The Role of Muddy Hyperpycnites in Shelfal Mudstones and Their Effect on Reservoir Quality: Examples From the Geneseo Formation of New York, USA*

Ryan D. Wilson[1] and Juergen Schieber[2]

Search and Discovery Article #51179 (2015)**
Posted October 13, 2015

*Adapted from oral presentation given at AAPG Annual Convention & Exhibition, Denver, Colorado, May 31-June 3, 2015

[1]Geological Sciences, Indiana University, Bloomington, Indiana, United States (rydawils@indiana.edu)
[2]Geological Sciences, Indiana University, Bloomington, Indiana, United States

Abstract

Unconventional reservoir character varies at the mm- to km-scale vertically and laterally. This variability occurs in systematic ways that can be deciphered utilizing process-based models within a genetic framework. Variations in mudstone properties have a dramatic effect on prodicibility in shale reservoirs, however, the relative controls are not well understood. Detailed facies analysis, geochemistry, and petrography of the lower Genesee Group in the Northern Appalachian Basin (NAB) shows a wealth of sedimentary textures and fabrics that indicate mud deposition by lateral transport across and along the shelf under energetic conditions. Intervals of silt-rich mudstones and muddy siltstones with internal scours, diffuse stratification, soft-sediment deformation, normal and inverse lamina-set grading, and a reduced intensity and diversity of bioturbation occur in multiple facies types and "interrupt" what appears to be the overall background sedimentation. These intervals and their sedimentary features are interpreted as products of high-density fluvial discharge events, which generated turbulent flows that carried fine-grained clastics several tens of kilometers offshore from the paleoshoreline. Recognizing these sediments as products of river-flood- and storm-wave-generated offshore-directed underflows challenges previous depositional models for organic-rich mudstones in the lower Genesee succession, which call for clastic starvation and suspension settling of clay and silt in a deep stratified basin. In the Genesee Group, these observations imply rapid deposition of fine-grained intervals from hyperpycnal plumes in a setting favoring preservation of organic-rich mudstones, and suggest that similar reappraisals of depositional setting are necessary for comparable mudstone successions elsewhere in the Appalachian Basin. The described strata are yet another example for a carbonaceous mudstone succession that was deposited under comparatively energetic conditions, reflects multiple modes of sediment transport and deposition, and records significant carbon burial without a need for anoxic bottom waters. Through understanding the dynamic nature of mudstone depositional environments, process-based modeling can be conducted much more accurately at the reservoir scale, and can account for subtle changes in composition, cementation, porosity/permeability, as well as organic-matter type.

References Cited

Maynard, J.B., 1981, Carbon Isotopes as Indicators of Dispersal Patterns in Devonian-Mississippian Shales of the Appalachian Basin: Geology, v. 9, p. 262-265.

Schieber, J., 2013, SEM Observations on ION-milled Samples of Devonian Black Shales from Indiana and New York: The Petrographic Context of Multiple Pore Types: AAPG Memoir 102, p. 153-172.

Ver Straeten, C.A., 2004, K-bentonites, Volcanic Ash Preservation, and Implications for Lower to Middle Devonian Volcanism in the Acadian Orogen, Eastern North America: Geological Society of America Bulletin, v. 116, p. 474-489.

Wilson, R.D., and Schieber, J., 2014, Muddy Prodeltaic Hyperpycnites In the Lower Genesee Group of Central New York, USA: Implications For Mud Transport In Epicontinental Seas: Journal of Sedimentary Research, v. 84, no. 10, p. 866-874.

Zavala, C., Arcuri, M., Meglio, M.D., Diaz, H.G., and Contreras, C., 2011, A genetic facies tract for the analysis of sustained hyperpycnal flow deposits, in Slatt, R.M., and Zavala, C., eds., Sediment Transfer from Shelf to Deep Water: Revisiting the Delivery System: American Association of Petroleum Geologists, Studies in Geology 61, p. 31–51.

The Role of Muddy Hyperpycnites in Shelfal Mudstones and Their Effect on Reservoir Quality: Examples From the Geneseo Formation of New York, USA

Ryan D. Wilson and Juergen Schieber

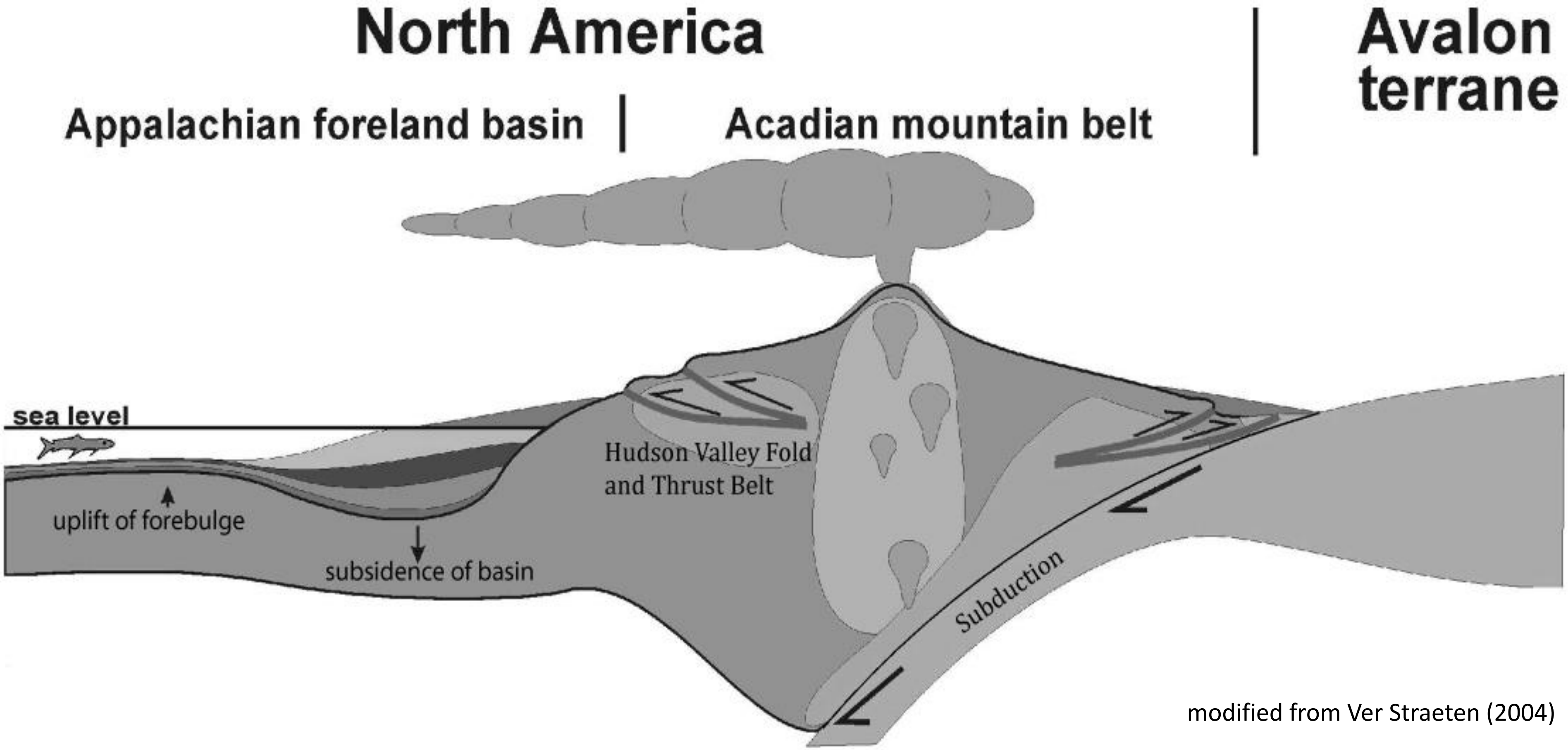
IU Shale Research

6/1/2015

Outline of Talk

- **Introduction**
  - **Devonian Appalachian Basin Stratigraphy and Paleoenvirons**
  - **Study Area**
- **Stratigraphic Expression**
  - **Litho- and Sequence-stratigraphy**
- **Depositional Environment**
  - **Proximal-Distal relationships**
  - **Products of wave-aided hyperpycnal flows**
- **Chemical and Compositional Attributes**
  - **Stable carbon isotopes of organic-matter**
  - **High-resolution X-ray fluorescence and XRD**
- **Pore Characterization**
- **Conclusions**

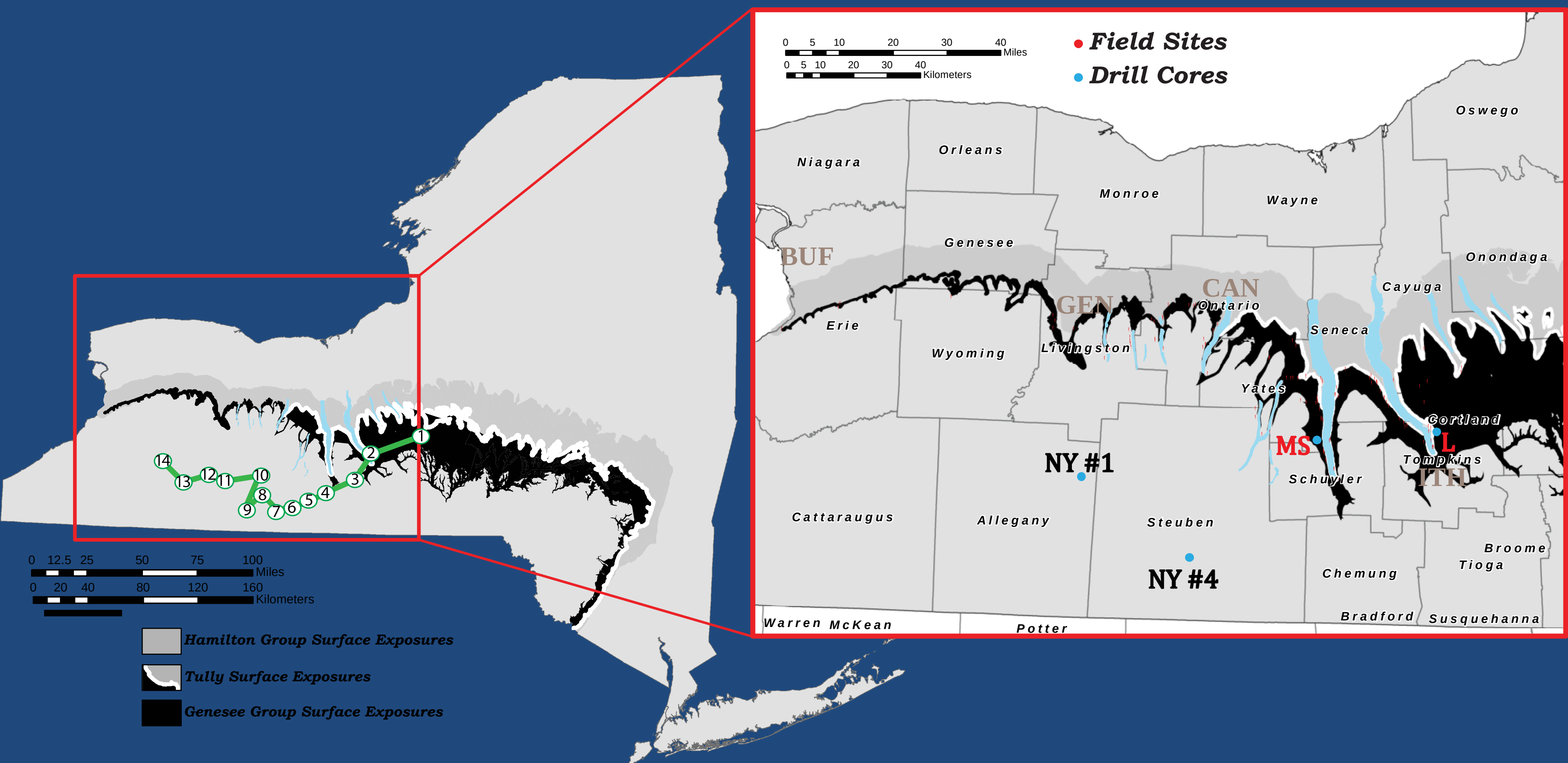
Acadian Orogeny



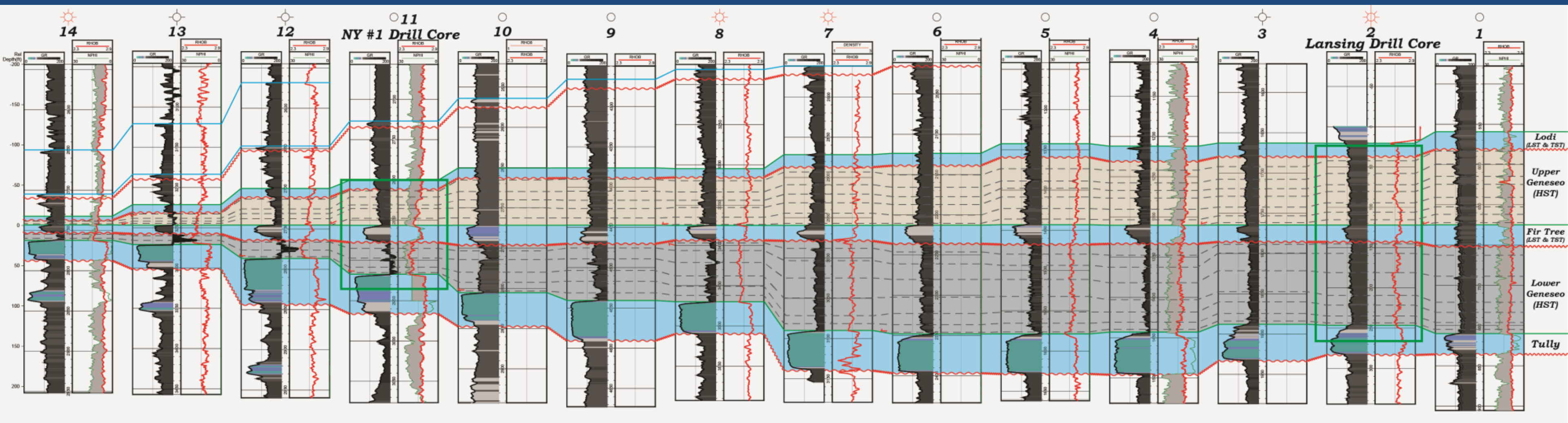
Marcellus and other Devonian organic-rich mudrocks formed primarily on the cratonward side of the foreland basin. Primary control for organic-richness is likely *decreased dilution* from siliciclastics coming from the mountains to the east

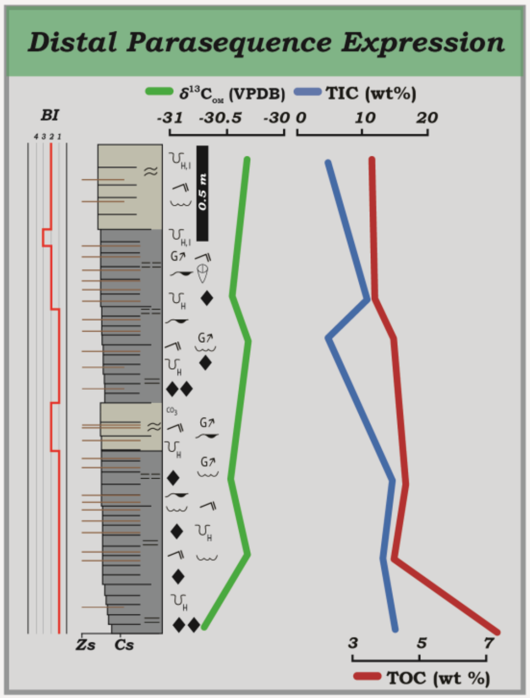
Study Area

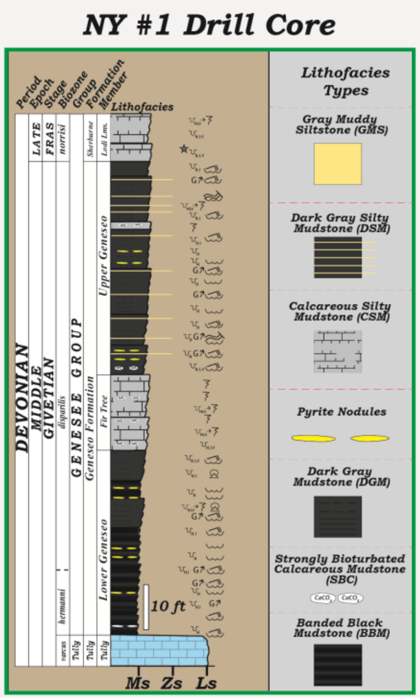
Finger Lakes region of New York (Cayuga Lake).

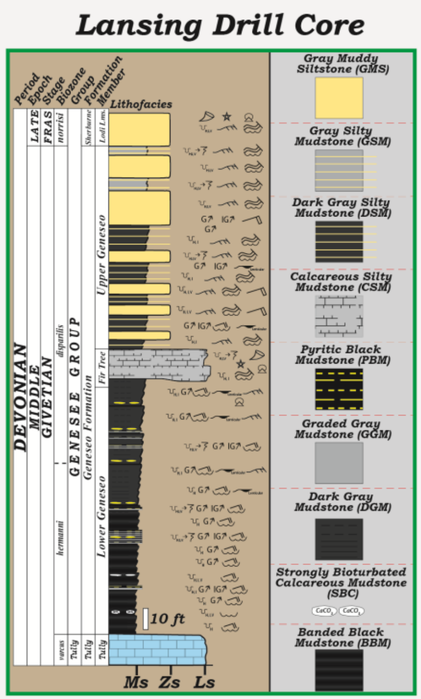


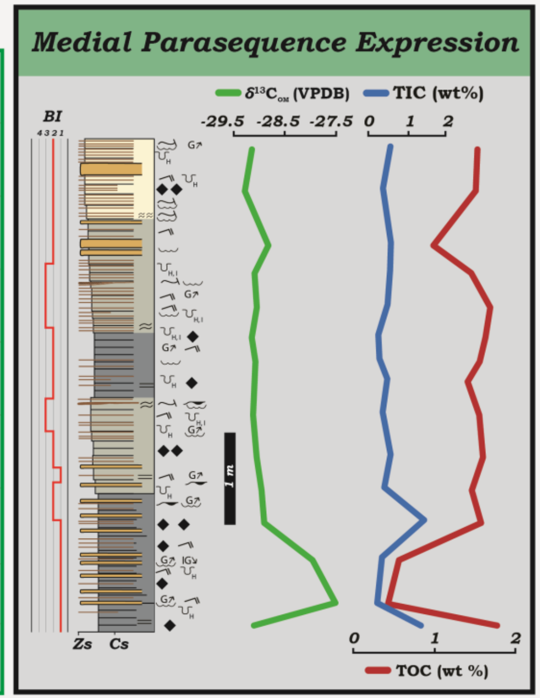
Stratigraphy



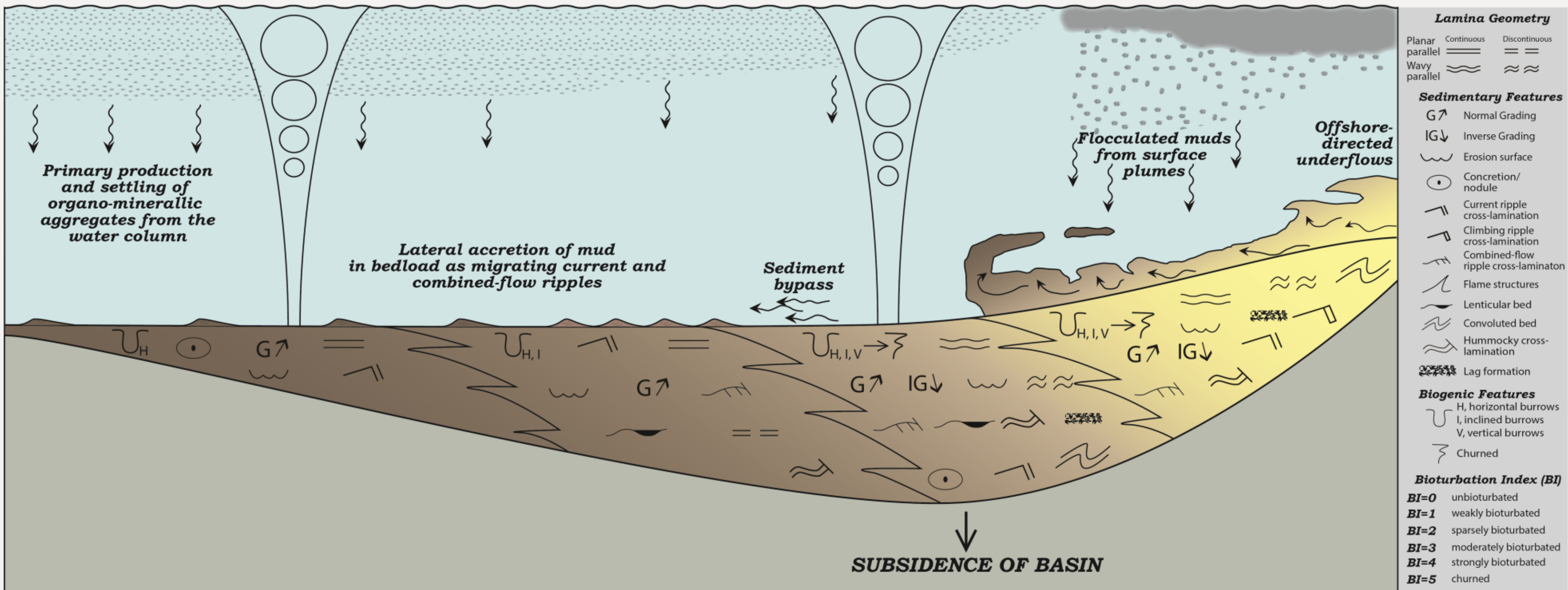








Geneseo EOD



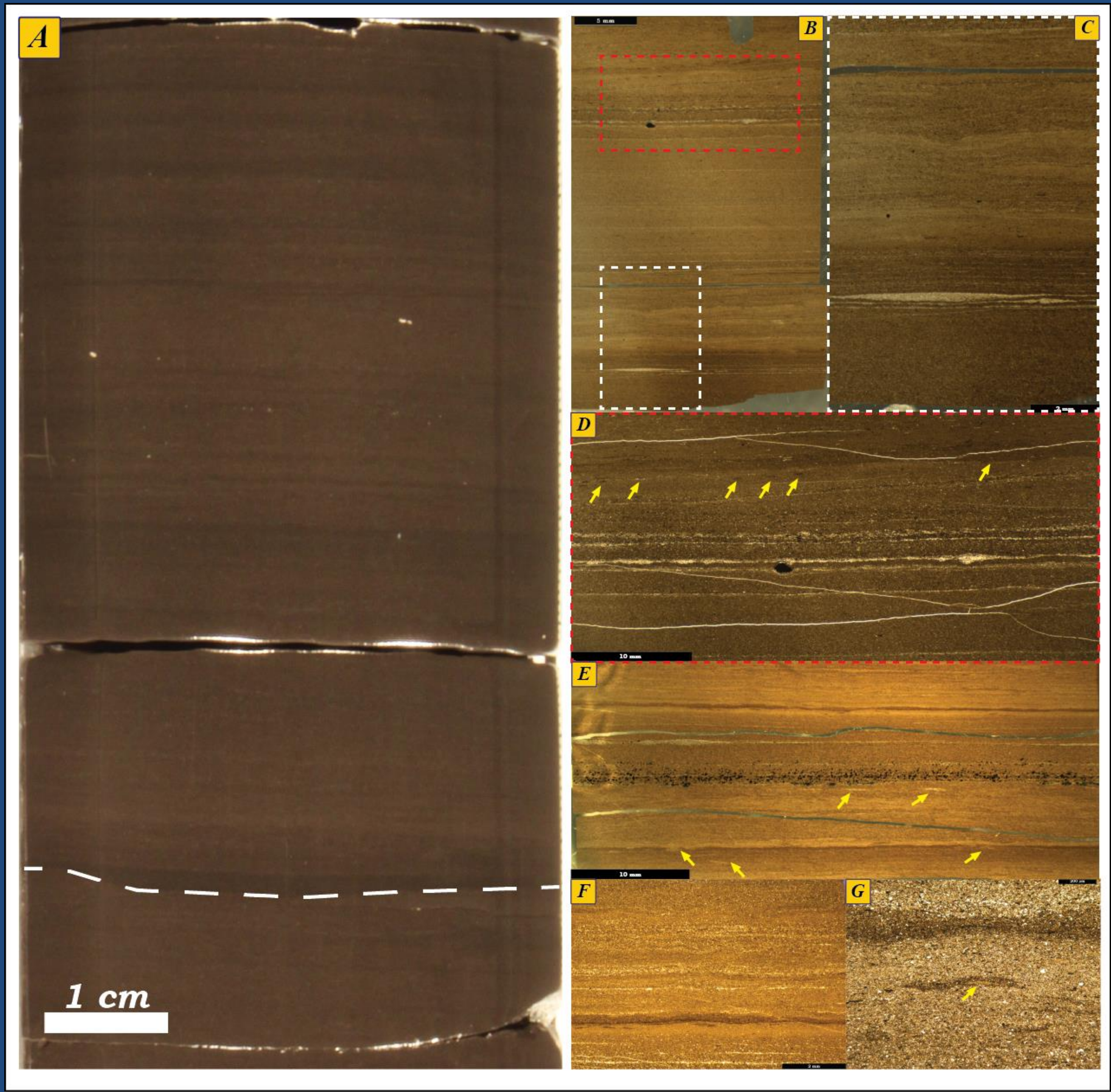
Depositional Environment	*Low clastic input, storm wave shelf, distal*	*Moderate clastic input, storm wave shelf, distal*	*Varying clastic input (high to low), storm wave shelf, medial*	*High clastic input, storm wave shelf, medial to proximal*
Trace Fossil Type	*Crypto-bioturbation, Chondrites, Helminthopsis, Planolites, Phycosiphon*	*Crypto-bioturbation, Chondrites, Paleophycus, Planolites, Phycosiphon, Teichichnus, Thalassinoides*	*Chondrites, fugichnia, navichnia, Paleophycus, Planolites, Phycosiphon, Teichichnus, Thalassinoides*	*fugichnia, navichnia, Paleophycus, Phycosiphon, Thalassinoides*
Hi Ecologic Stress Lo	*Slow sedimentation rate Soupground substrate Suboxic to dysoxic benthic redox conditions*	*Dysoxic benthic redox conditions*		*Unstable salinity Intense wave action Fast sedimentation rate*
5 Bioturbation Intensiy 0				

Geneseo Organic-rich Facies

A) **Hand sample (core) image showing erosional scours infilled by darker muds (dashed line) and repeated light and dark bands with evidence of a surface mixed layer.**

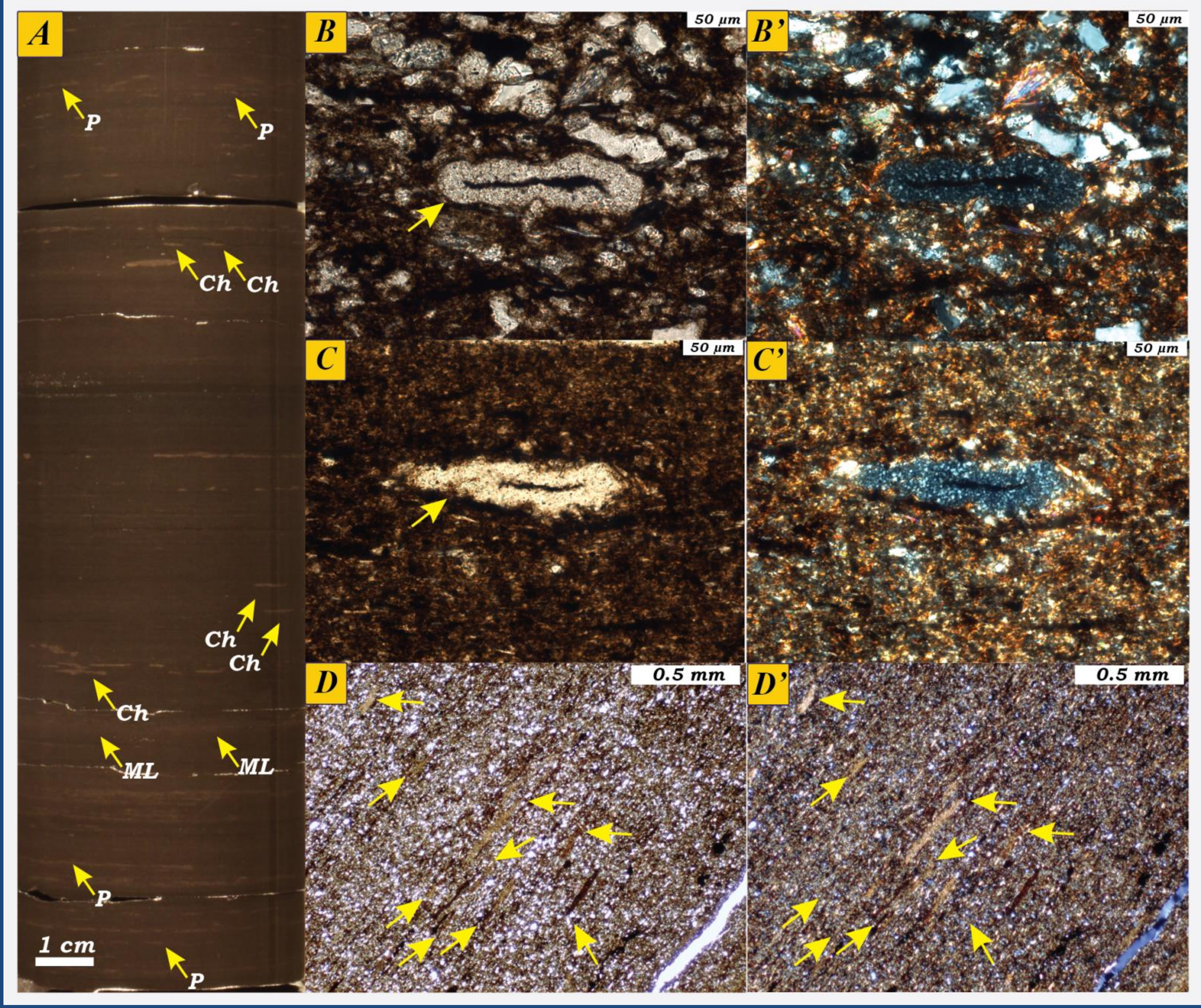
B,C,D) **continuous to discontinuous, planar parallel silt laminae, diffuse bed boundaries, indicating mixing of surface layer boundaries by shallow burrowing benthic organisms, such as polychaetes or nematodes.**

E,F,G) **Cryptic bioturbation (horizontal mixing) with small silt-filled burrows and disrupted lamina (arrows).**



Geneseo Organic-rich Facies

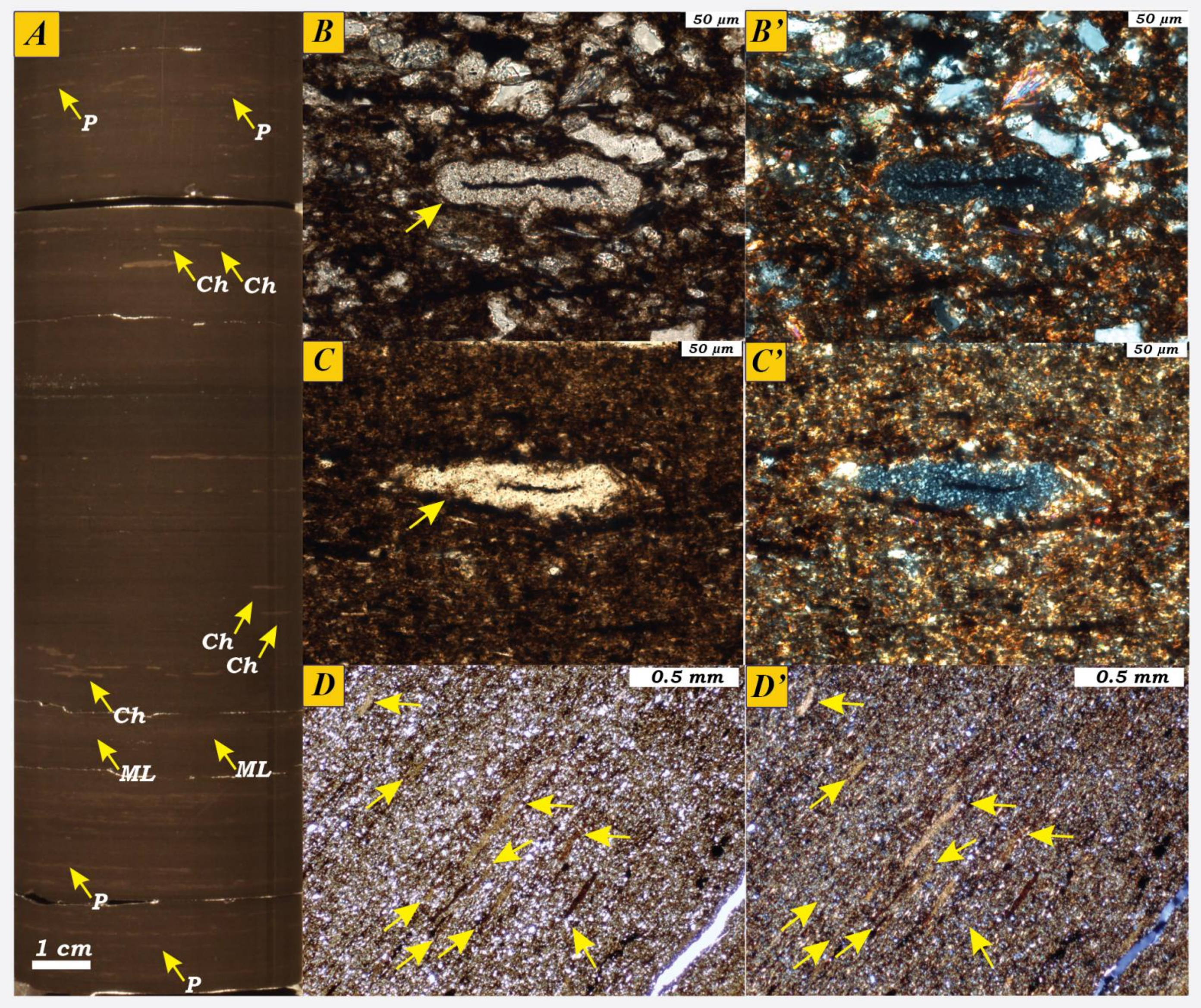
A) Sparsely to moderately bioturbated very dark gray mudstone. Note lamina/laminaset "blending", where meiofauna (e.g., nematodes, polychaetes) had colonized the seafloor, and horizontally mixed (ML) the water-rich sediments, indicating sufficient oxygen and time for a mixed layer to develop.



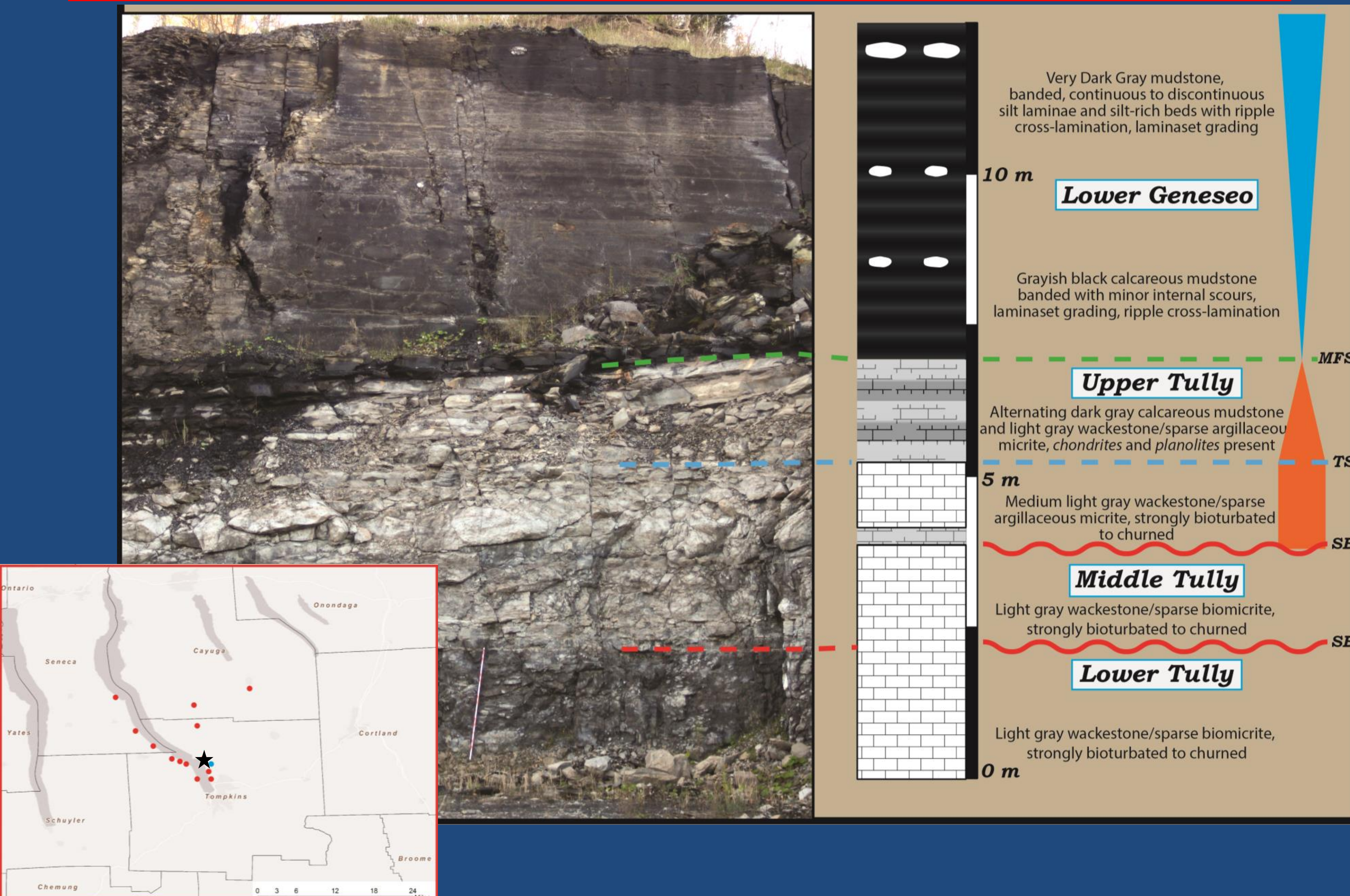
Geneseo Organic-rich Facies

B-C') Photomicrograph of agglutinated benthic foraminifera (yellow arrow) with partial internal fill that prevented complete collapse (plane-polarized light). Foraminifera are eukaryotic organisms, and as such require some oxygen to persist.

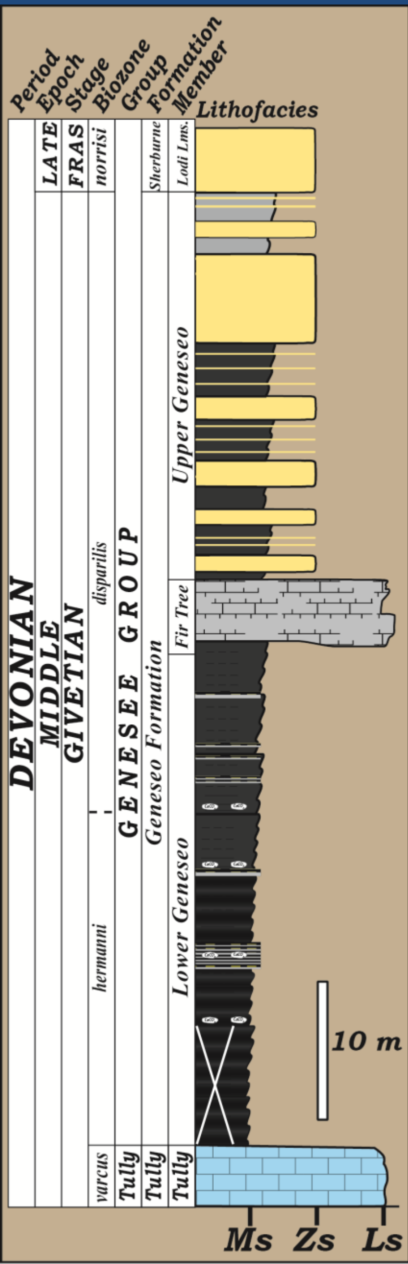
D-D') Scattered benthic fecal pellets in the shale matrix (PPL and XPL, rotated 45°). The pellets (yellow arrows) are flattened by compaction, and consist of mixture of silt and clays that were ingested by sediment feeding organisms.

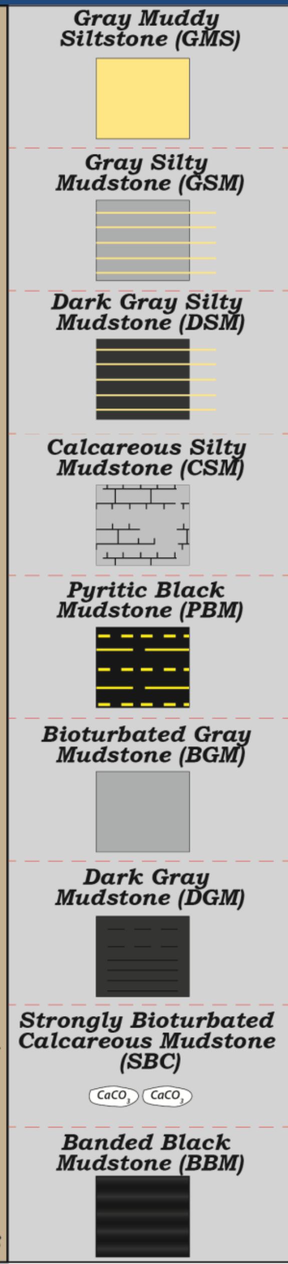


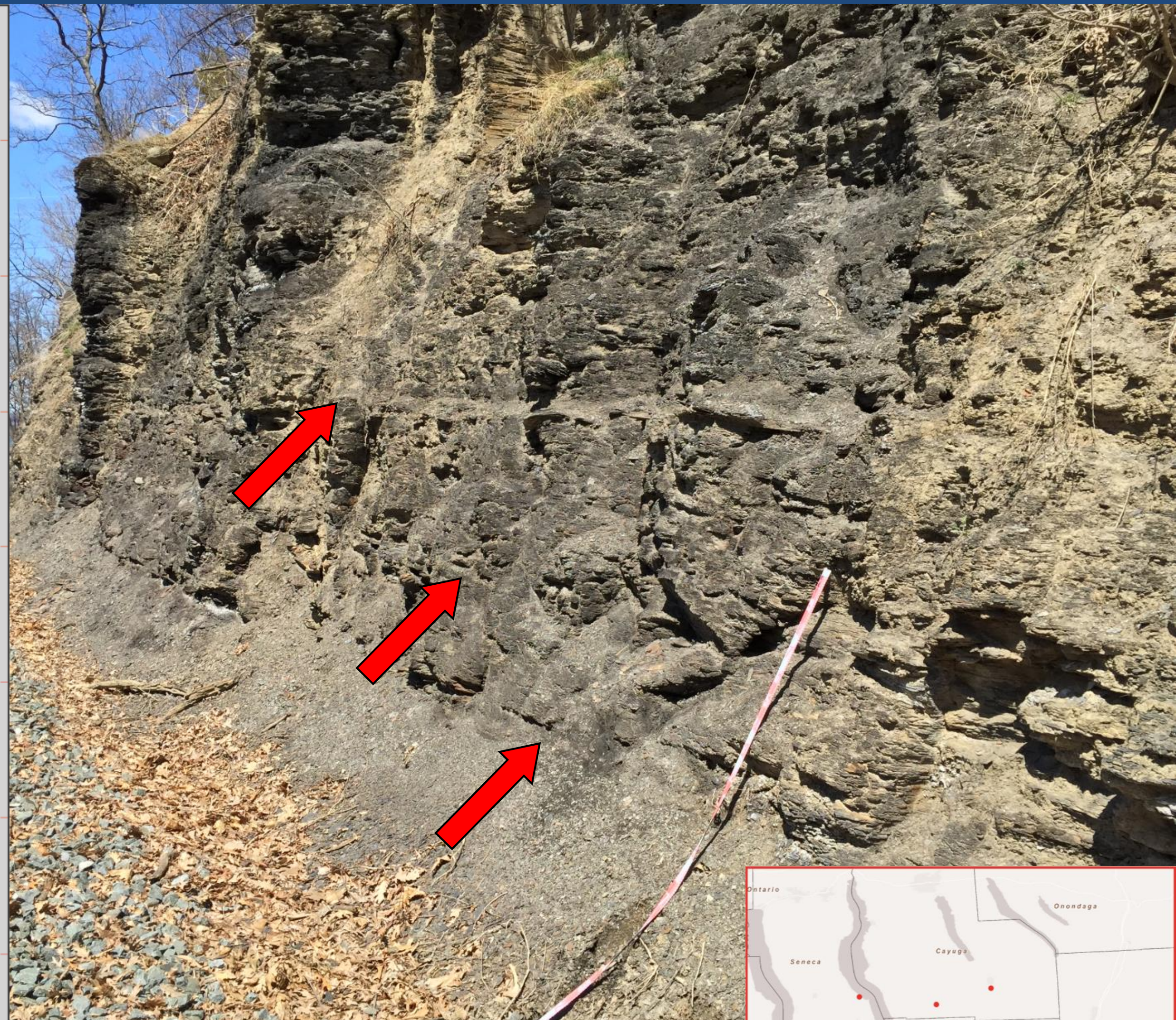
Cayuga Crushed Stone, NY

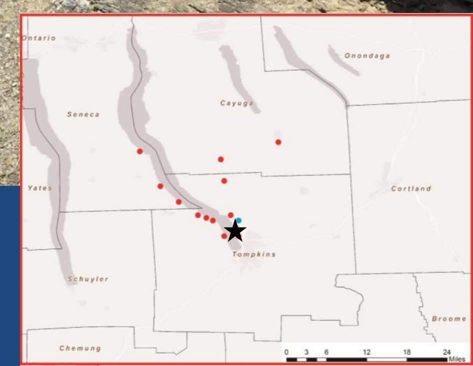


Blackchin RR Cut, NY

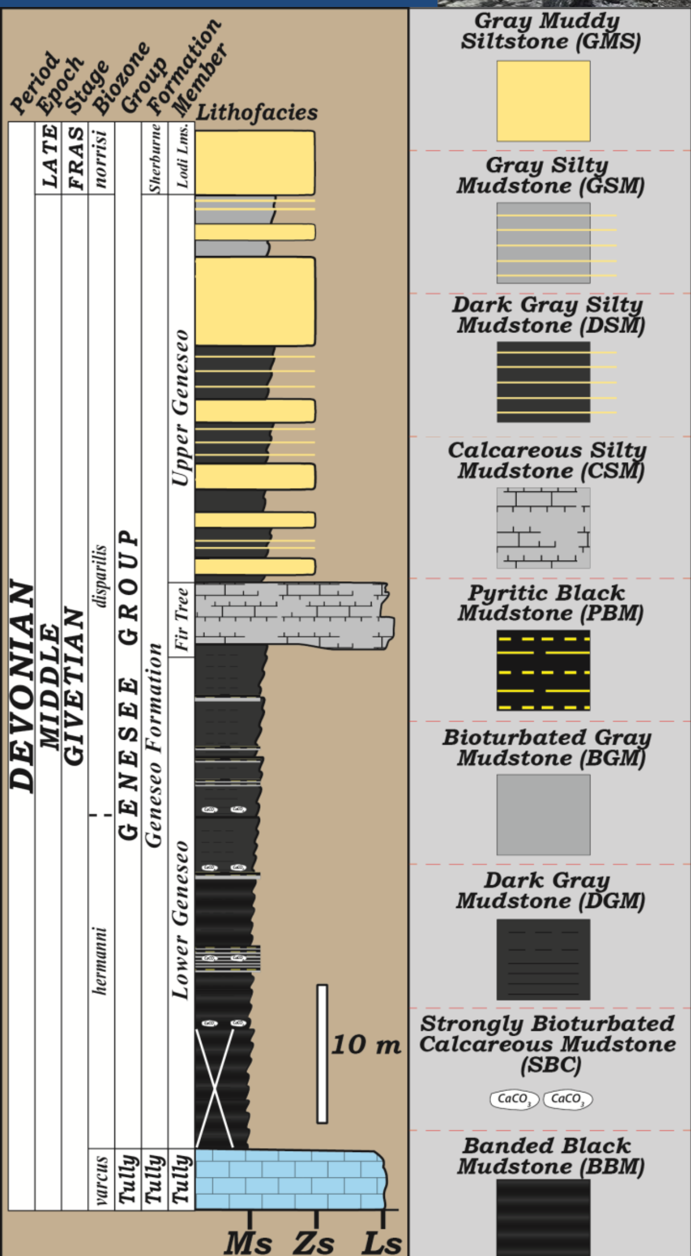


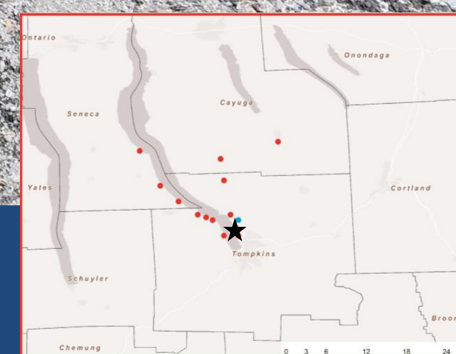






Blackchin RR Cut, NY





Wave-aided Hyperpycnite

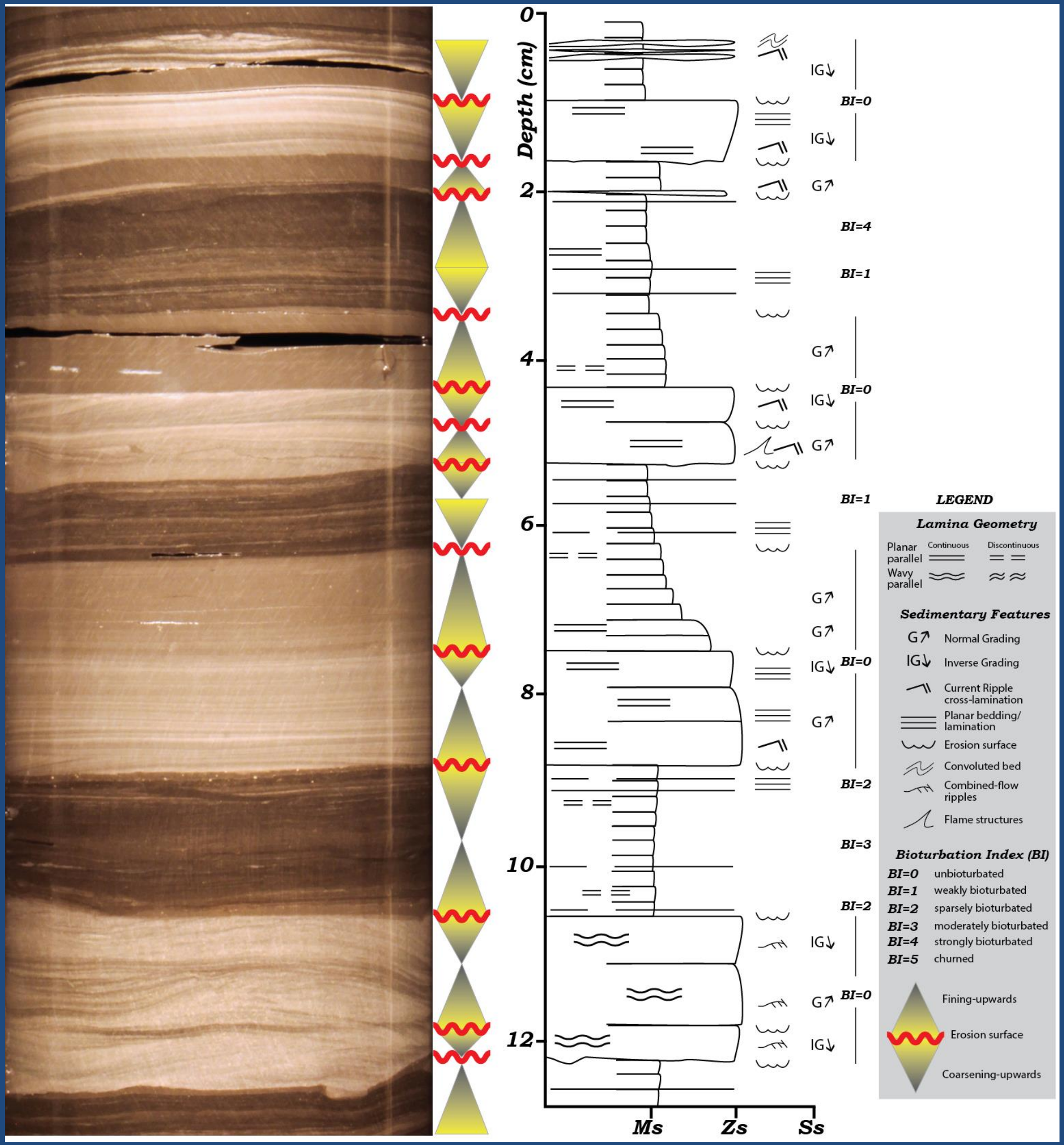
Outcrop appearance of a silt-rich hyperpycnite with a basal scour, hummocky cross-lamination, and current-ripple cross-lamination showing normal and inverse grading (normal and inverted triangles)

Wave-aided Hyperpycnite

Outcrop appearance of a silt-rich hyperpycnite with a basal scour, hummocky cross-lamination, and current-ripple cross-lamination showing normal and inverse grading

Wave-aided Hyperpycnite

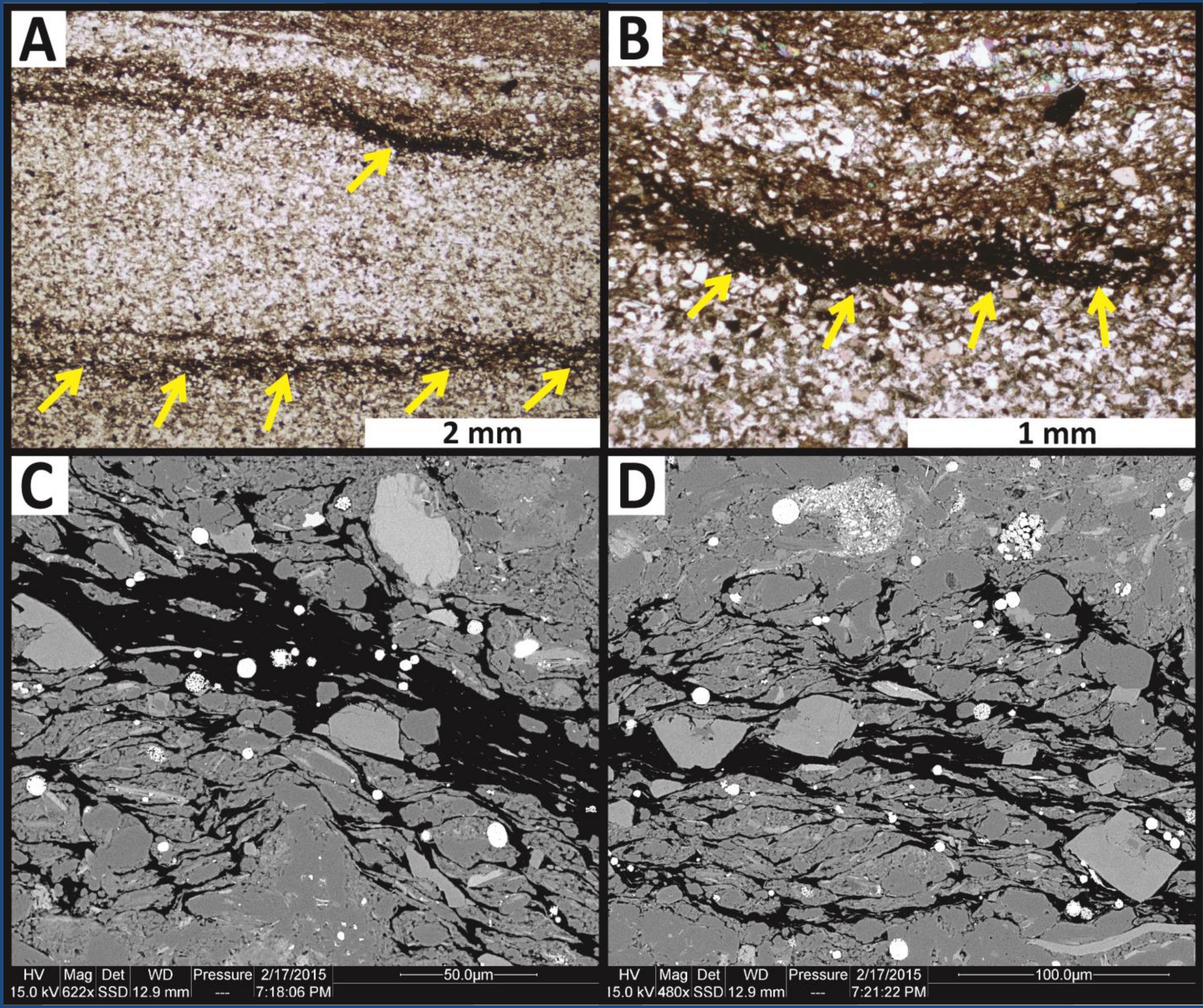
Photograph and detailed measured section (Ms= mudstone, Zs= siltstone, Ss= sandstone) of interbedded moderately bioturbated silty mudstone and unbioturbated muddy siltstones.



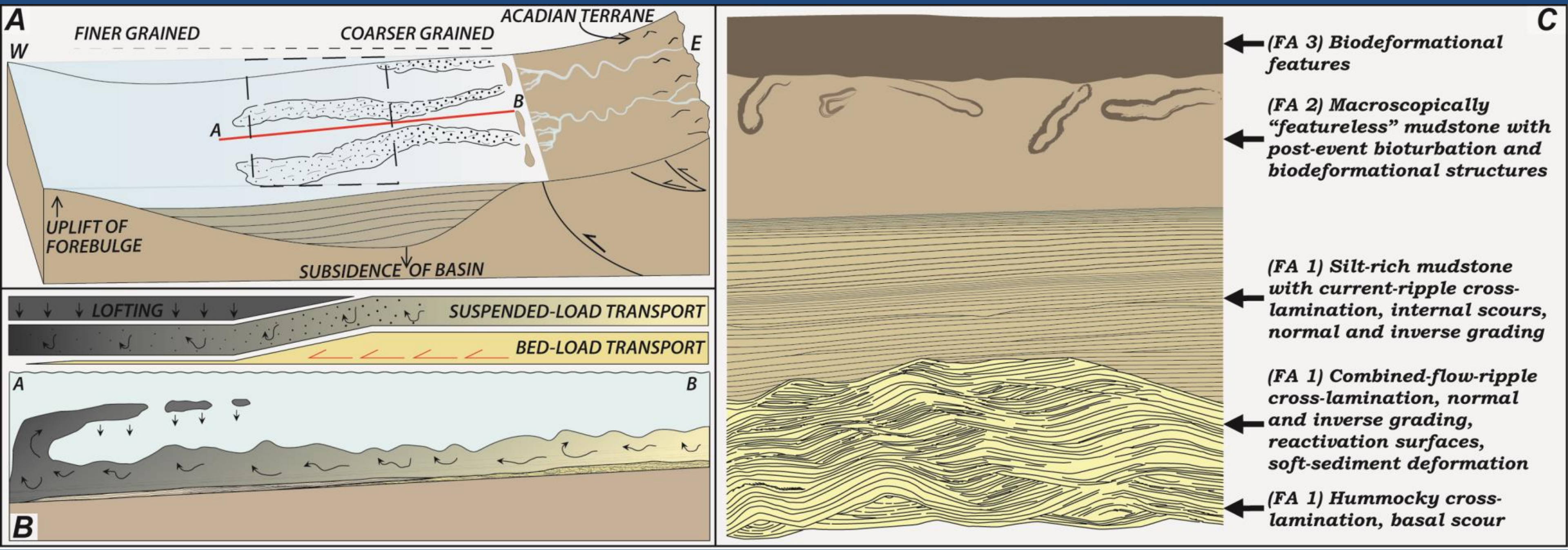
Terrestrial Phytodetritus

A) and B) Photomicrographs showing terrestrial phytodetritus in clay-rich portions of hyperpycnites (yellow arrows).

C) and D) Backscatter image detailing the cellular structure of terrestrial phytodetritus.



Wave-aided Hyperpycnite



A) Idealized sketch of the Northern Appalachian Basin during the Devonian, with conceptual sketch for river-fed hyperpycnal flows (A-B cross-section used in Figure B). **B)** Conceptual diagram showing the internal arrangement of facies deposited from sustained hyperpycnal flows in a marine environment (modified from Zavala et al., 2011). **C)** Photograph of presumed hyperpycnite from the showing the product of a sustained hyperpycnal flow in the Geneseo Formation, with facies-divisions outlined.

Outline of Talk

- **Introduction**
  - Devonian Appalachian Basin Stratigraphy and Paleoenvirons
  - Study Area
- **Stratigraphic Expression**
  - Litho- and Sequence-stratigraphy
- **Depositional Environment**
  - Proximal-Distal relationships
  - Products of wave-aided hyperpycnal flows
- **Chemical and Compositional Attributes**
  - Stable carbon isotopes of organic-matter
  - High-resolution X-ray fluorescence and XRD
- **Pore Characterization**
- **Conclusions**

Stable Isotopes of Organic-Matter

- **Middle-Late Devonian black shales of the Eastern U.S. have high organic-carbon content**
  - ✓ Typically 3-25% TOC
  - ✓ Type II and Mixed Type II/III Kerogen is present
- **Maynard (1981) found that the isotopic composition of OM relate to shoreline proximity**
  - Less negative isotopic values (-26.5‰) associated with terrestrial dominated organic-matter
  - More negative isotopic values (-30‰) reflect sediment with more labile organic matter, in a more distal, lower energy, oxygen stressed environment

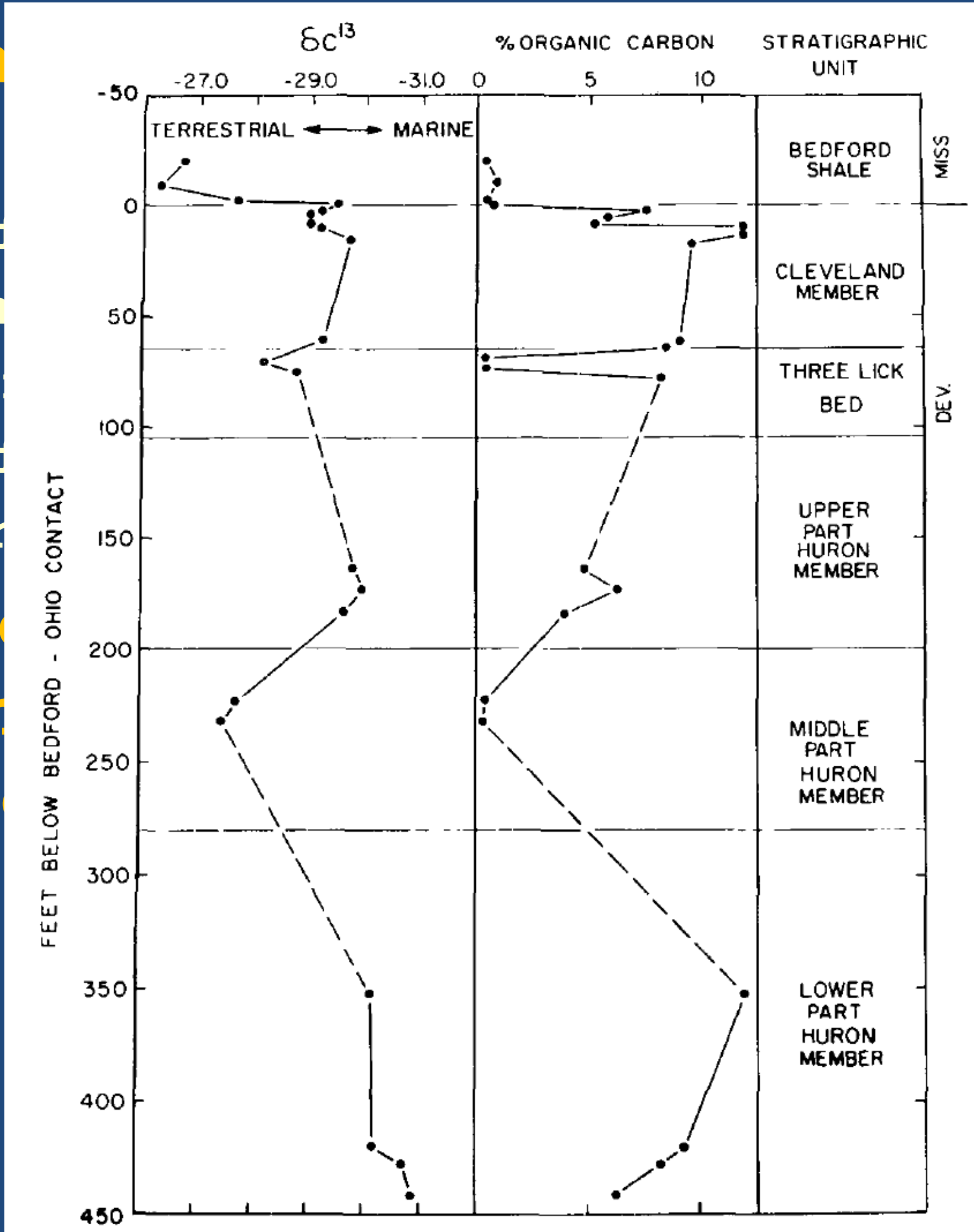
Stable Isotopes of Organic-Matter

- **Using the stable isotopic compositions of organic matter, it is possible to:**
  - ✓ **Identify Sources of OM (Terrestrial vs. Marine)**
  - ✓ **Proximity to Shoreline (Proximal vs. Marine)**
  - ✓ **Oxygenation levels (preservation of labile organics?)**
  - ✓ **Identify shallowing upwards cycles (Parasequences)**
  - ✓ **Diagenetic and Thermal alteration**
- **Using Isotopic compositions can deliver useful insight in vertical and lateral depositional parameters within a given interval**

Maynard, 1981

Stable Isotopes of Organic-Matter

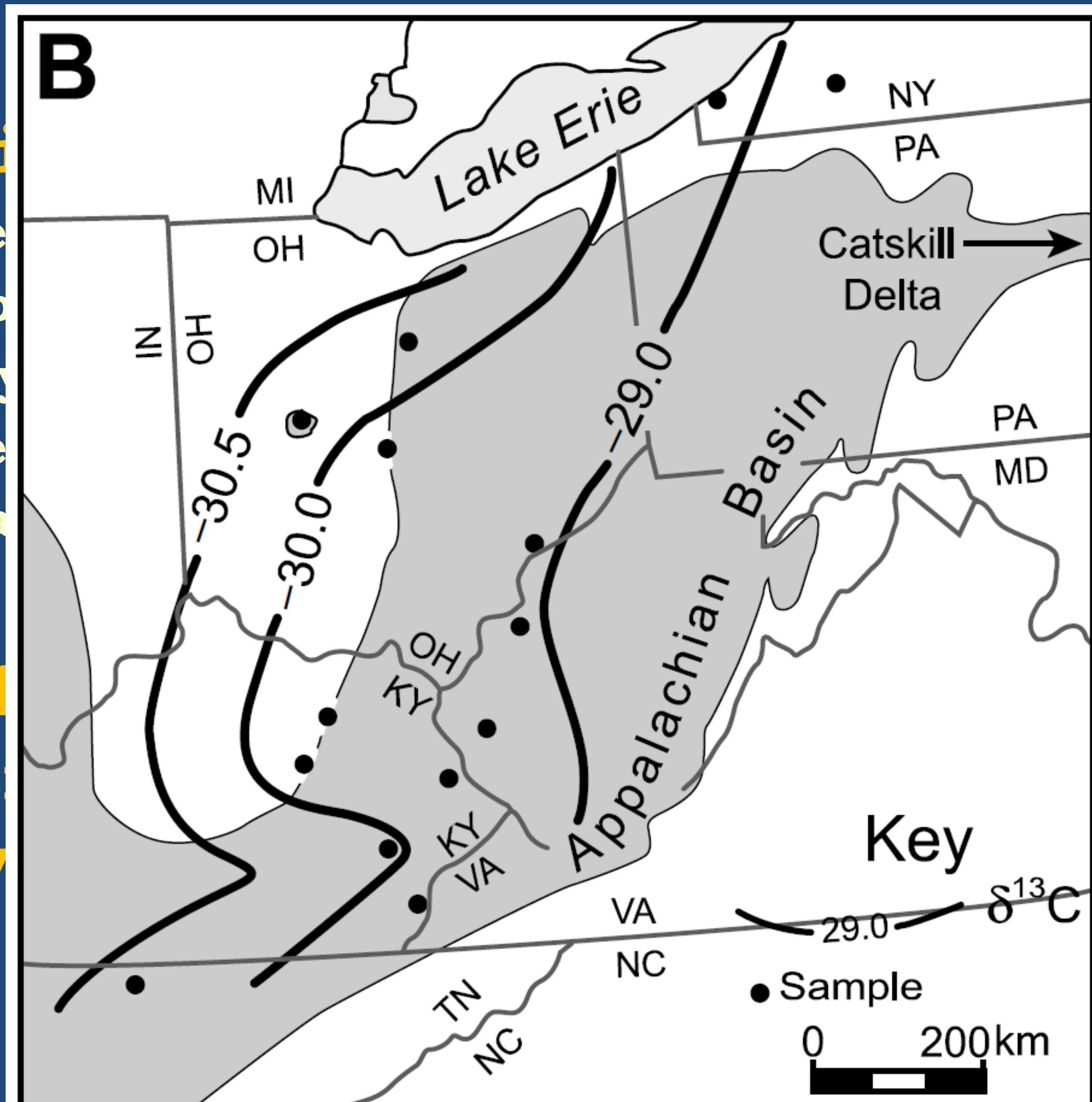
- Using th… …tions of organic
  - ✓ Identi… …rine)
  - ✓ Proxin… …ne)
  - ✓ Oxyge… …organics?)
  - ✓ Identi… …equences)
  - ✓ Diager…
- Using Is… …deliver useful in… …ral depositi… …given interval



Maynard, 1981

Stable Isotopes of Organic-Matter

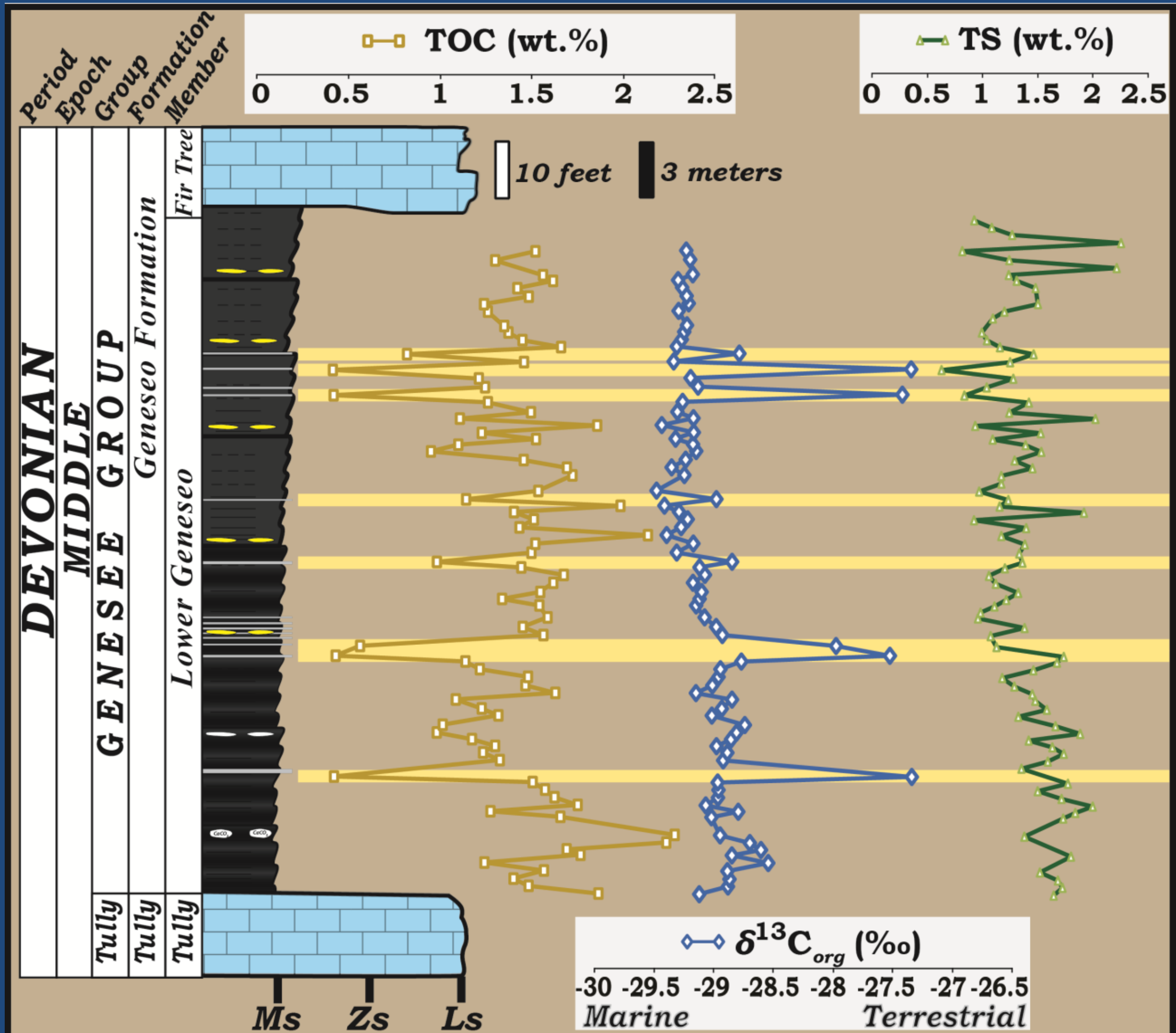
- Using … ons of organi…
  - ✓ Ide… e)
  - ✓ Pro…
  - ✓ Oxy… anics?)
  - ✓ Ide… ences)
  - ✓ Dia…
- Using … iver useful … depos… ven interv…



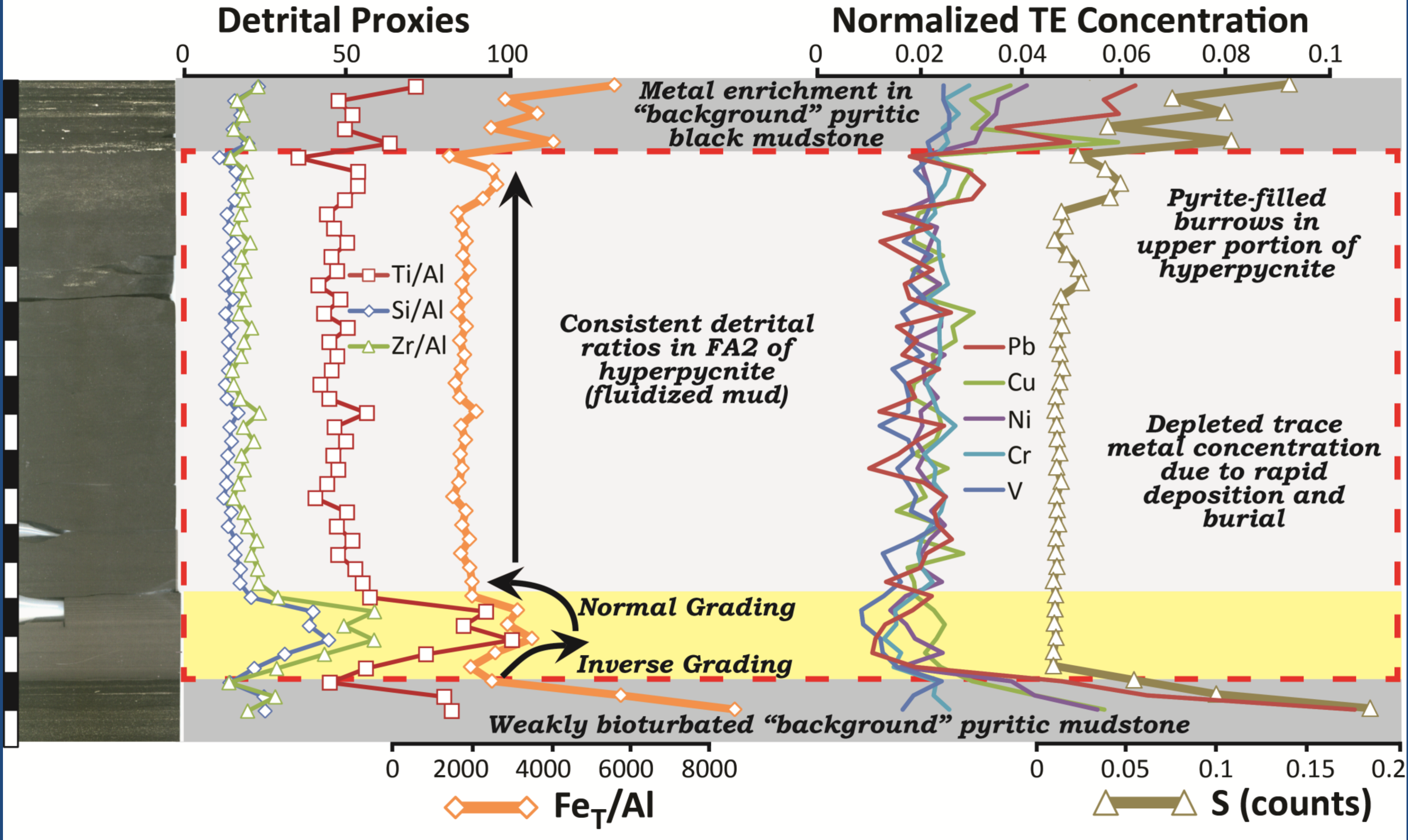
Maynard, 1981

Lower Geneseo Member

- Detailed measured section (Ms= mudstone, Zs= siltstone, Ss= sandstone)
- Geochemical profiles shown include total organic carbon (TOC), the stable carbon isotope ratios of organic carbon ($\delta^{13}C_{org}$), and total sulfur (TS).
- Yellow horizontal lines highlight identified hyperpycnites in this drill core



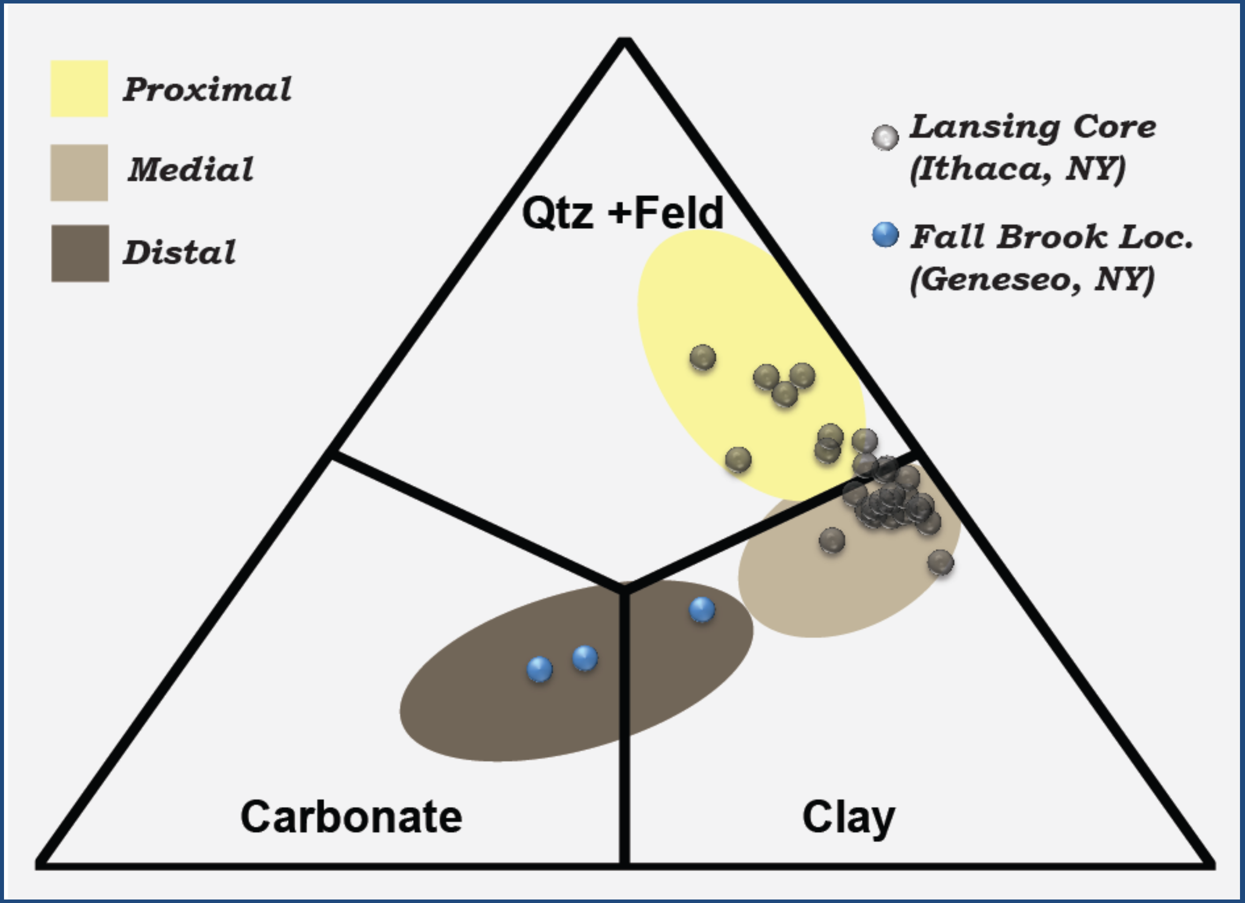
High-Resolution XRF



Geneseo Mineralogy

Ternary diagram showing compositional relationship with depositional setting

- Proximal – Medial setting influenced by fluvial discharge events are clastic dominated (more ductile)
- Distal setting where these events did not contribute sediments show increased clay content as well as early diagenetic carbonate cements (more brittle)



Outline of Talk

- **Introduction**
  - **Devonian Appalachian Basin Stratigraphy and Paleoenvirons**
  - **Study Area**
- **Stratigraphic Expression**
  - **Litho- and Sequence-stratigraphy**
- **Depositional Environment**
  - **Proximal-Distal relationships**
  - **Products of wave-aided hyperpycnal flows**
- **Chemical and Compositional Attributes**
  - **Stable carbon isotopes of organic-matter**
  - **High-resolution X-ray fluorescence and XRD**
- **Pore Characterization**
- **Conclusions**

Phyllosilicate Framework Pores (PF)

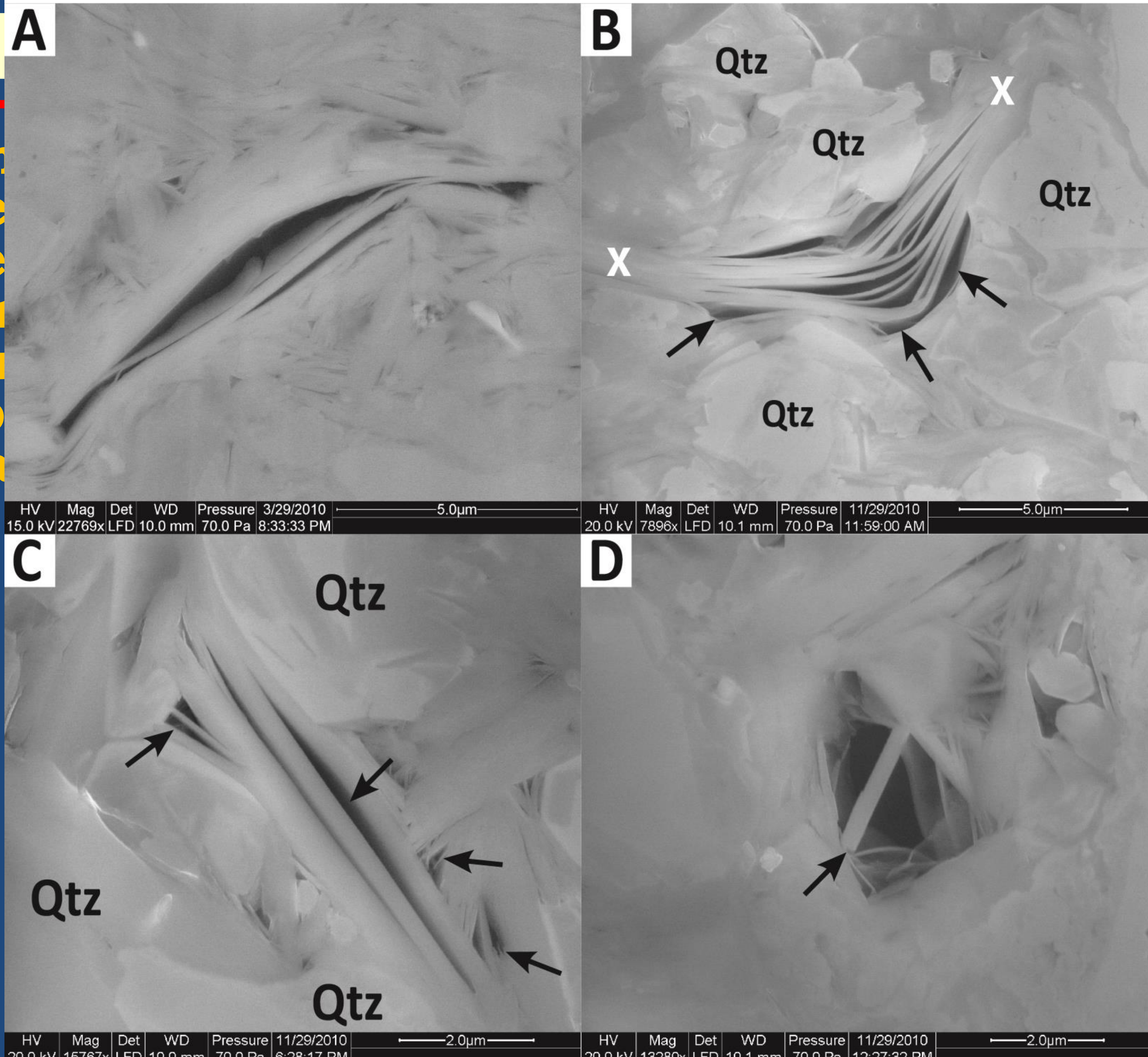
- **They consist of triangular openings that are defined by a clay mineral framework, and are best developed in pressure shadows adjacent to larger and compaction resistant grains (pyrite, quartz, calcite), and in compaction protected spaces between such grains (up to 1500 nanometers).**

  - **PF pores are abundantly observed in hyperpycnal intervals with increased contents of silt and terrestrial phytodetritus. Increased silt content provides compaction resistant grains to create pressure shadows that prevent collapse of phyllosilicate frameworks.**

[F]

➢ Th e
de re
be t to
la ite,
qu ed
sp
na

➢ als
itus.
ains

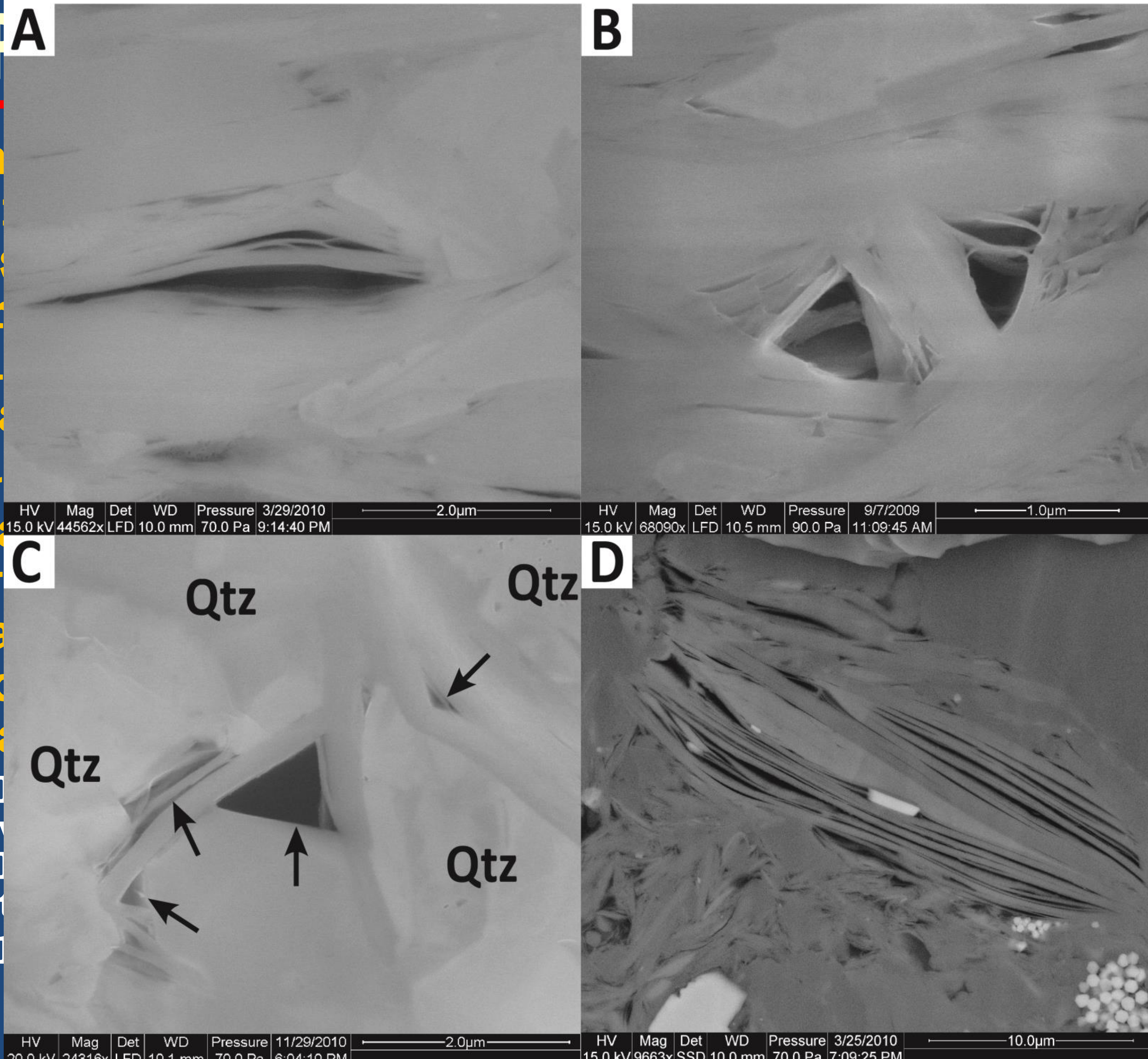


Phyllosilicate Framework Pores (PF)

- They consist of triangular openings that are defined by a clay mineral framework, and are best developed in pressure shadows adjacent to larger and compaction resistant grains (pyrite, quartz, calcite), and in compaction protected spaces between such grains (up to 1500 nanometers).
- Diagenetic mineral growth (quartz, dolomite, pyrite) also enhances PF pores by "clamping" clay flakes in place prior to compaction (Schieber, 2013), or by acting as a proppant that prevents collapse of triangular openings
  - PF pores are abundantly observed in hyperpycnal intervals with increased contents of silt and terrestrial phytodetritus. Increased silt content provides compaction resistant grains to create pressure shadows that prevent collapse of phyllosilicate frameworks.

P… F)

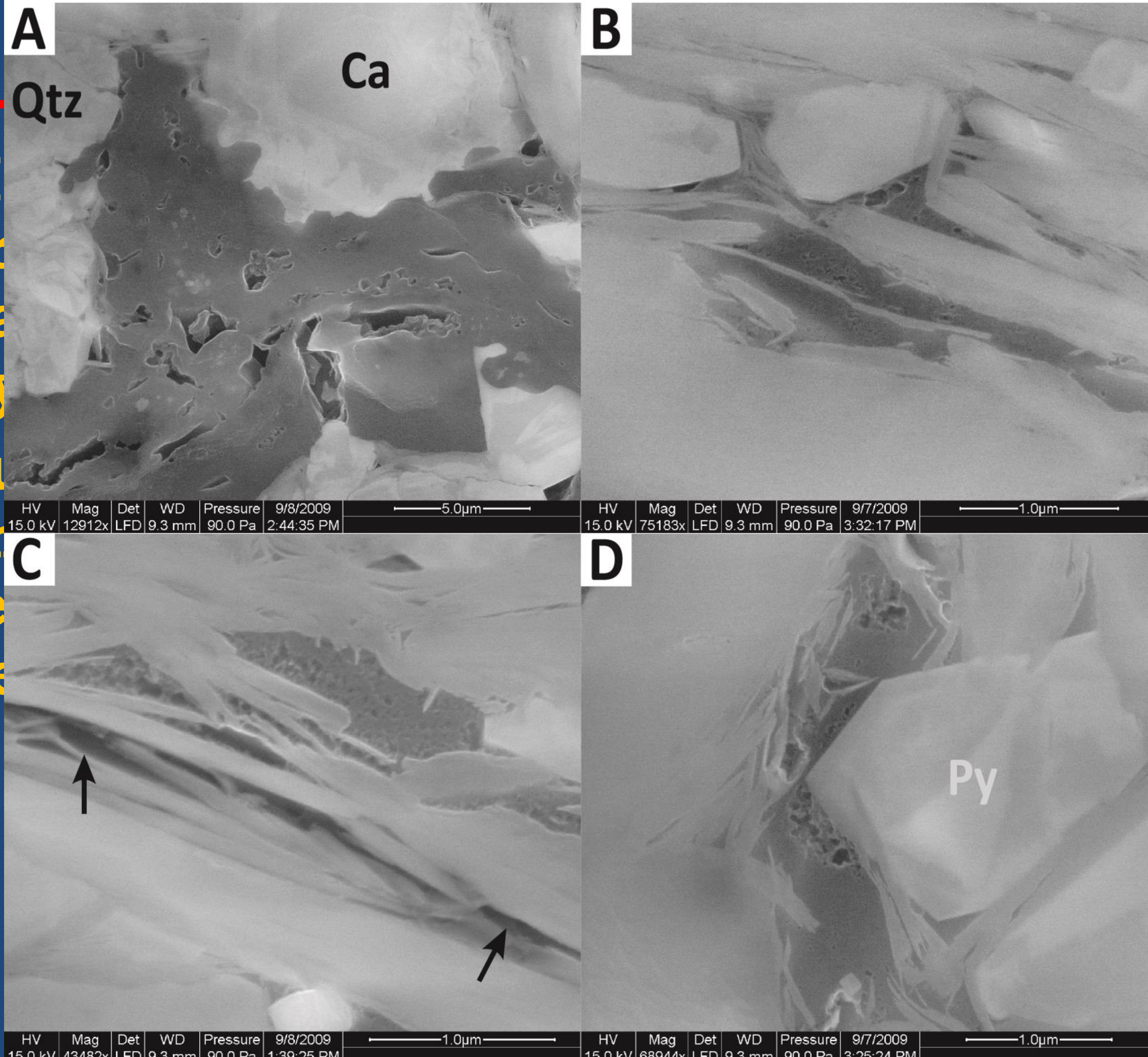
- Th… e
  de… re
  be… t to
  lar… te,
  qu… d
  sp…
  na…
- Di… e,
  py… g”
  cla…
  (So…
  tha… s
  - … als
    … itus.
    … ains



Organic Matter Pores (OM)

- **Micropores found in Kerogen blebs and organo-clay aggregates (10-500 nanometers wide) are a product of hydrocarbon maturation.**
- **Subsequent to hydrocarbon generation and expulsion, porosity is created in the residual organic matter in the form of kerogen particles.**
  - ✓ **OM pores dominate in the "background" organic-rich mudstones that were not affected by event sedimentation and clastic dilution.**
  - ✓ **Pore development in Geneseo OM is quite variable and most likely reflects different diagenetic reactivity of the various organic macerals that were originally buried within these sediments.**

- M … nd
  or
  na
  hy
- Su … on
  ar … the
  re … of
  ke
  - ✓ … on
  - ✓ … most
    … ous
    … se



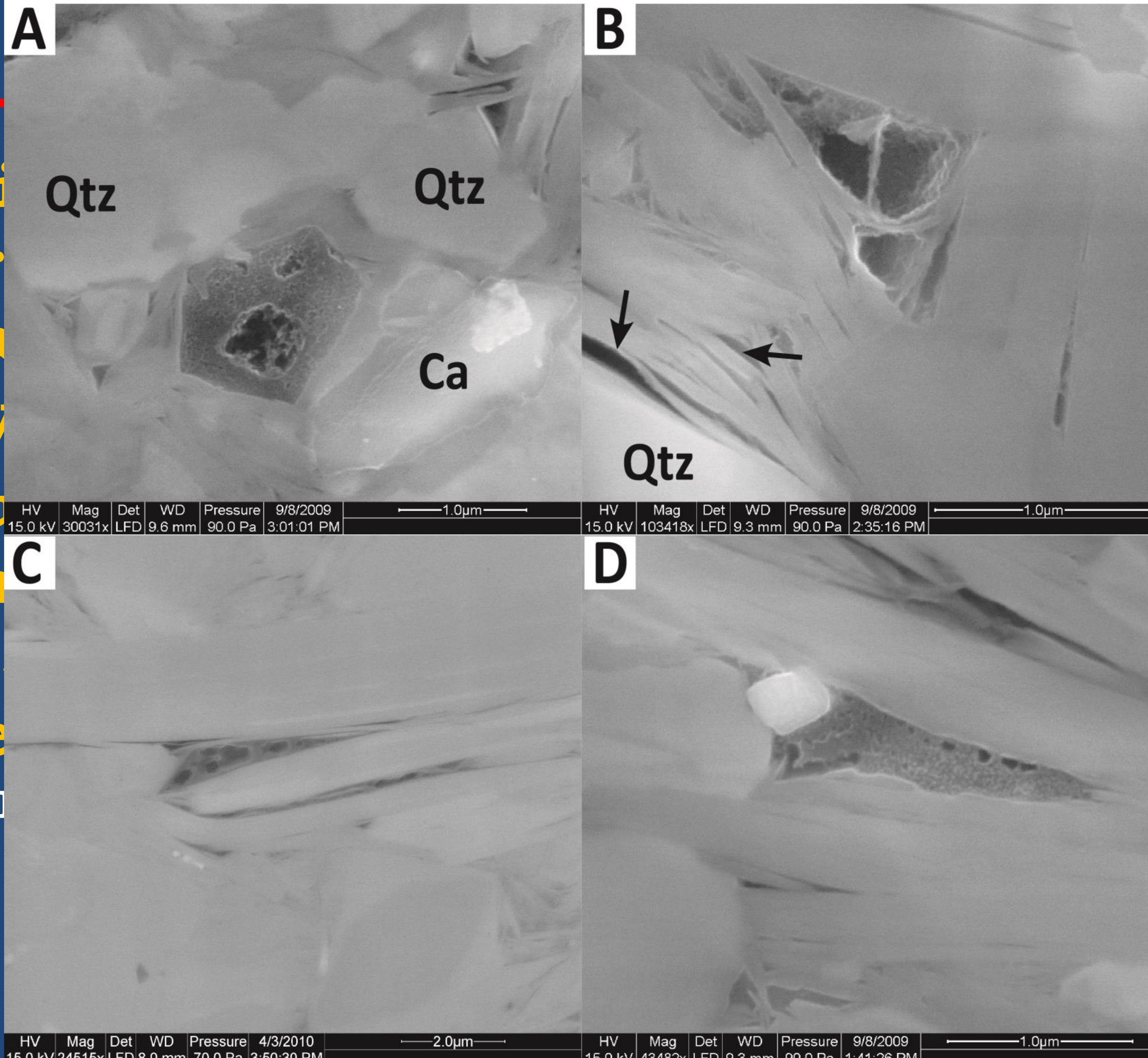
Organic Matter Pores (OM)

- **Micropores found in Kerogen blebs and organo-clay aggregates (10-500 nanometers wide) are a product of hydrocarbon maturation.**
- **Subsequent to hydrocarbon generation and expulsion, porosity is created in the residual organic matter in the form of kerogen particles.**
  - ✓ **Better developed and dominate porosity time in distal facies**

- Mi… nd
- or…
- na…
- hy…

- Su… on
- an… the
- re… of
- ke…

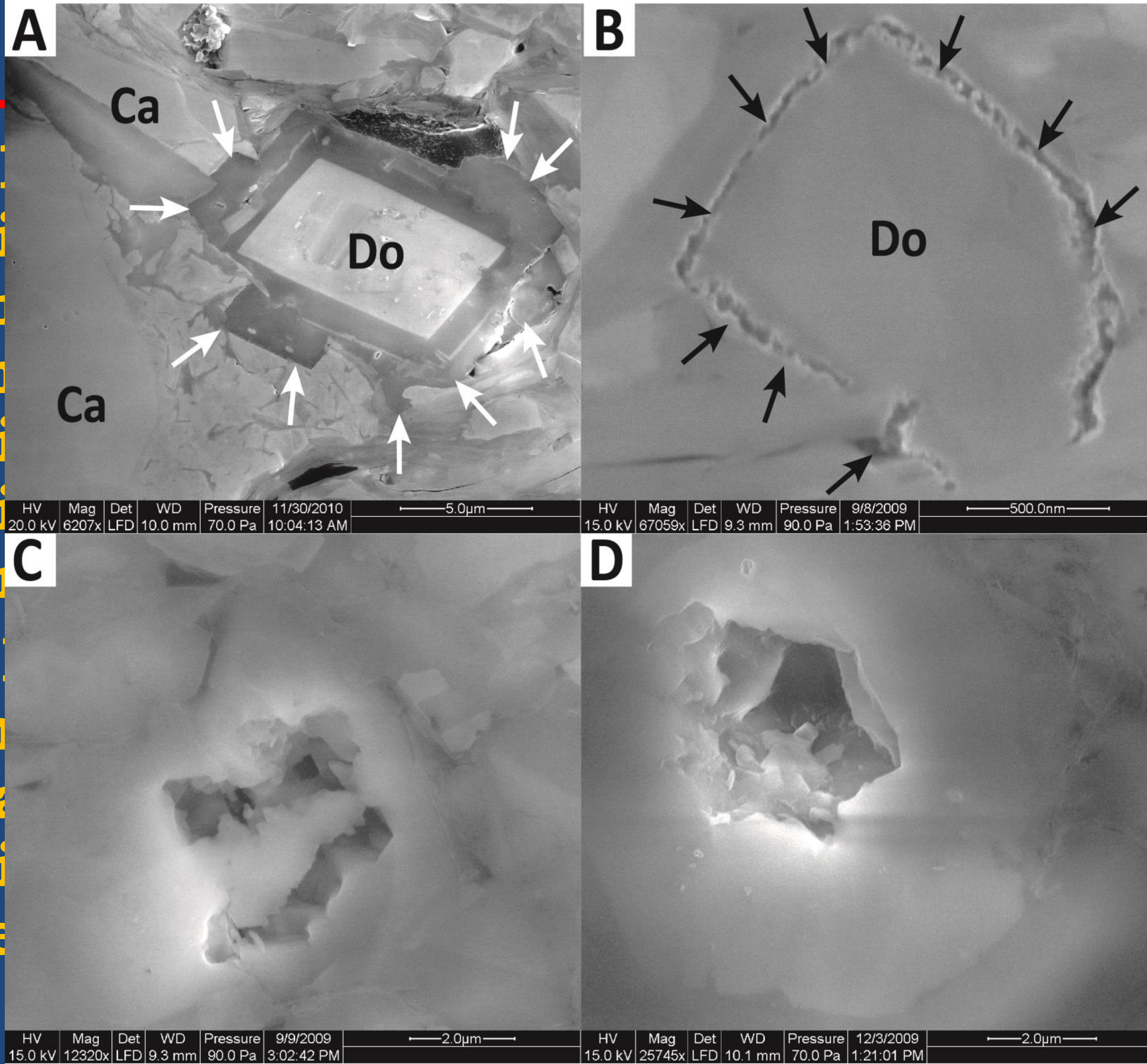
✓ I… acies



Carbonate Dissolution Pores (CD)

- These pores are due to partial dissolution of carbonate grains (50-500 nm wide). They are dominantly found in the CSM and SBC facies, and partial dissolution is probably a product of late diagenetic carboxylic and phenolic acids preceding hydrocarbon generation.
- CD pore development starts along the margins of carbonate grains. In rare cases, the entire grain may be dissolved, leaving a void space with a remnant skeleton of the original grain

- Th
di … 500
n … nd
in … ial
di … late
di … cids
pr
- C … he
m
ca
di … a
re … in



Conclusions

- **The Geneseo Formation does not reflect stagnant/anoxic basinal conditions**
  - ✓ Abundant evidence for benthic life
  - ✓ Sedimentary fabrics and textures indicate multiple modes of sediment transport and deposition
- **Products of wave-aided hyperpycnal flows have been recognized in this organic-rich mudstone succession**
  - ✓ Characteristic physical, chemical, and biologic attributes
- **This study reports SEM observation of multiple pore types from a fluvial influenced organic-rich mudstone succession and supports the notion that depositional environment and transport mechanisms strongly affect reservoir quality and distribution**
  - Reservoir quality increases towards the distal setting
    - ✓ Increased TOC, increased $CaCO_3$ cements, marine-dominated organic matter with development of kerogen micropores

Thank You!

Acknowledgements

- IU Shale Research Consortium
- New York State Museum, Taury Smith, Jim Leone, Alexa Leone
- Janok Bhattacharya and James MacEachern
- AAPG, GSA, SEPM, and IU Student Research Grants

IU SHALE RESEARCH CONSORTIUM

wintershall
ExxonMobil
MARATHON
Anadarko Petroleum Corporation
ConocoPhillips
Statoil
Chevron
WHITING
Shell