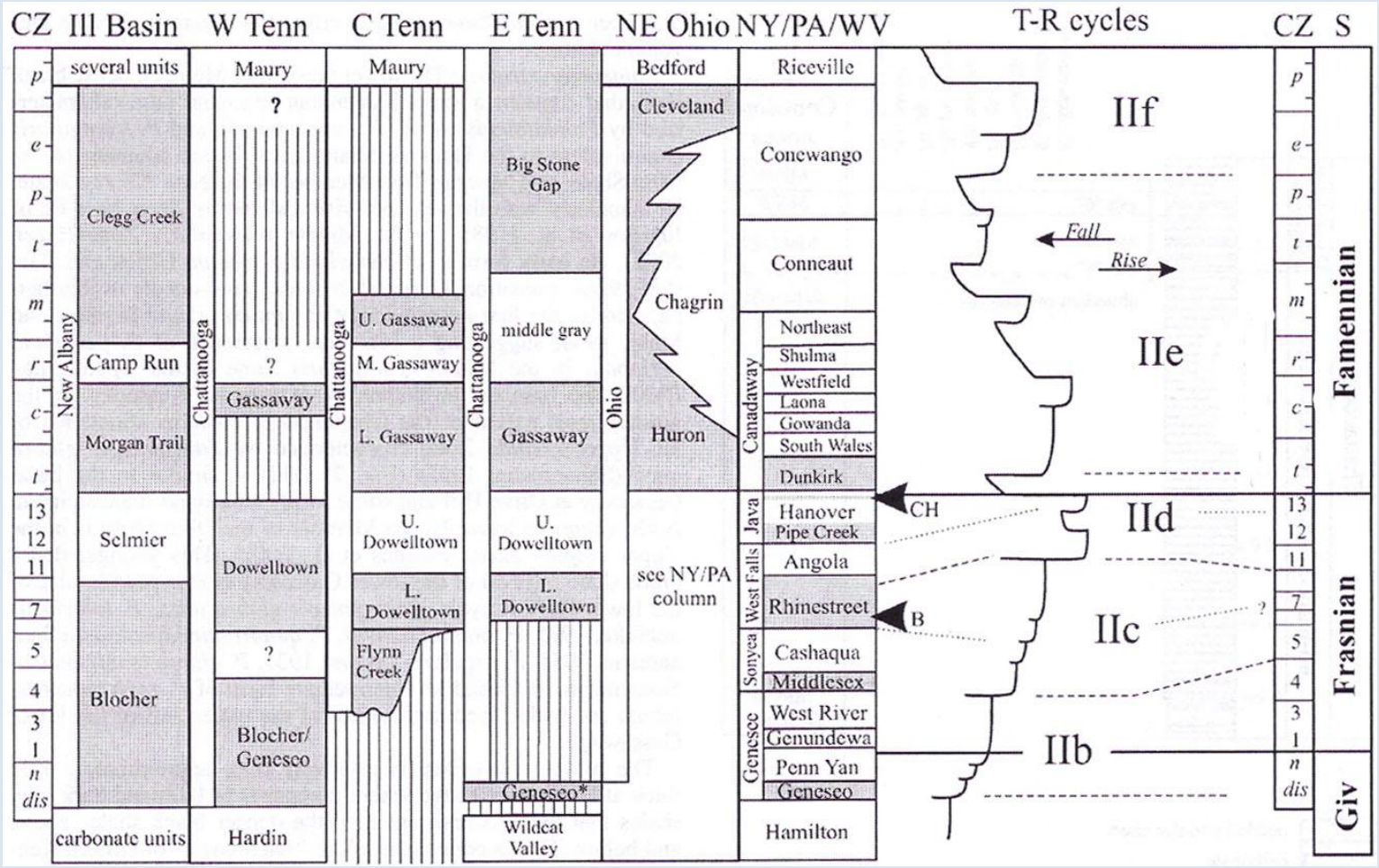


Third order sequences of the Uralian foreland and the Catskill Delta



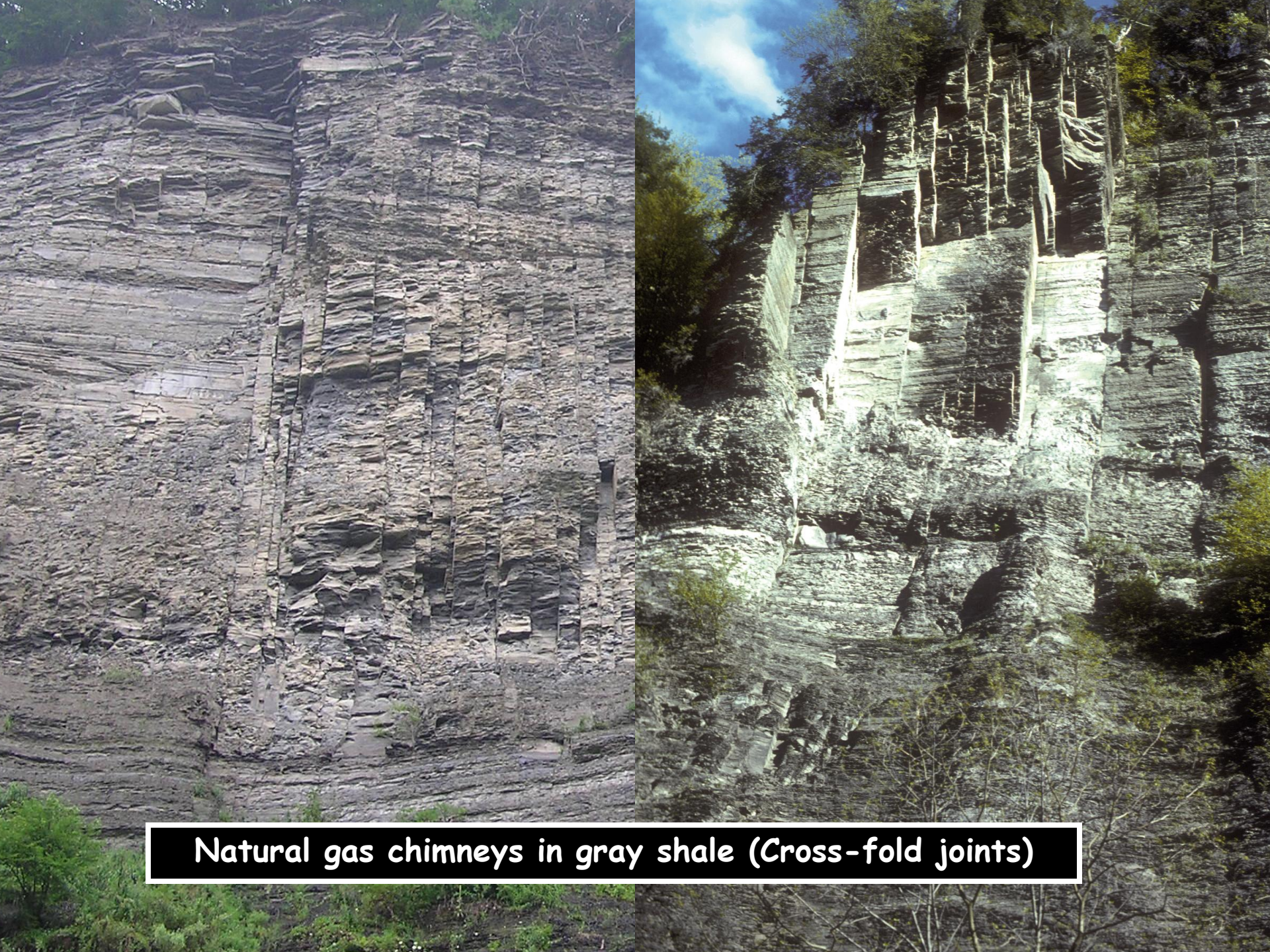
House et al., 2000

A correlation chart for the black shales of eastern North America



25 million year amalgamation

Over, 2007



Natural gas chimneys in gray shale (Cross-fold joints)