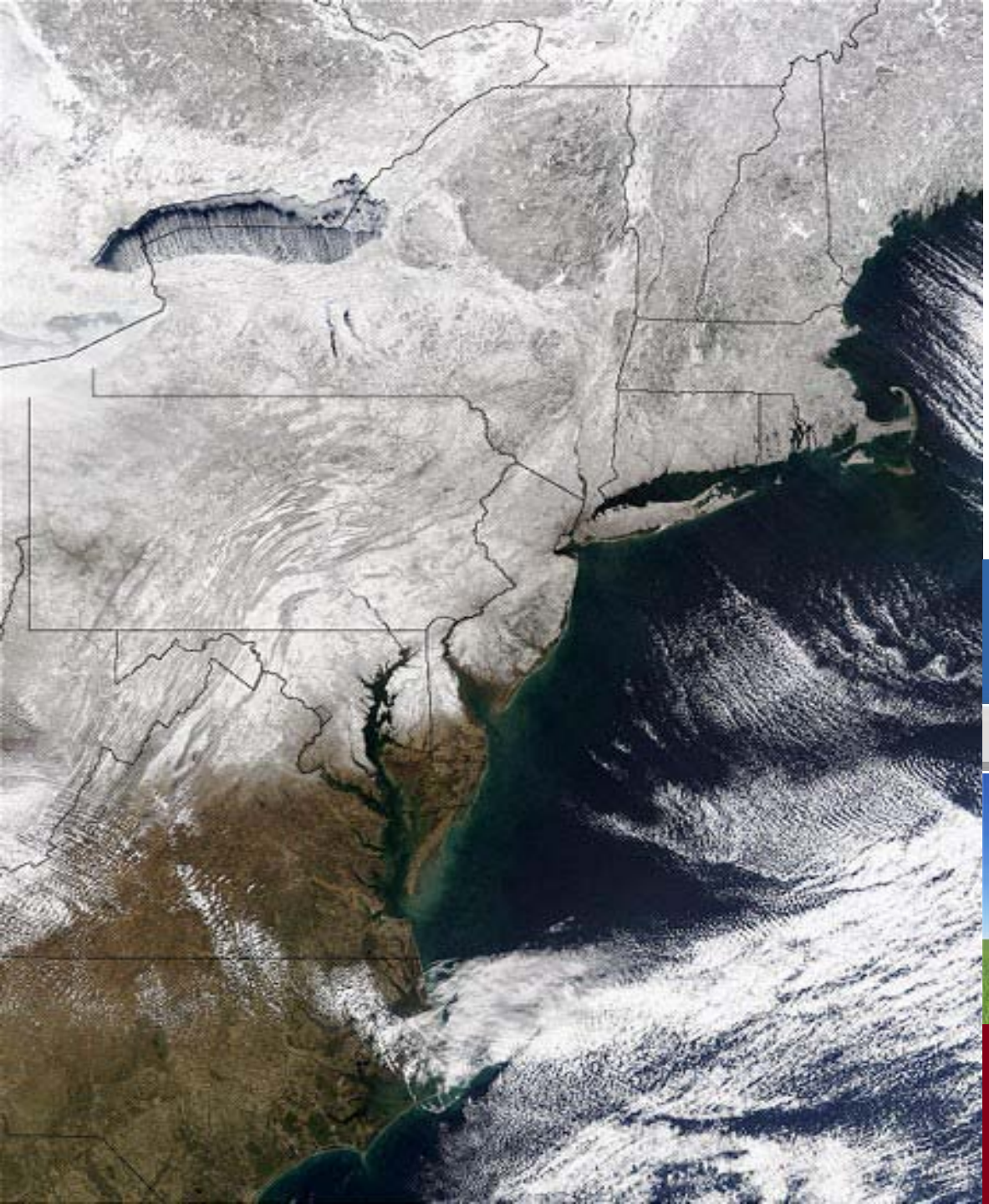
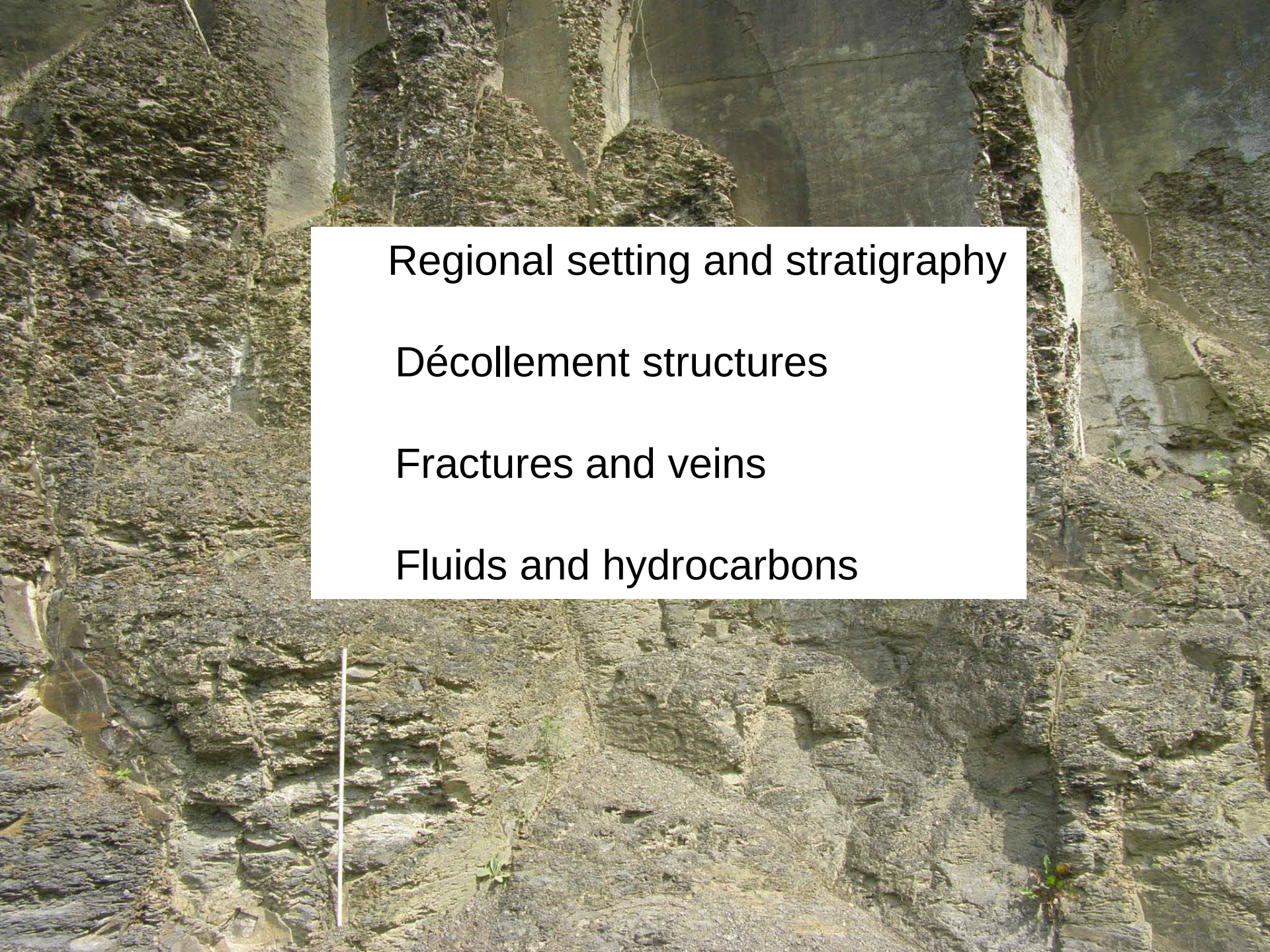


"Detachment Structures Document Widespread Foreland Deformation in the Basal Marcellus Formation, Central New York State"

Bruce Selleck and Dana Bohan
Department of Geology
Colgate University

Thanks to:
Fronterra Geosciences, Cabot Oil and Gas, Hanson Aggregates Inc. , Seneca Stone Corp. and Julian, Jacquie, Ali, Jacky



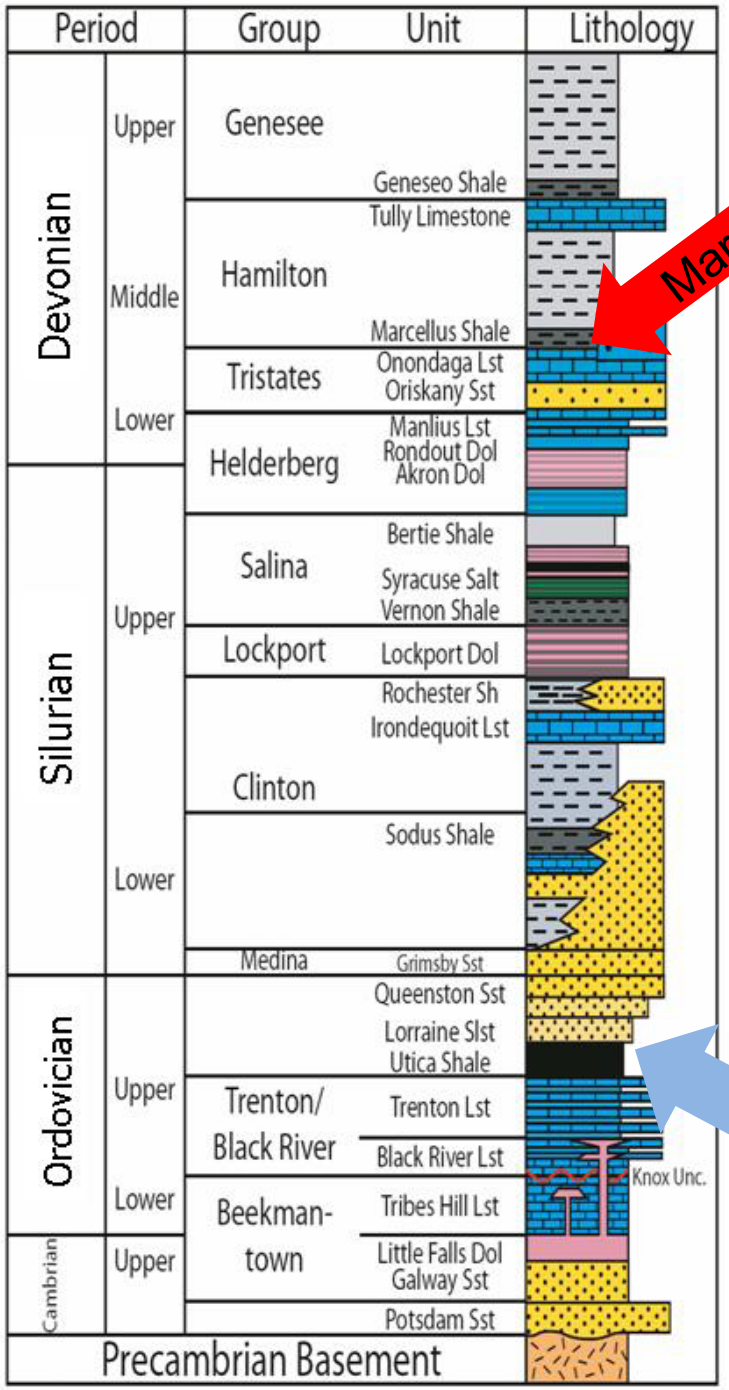
Regional setting and stratigraphy

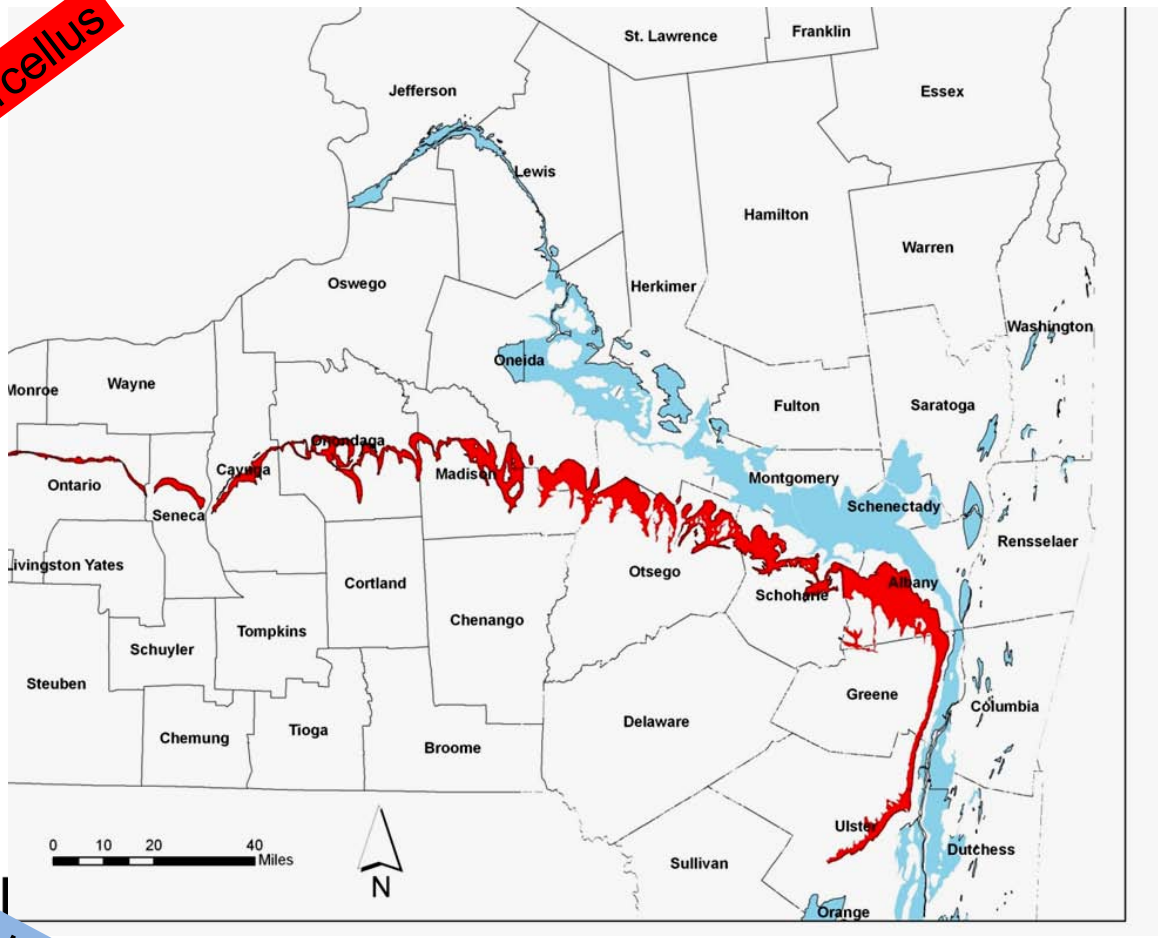
Décollement structures

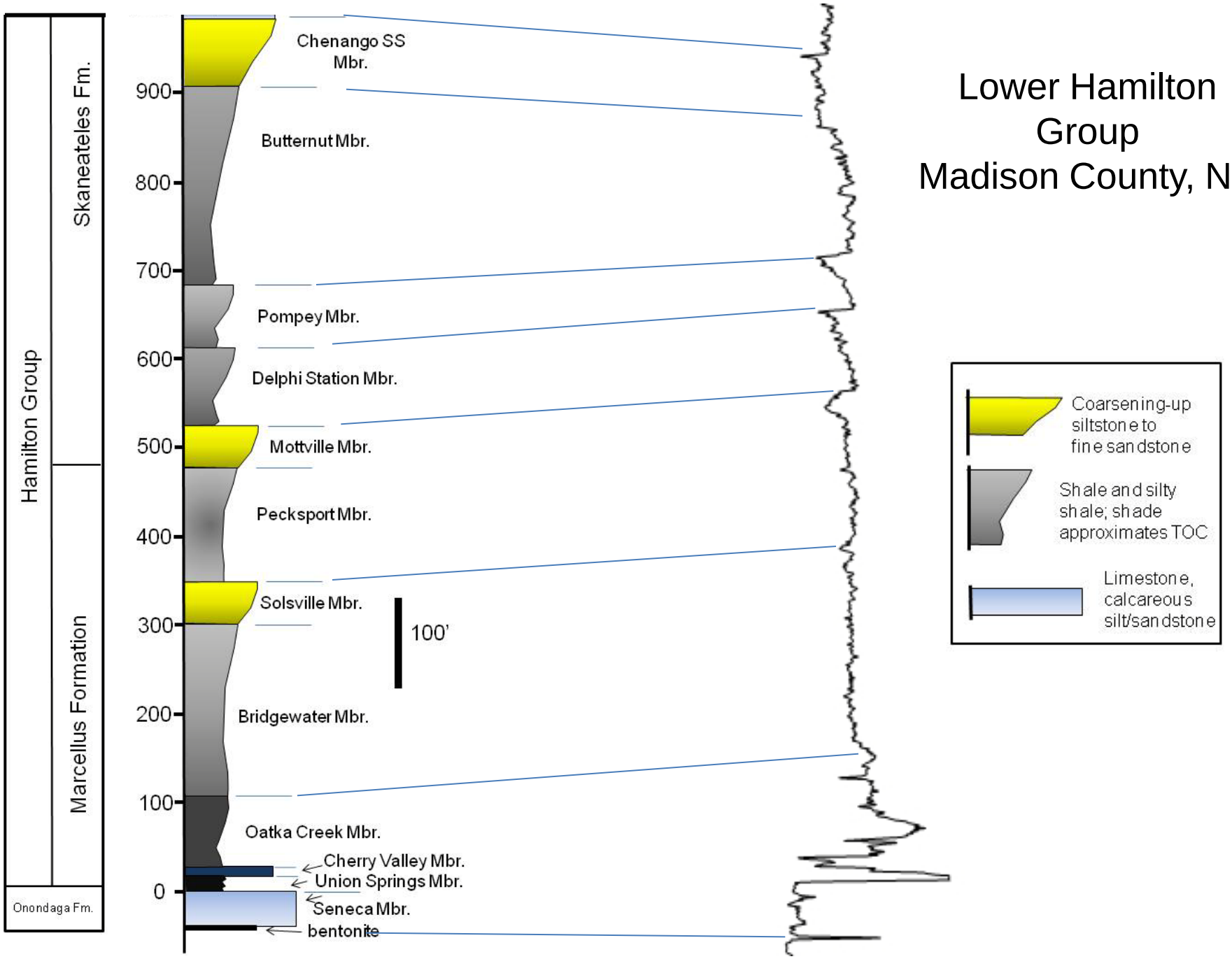
Fractures and veins

Fluids and hydrocarbons

New York's gas shale units






Outcrop (Cooper, 1934, Rickard, 1984)
Gapski 1 GR (southern Madison Co., NY)
Lower Hamilton Group
Madison County, NY
Hamilton Group
Skaneateles Fm.
Marcellus Formation
Onondaga Fm.
900
800
700
600
500
400
300
200
100
0
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
100'
Coarsening-up siltstone to fine sandstone
Shale and silty shale; shade approximates TOC
Limestone, calcareous silt/sandstone

Gapski 1 GR
Madison Co. NY

Hanson Quarry,
Oriskany Falls, NY

Marcellus Formation (=Marcellus Subgroup)

Oatka Creek Member

Cherry Valley Member
=~10’

Union Springs Member
=30’

Onondaga Fm.

Seneca Member
=~25’

Moorehouse Member

bentonite

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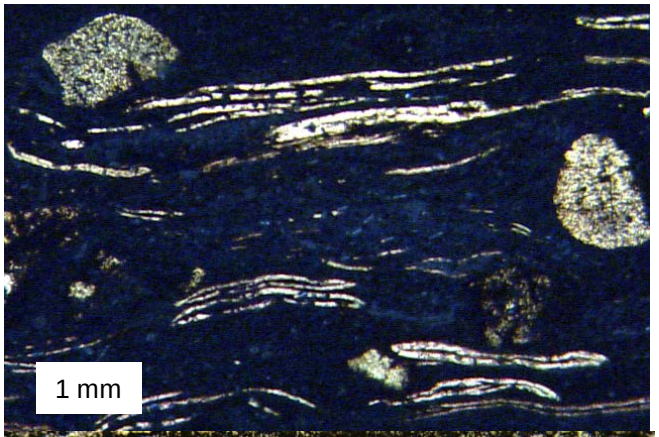
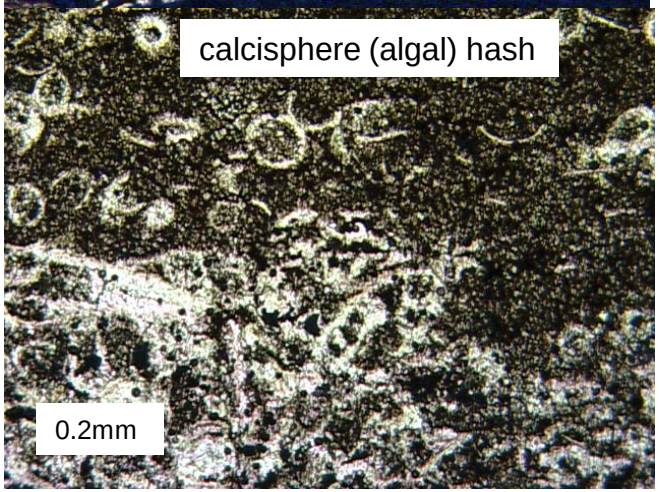
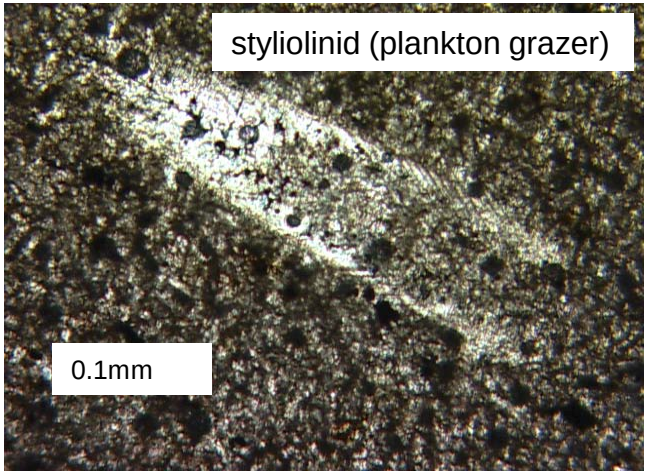
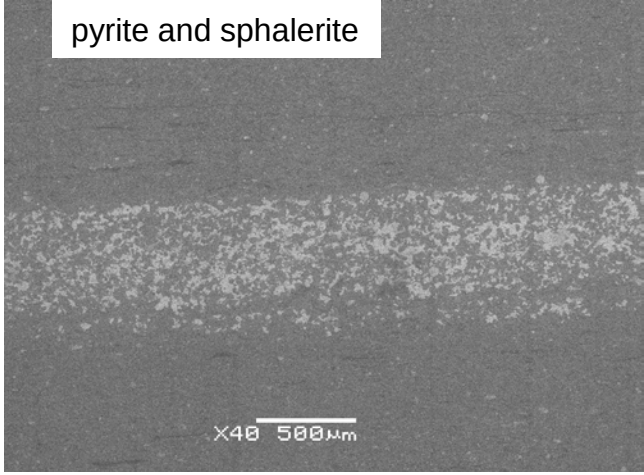
Moorehouse Member

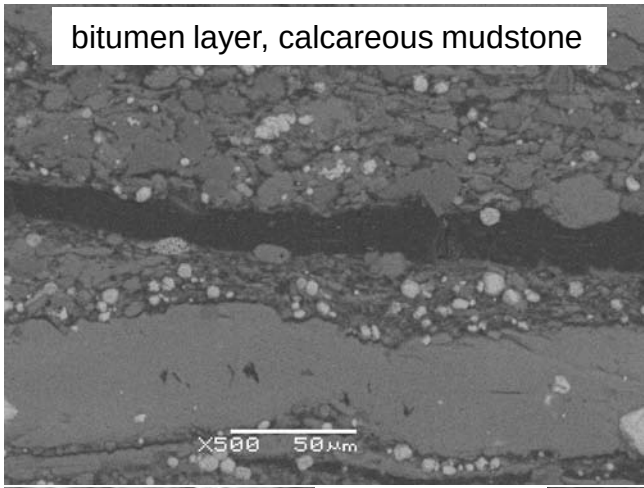
brach-crinoid - sargassum-like epiplanktic?

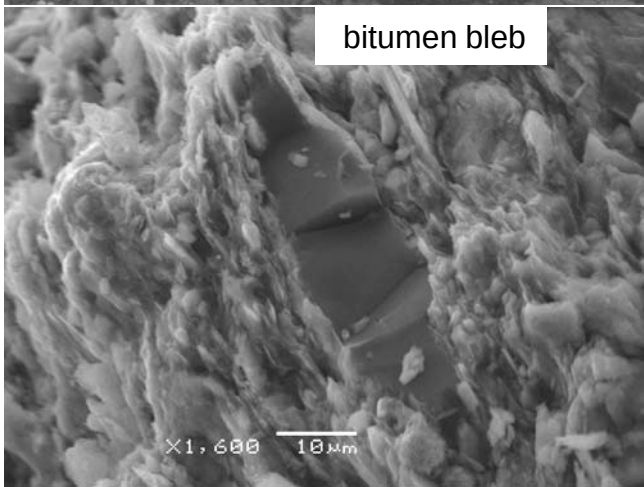












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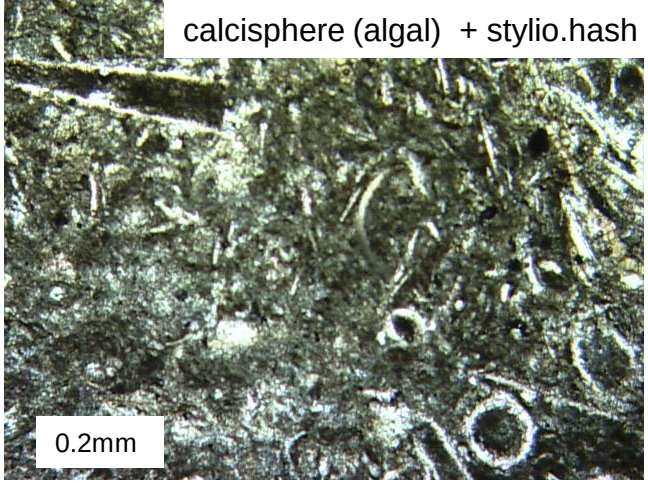
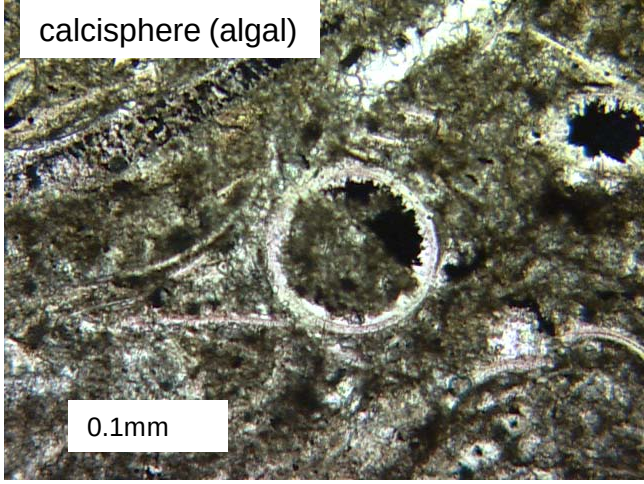
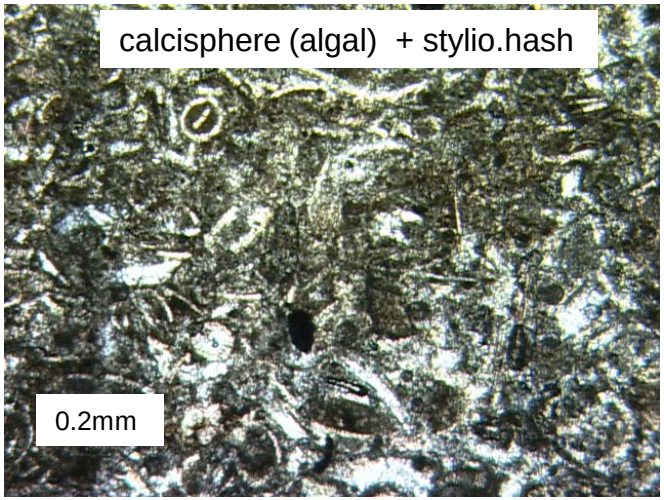
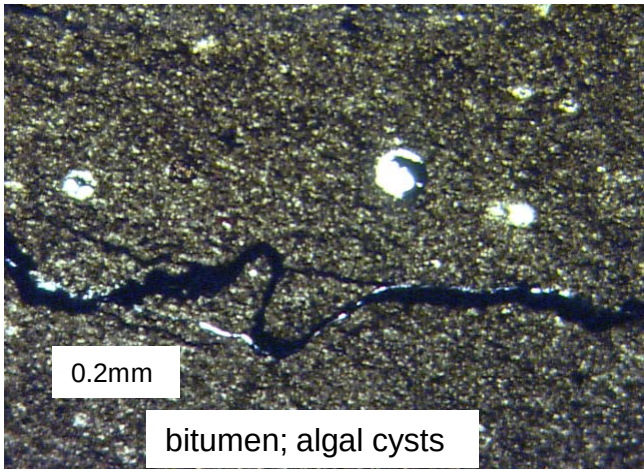
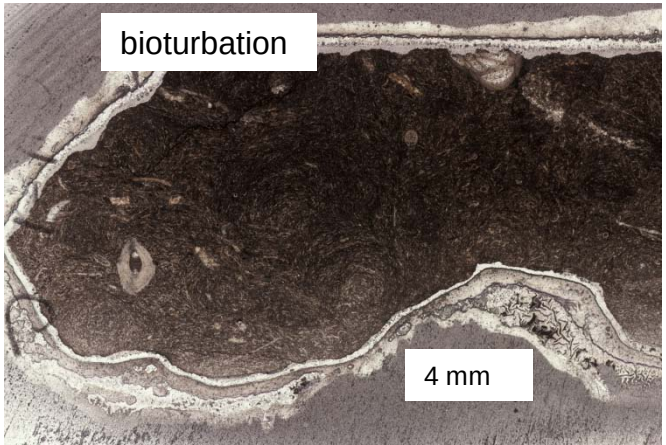
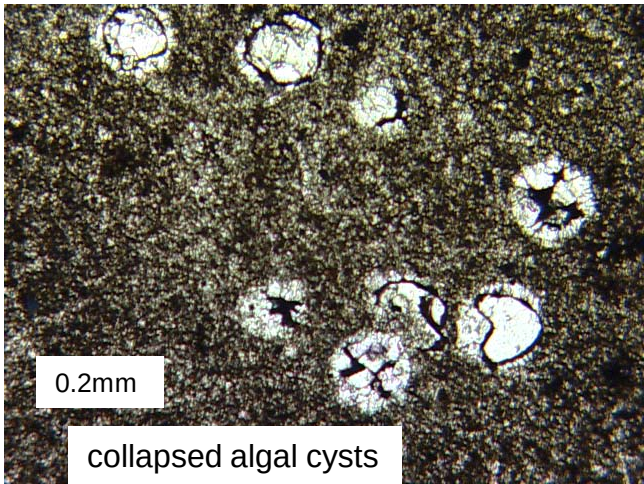


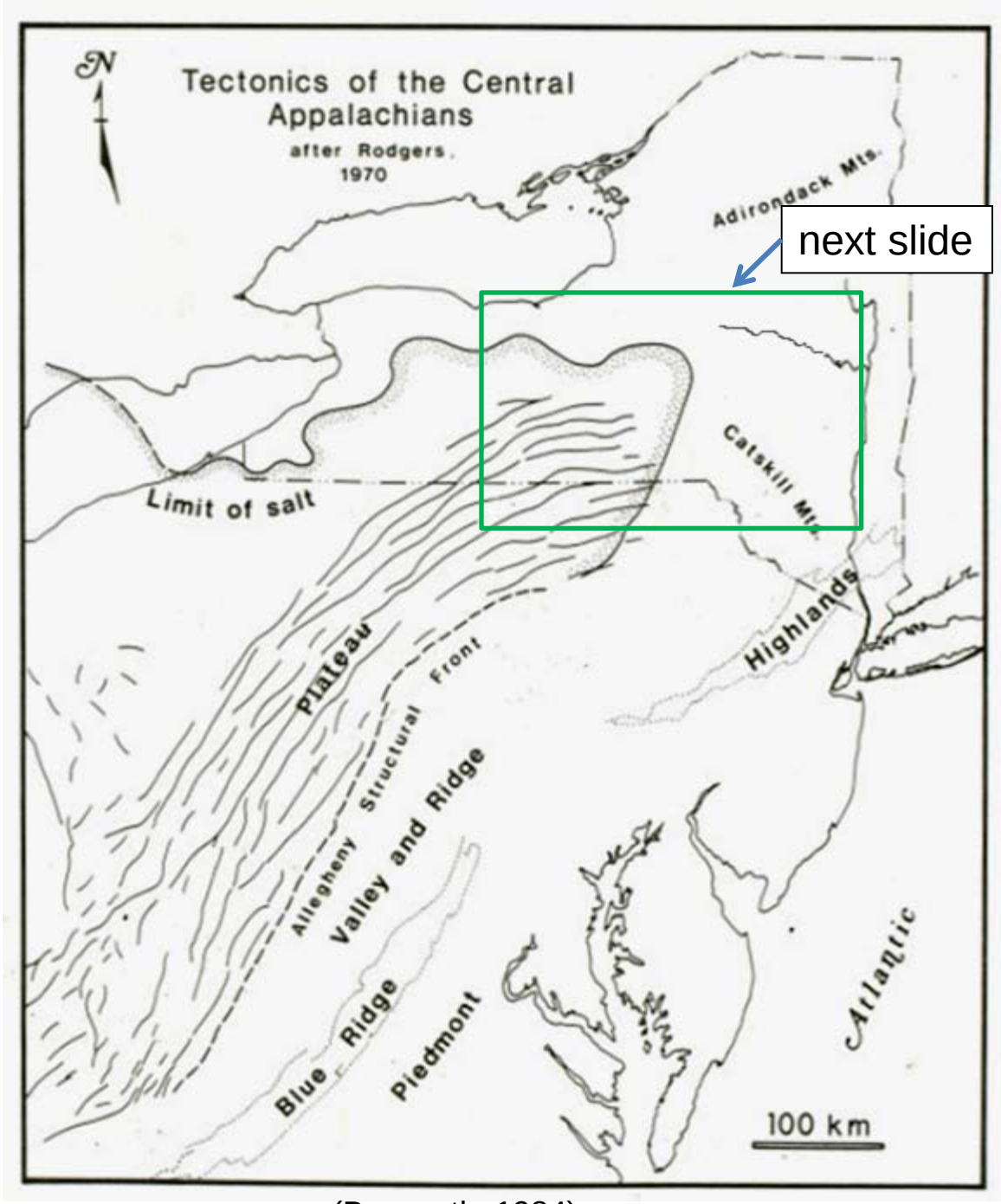










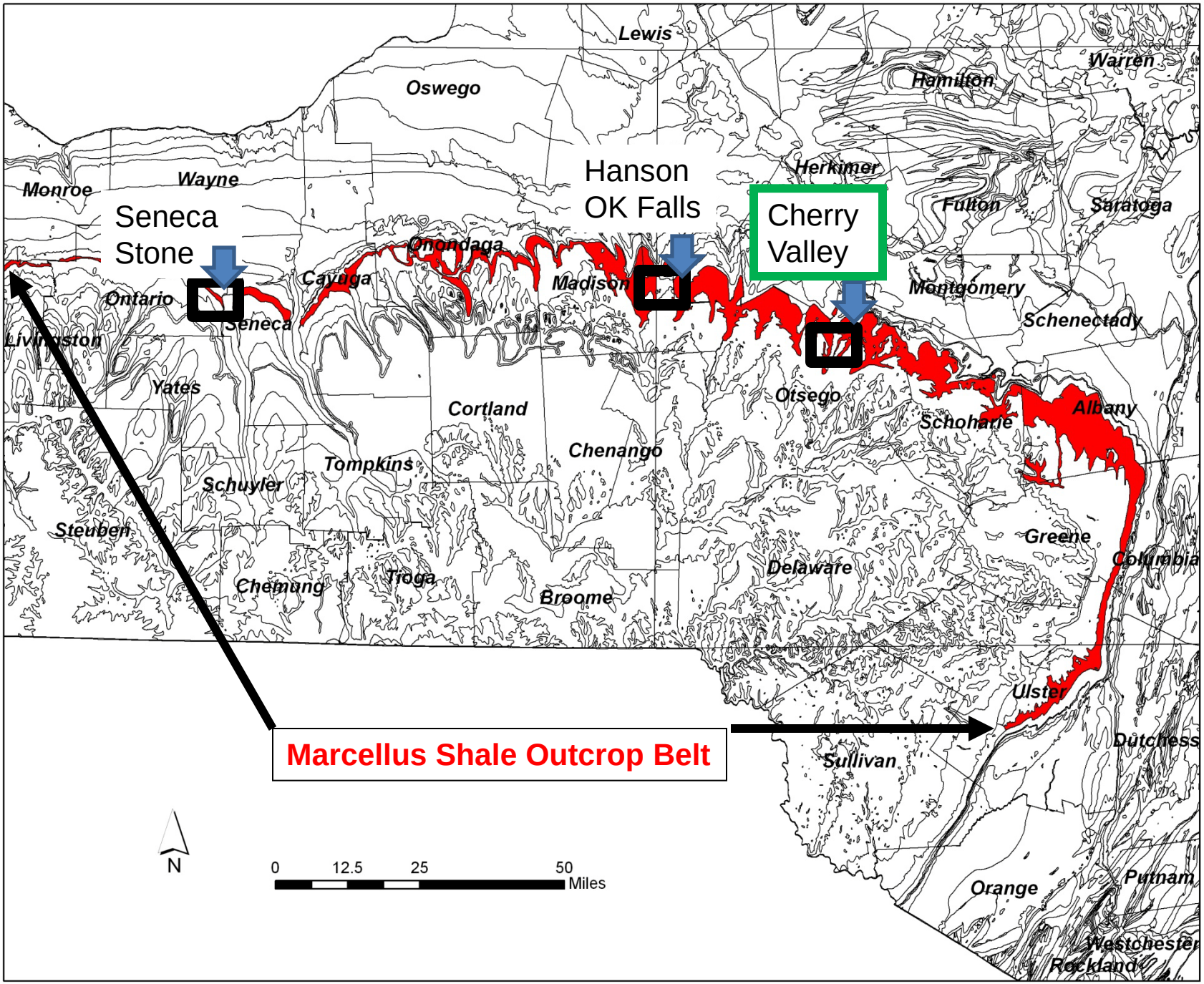


(Bosworth, 1984)

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


Lewis
Oswego
Warren
Hamilton
Herkimer
Monroe
Wayne
Hanson
OK Falls
Seneca
Stone
Cherry
Valley
Fulton
Saratoga
Onondaga
Cayuga
Madison
Montgomery
Ontario
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Schenectady
Livingston
Yates
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Albany
Cortland
Schoharie
Chenango
Tompkins
Schuyler
Steuben
Greene
Columbia
Delaware
Chemung
Tioga
Broome
Ulster
Marcellus Shale Outcrop Belt
Dutchess
Sullivan
N
0
12.5
25
50
Miles
Orange
Putnam
Westchester
Rockland

Marcellus Formation (=Marcellus Subgroup)

Oatka Creek Member

Cherry Valley Member =~10’

Union Springs Member =30’

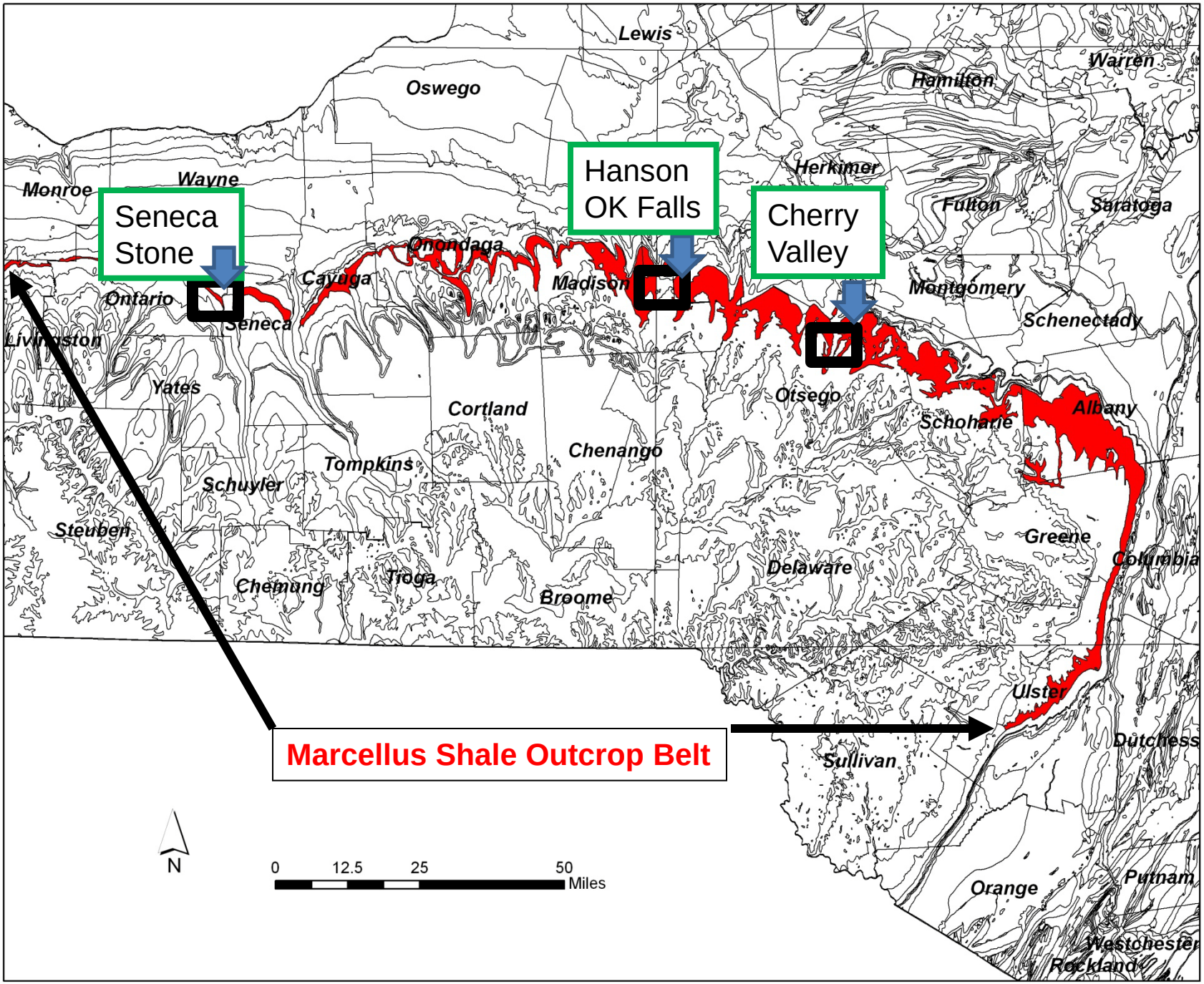
Onondaga Fm.

Seneca Member =~25’

Moorehouse Member

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

Cleavage duplex structures described here by Bill Bosworth in 1984


Lewis
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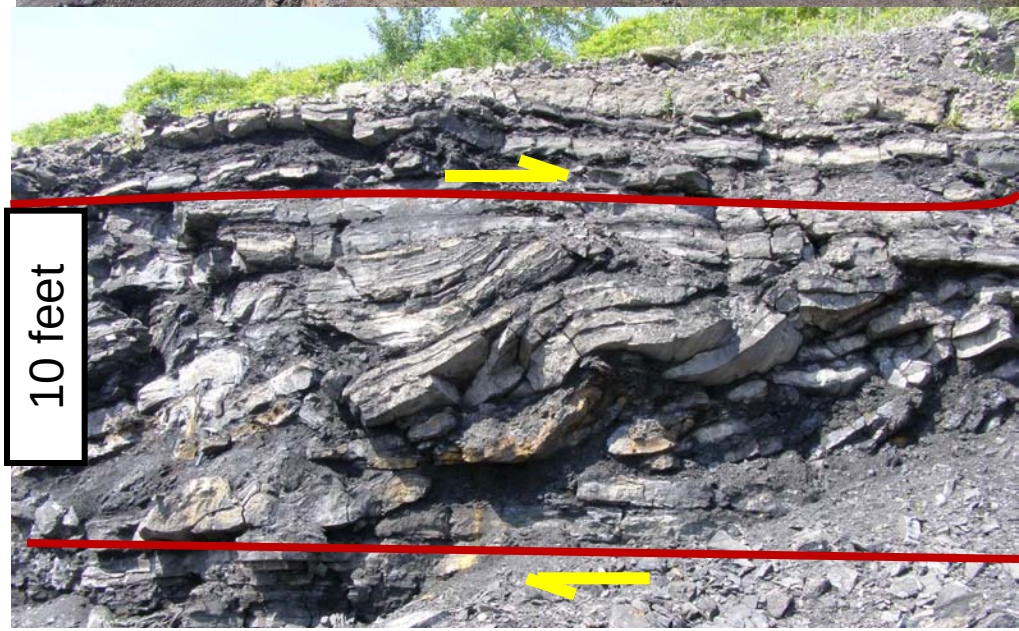
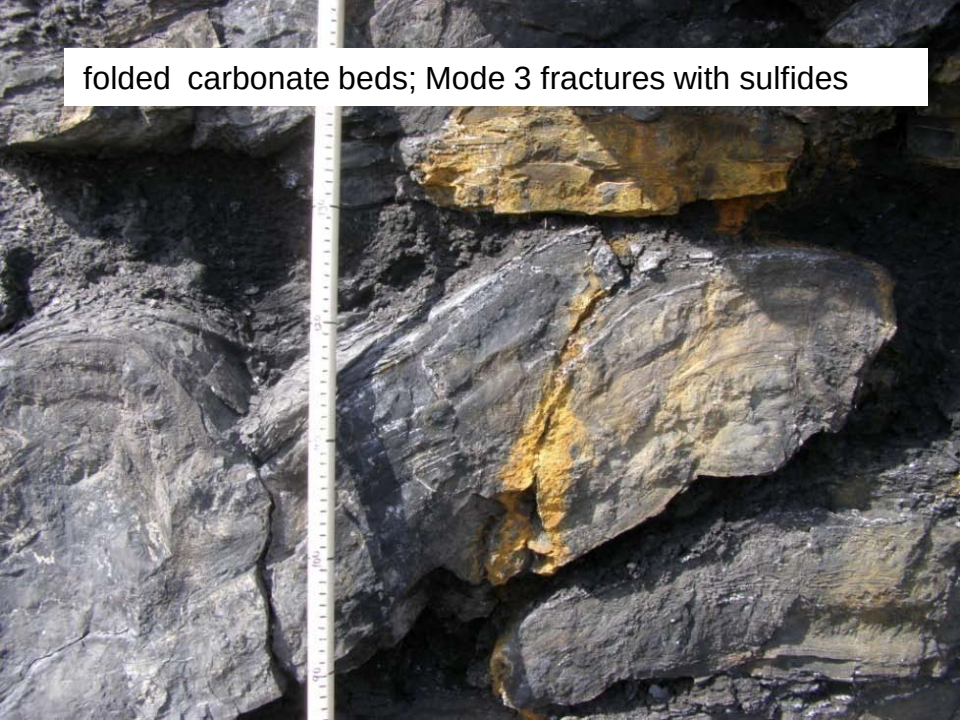


imbricate stacking of carbonate slabs and folding of carbonate beds - view looking west



folded carbonate beds; Mode 3 fractures with sulfides

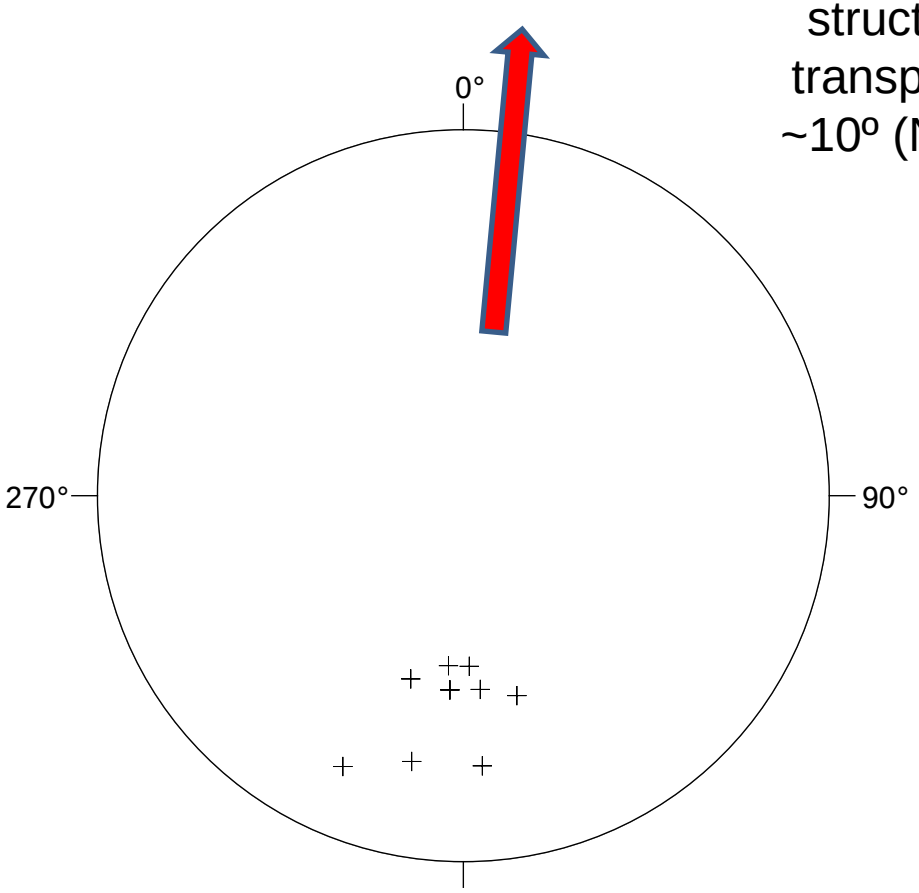
lineated, polished cleavage surface on carbonate bed

limestone masses in mudstone matrix

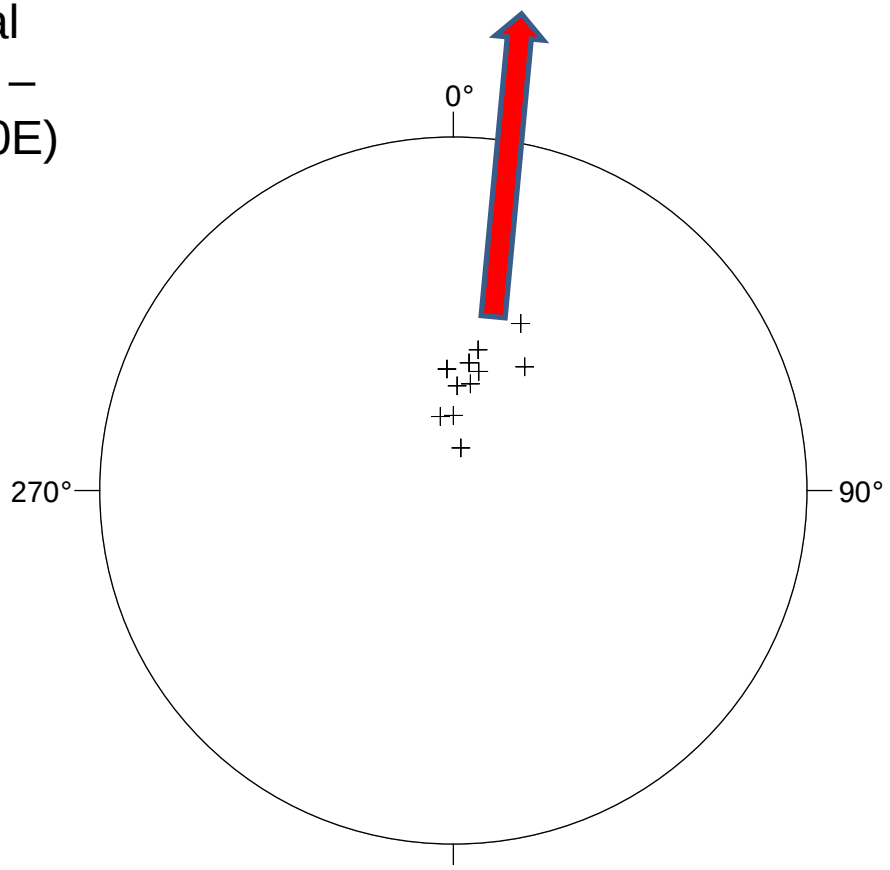
Mode 1 extension fractures - carbonate beds

Hanson Quarry, Oriskany Falls, NY

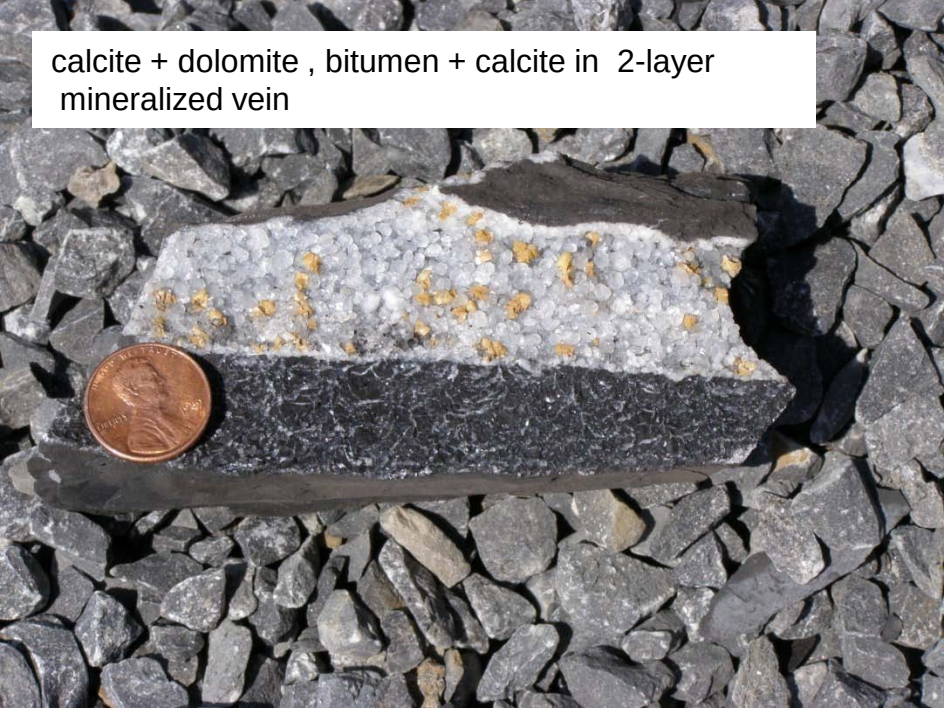
structural transport – ~10º (N10E)



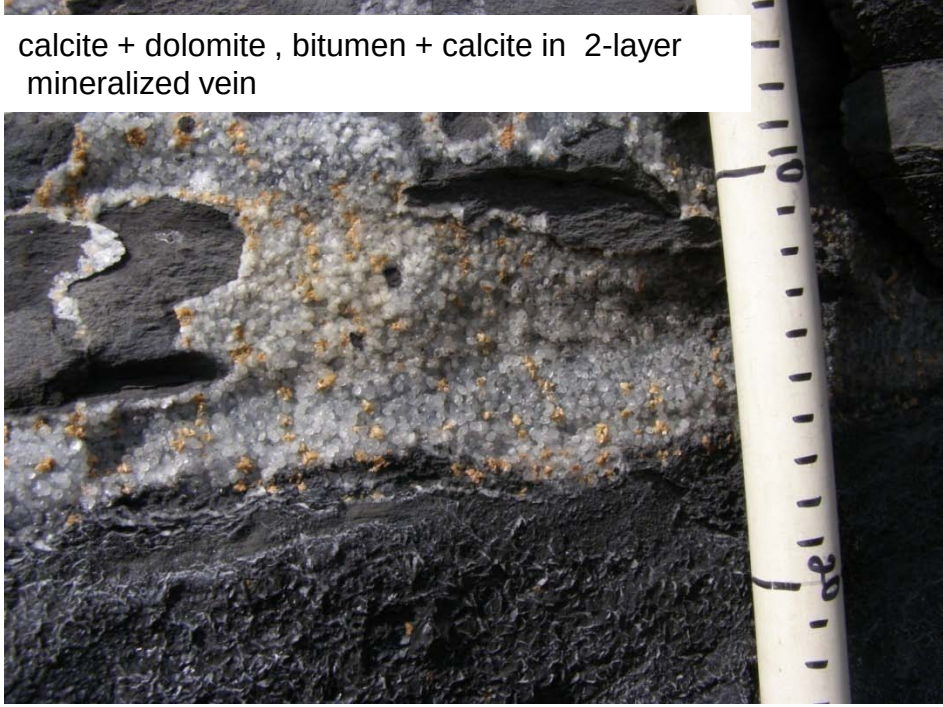
(lineations – lower hemisphere projection)



(poles to bedding plane thrusts- lower hemisphere projection)



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



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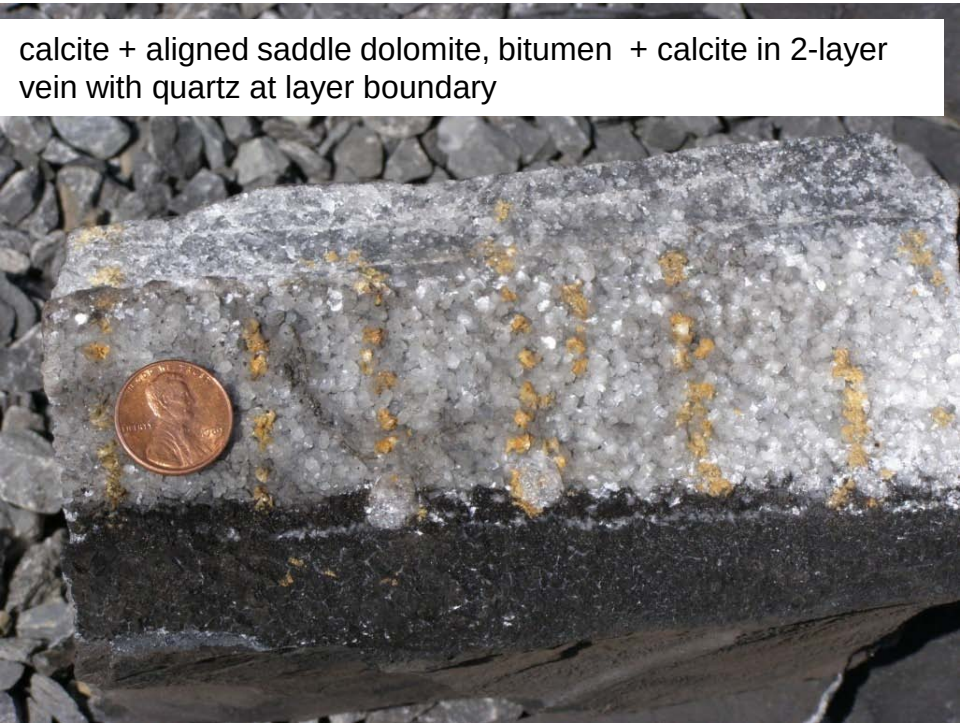
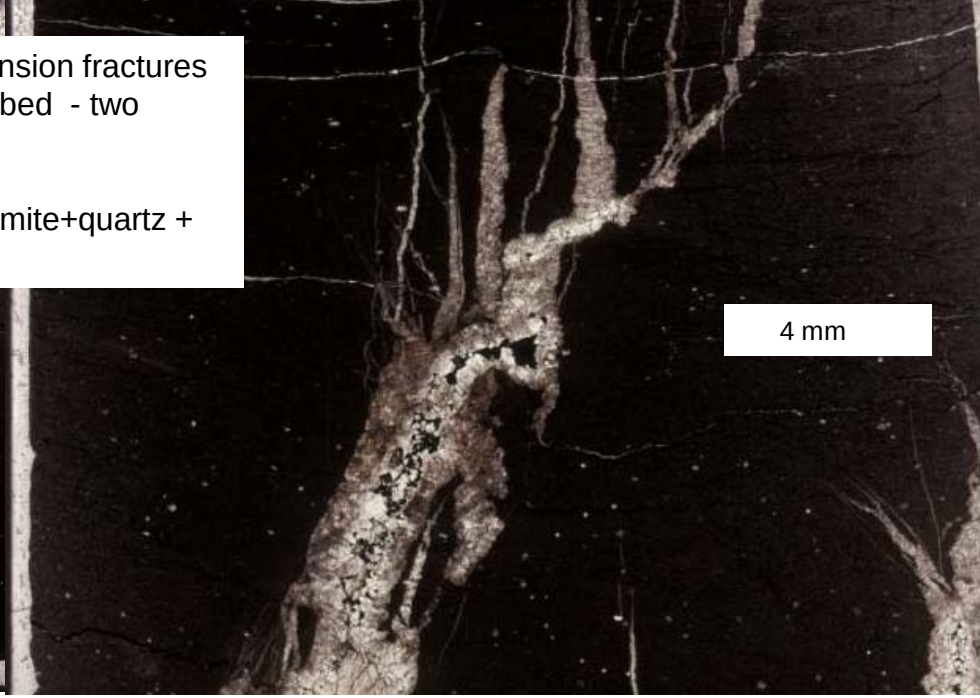
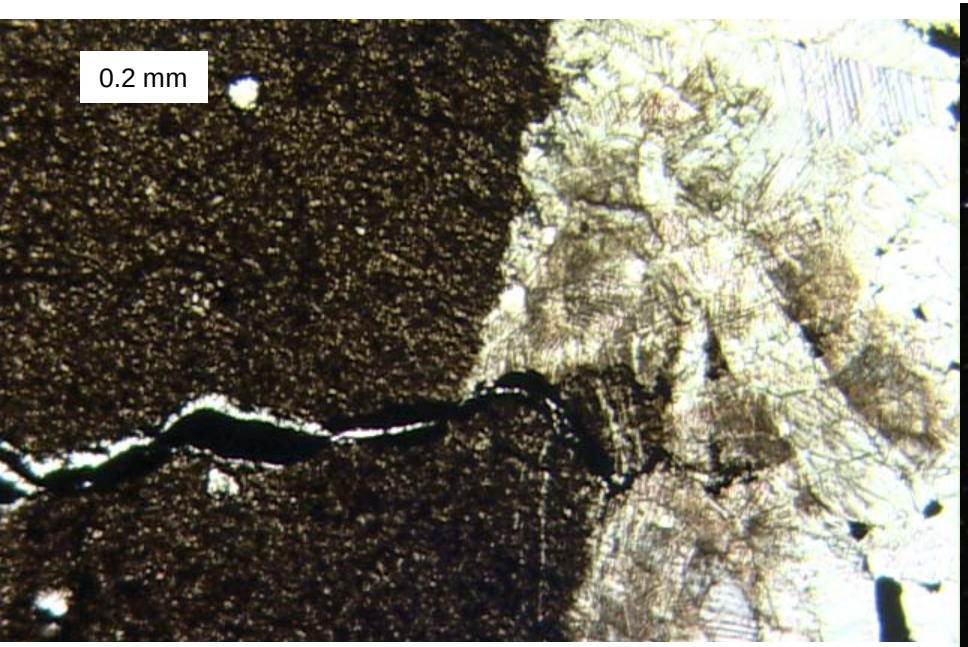


calcite + aligned saddle dolomite, bitumen + calcite in 2-layer vein with quartz at layer boundary

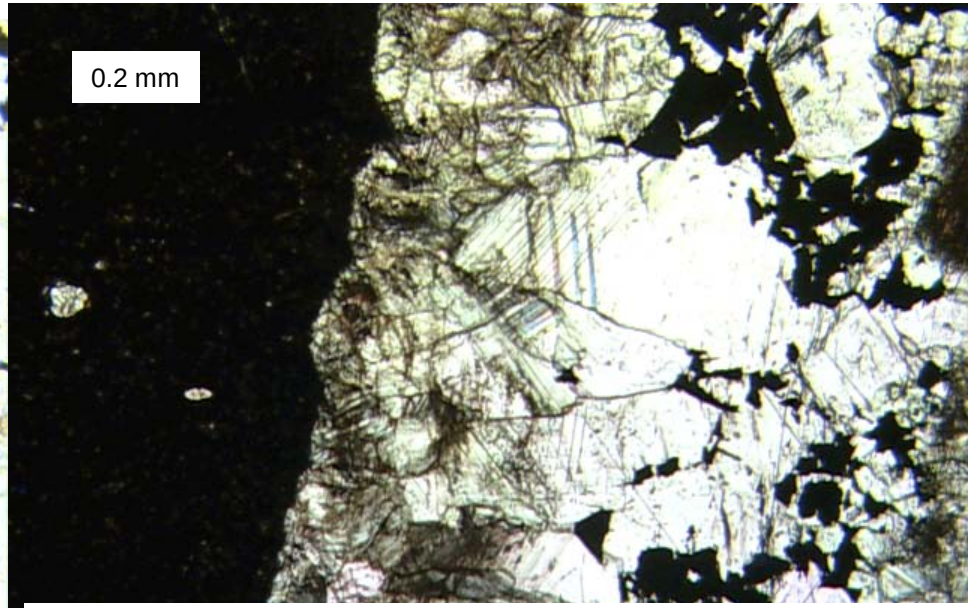
mineralized dilatent voids on bedding-plane fault surface

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

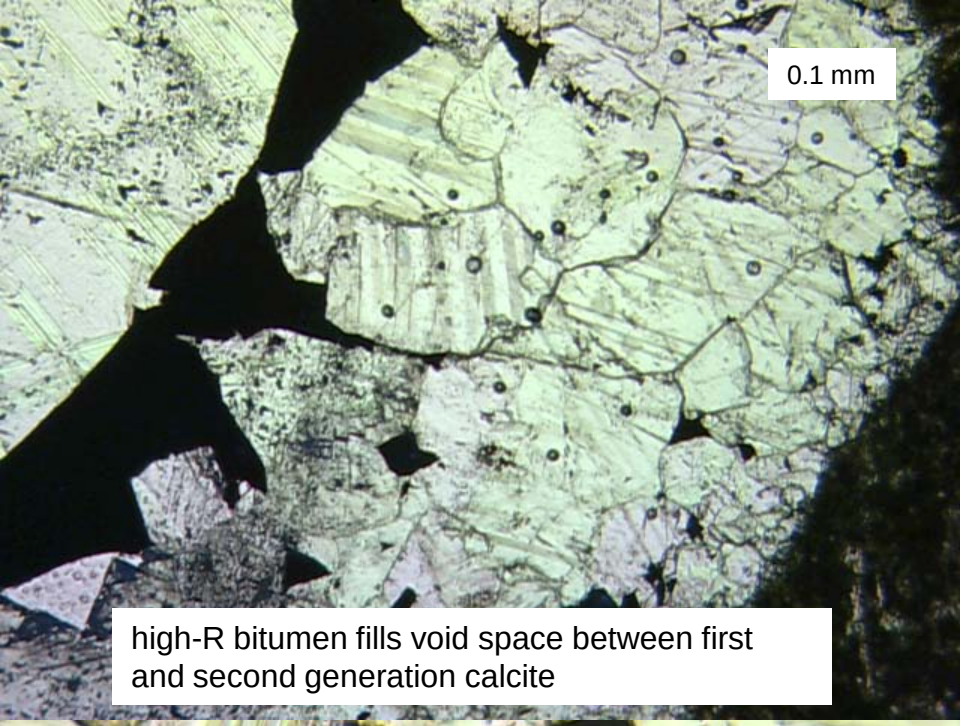




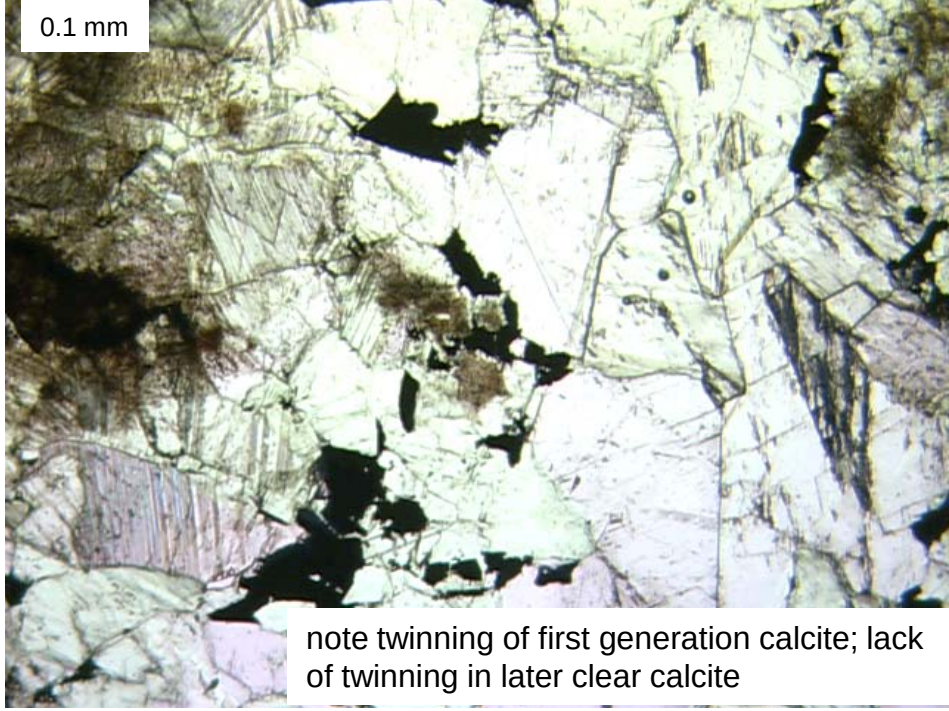
bitumen layer with calcite-filled shrinkage void intersects calcite vein; note brown staining of first-generation calcite cement



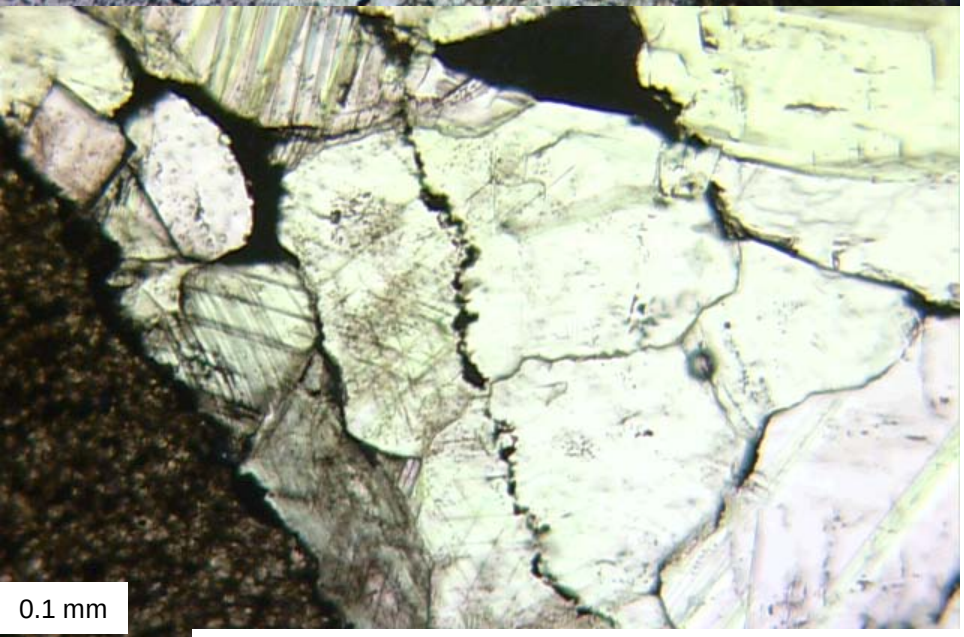
2 generations of calcite in vein; early generation stained by disseminated hydrocarbon; second generation clear and associated with high-reflectance (hi-R) bitumen (‘anthraxolite”)



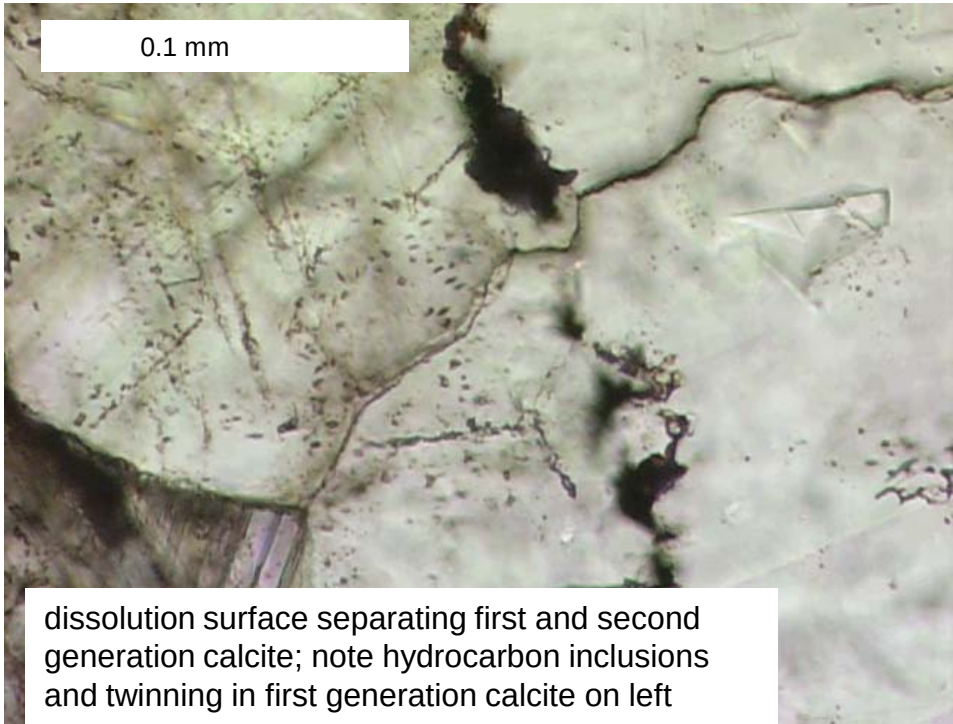
high-R bitumen fills void space between first and second generation calcite



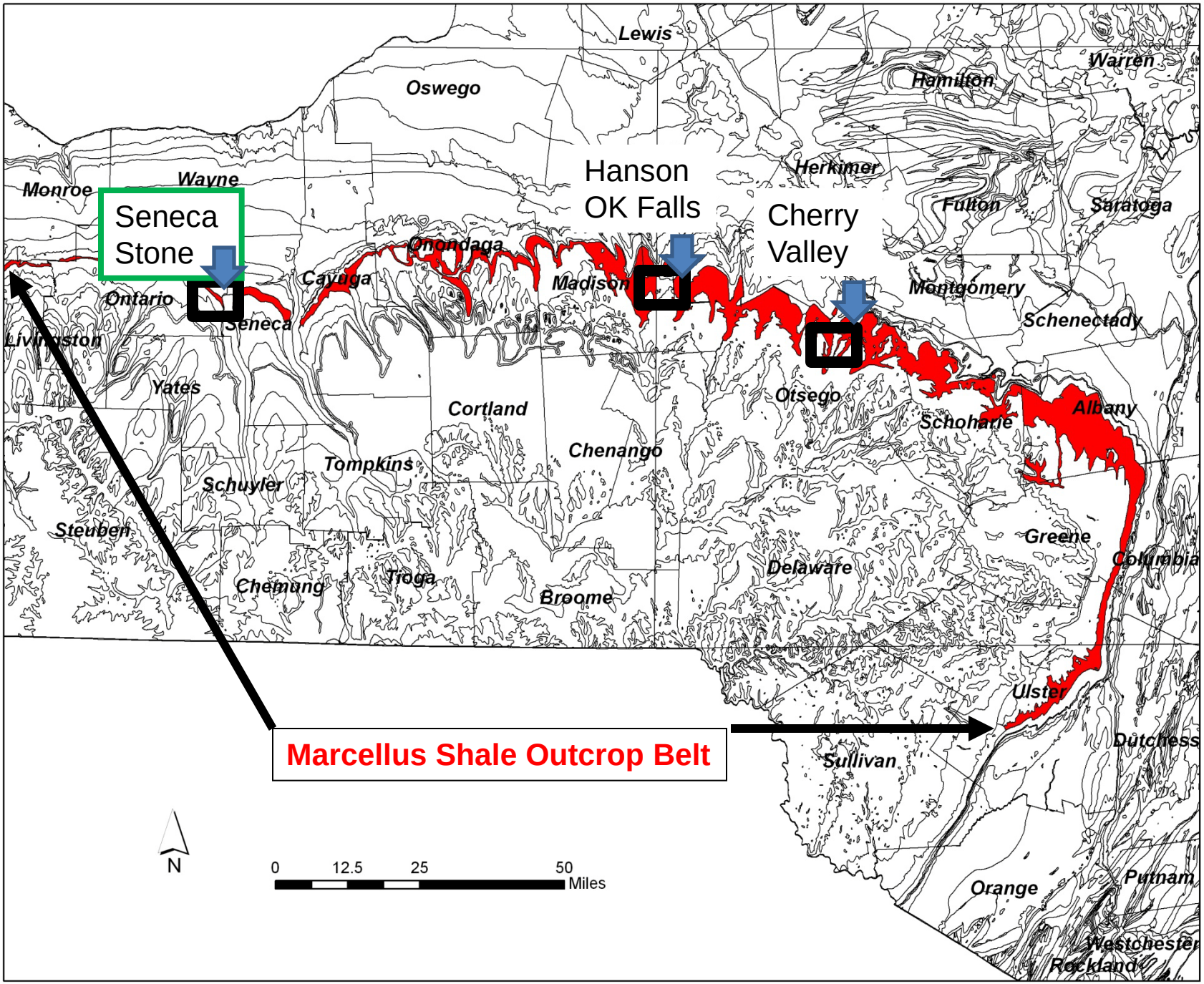
note twinning of first generation calcite; lack of twinning in later clear calcite



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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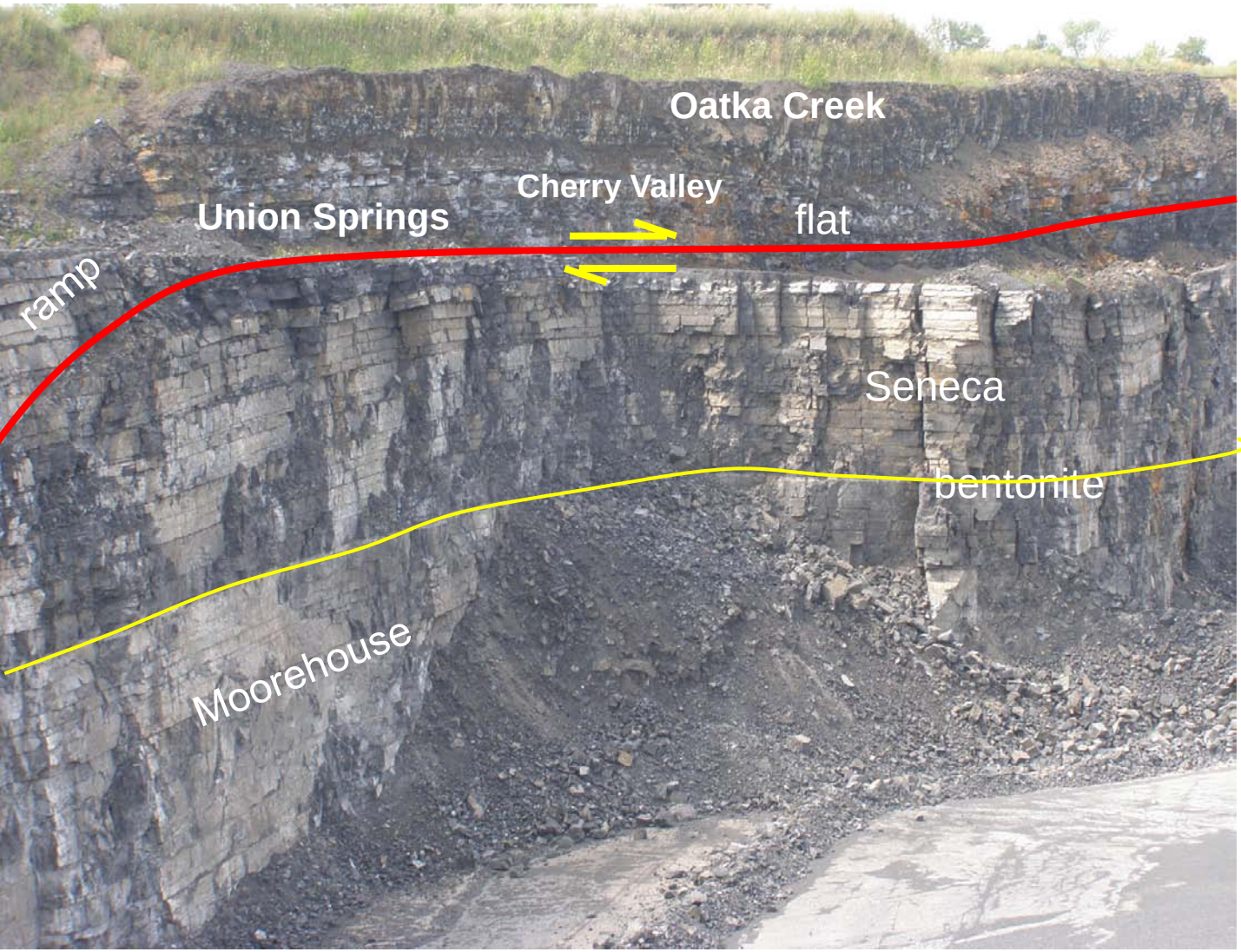
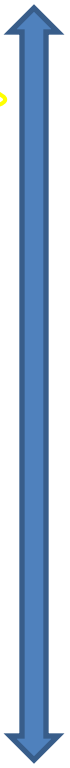
Seneca Stone Quarry, Fayette, NY





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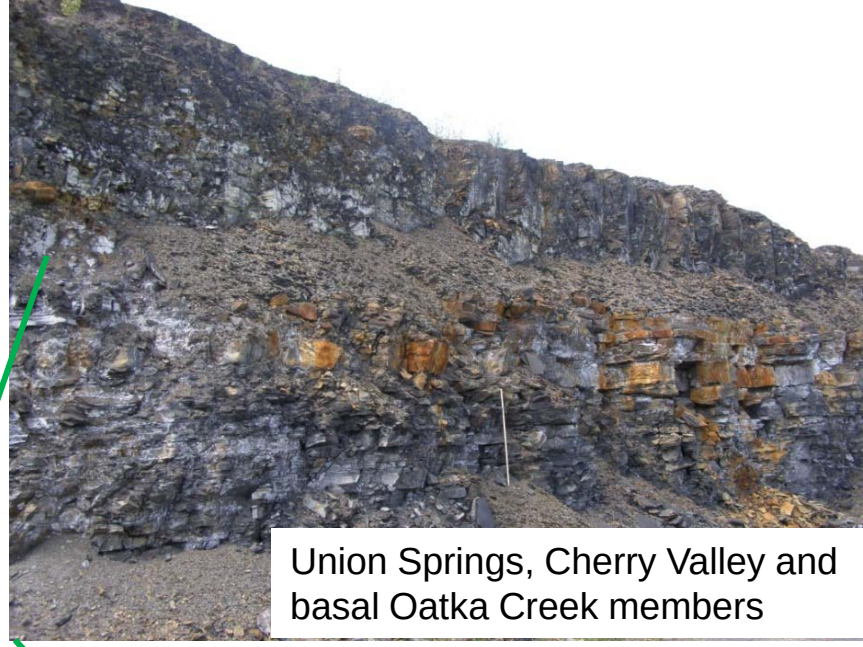
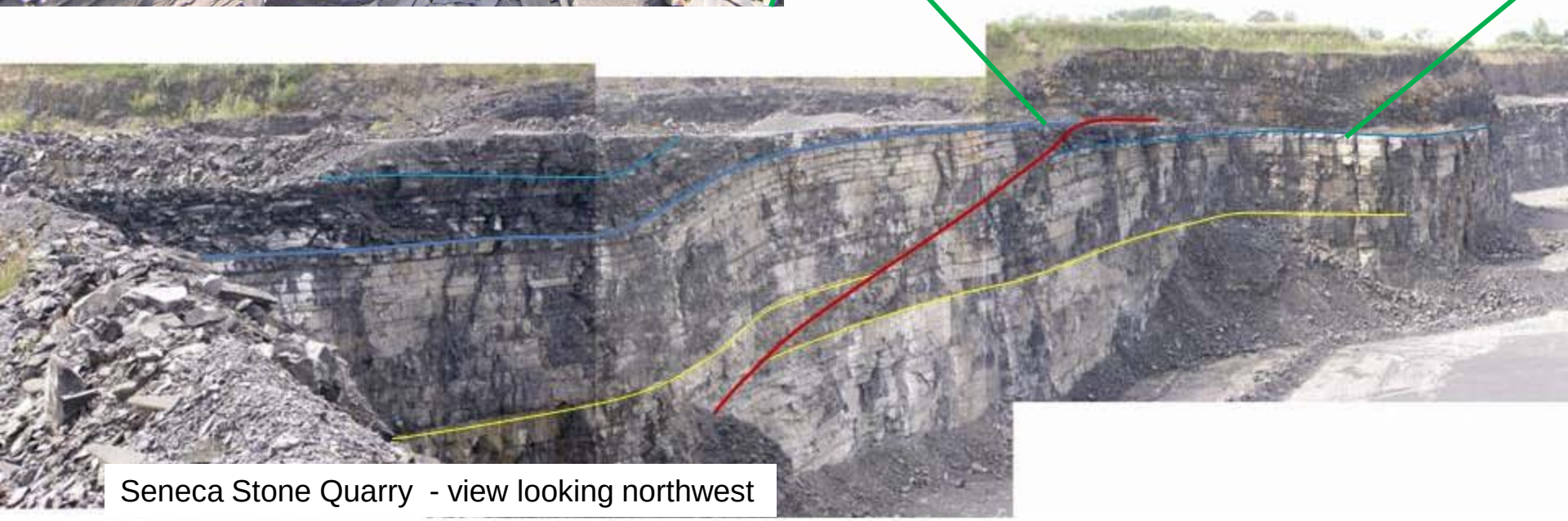
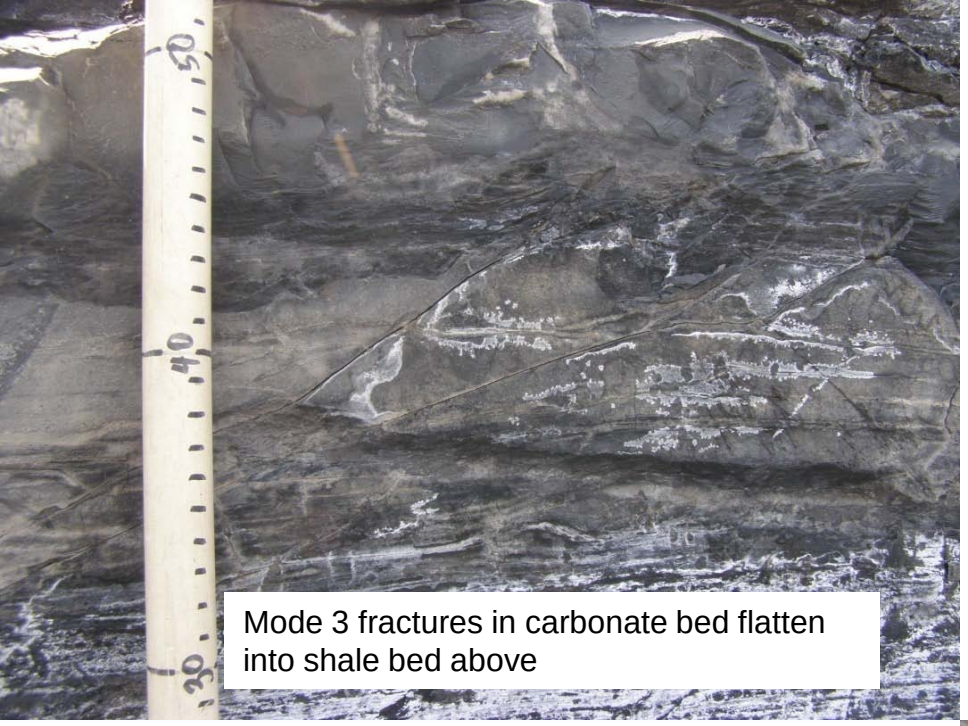
fracture intensification in basal Oatka Creek



Union Springs, Cherry Valley and basal Oatka Creek members



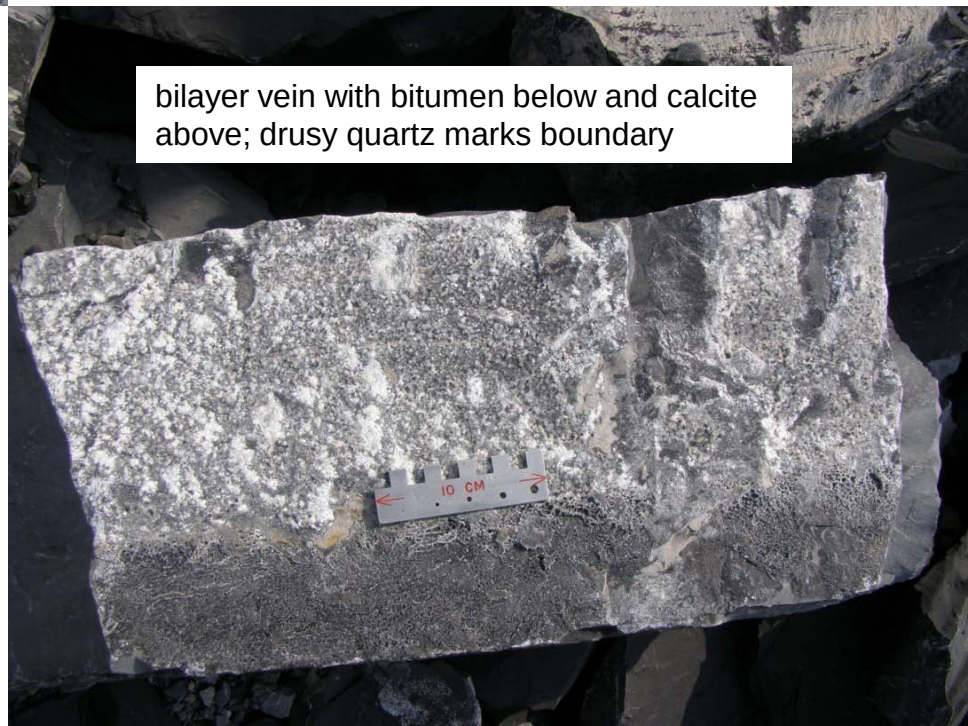
Seneca Stone Quarry - view looking northwest



Mode 3 fractures in carbonate bed flatten into shale bed above

intersection of cleavage with bedding surface in shale, Union Springs

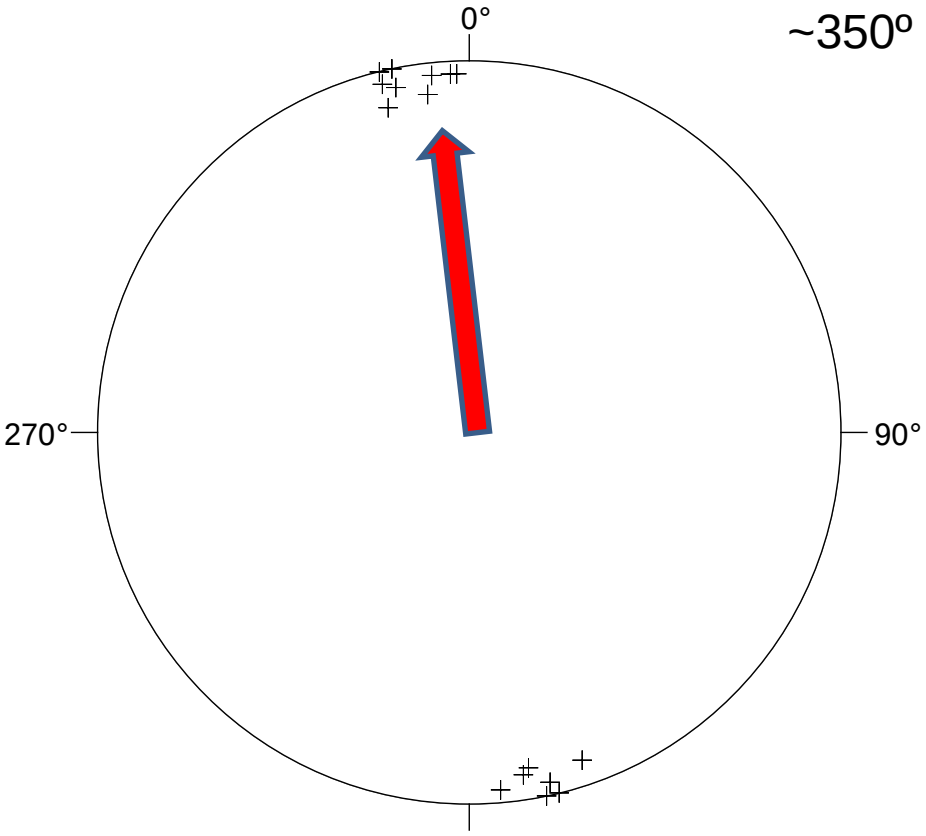
near horizontal lineations on bedding surface in Union Springs



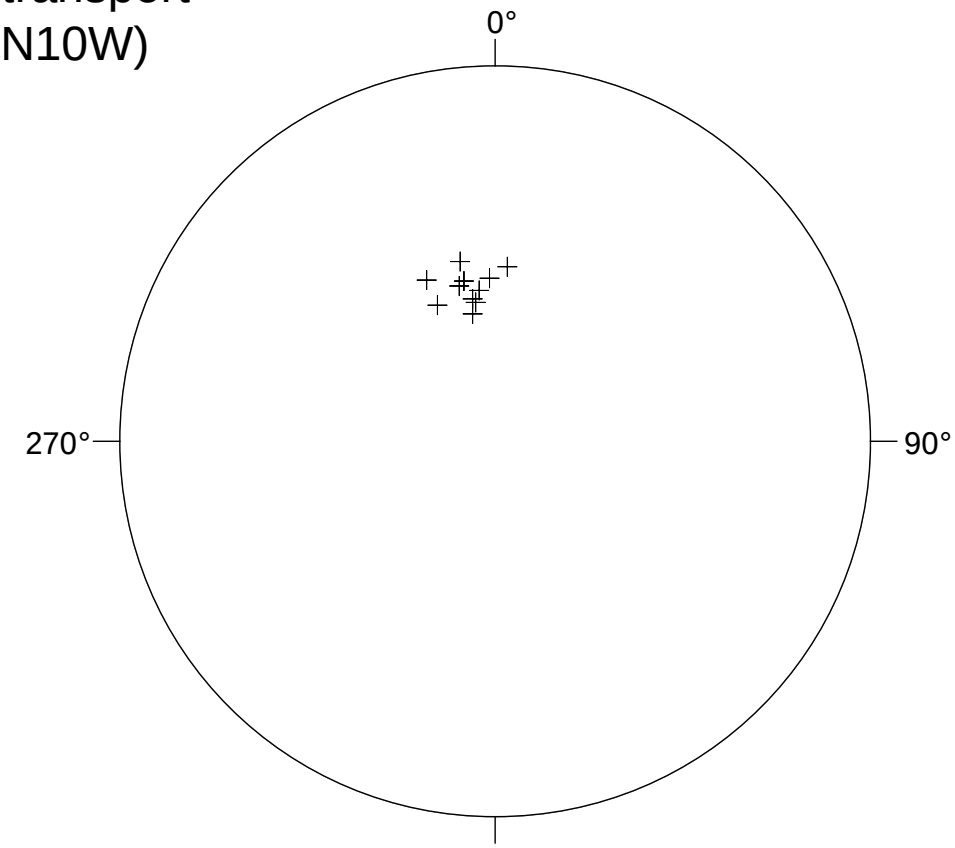
bilayer vein with bitumen below and calcite above; drusy quartz marks boundary

Seneca Stone Quarry, Fayette, NY

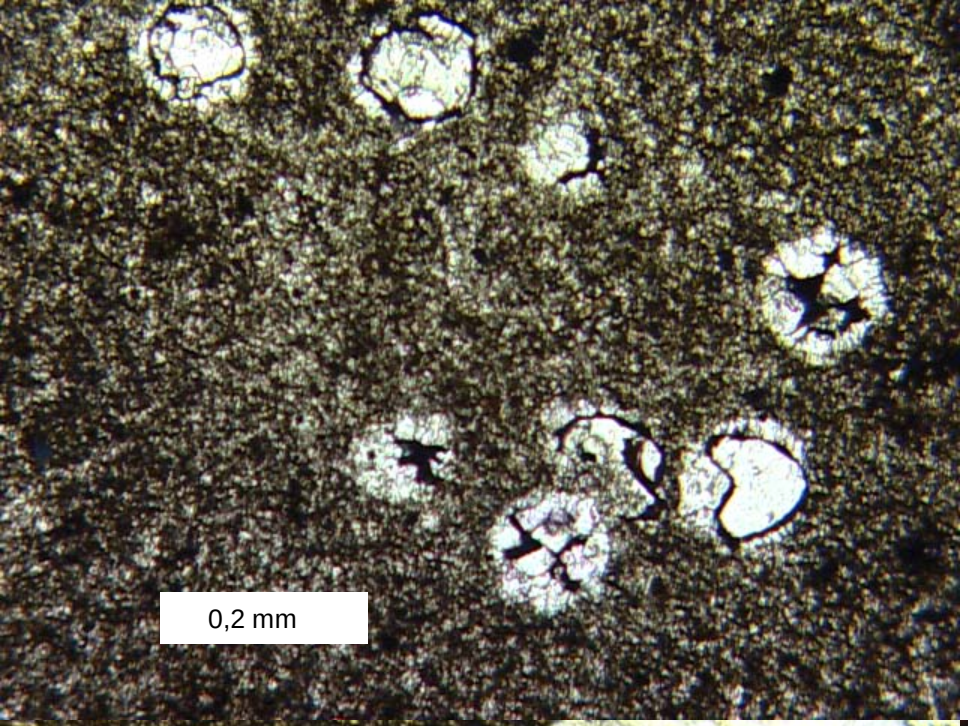
structural transport
~350º (N10W)



(lineations on bedding in Union Springs – lower hemisphere projection)



(poles to cleavage and Mode 3 fractures lower hemisphere projection)



Hydrocarbon maturation:

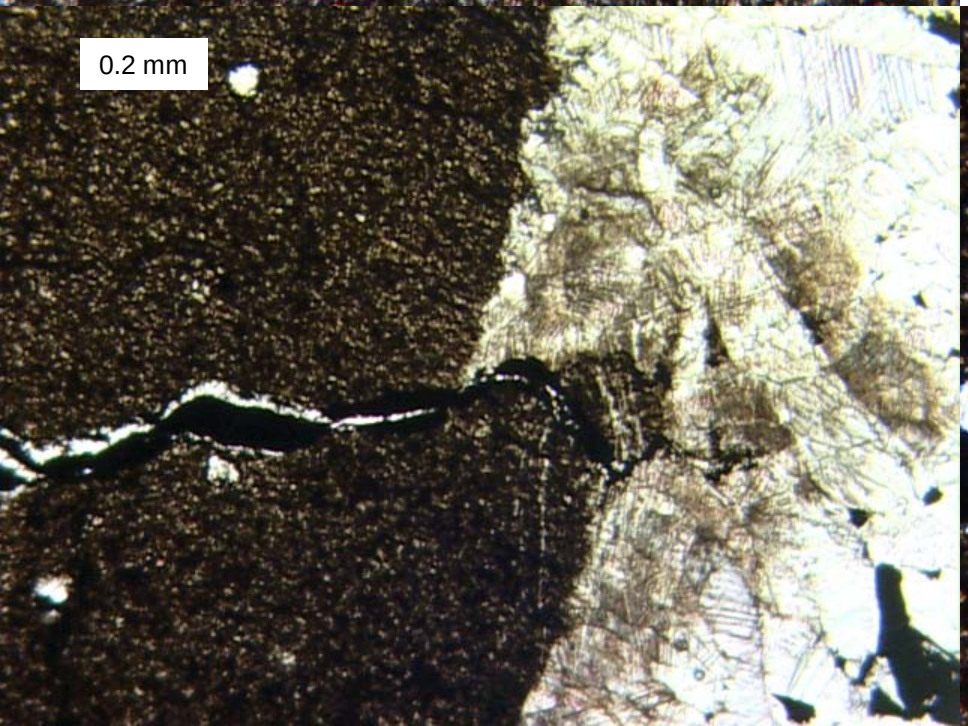
Key points:

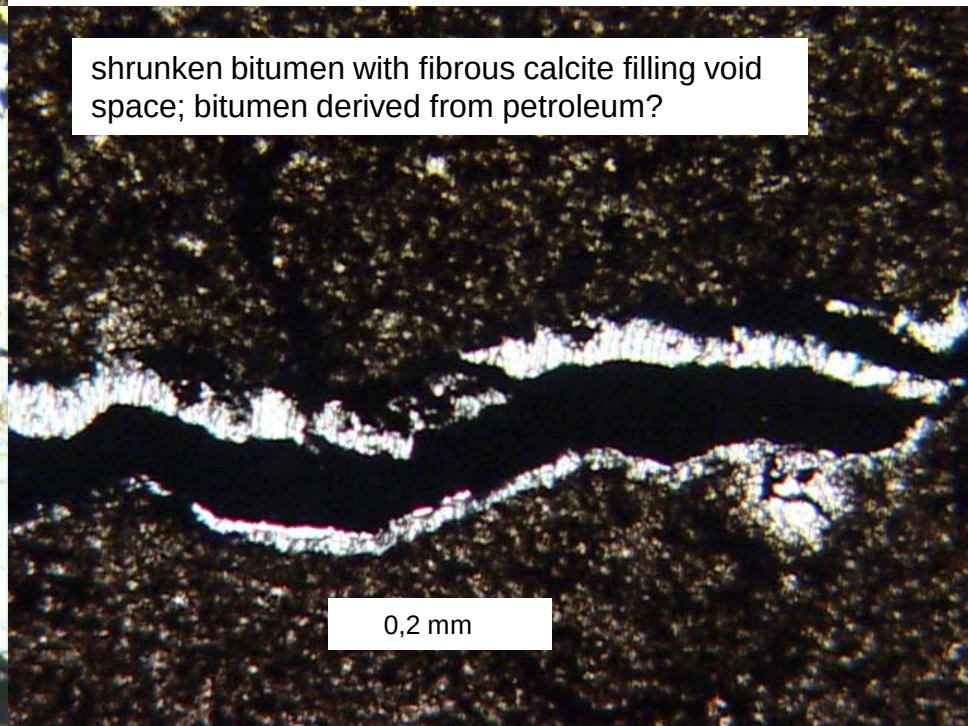
organic source is algal; algal cysts and calcispheres are common

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





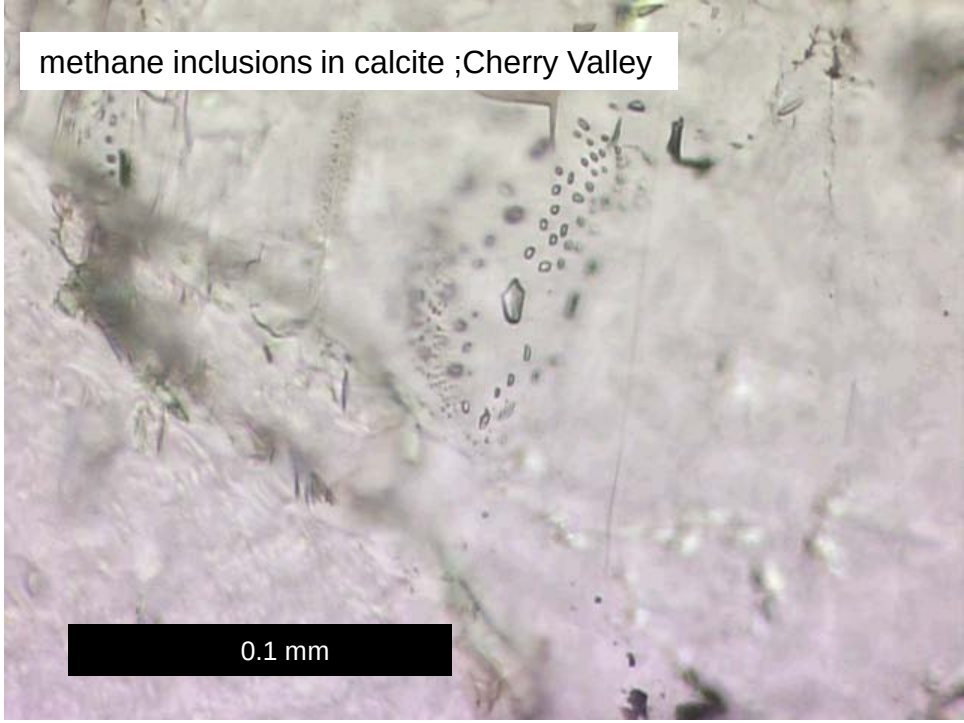
Fluid inclusions:

Key points:

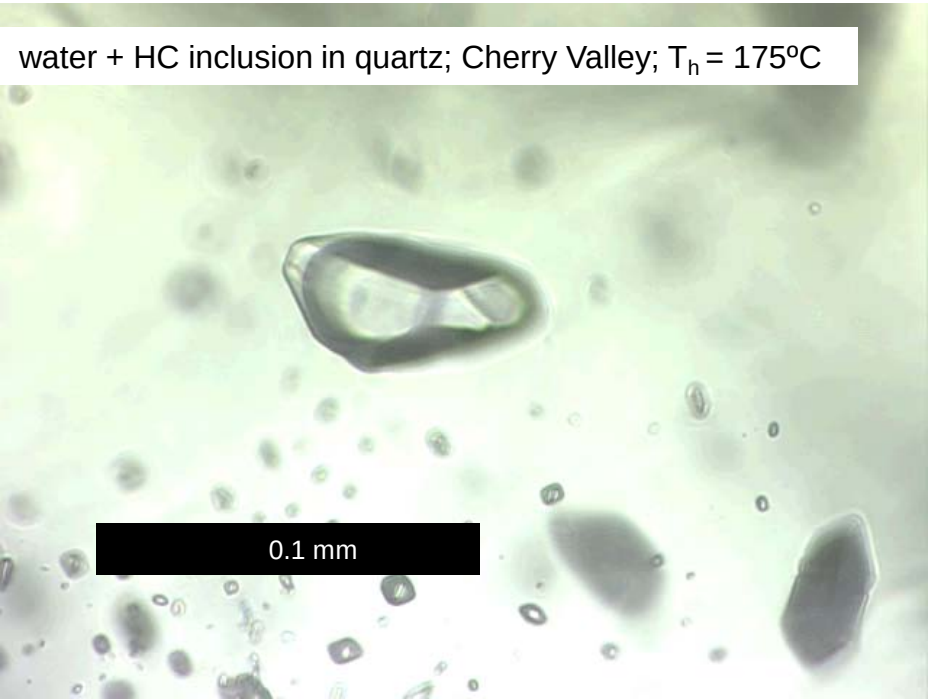
aqueous (water-rich) inclusions very rare; methane inclusions very common

water + hydrocarbon (HC) inclusions are water poor

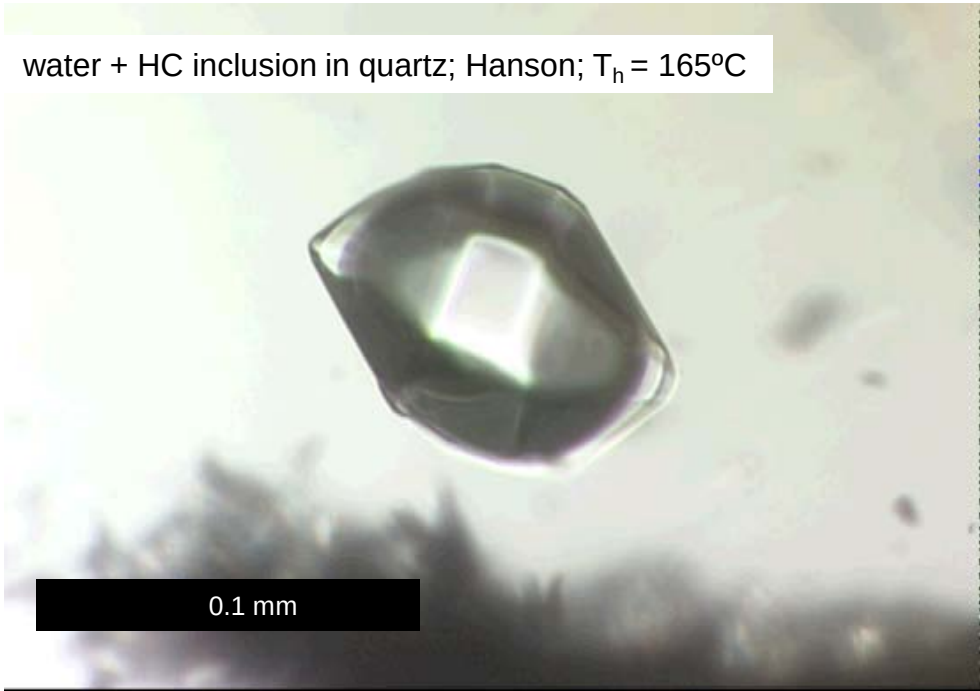
T_h of water + HC inclusions in quartz range from145-180ºC, establishing minimum T of vein development; temperatures above the ‘oil window’



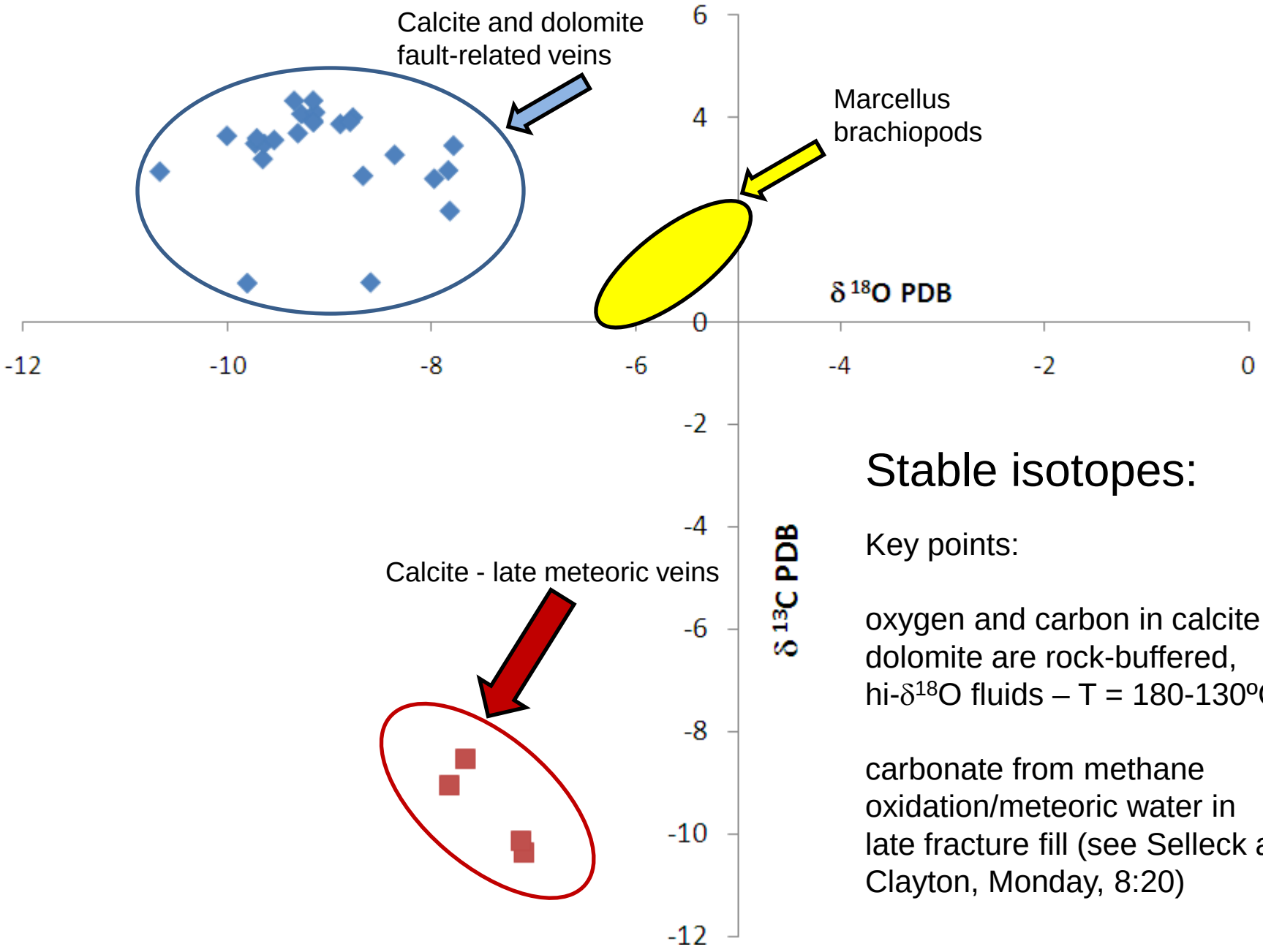
methane inclusions in calcite ;Cherry Valley



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



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

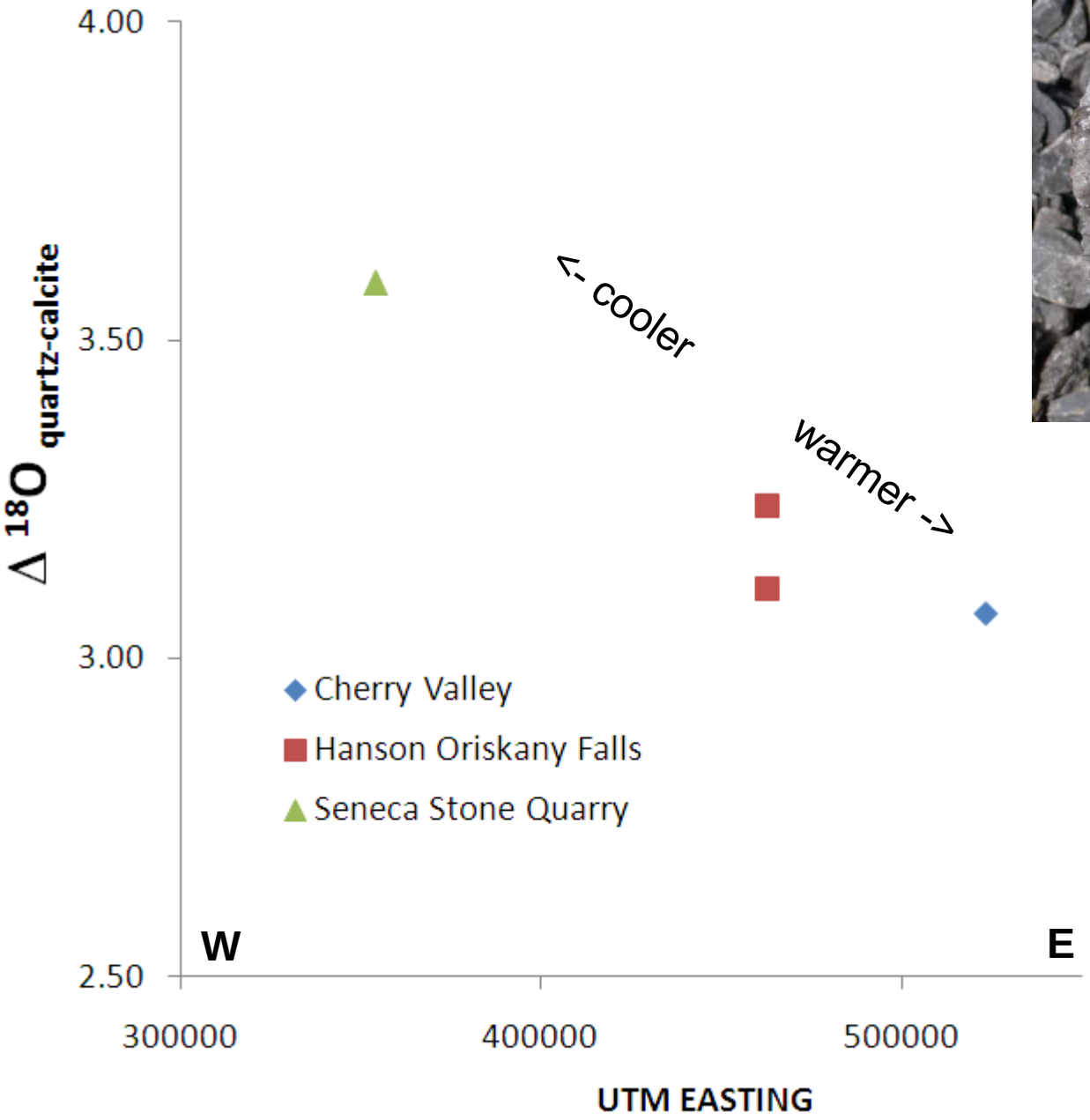


Stable isotopes:

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 (see Selleck and Clayton, Monday, 8:20)



Key point:

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

Summary:

Thrust faulting and duplex development occurs within the basal Marcellus Formation at the northern limit of the Appalachian foreland and does not depend on presence or absence of Silurian salt

Deformation occurred during hydrocarbon maturation

Elevated fluid pressures likely reduced rock strength and promoted deformation

Fracture and vein mineralization was 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

Zones of thrust faulting contain abundant natural fractures and vuggy porosity forming reservoir systems that may not require hydraulic fracturing