[AV]Deformation in the Appalachian Foreland: Detachment Structures in the Basal Marcellus Shale, Central New York*

Bruce Selleck[1]

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Abstract

Deformation in the basal Marcellus Subgroup (Union Springs, Cherry Valley and Oatka Creek Formations) is of interest to developers of gas resources in the Appalachian foreland of New York and Pennsylvania. Road cut and quarry exposures in a 180-km along-strike zone in the Marcellus outcrop belt document a recurrent pattern of north -directed overthrusting. These detachment structures are present in areas lacking subsurface Silurian salt (Cherry Valley, (Bosworth, 1984), and Oriskany Falls, NY), and to the west where salt is present (northern Cayuga Lake Valley). Detachment is localized within the 25-60 ft-thick Union Springs, and within bentonite horizons in the underlying Onondaga Formation. Horizontal motion in the Union Springs was accommodated within carbonaceous shale, with striated and polished surfaces developed on stiffer, bounding carbonate units. Carbonate beds are cut by ramp faults with cm- to m-scale displacement. Shale layers are thickened to form imbricate, cleaved and polished shale 'wads'. Black shale of the overlying Oatka Creek Formation lacks evidence of thrust-related deformation at the detachment fault localities; however, vertical jointing is intensified and may provide enhanced permeability. Fractures and mineralized veins in the décollement zones provide important constraints on the timing of motion relative to hydrocarbon maturation. Veins document two major episodes of mineralization; early calcite- and quartz-crystal growth occurred during evolution of fluid hydrocarbons; a second phase of calcite-dolomite mineralization was accompanied by emplacement of high-reflectance bitumen in vein pore space. Veins preserve significant vuggy porosity. Fluid inclusion and stable isotope data indicate temperatures of mineralization ranged from 145-160^{o}C in the eastern site (Cherry Valley) to 120-135 ^{o}C in the western (Cayuga Lake) site. Hydrocarbon-rich fluid inclusions in quartz are common.

Carbonate stable isotopes are consistent with mineral precipitation from an aqueous phase in equilibrium with the carbonate units of the Union Springs Formation.

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Décollement systems in the Onondaga and basal Marcellus may be recognized in seismic and well-log data. Based on outcrop observations, these faults should form zones of enhanced porosity and permeability within the Marcellus hydrocarbon system and are accessible targets for horizontal development.

References

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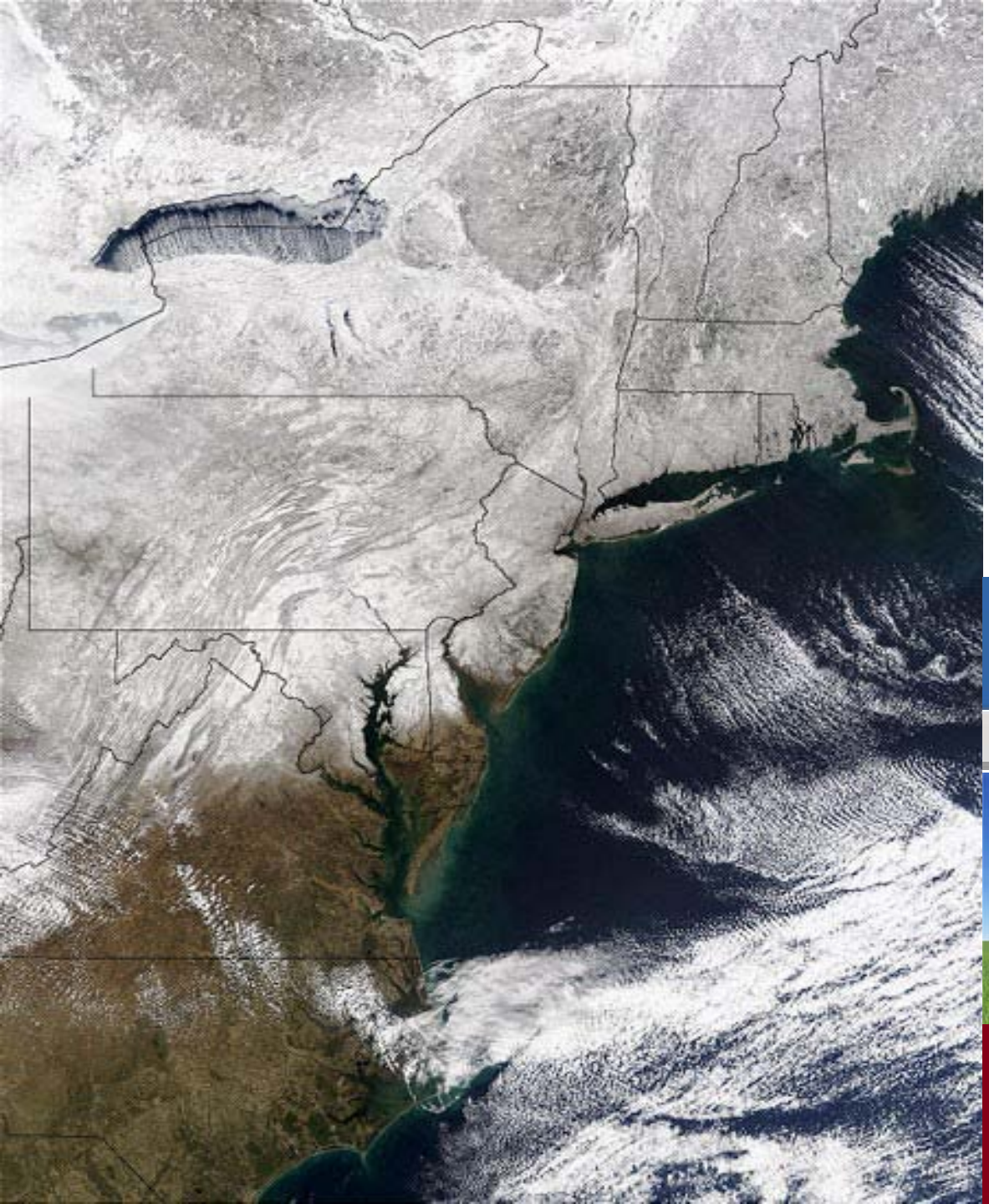

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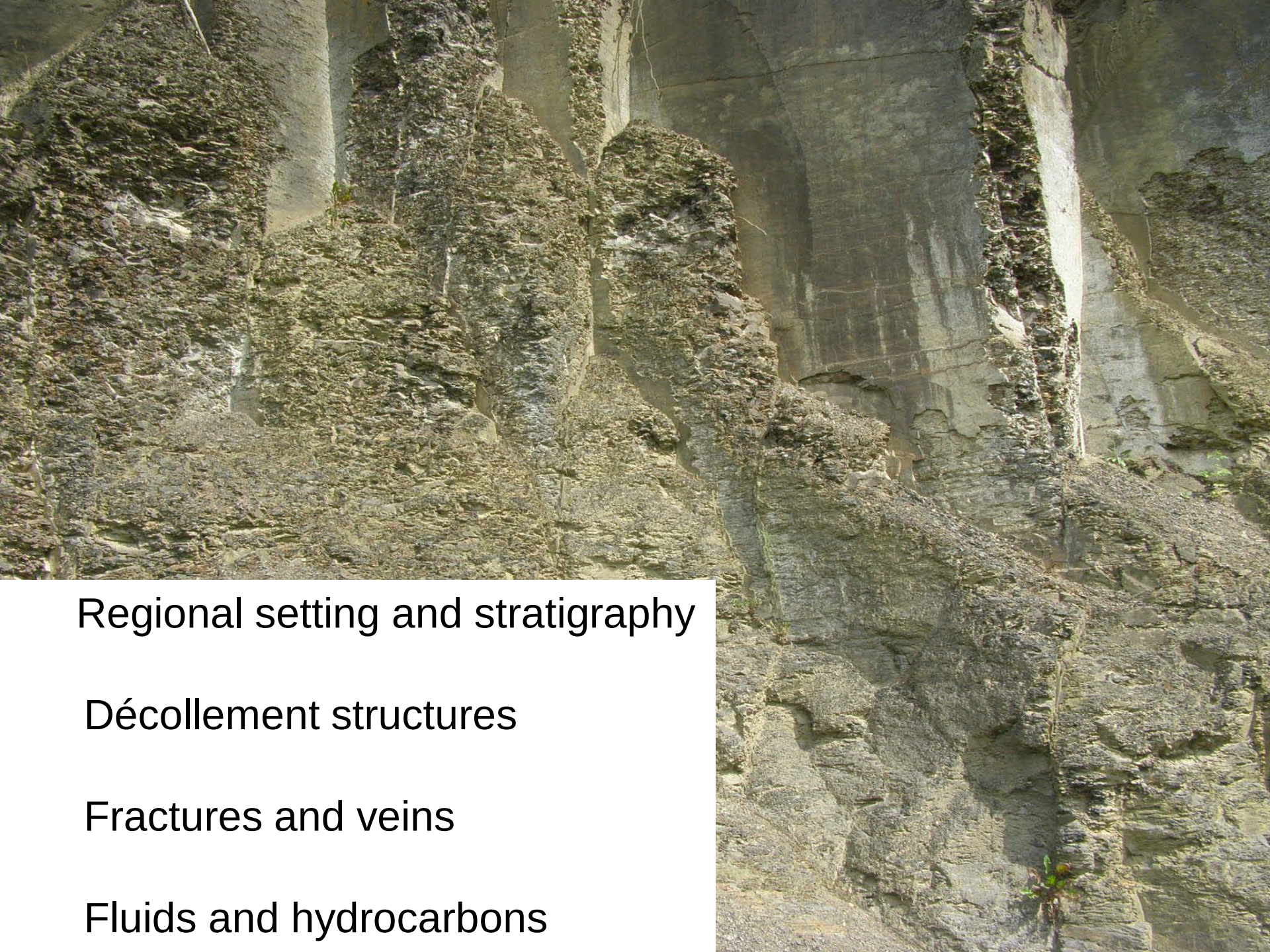
Colgate University

Thanks to:

Fronterra Geosciences, Cabot Oil and Gas, Hanson Aggregates Inc. , Seneca Stone Corp.

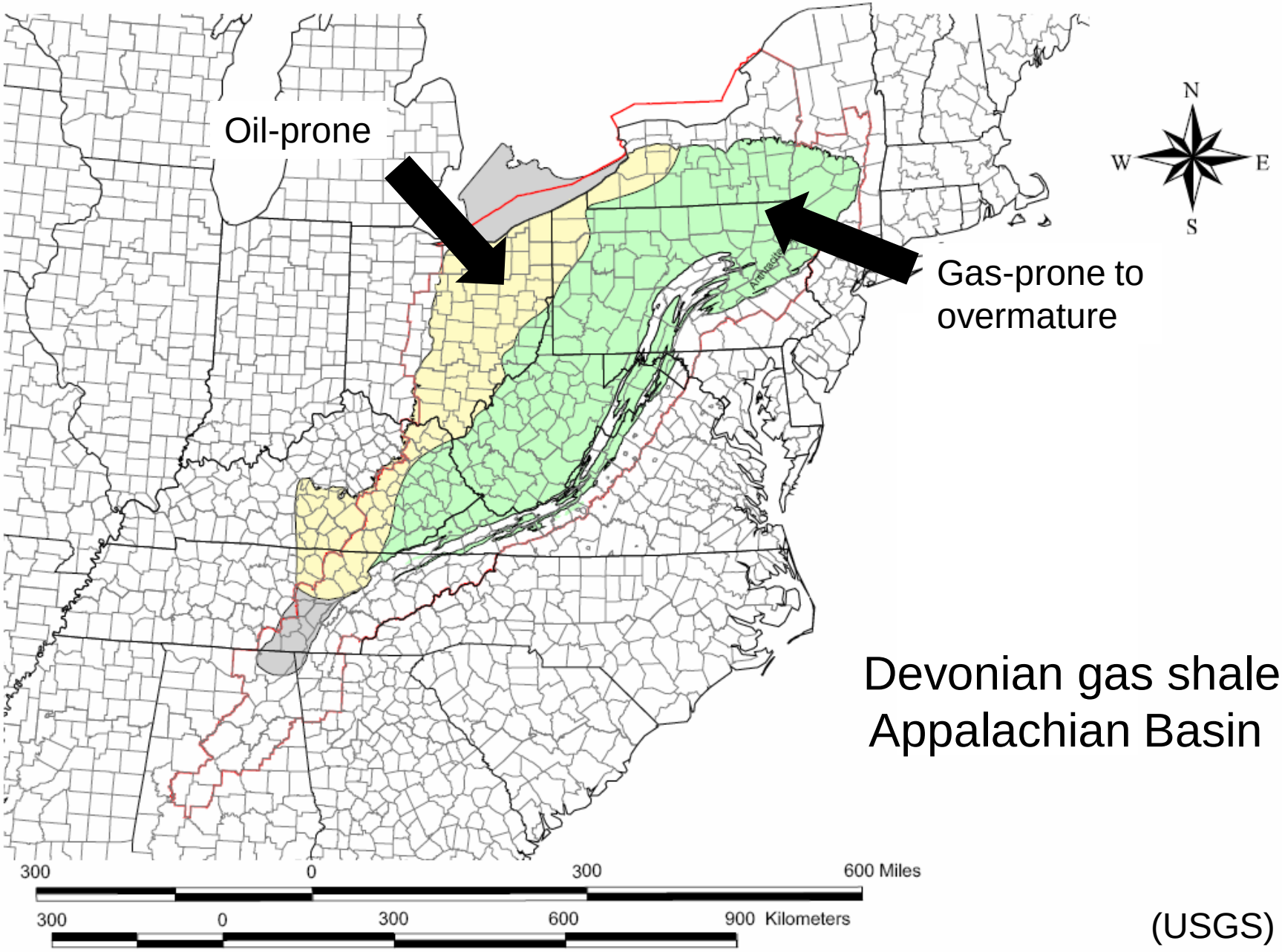


Regional setting and stratigraphy

Décollement structures

Fractures and veins

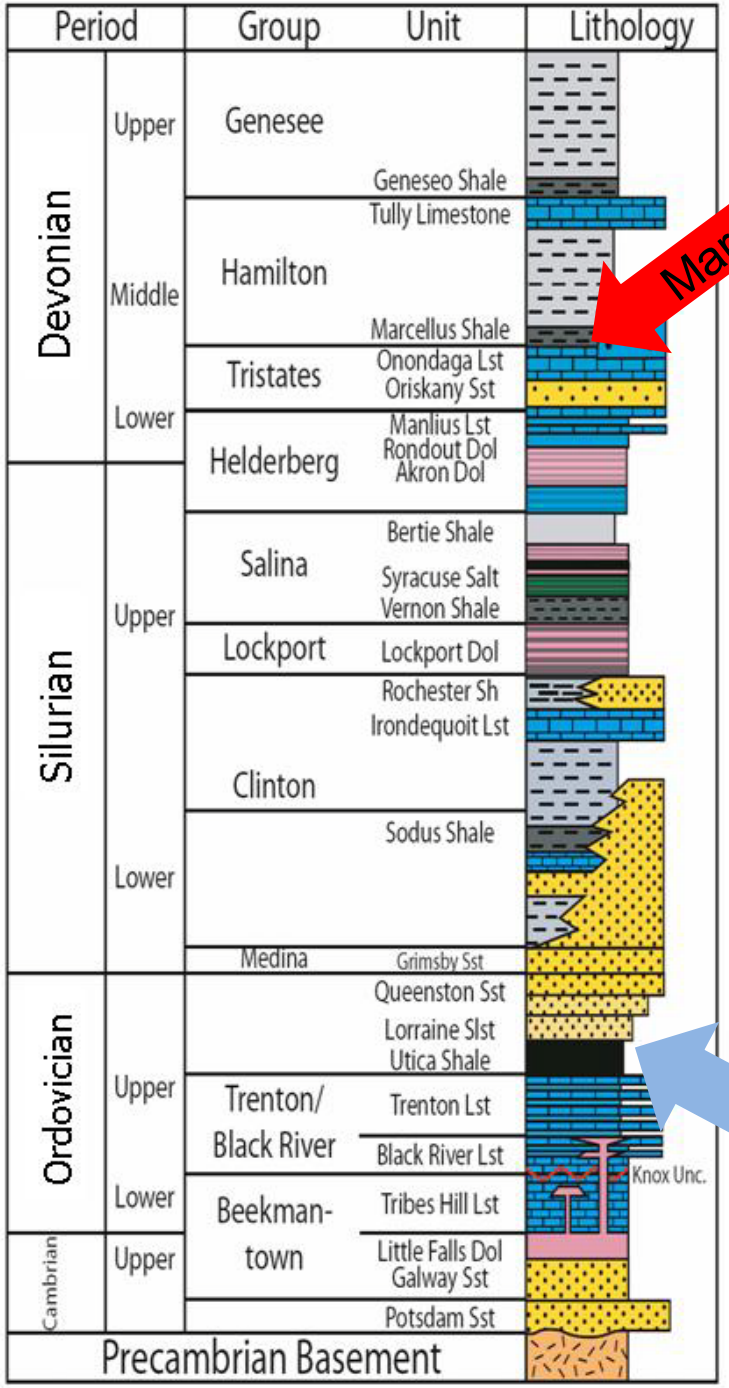
Fluids and hydrocarbons

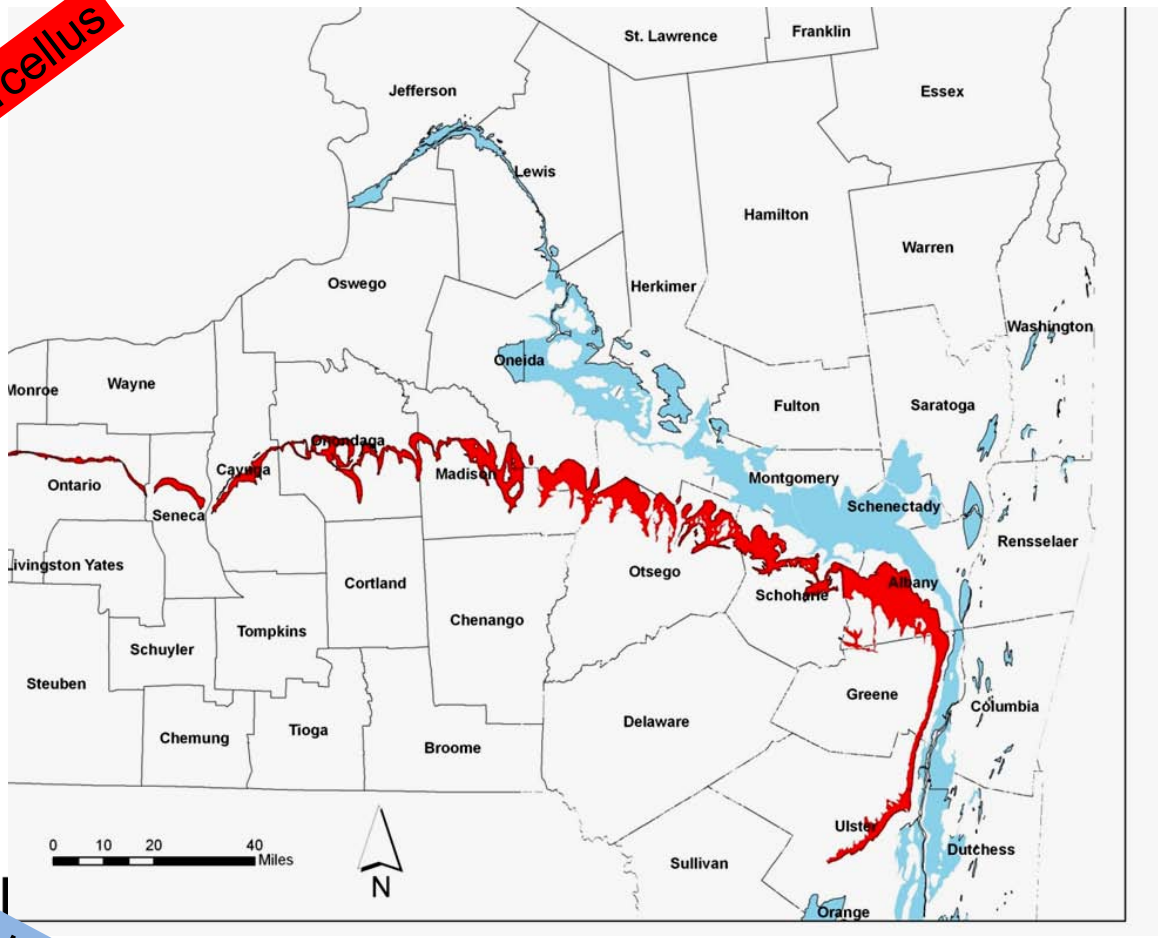


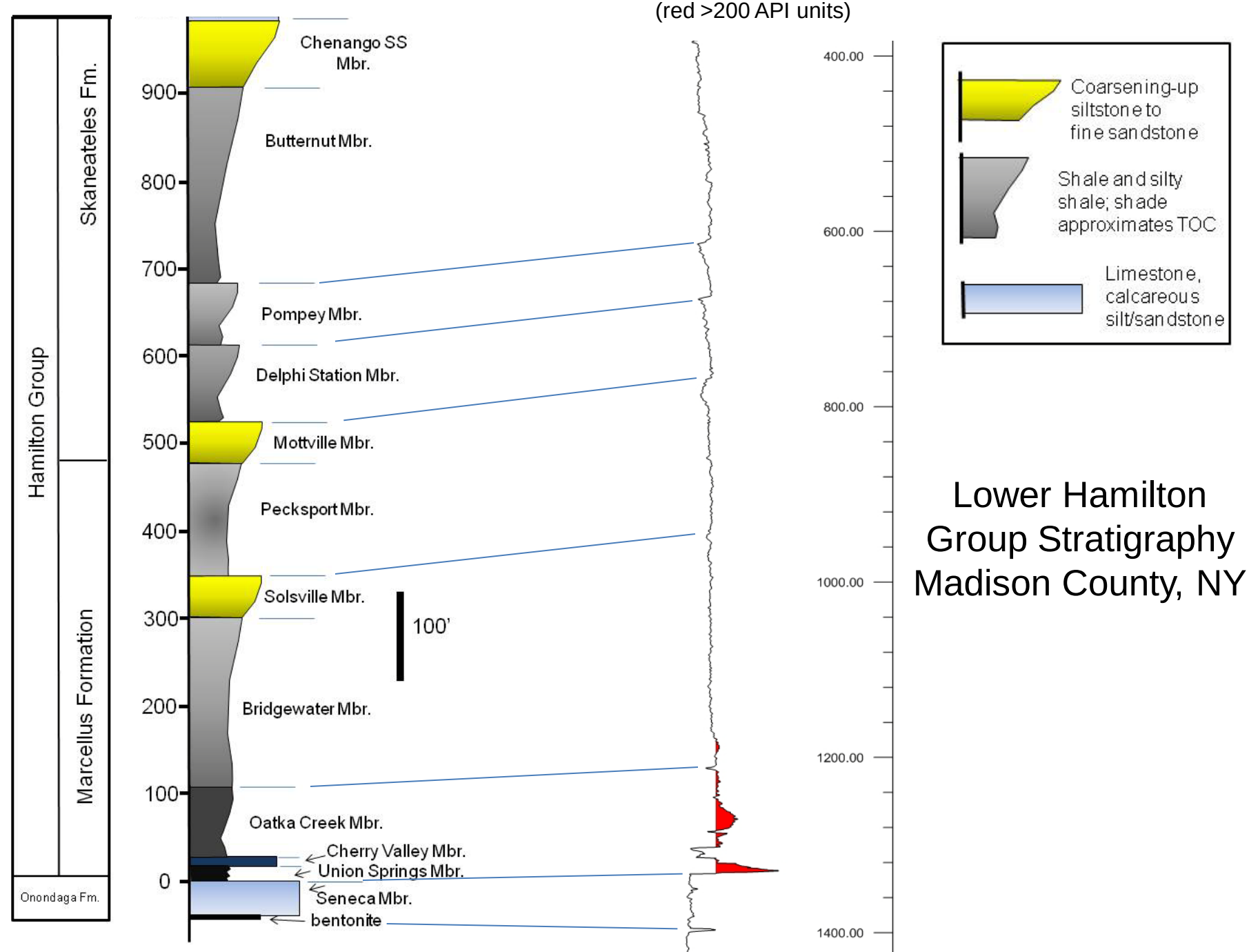
Devonian gas shale
Appalachian Basin

(USGS)

New York's gas shale units






Outcrop (Cooper, 1934, Rickard, 1984)
Gapski 1 GR (southern Madison Co., NY)
(red >200 API units)
Hamilton Group
Skaneateles Fm.
Marcellus Formation
Onondaga Fm.
Chenango SS Mbr.
Butternut Mbr.
Pompey Mbr.
Delphi Station Mbr.
Mottville Mbr.
Pecksport Mbr.
Solsville Mbr.
Bridgewater Mbr.
Oatka Creek Mbr.
Cherry Valley Mbr.
Union Springs Mbr.
Seneca Mbr.
bentonite
900
800
700
600
500
400
300
200
100
0
100'
400.00
600.00
800.00
1000.00
1200.00
1400.00
Coarsening-up siltstone to fine sandstone
Shale and silty shale; shade approximates TOC
Limestone, calcareous silt/sandstone
Lower Hamilton Group Stratigraphy Madison County, NY

Marcellus Formation (=Marcellus Subgroup)

Oatka Creek Member

Cherry Valley Member =~10’

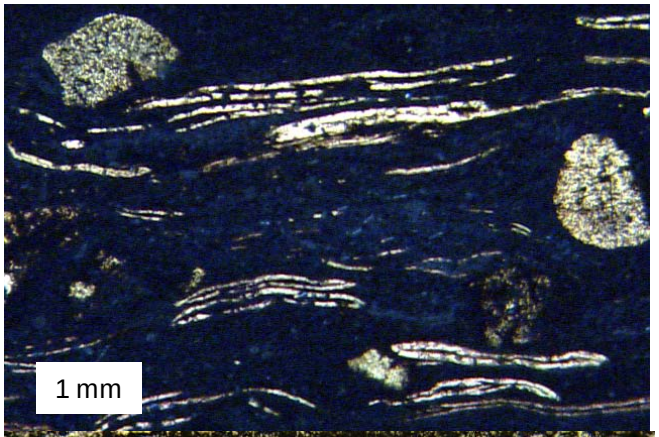
Union Springs Member =30’

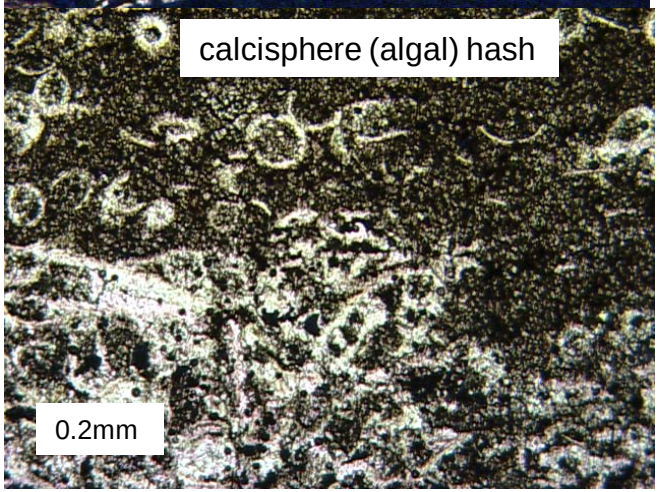
Onondaga Fm.

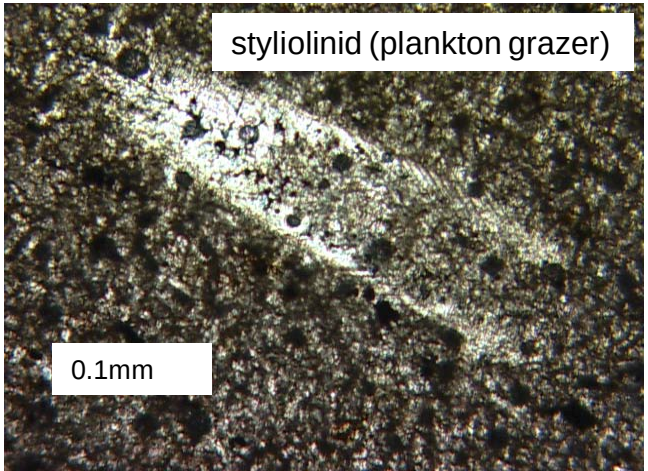
Seneca Member =~25’

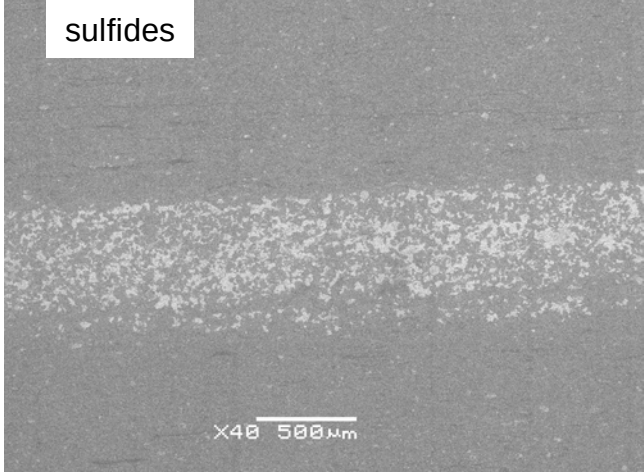
Moorehouse Member

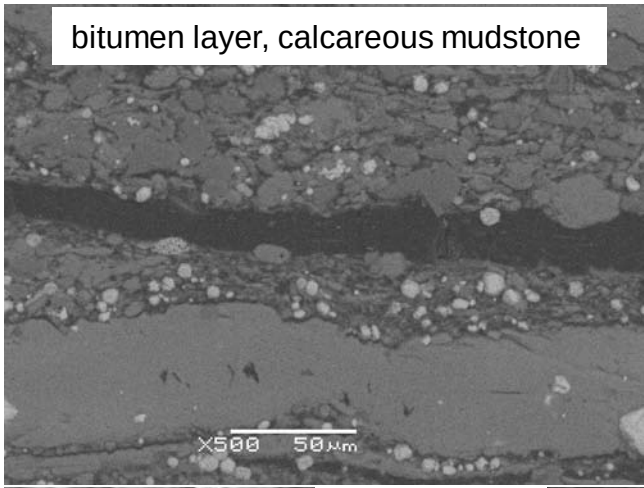
brach-crinoid - sargassum-like epiplanktic?

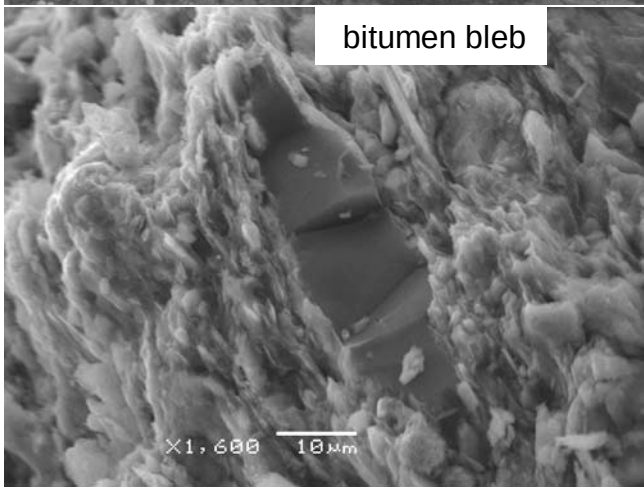












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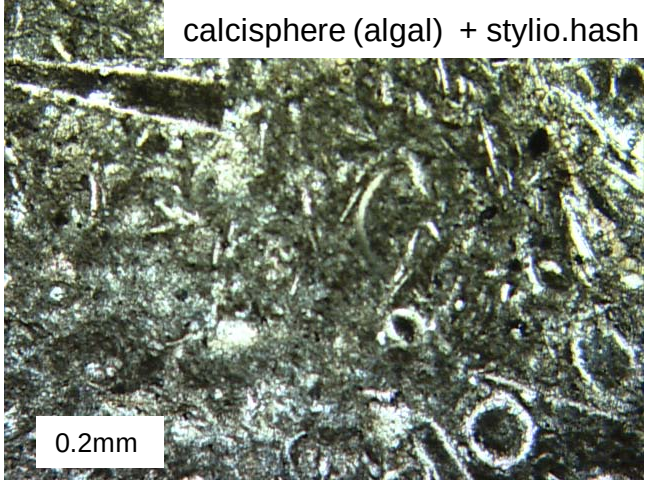
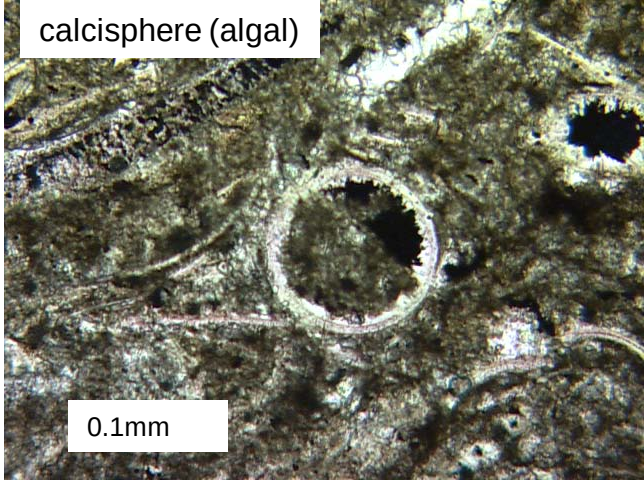
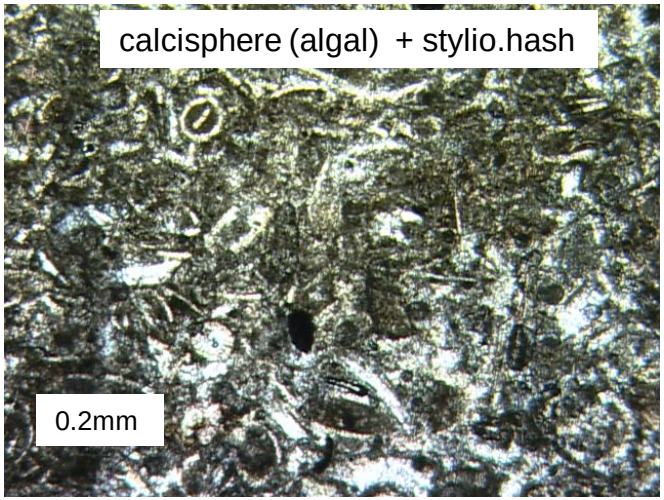
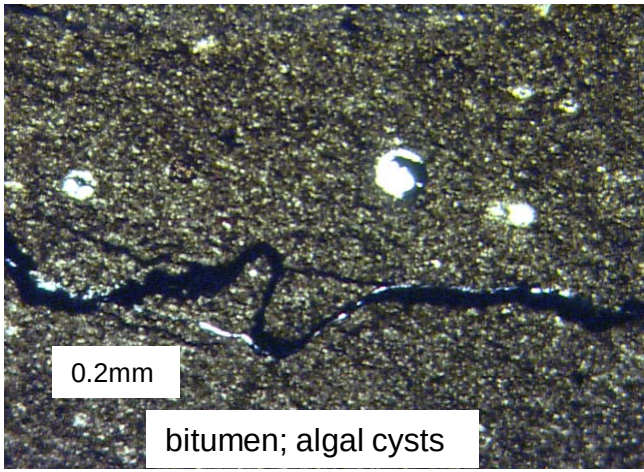
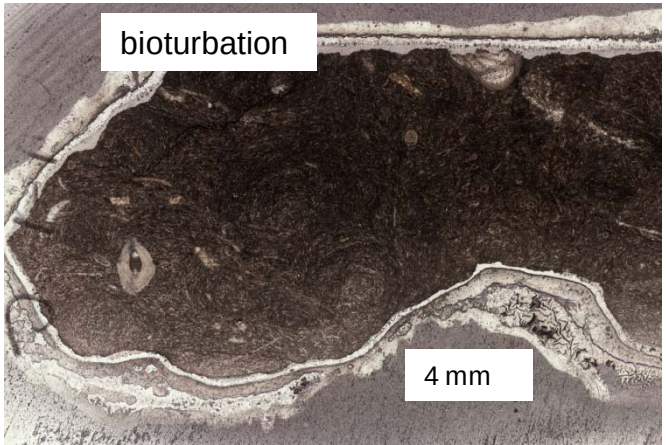
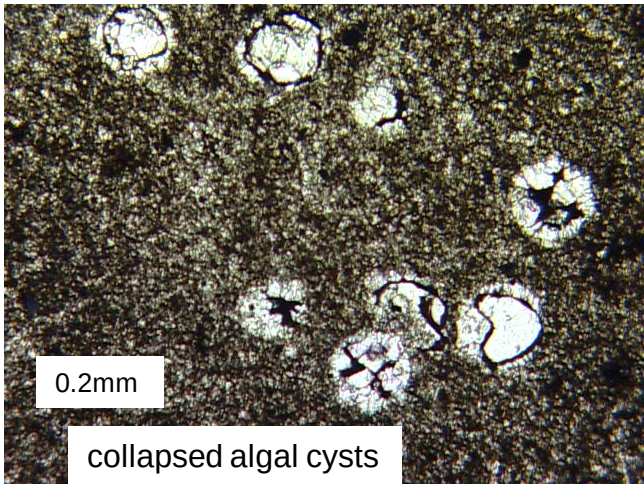


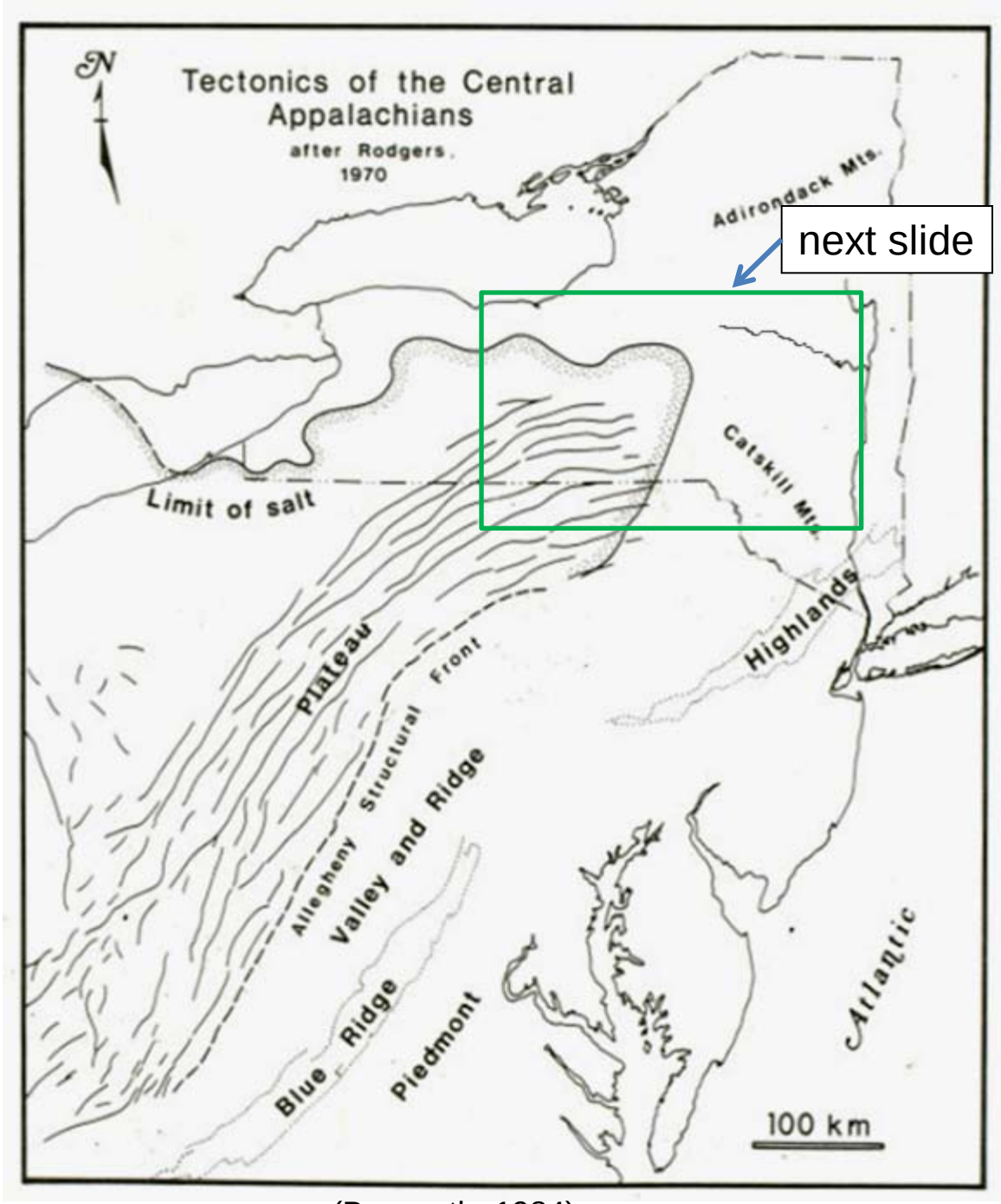










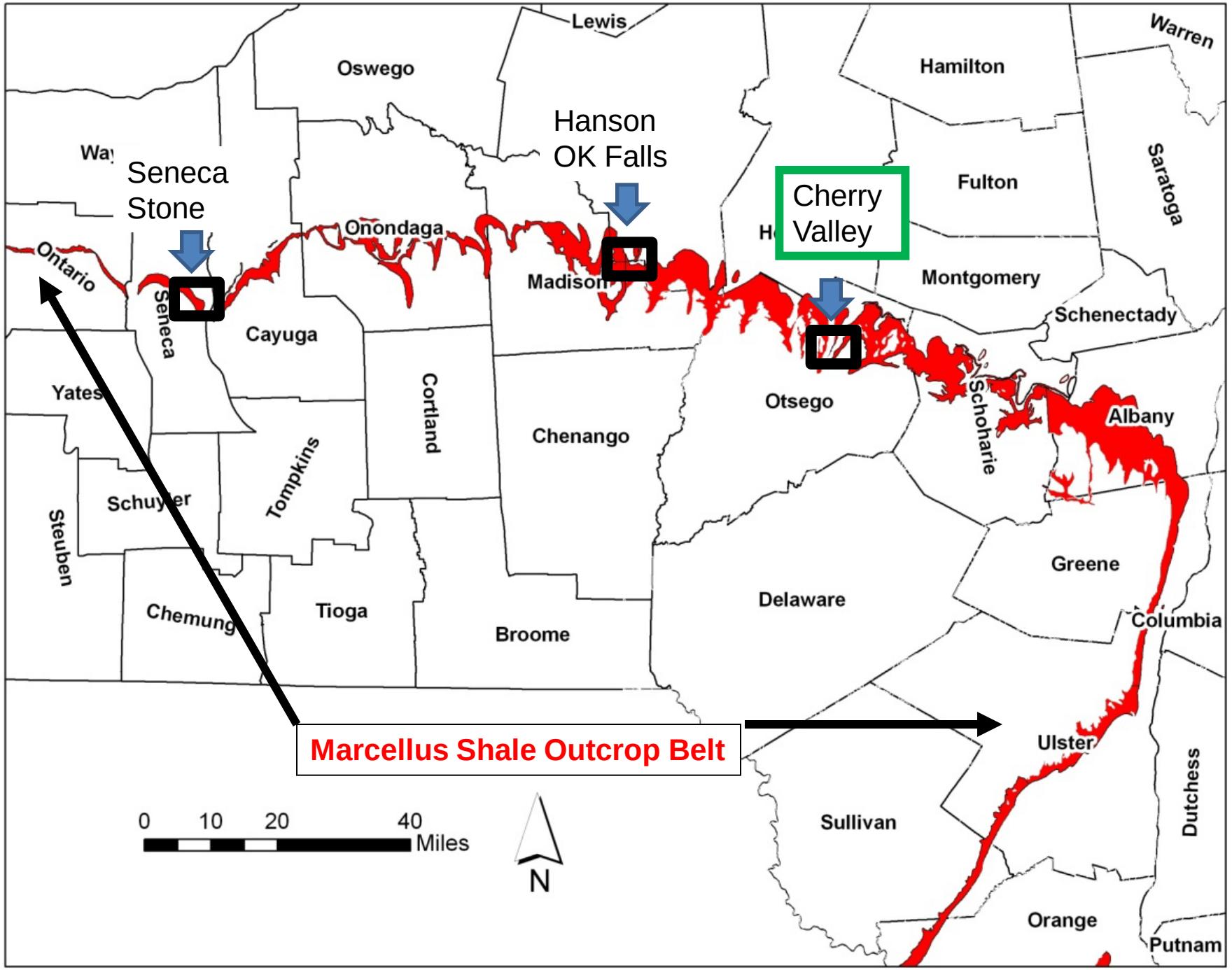


(Bosworth, 1984)

In the Appalachian Plateau Province, most detachment structures develop within the Silurian Salina Group salt beds.

However, duplex structures and cleavage development in the Marcellus Formation has been recognized for some time.

e.g. Bosworth, 1984
Nickelsen, 1986
Evans, 1994


Seneca
Stone
Hanson
OK Falls
Cherry
Valley
Marcellus Shale Outcrop Belt
Lewis
Oswego
Hamilton
Warren
Fulton
Saratoga
Onondaga
Ontario
Madison
Montgomery
Schenectady
Seneca
Cayuga
Yates
Cortland
Chenango
Otsego
Schoharie
Albany
Tompkins
Steuben
Schuyler
Greene
Delaware
Columbia
Chemung
Tioga
Broome
Ulster
Sullivan
Dutchess
Orange
Putnam
0 10 20 40 Miles
N

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Onondaga Fm.

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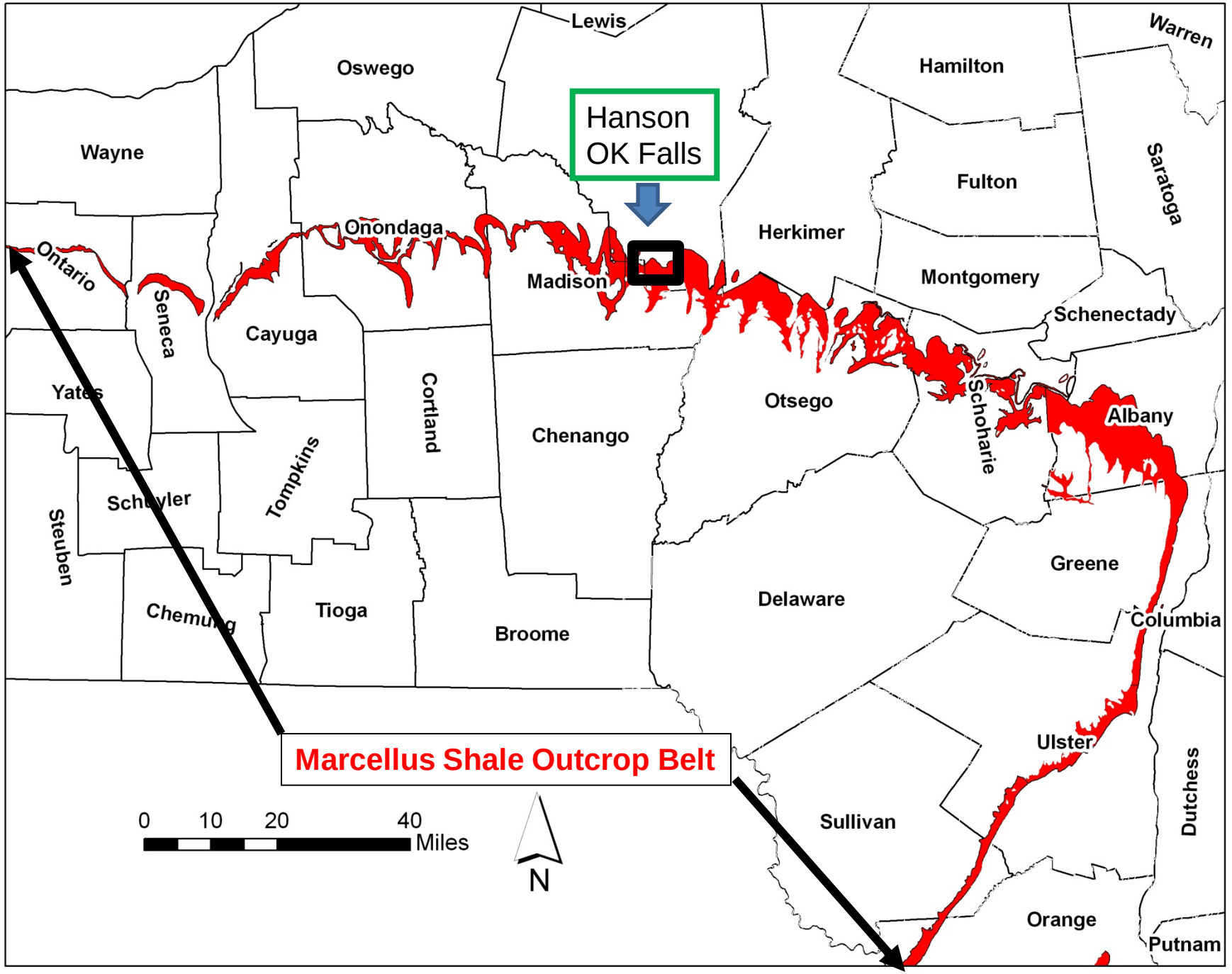
Moorehouse Member

dm-scale thrust displacement on south dipping ramp, Cherry Valley Member

Cleavage duplex structures described here by Bill Bosworth in 1984


Lewis
Oswego
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Hamilton
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Onondaga
Herkimer
Ontario
Madison
Montgomery
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Schenectady
Cayuga
Yates
Cortland
Otsego
Schoharie
Albany
Chenango
Tompkins
Schuyler
Steuben
Greene
Delaware
Chemung
Tioga
Broome
Columbia
Ulster
Sullivan
Dutchess
Orange
Putnam
Marcellus Shale Outcrop Belt
0 10 20 40
Miles
N

Hanson Quarry, Oriskany Falls, NY

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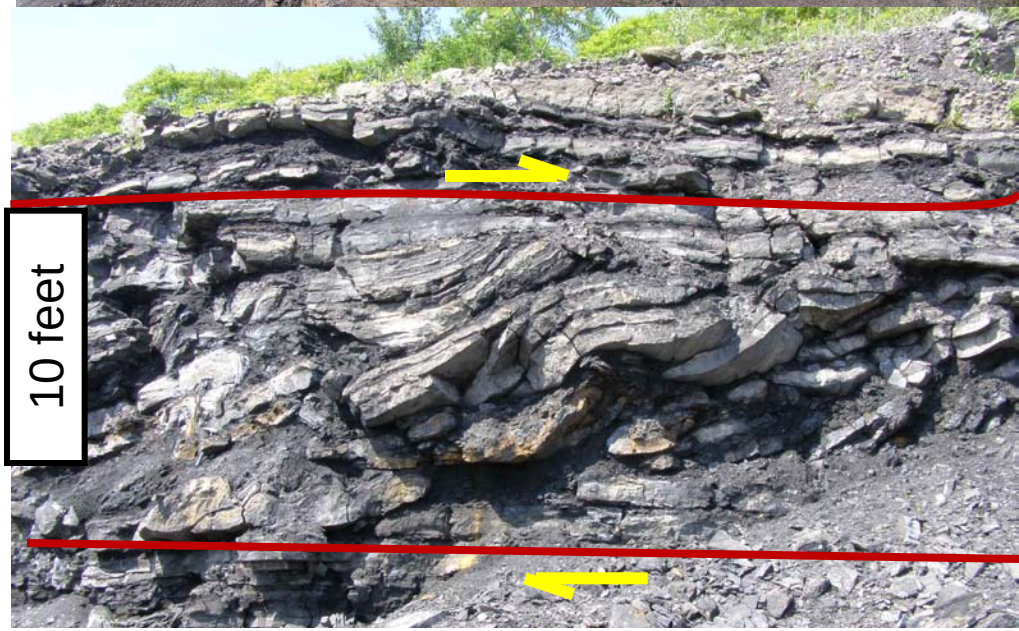
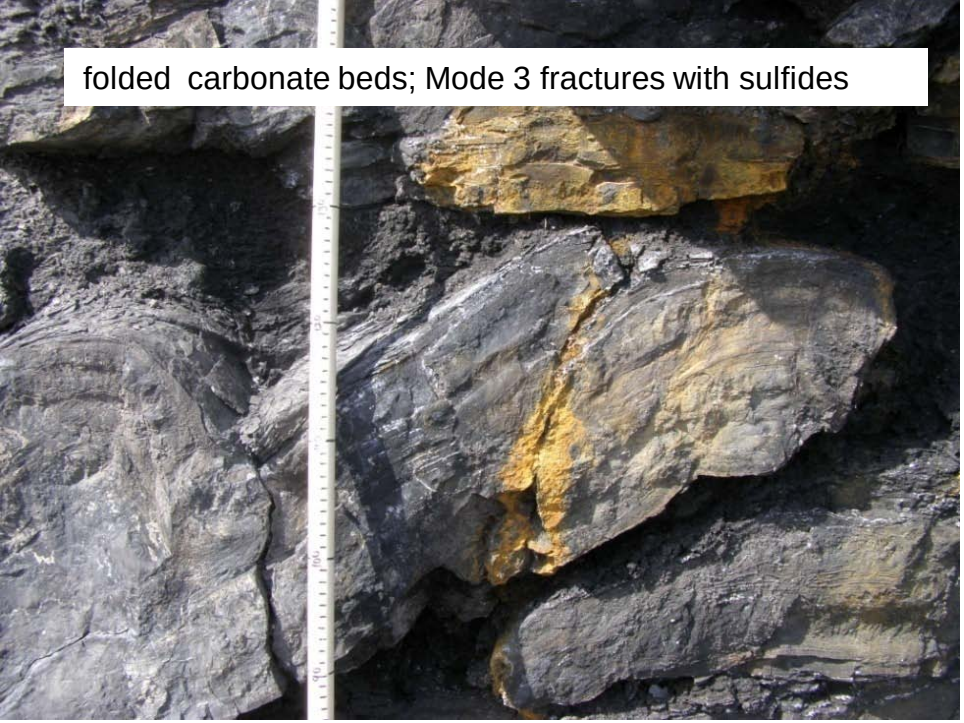


imbricate stacking of carbonate slabs and folding of carbonate beds - view looking west

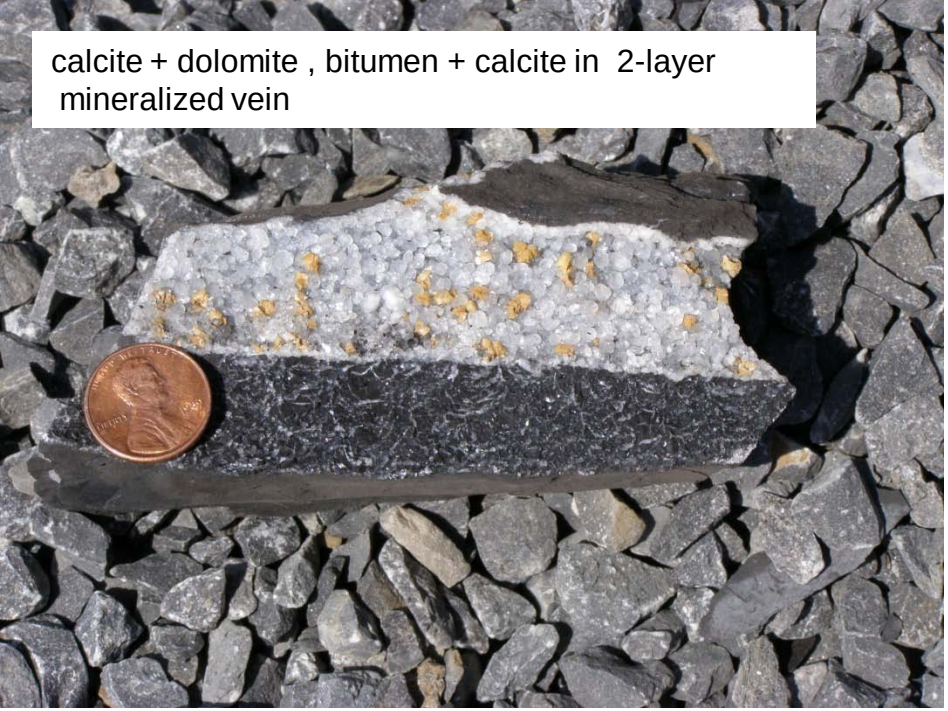


folded carbonate beds; Mode 3 fractures with sulfides

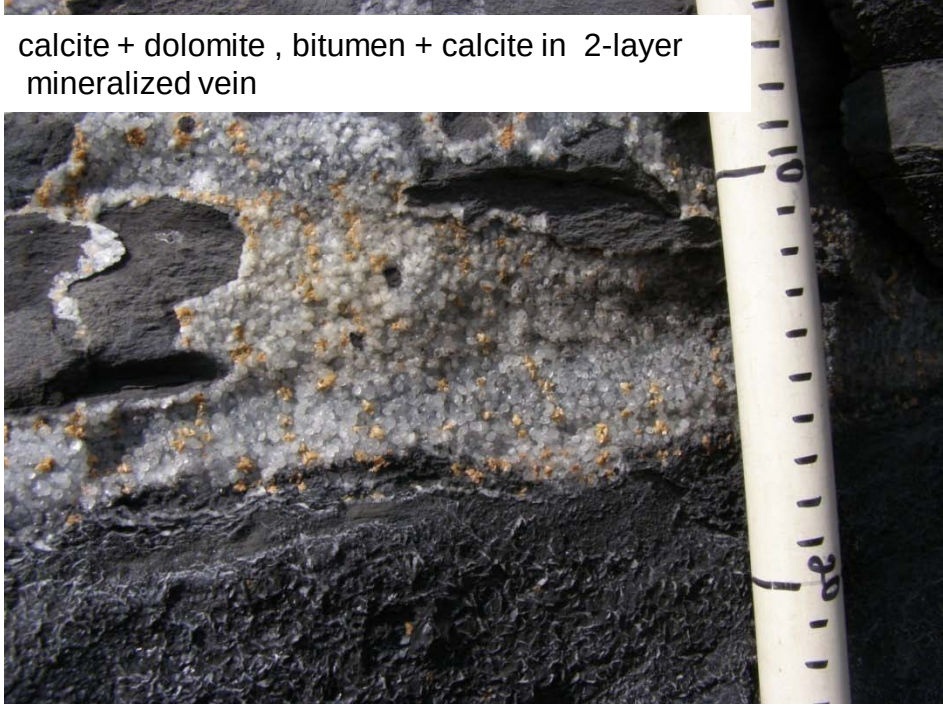
lineated, polished cleavage surface on carbonate bed

limestone masses in mudstone matrix

Mode 1 extension fractures - carbonate beds



calcite + dolomite , bitumen + calcite in 2-layer mineralized vein



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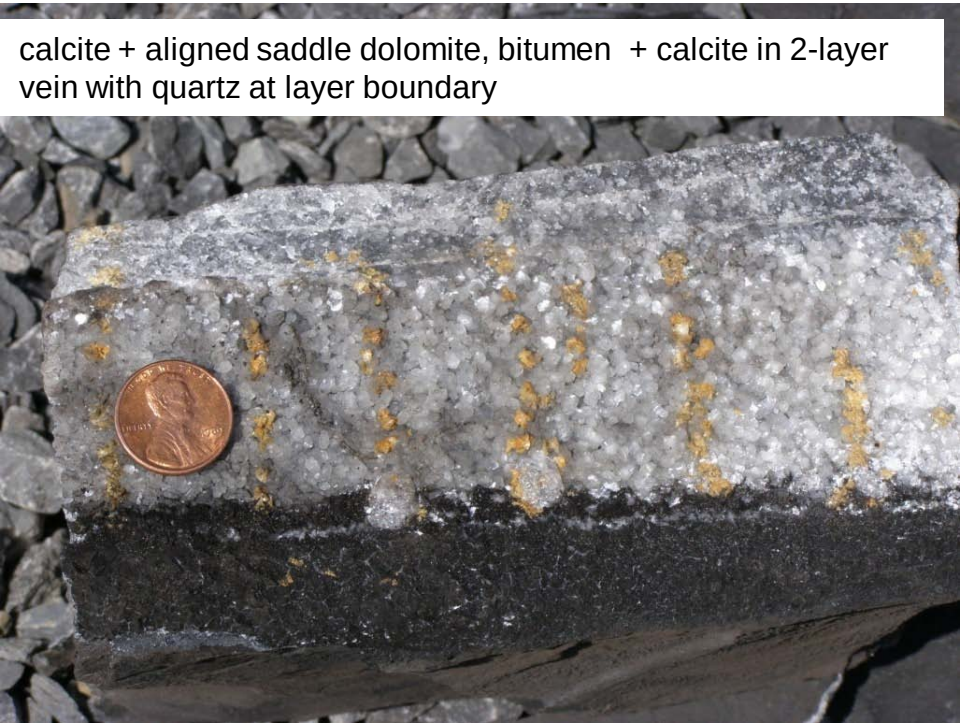
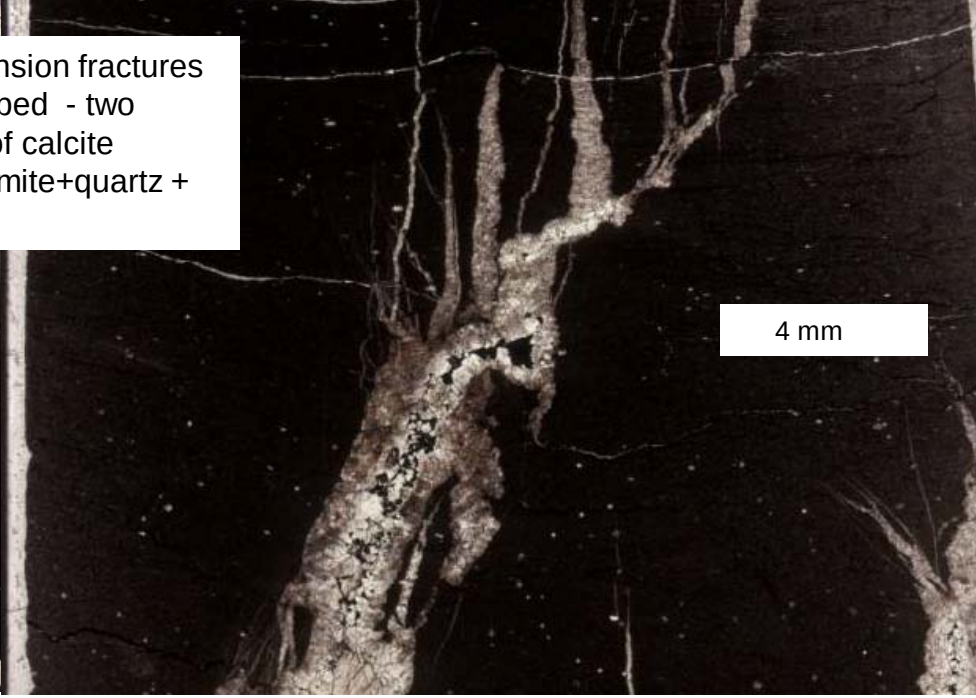
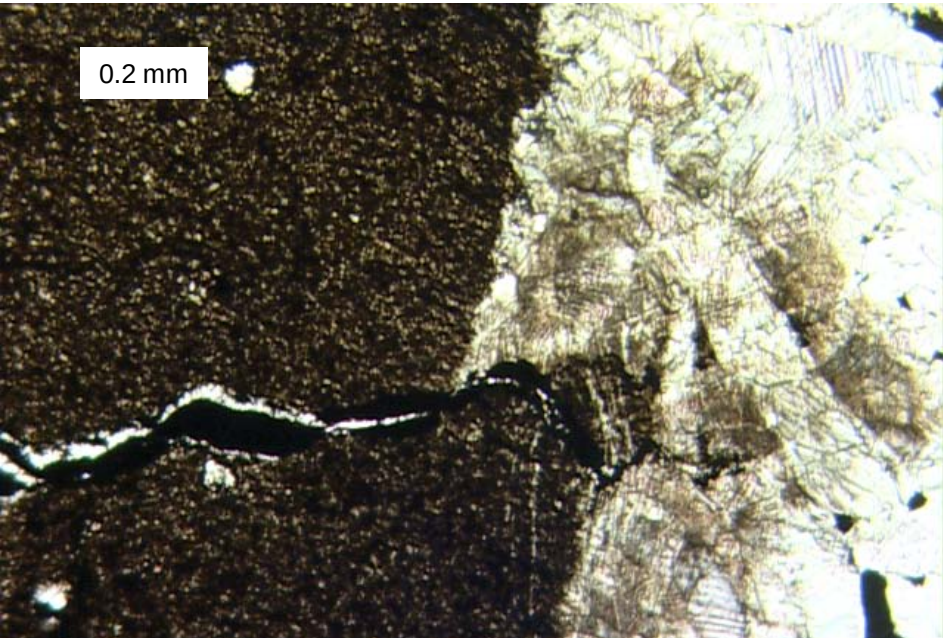


calcite + aligned saddle dolomite, bitumen + calcite in 2-layer vein with quartz at layer boundary

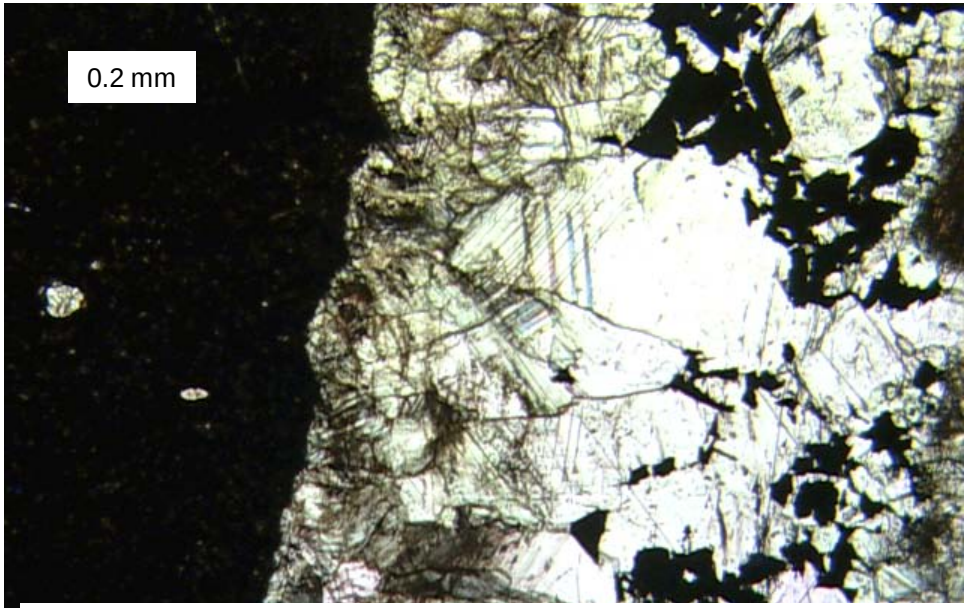
mineralized dilatent voids on bedding-plane fault surface

veins fill extension fractures in carbonate bed - two generations of calcite cement+dolomite+quartz + bitumen

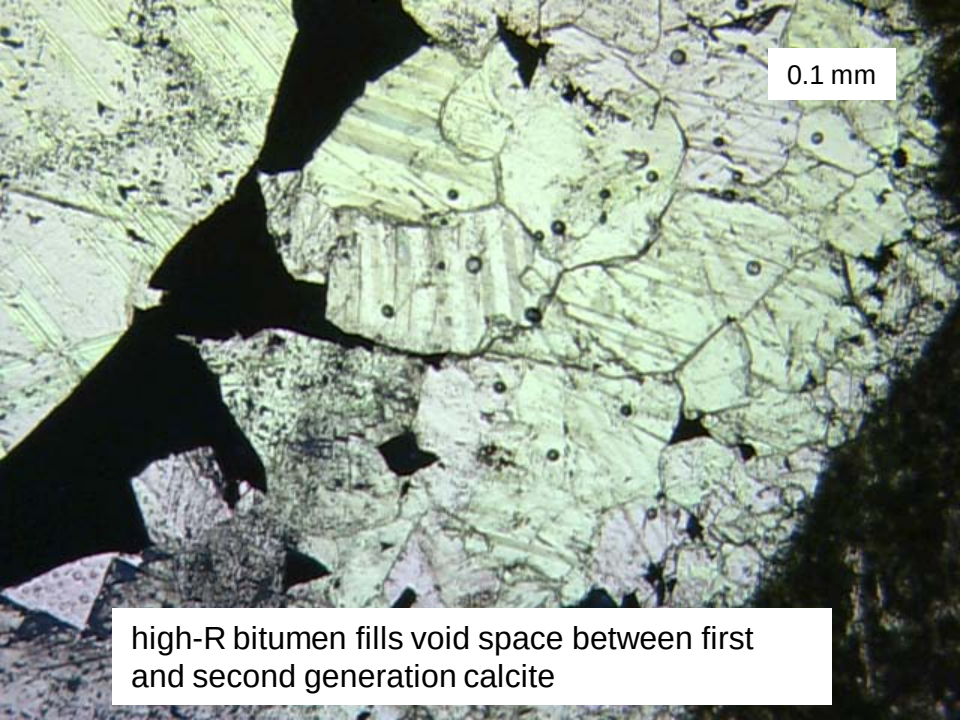




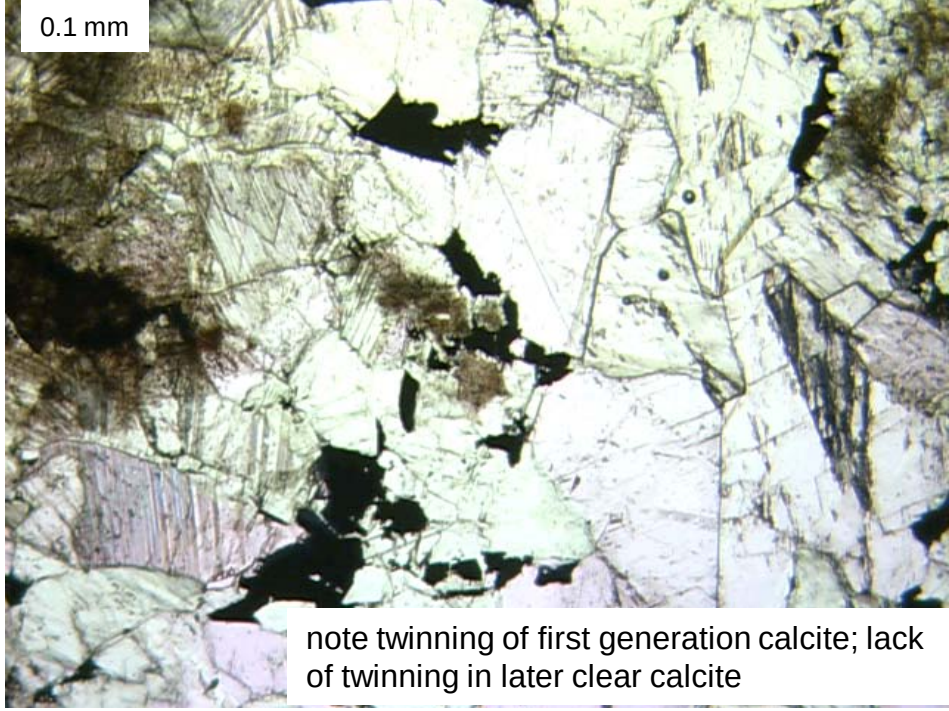
bitumen layer with calcite-filled shrinkage void intersects calcite vein; note brown staining of first-generation calcite cement



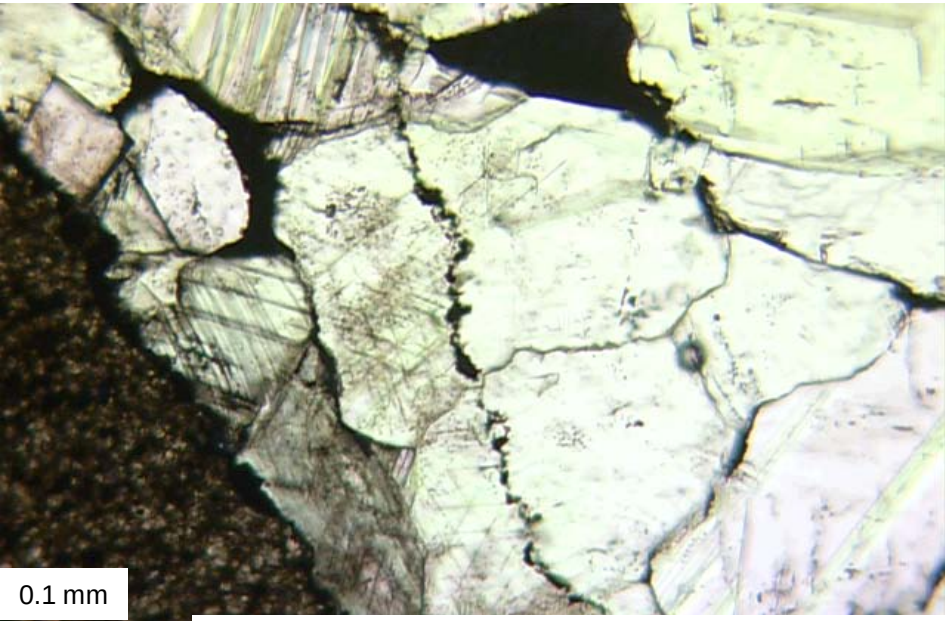
2 generations of calcite in vein; early generation stained by disseminated hydrocarbon; second generation clear and associated with high-reflectance (hi-R) bitumen (‘anthraxolite”)



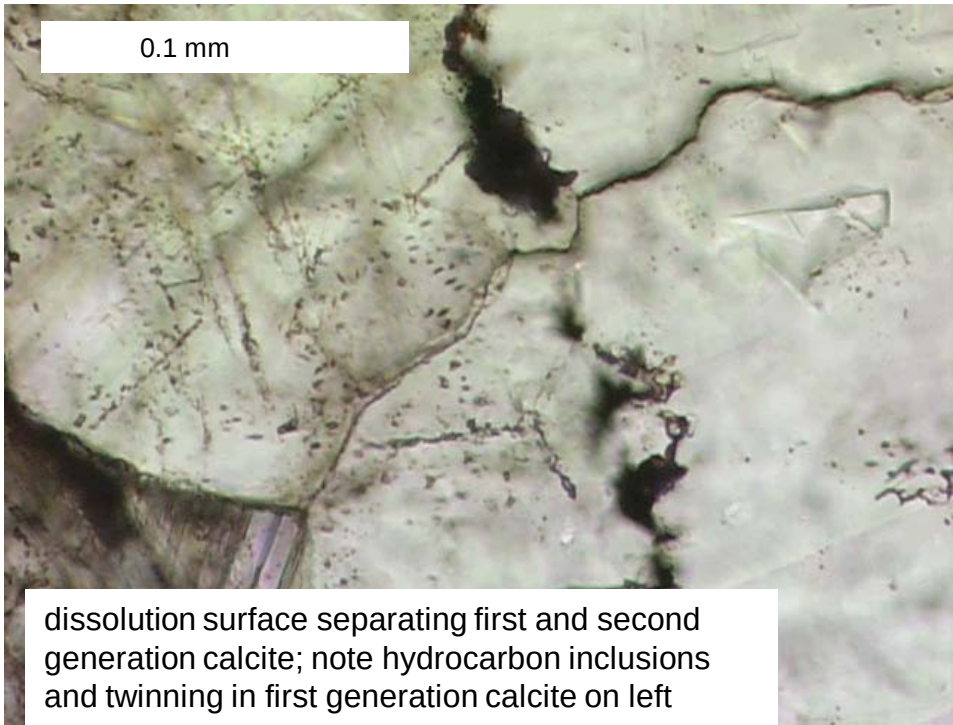
high-R bitumen fills void space between first and second generation calcite



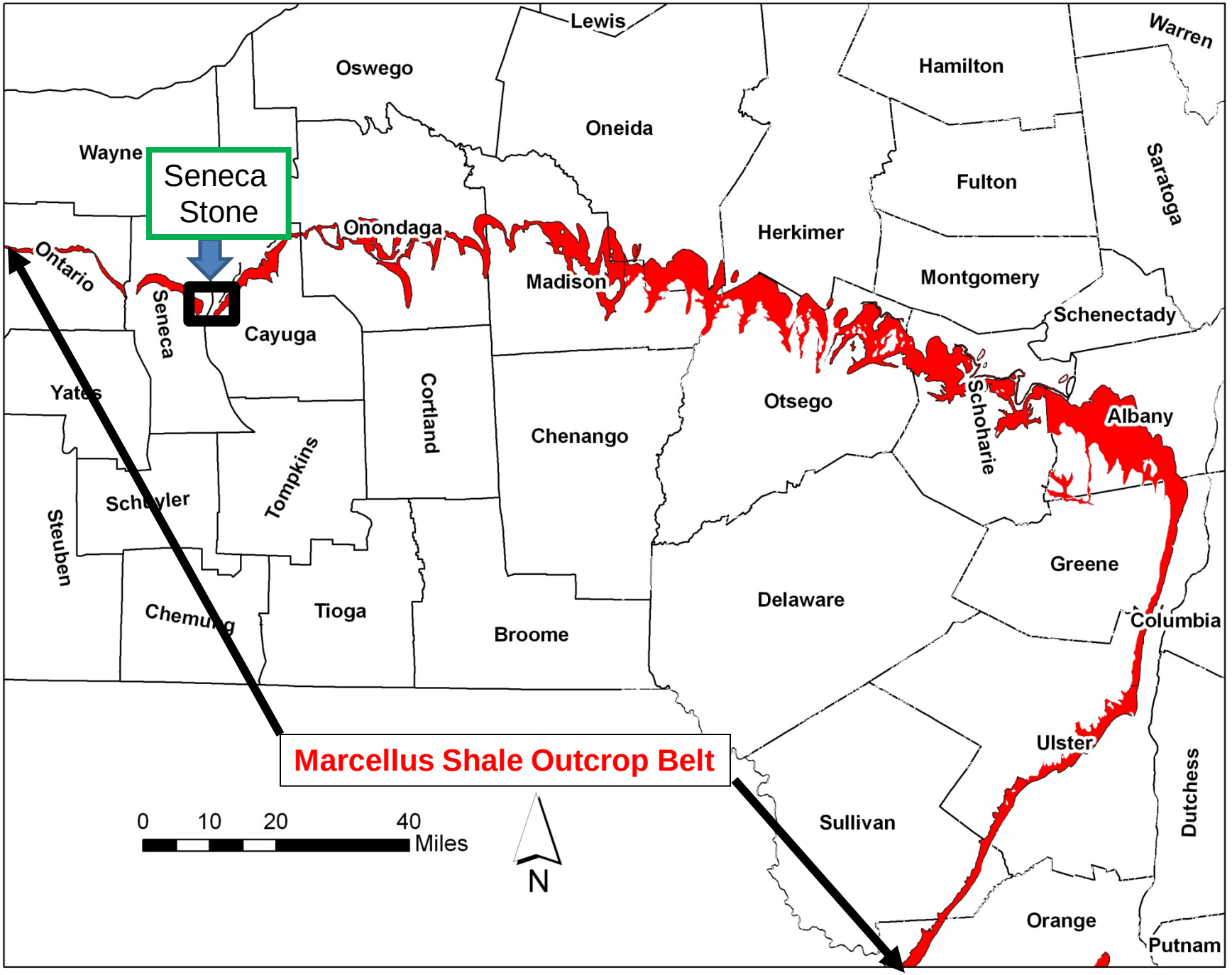
note twinning of first generation calcite; lack of twinning in later clear calcite



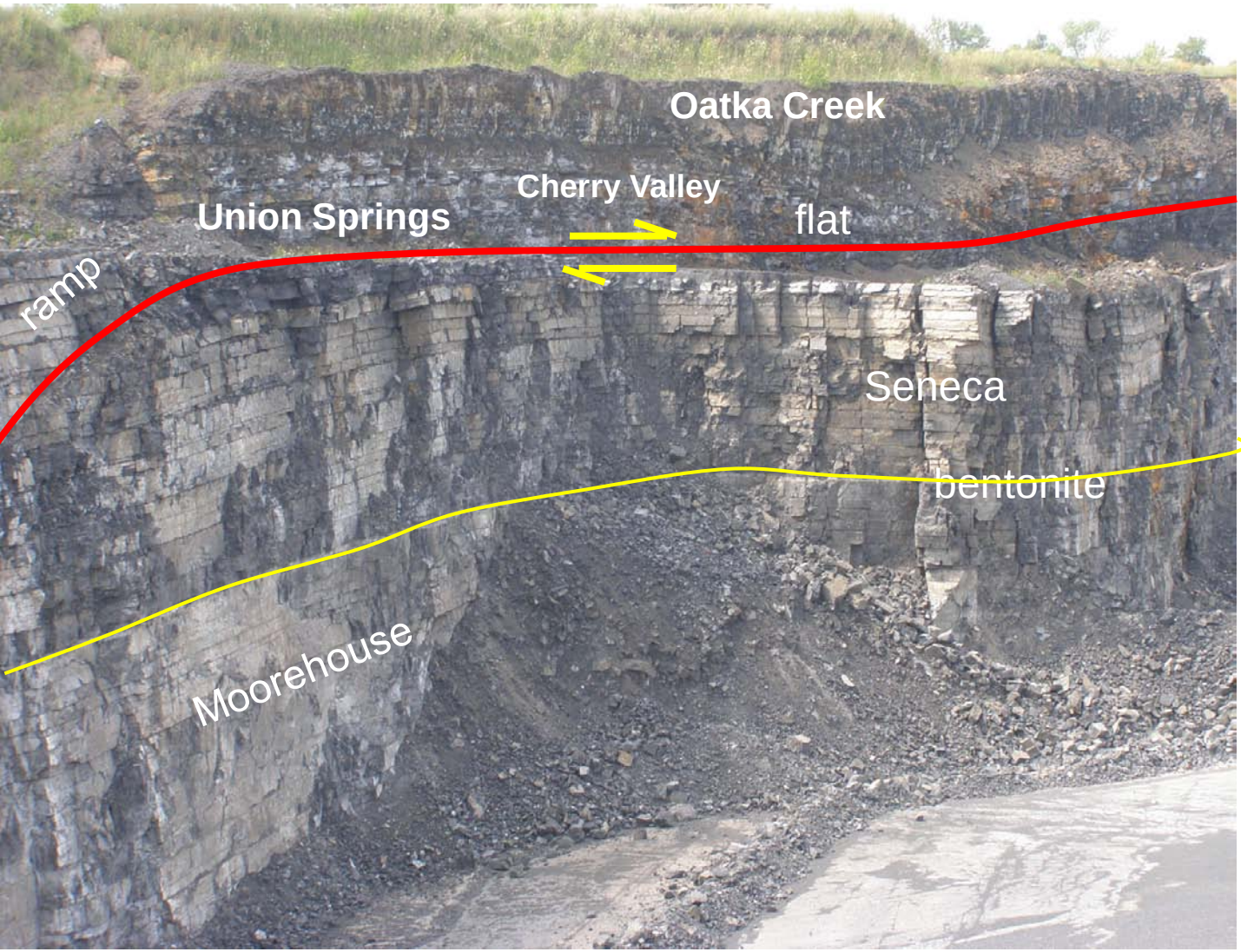
dissolution surface decorated with high-R bitumen separates first and second generation calcite

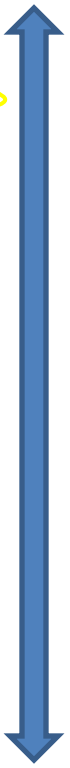


dissolution surface separating first and second generation calcite; note hydrocarbon inclusions and twinning in first generation calcite on left


Seneca Stone
Lewis
Oswego
Oneida
Hamilton
Warren
Wayne
Fulton
Saratoga
Onondaga
Herkimer
Ontario
Madison
Montgomery
Seneca
Schenectady
Cayuga
Yates
Cortland
Otsego
Schoharie
Albany
Chenango
Tompkins
Schuyler
Steuben
Greene
Delaware
Chemung
Tioga
Broome
Columbia
Ulster
Dutchess
Sullivan
Orange
Putnam
Marcellus Shale Outcrop Belt
0 10 20 40
Miles
N

Seneca Stone Quarry, Fayette, NY





Marcellus Formation (=Marcellus Subgroup)

Onondaga Fm.

Oatka Creek Member

Cherry Valley Member =~10’

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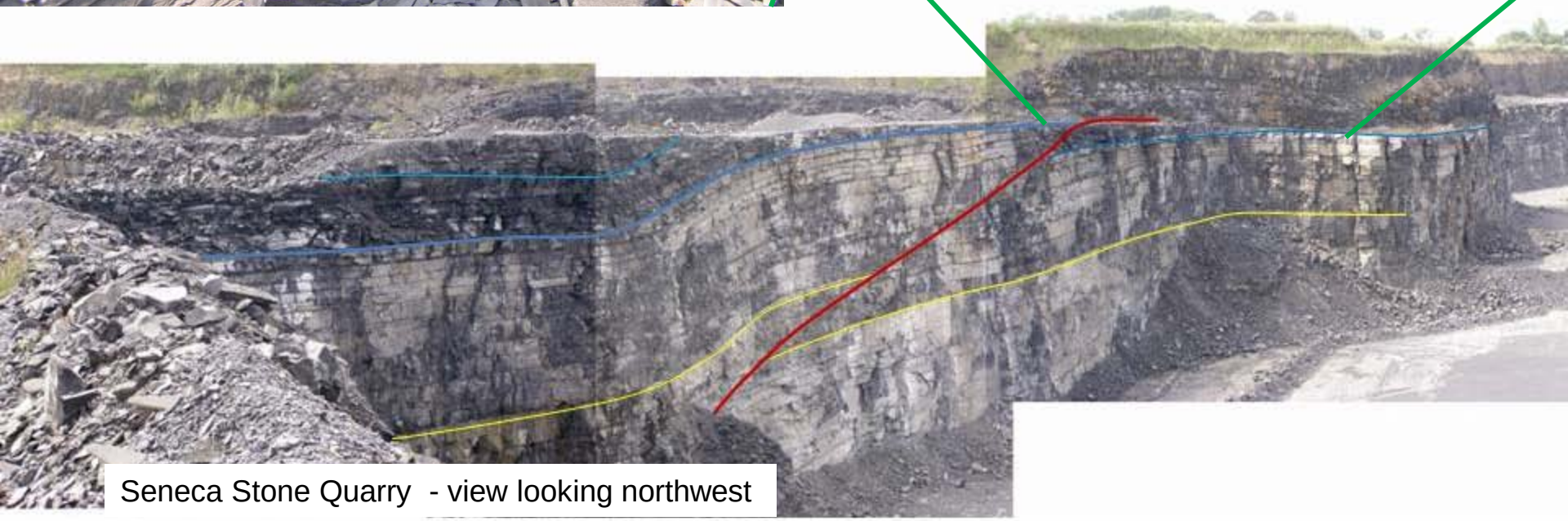
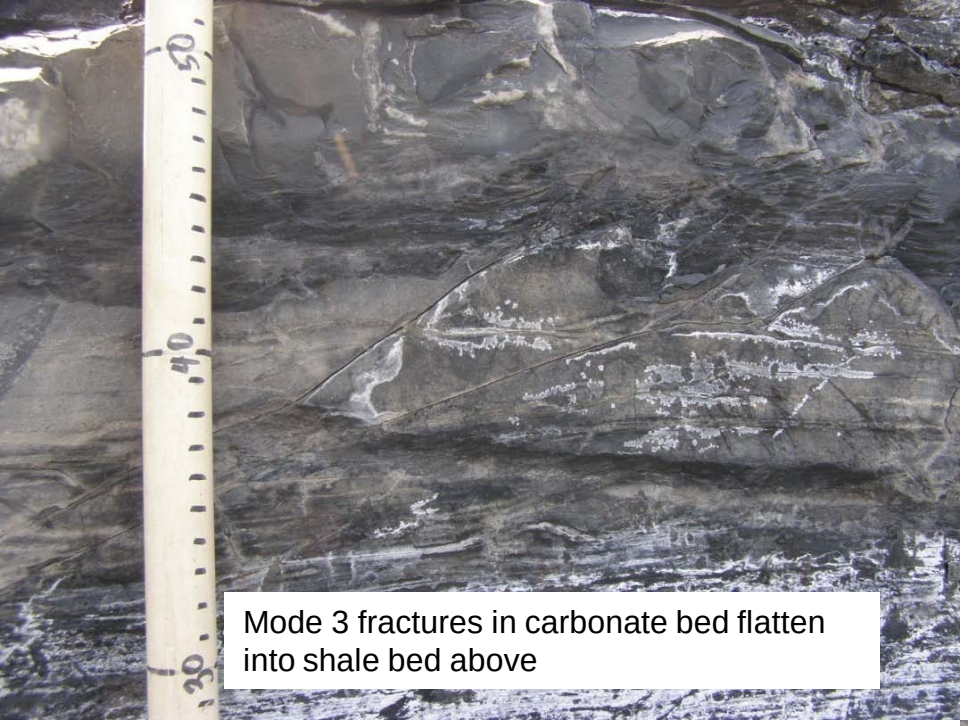
Moorehouse Member

fracture intensification in basal Oatka Creek

Union Springs, Cherry Valley and basal Oatka Creek members



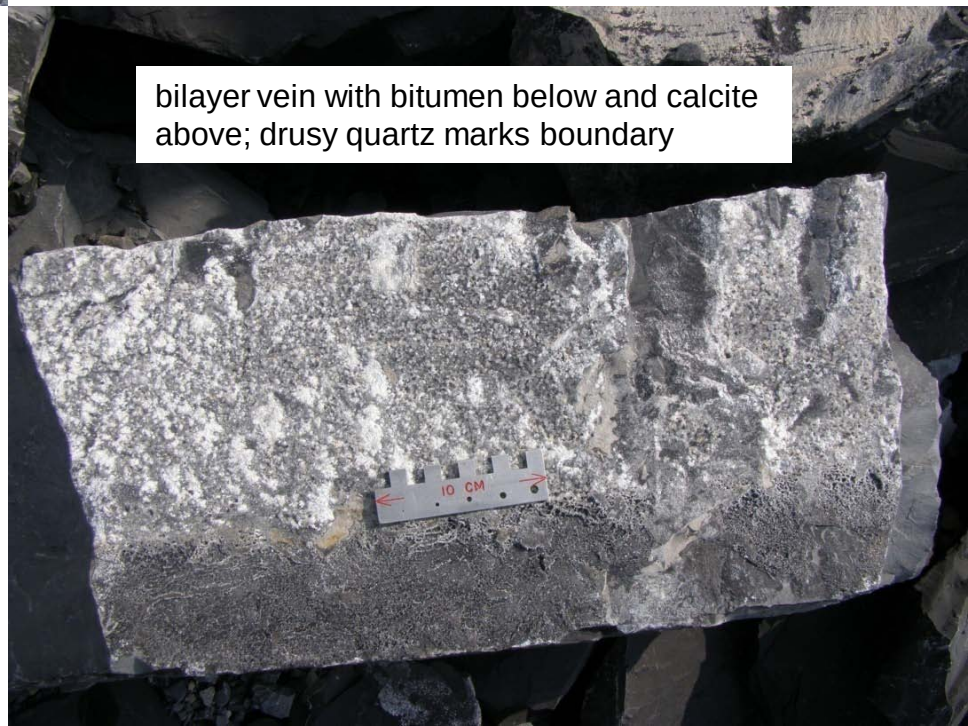
Seneca Stone Quarry - view looking northwest



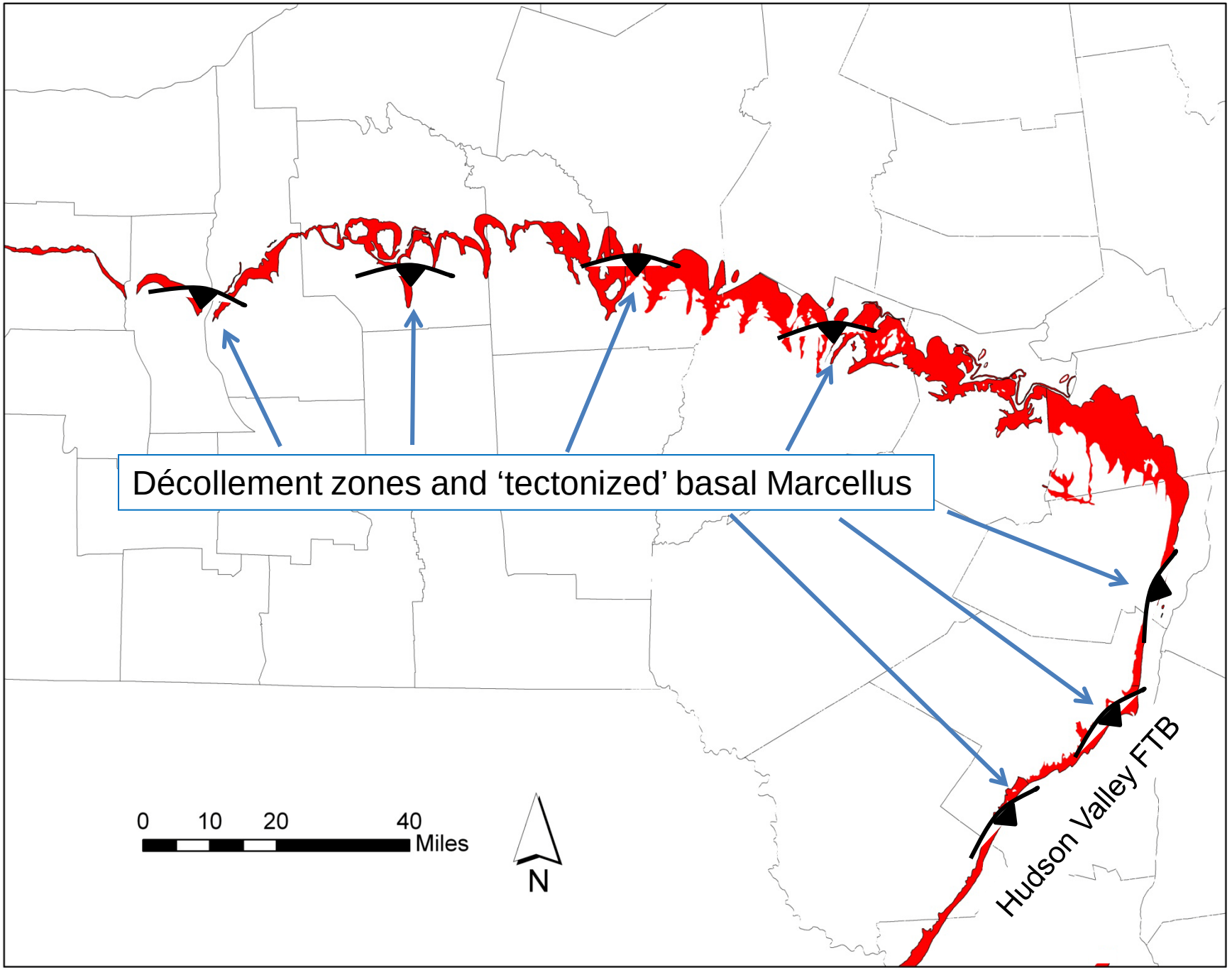
Mode 3 fractures in carbonate bed flatten into shale bed above

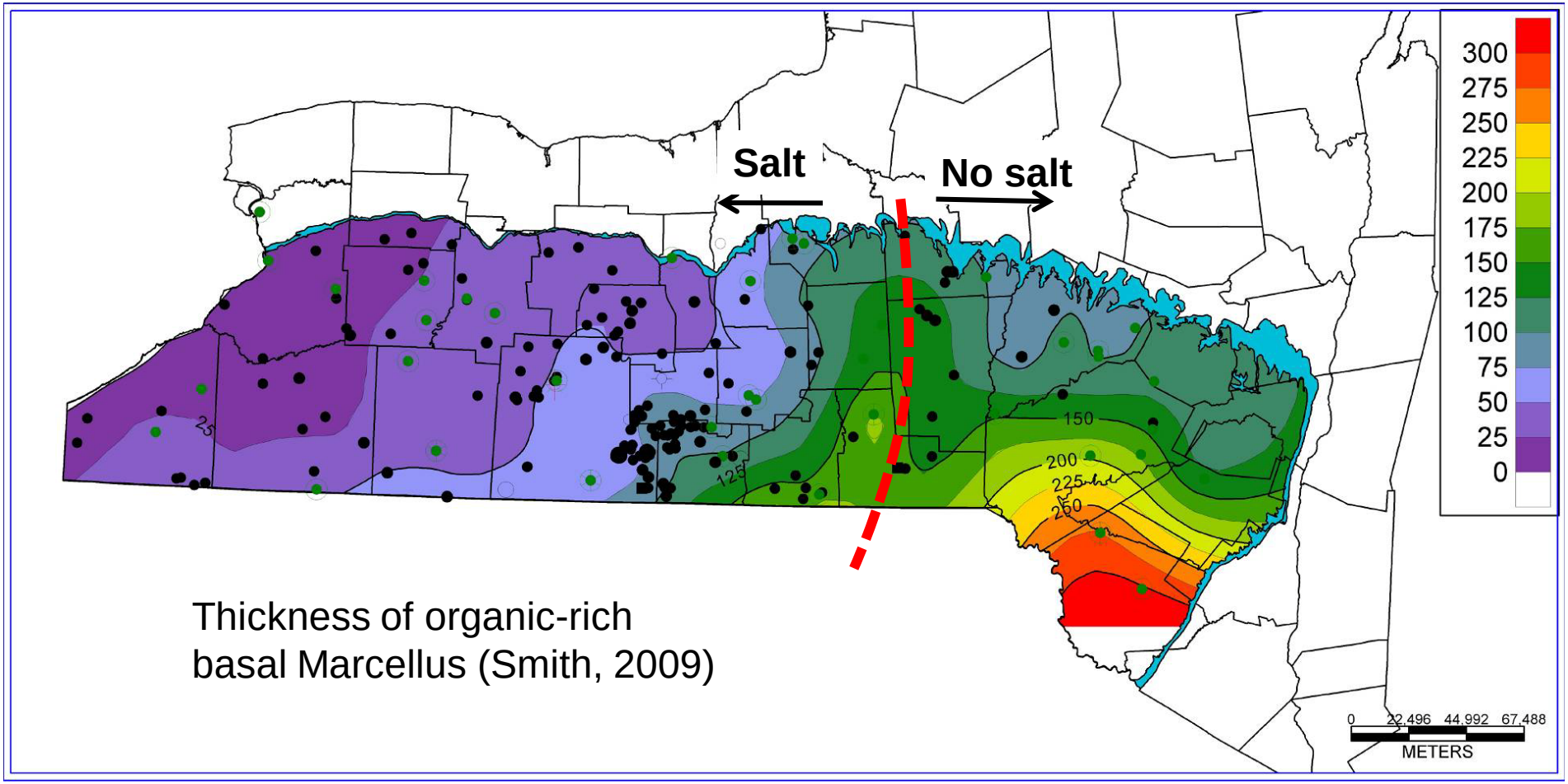
intersection of cleavage with bedding surface in shale, Union Springs Member

near horizontal lineations on bedding surface in Union Springs



bilayer vein with bitumen below and calcite above; drusy quartz marks boundary

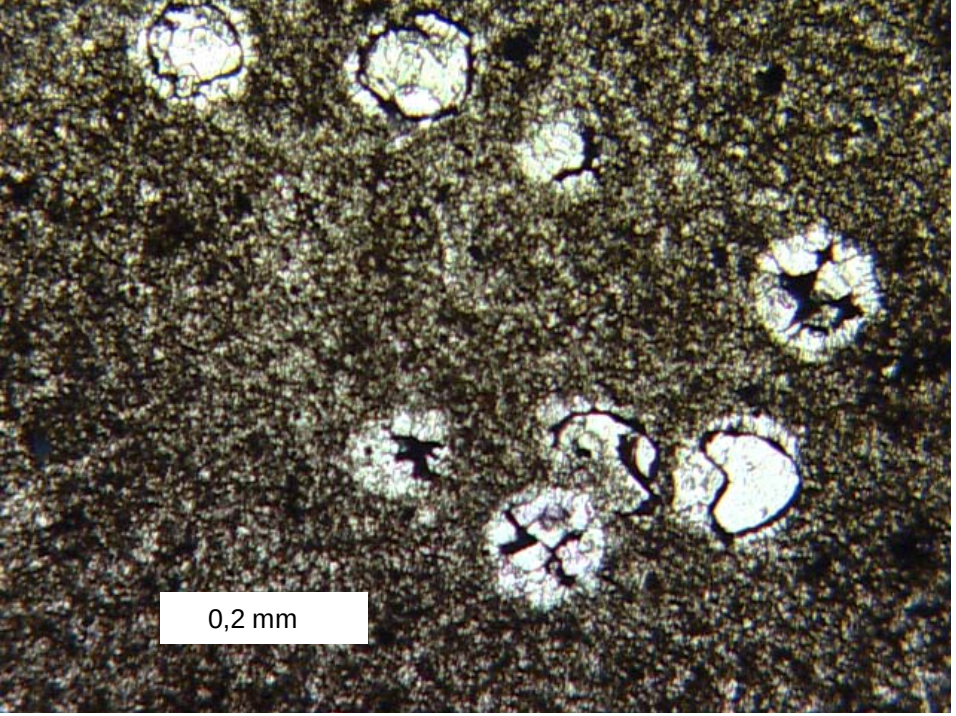

Décollement zones and ‘tectonized’ basal Marcellus
0 10 20 40
Miles
N
Hudson Valley FTB



Thickness of organic-rich basal Marcellus (Smith, 2009)

The basal Marcellus behaves as a ductile slip surface/décollement zone **east and west** of the 'no salt' line.

How much thickness variation is due to **structural** thickening and thinning?



Hydrocarbon maturation:

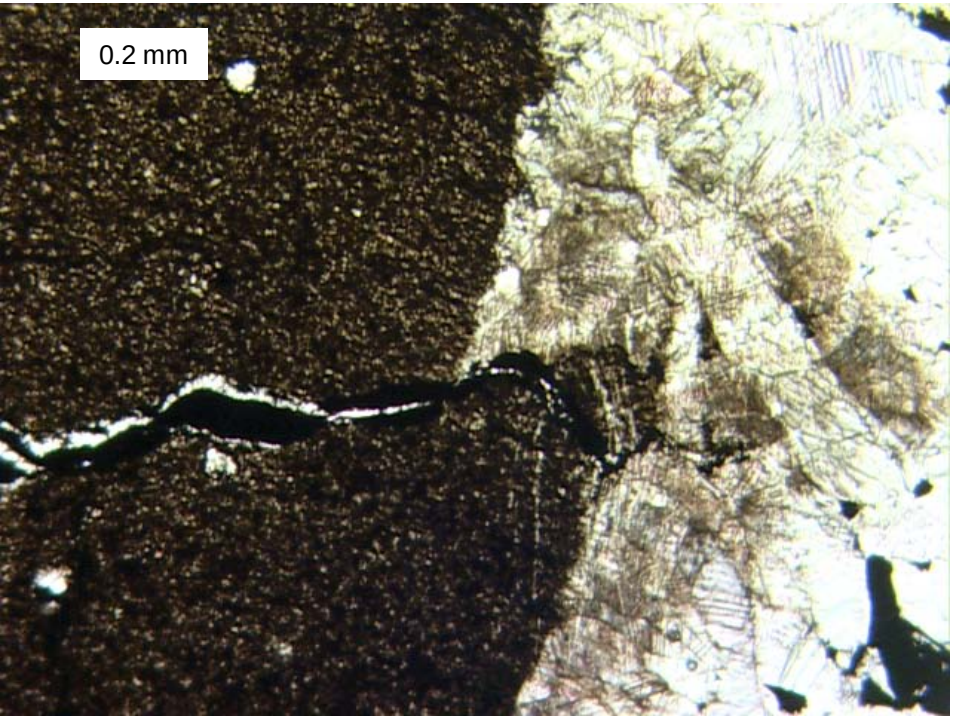
Key points:

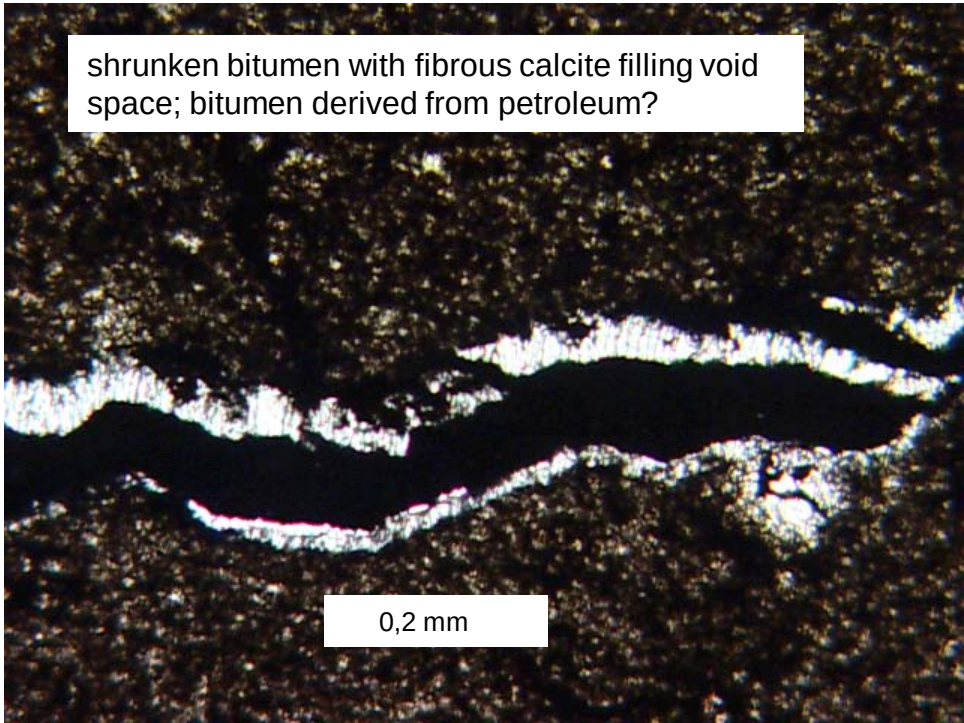
organic source is algal; algal cysts and calcispheres are common

early hydrocarbon maturation produced liquid petroleum which migrated into veins

trapped petroleum later cooked to hi-R bitumen, opening pore space

later hi-R bitumen associate with late cements





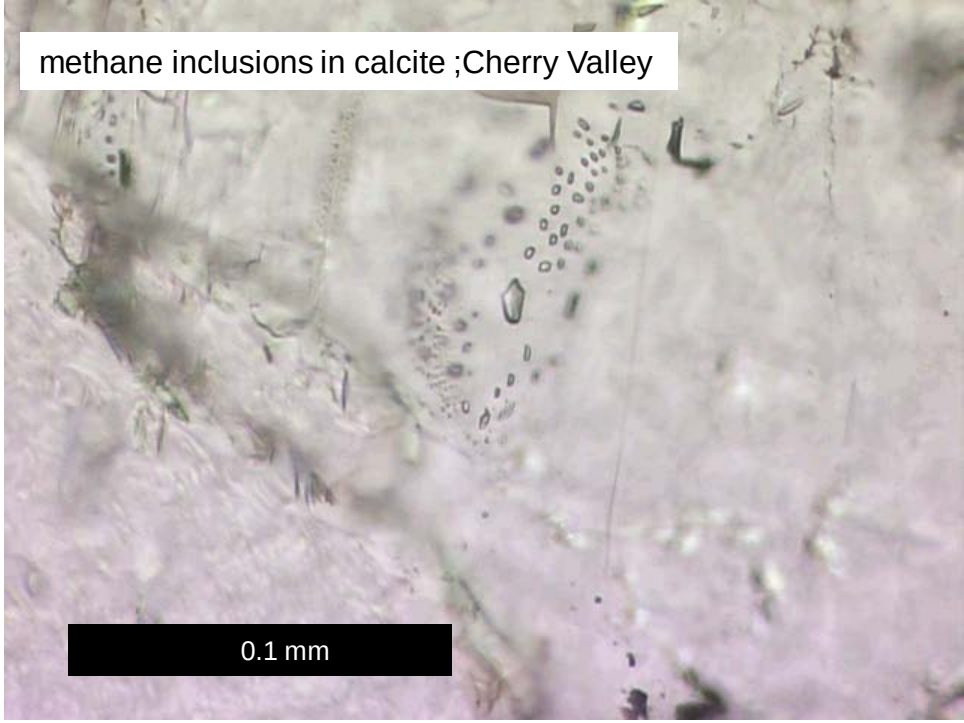
Fluid inclusions:

Key points:

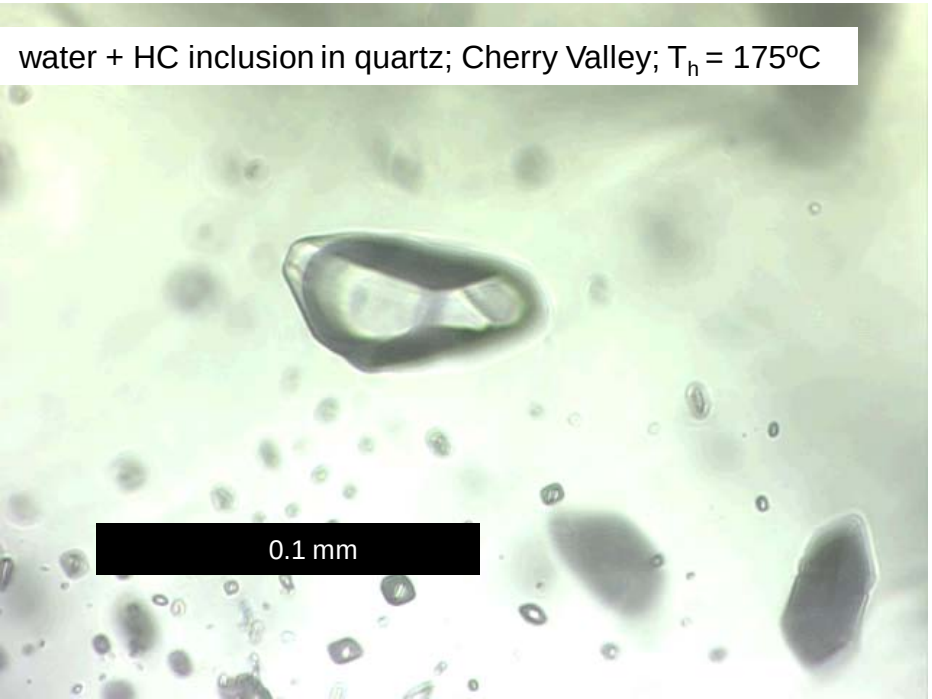
aqueous (water-rich) inclusions very rare; methane inclusions very common

water + hydrocarbon (HC) inclusions are water poor

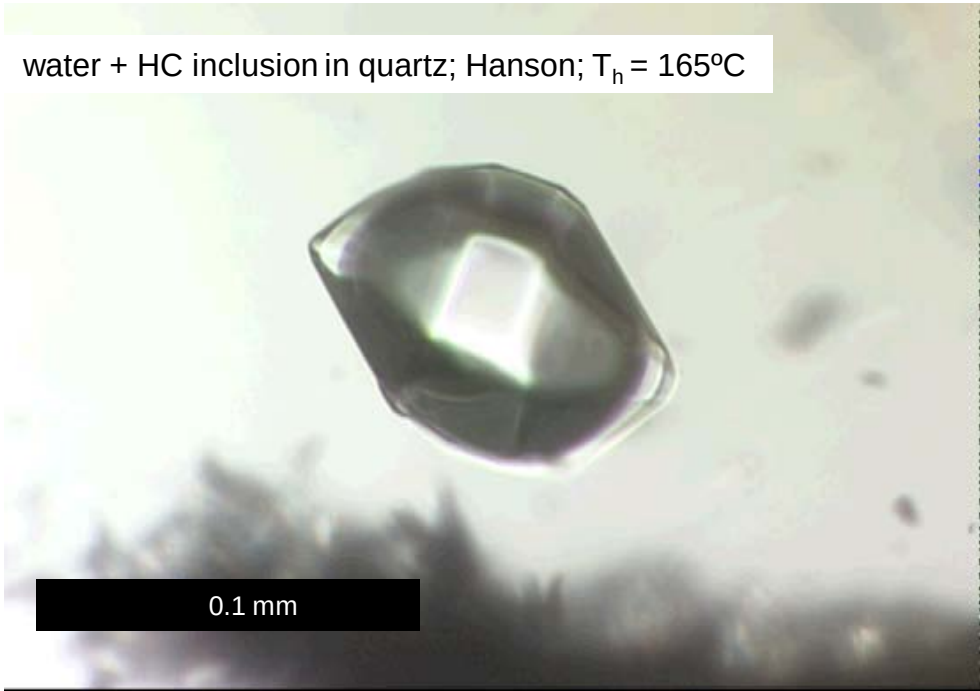
T_h of water + HC inclusions in quartz range from145-180ºC



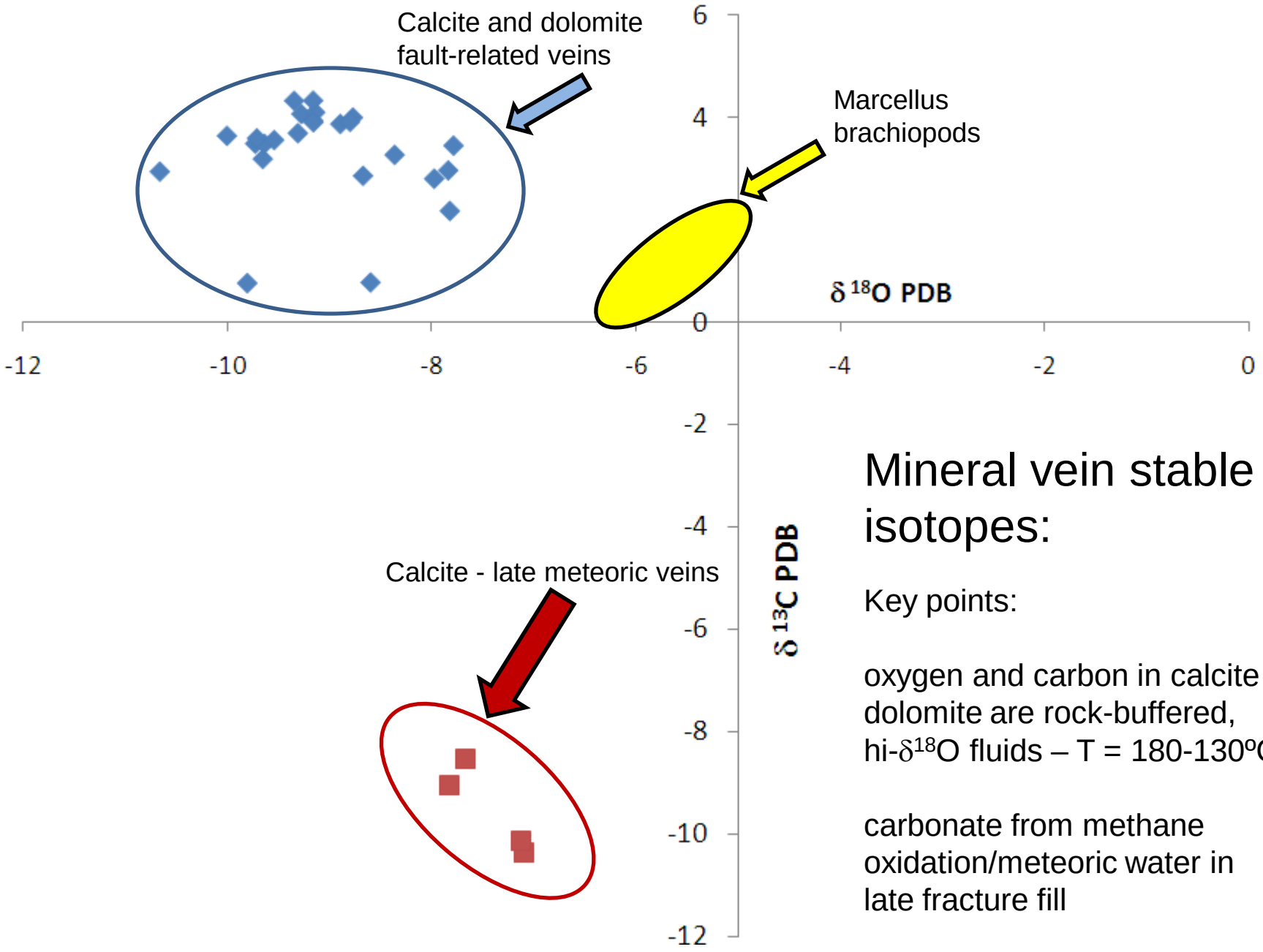
methane inclusions in calcite ;Cherry Valley



water + HC inclusion in quartz; Cherry Valley; T_h = 175ºC



water + HC inclusion in quartz; Hanson; T_h = 165ºC

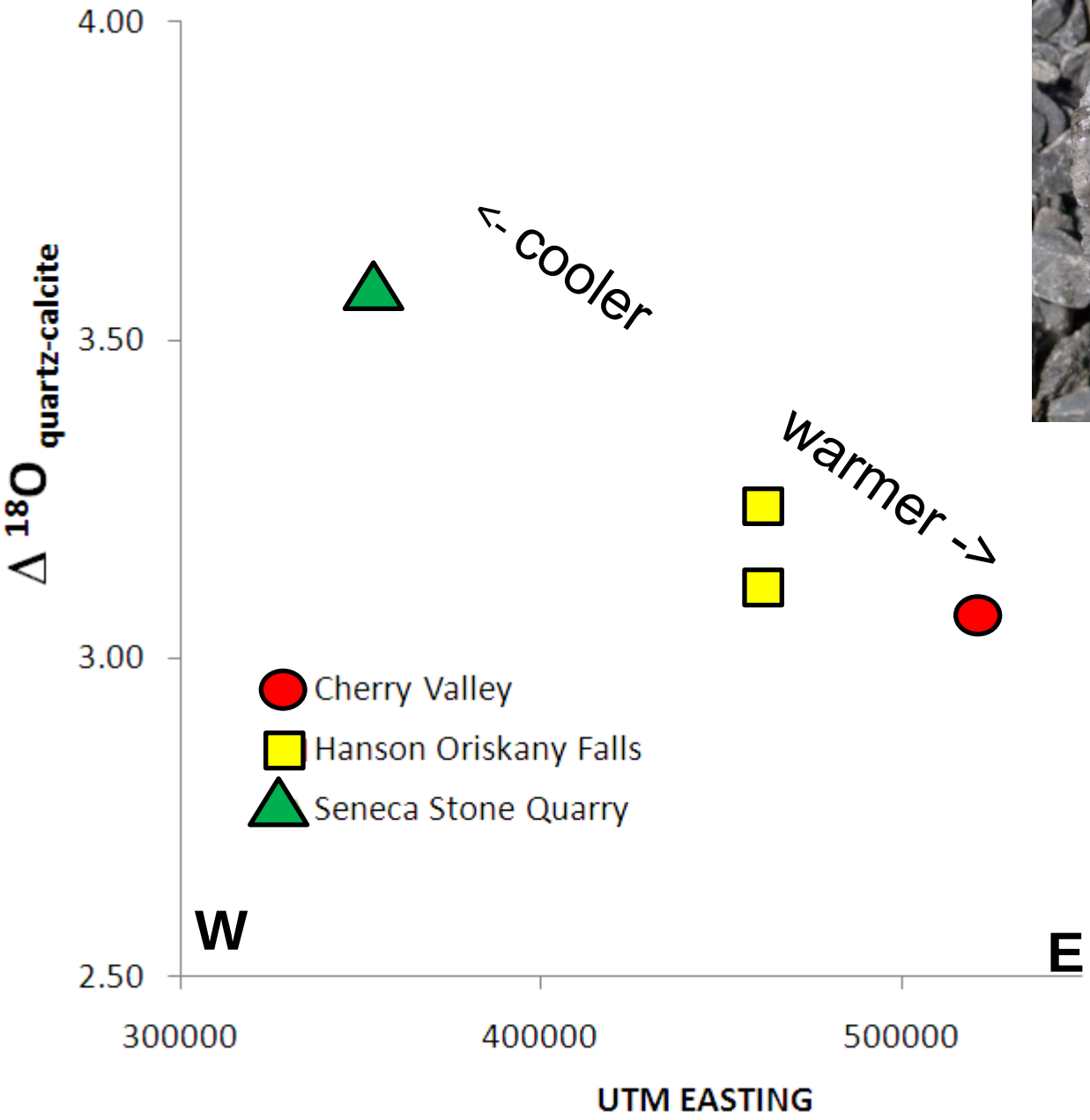


Mineral vein stable isotopes:

Key points:

oxygen and carbon in calcite and dolomite are rock-buffered, hi-$\delta^{18}O$ fluids – T = 180-130ºC

carbonate from methane oxidation/meteoric water in late fracture fill



Key point:

Quartz-calcite $\Delta^{18}O$ indicates lower T mineralization to west along the Marcellus outcrop belt

Summary:

Décollement is widespread within the basal Marcellus Formation at the northern limit of the Appalachian foreland

Deformation occurred during hydrocarbon maturation

Fracture and vein mineralization involved water + hydrocarbon fluids

Early petroleum fluids were later ‘overcooked’ to leave hi-R bitumen and low-C# gas

Fluid system reached temperatures of >170ºC at Cherry Valley; >140ºC Seneca Stone Quarry

Natural fluids remaining in the fault zones are relatively ‘dry’ – low water activity

Décollement zones contain abundant natural fractures and vuggy porosity