

An Investigation of Parasequences in the Camp Run Member of the Upper Devonian New Albany Shale*

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Abstract

Shales of the Camp Run Member of the New Albany Shale reflect the interplay between sea level variations, terrigenous supply, and surface productivity of the Late Devonian inland sea. In order to understand the drivers for parasequence development we are developing an integrated depositional model that combines sedimentological observations, petrography, geochemistry, and quantitative mineralogy. Parasequences show sharp basal contacts with some erosion of previously deposited sediment, are ideally characterized by black-gray cycles of decimeter thickness, but may also consist entirely of black shale. Geochemical and XRD analysis shows that regardless of coloration, TOC decreases upwards and is accompanied by a decrease of pyrite and marcasite. Siderite, in contrast, is present throughout and does not differ significantly between bottom and top.

Black-gray cycles like in the Camp Run are often thought to reflect alternating anoxic and dysoxic bottom waters, but the distribution of redox sensitive minerals, marcasite in particular, suggests that throughout parasequence deposition the redox boundary was within the sediment and varied in depth intermittently. Overlying waters were not anoxic, but fluctuated in their degree of oxygen depletion. Distribution of pyrite and marcasite was controlled by higher abundance of readily metabolized marine OM (feeding sulfate reducers) in the bottom part of parasequences, whereas siderite distribution reflects the background terrestrial OM (feeding fermenters and methanogens) within the sediment that is linked to detrital flux. Thus, parasequence development reflects the upwards change in the mixing ratio between marine OM and terrigenous sediment supply (clay, silt, terrestrial OM).

Whereas in a "classical" parasequence the quartz/clay ratio would be expected to increase upwards, the highest quartz/clay ratios occur in the bottom-most portion of parasequences and then ratios drop to a lower level and stay rather uniform for the rest of a given parasequence. Probably due to extreme sediment starvation and winnowing at the very base of the parasequence, and the very distal nature of these deposits respectively. In addition, the laminated character of the basal black portions of parasequences suggests that bottom current deposition of flocculated organo-clay aggregates may have generated sediment with better OM preservation potential due to intimate spatial association of labile marine OM and clays.

References Cited

Calvert, S.E., R.M. Bustin, and E.D. Ingall, 1996, Influence of water column anoxia and sediment supply on the burial and preservation of organic carbon in marine shales: *Geochimica et Cosmochimica Acta*, v. 60/ 9, p. 1577-1593.

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Lineback, J.A., 1968, Subdivision and depositional environments of New Albany Shale (Devonian-Mississippian) in Indiana: *The AAPG Bulletin*, v. 52/7, p. 1291-1303.

Website

Blakey, 2008, NAU Geology: Website accessed November 15, 2013. <http://www2.nau.edu/rcb7/>

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AAPG Annual Convention & Exhibition
Pittsburgh, PA
May 23, 2013

IU Shale Research

**Late
Devonian
(~360 Ma)**

Laurentia

**epicontinental
sea**

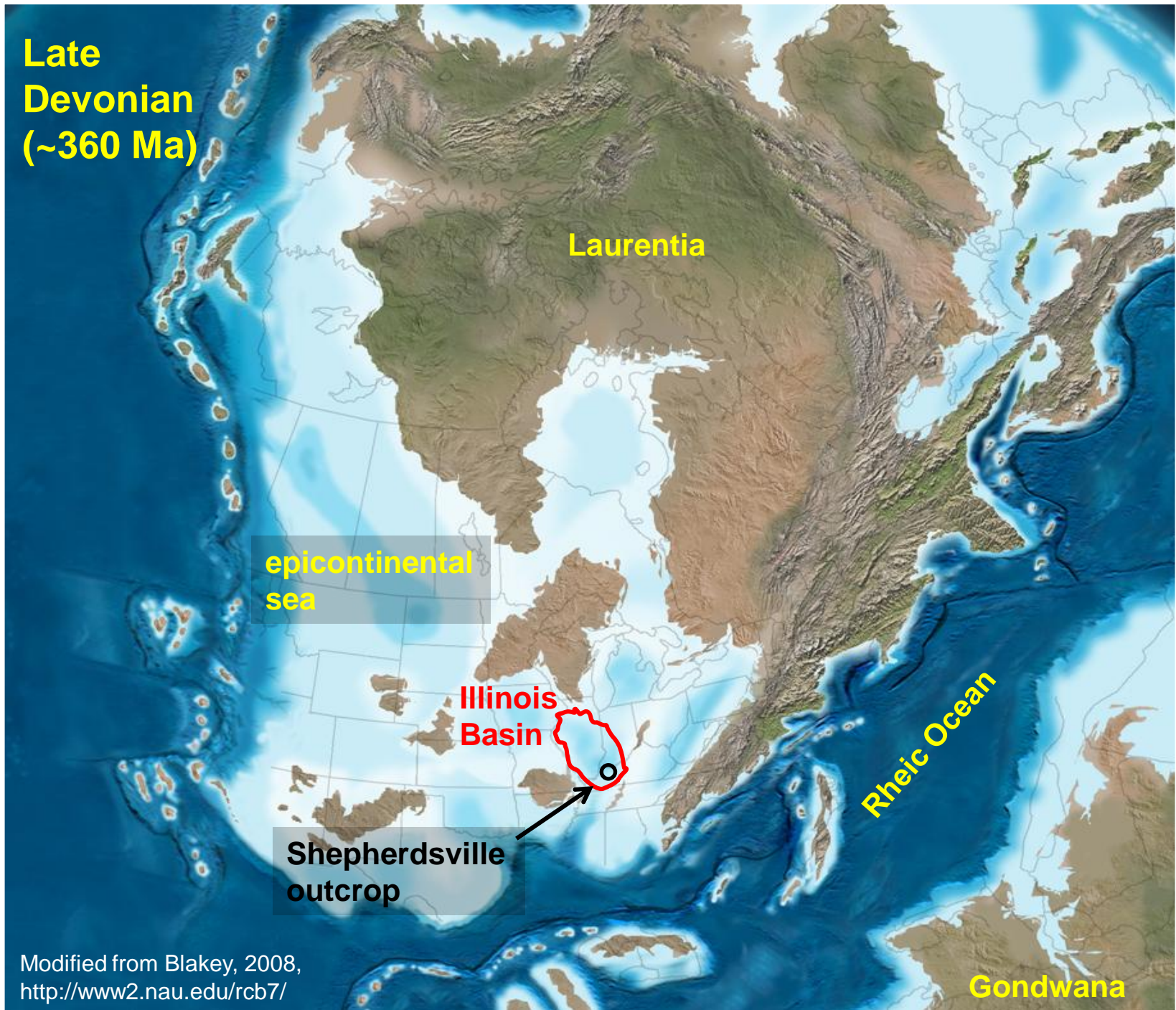
**Illinois
Basin**

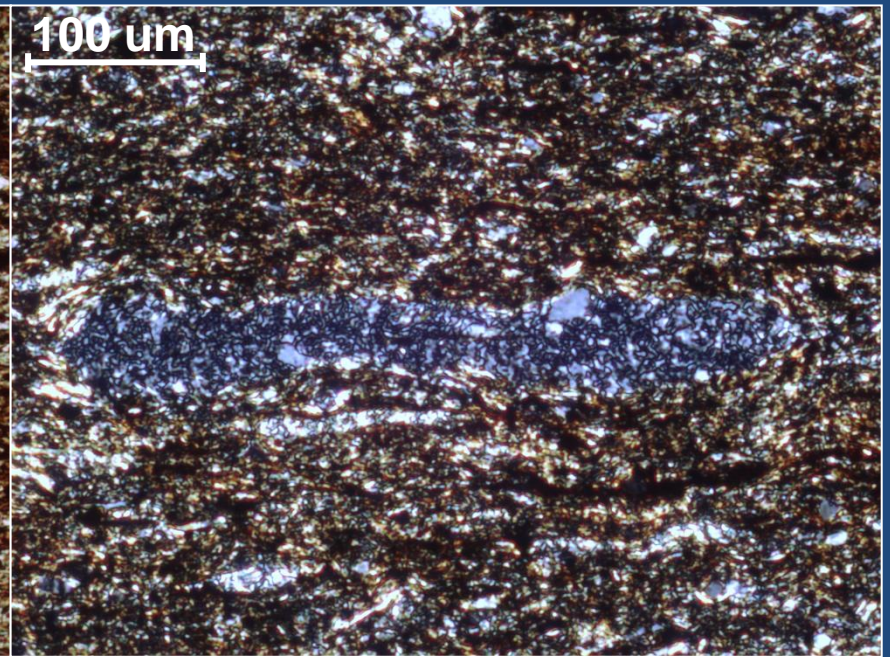
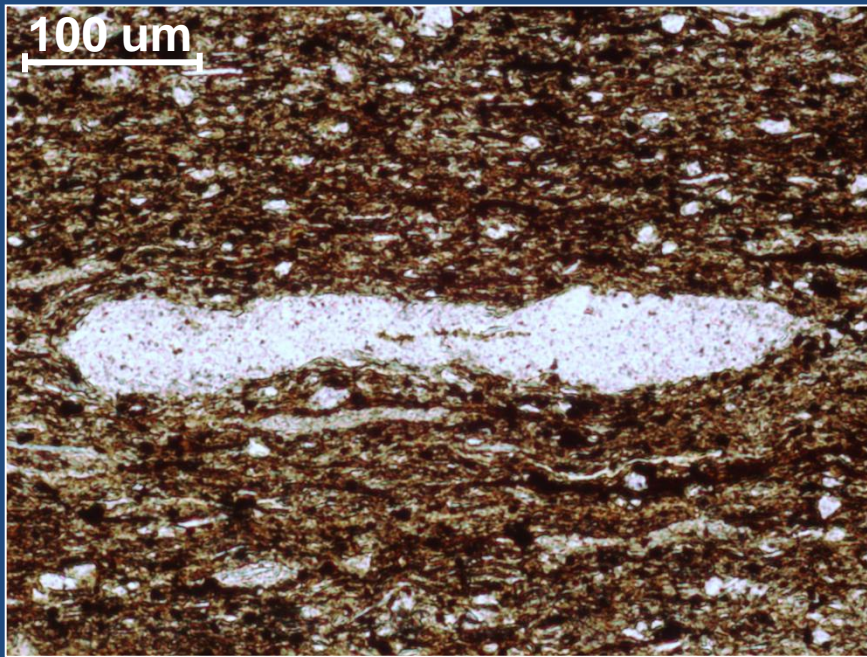
**Shepherdsville
outcrop**

Rheic Ocean

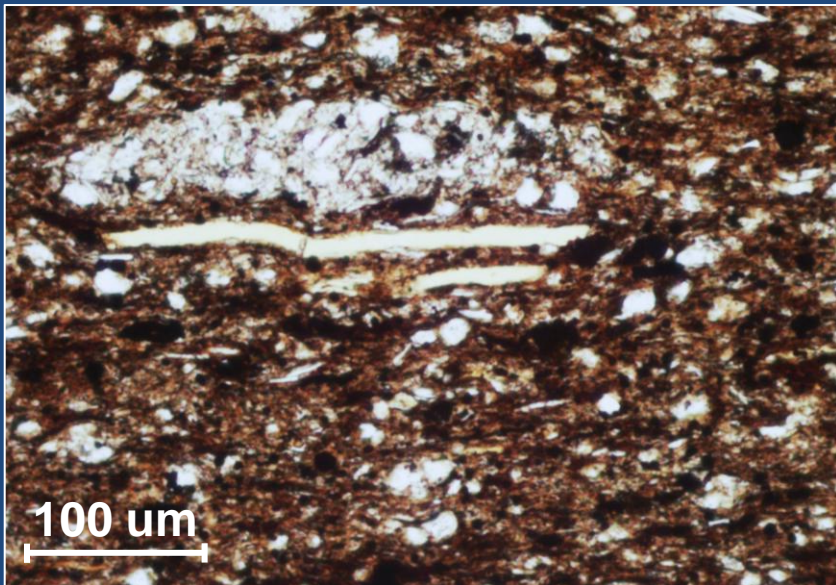
Gondwana

Modified from Blakey, 2008,
<http://www2.nau.edu/rcb7/>

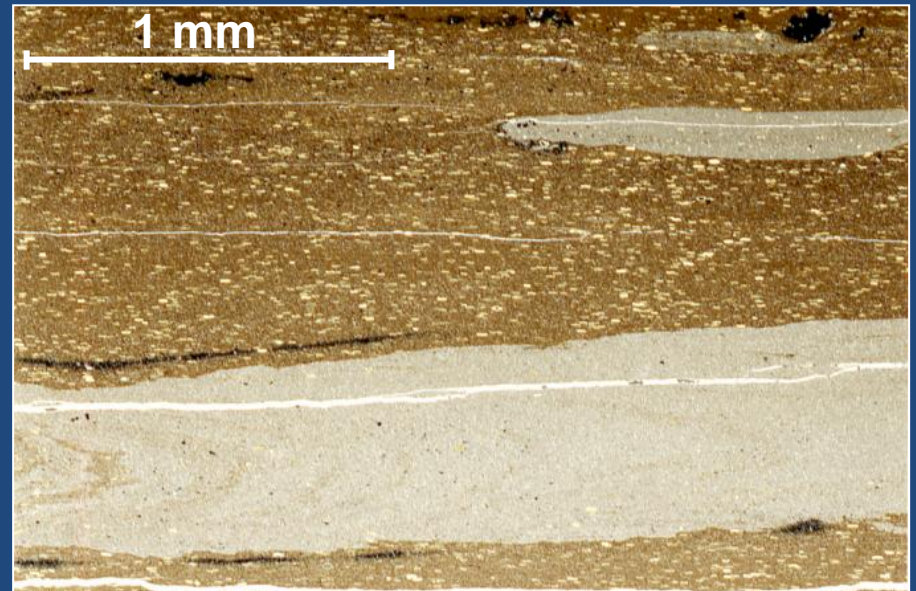




Transmitted light (left) and cross-polarized (right) photomicrographs of benthic agglutinated foraminifera composed of detrital quartz.



Transmitted light photomicrograph of a benthic fecal pellet composed of quartz silt and clay.

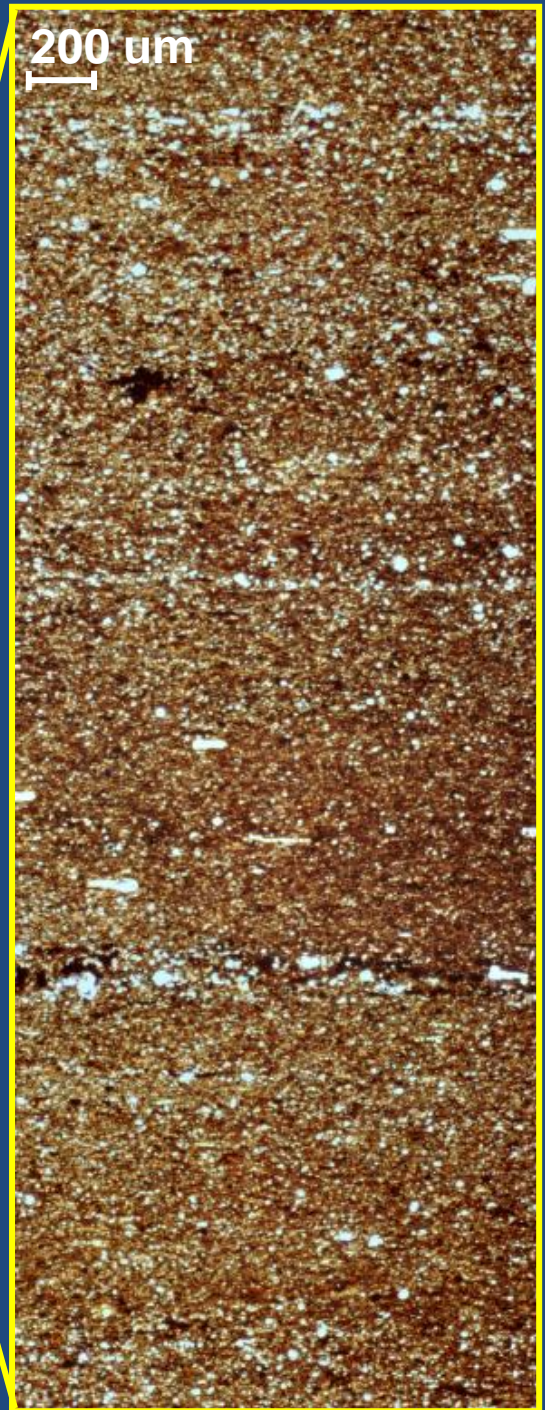


Thin section scan with zoophycos burrows (gray) surrounded by banded brownish-black shale.

Diffuse boundaries, gradational lamina



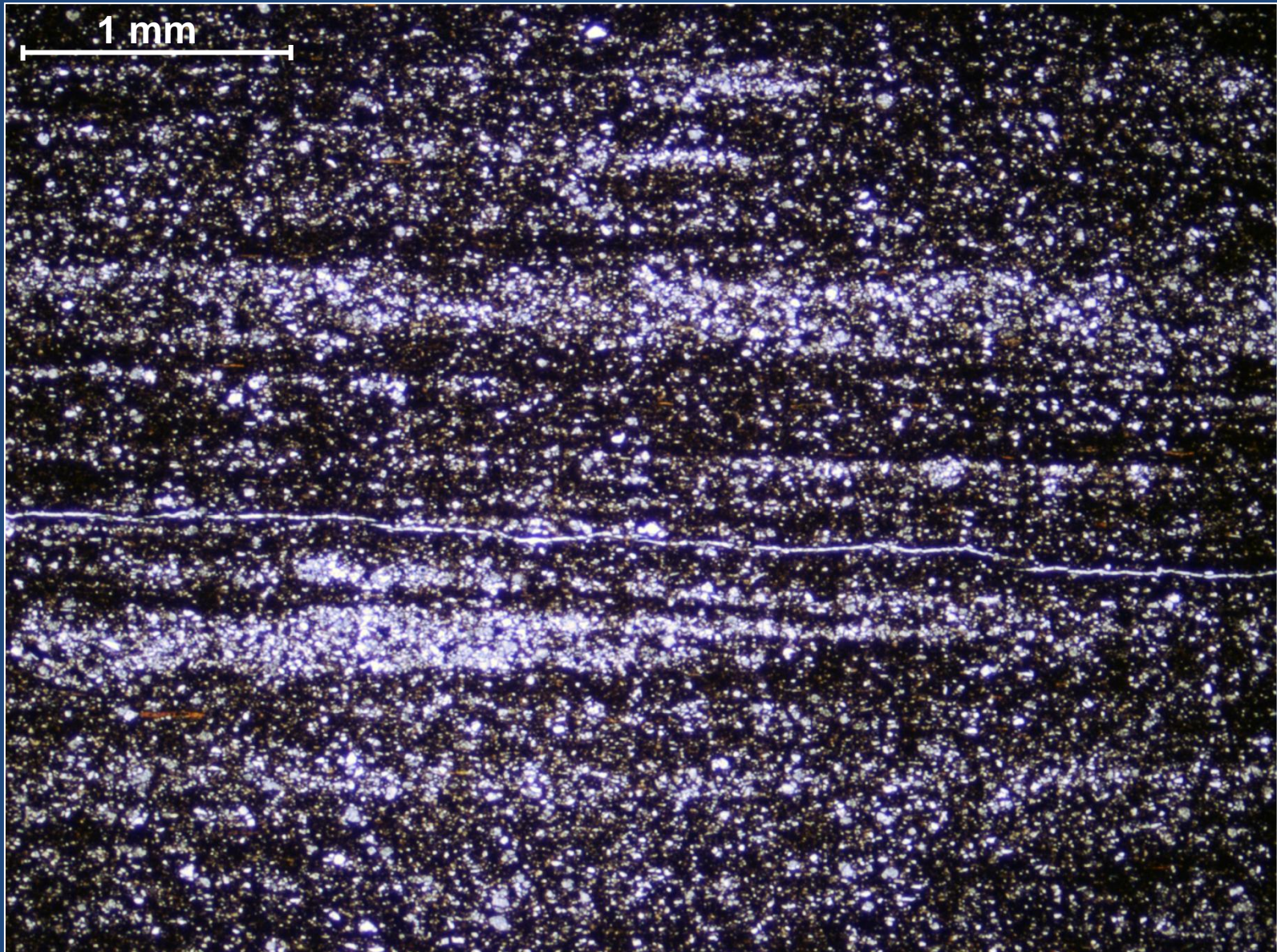
Indistinct laminae indicate this is not a primary depositional feature and most likely a result of infaunal small worms disturbing the sedimentary fabric, in this case the laminae would be described as “banded”.



Purely physical lamination looks different



Purely physical lamination looks different

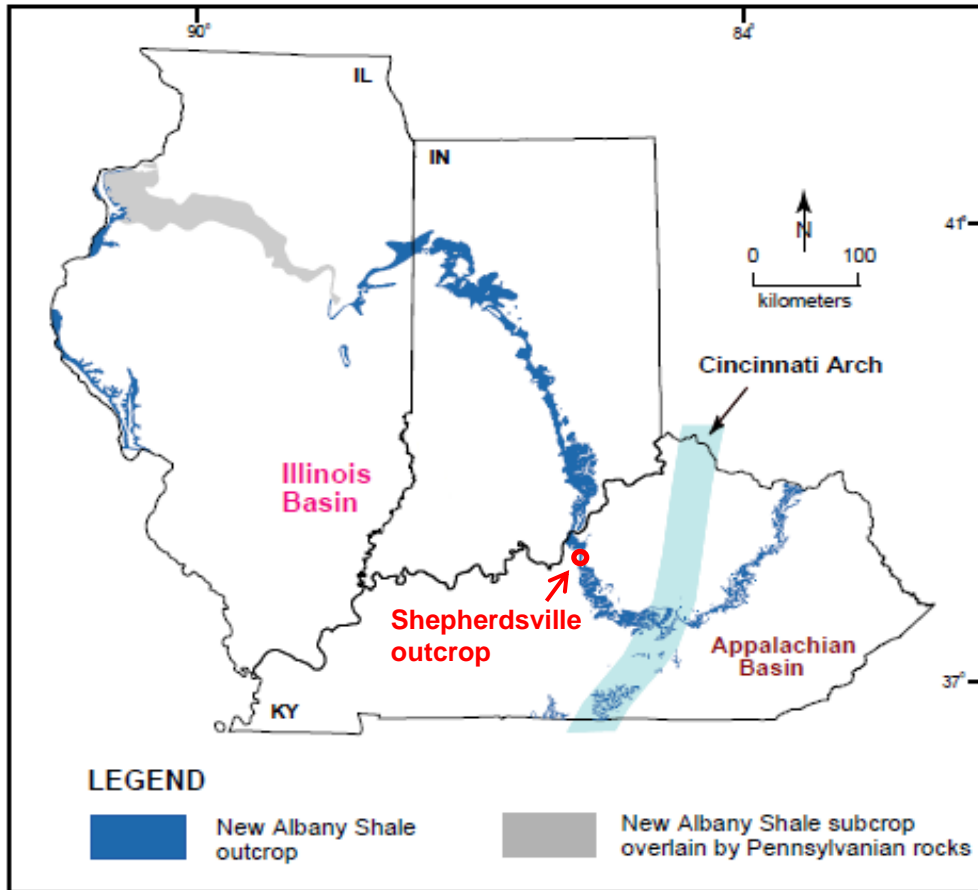


Transmitted light photomicrograph with distinct lamina, truncation and downlap indicates preserved mud ripples.

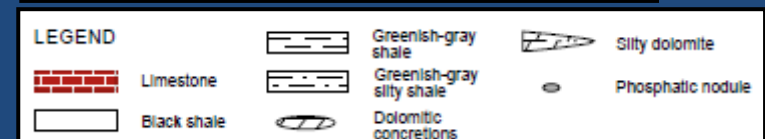
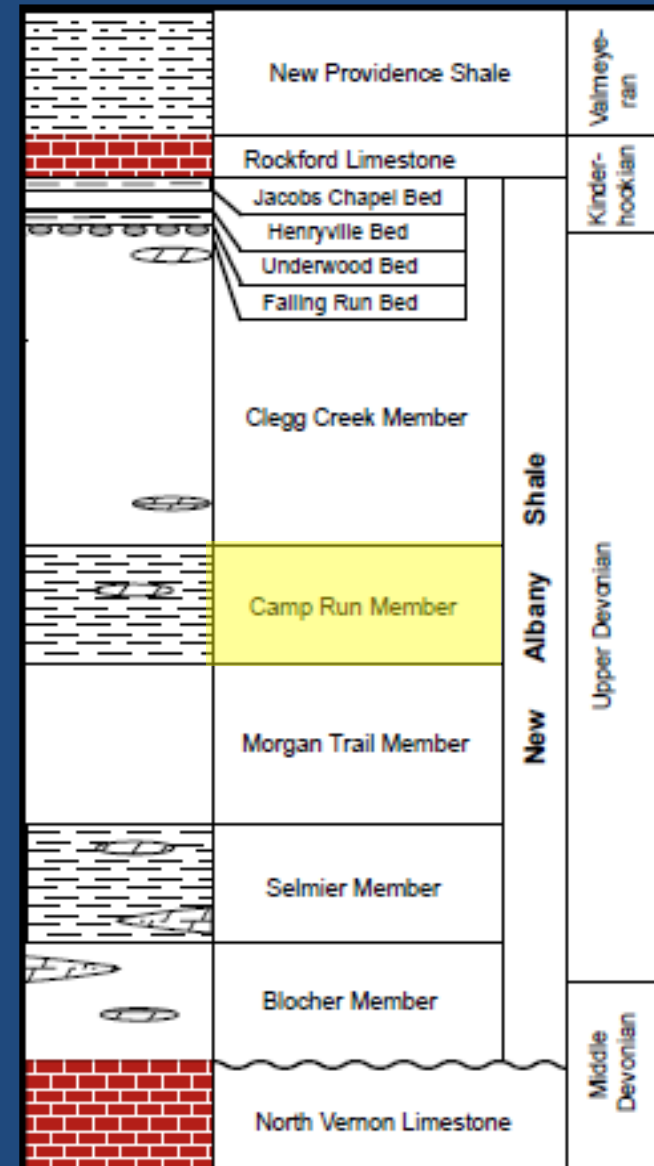
Evidence for benthic oxygen

- Benthic agglutinated foraminifera
- Benthic fecal pellets (clay/silt)
- Preserved burrow traces (zoophycos, chondrites, etc.)
- Gradation between laminae
- By analogy with modern ocean sediments these features suggest suboxic bottom waters that supported eukaryotic meiofaunal organisms in the uppermost few mm of the sediment (For example, Santa Barbara basin)

New Albany Shale

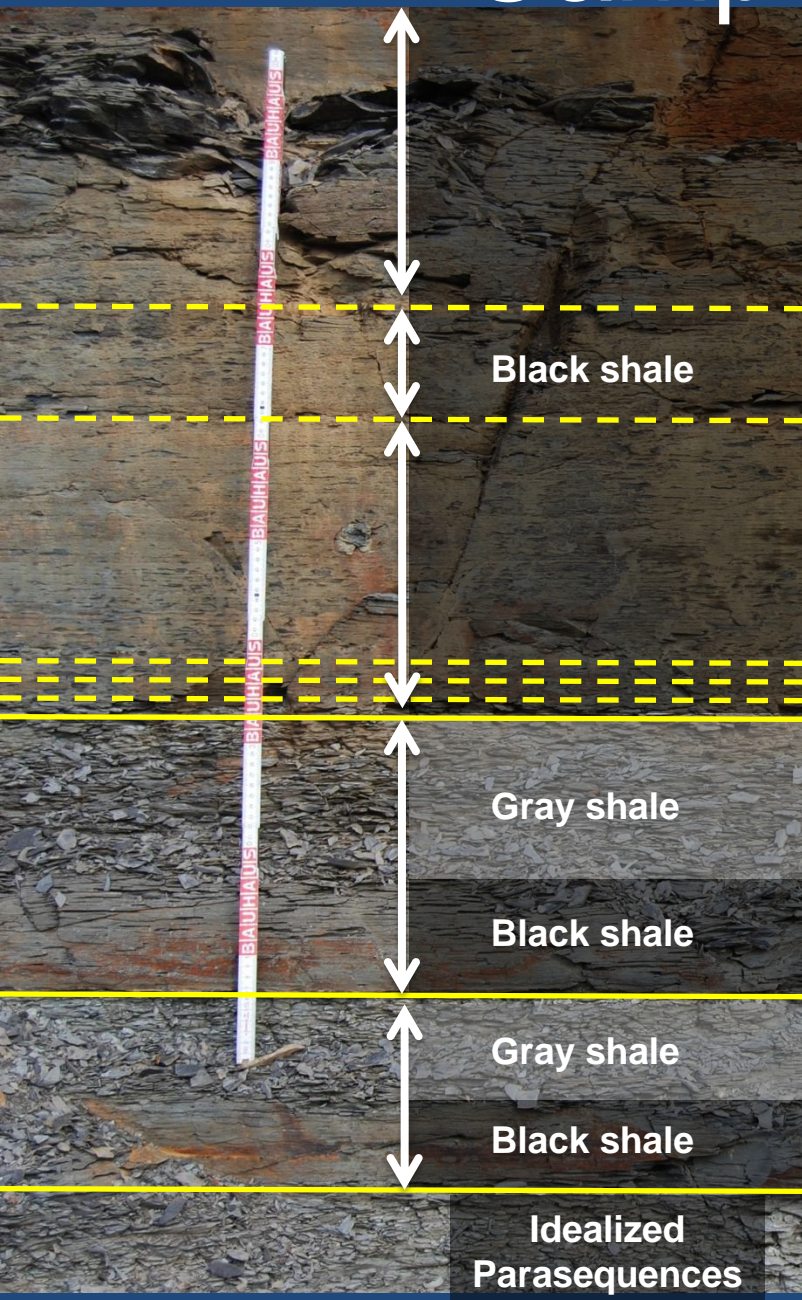


Modified from Lazar, 2007: Outcrop and subcrop of the New Albany Shale through Illinois, Indiana, and Kentucky



Modified from Lazar, 2007: Lithostratigraphic units of the New Albany Shale in Indiana and N. Kentucky (After Lineback, 1968,1970)

Camp Run Member



Silt

Black shale

Silt

Silt

Gray shale

Black shale

Silt

Gray shale

Black shale

Silt

Idealized
Parasequences

Three distinct facies:

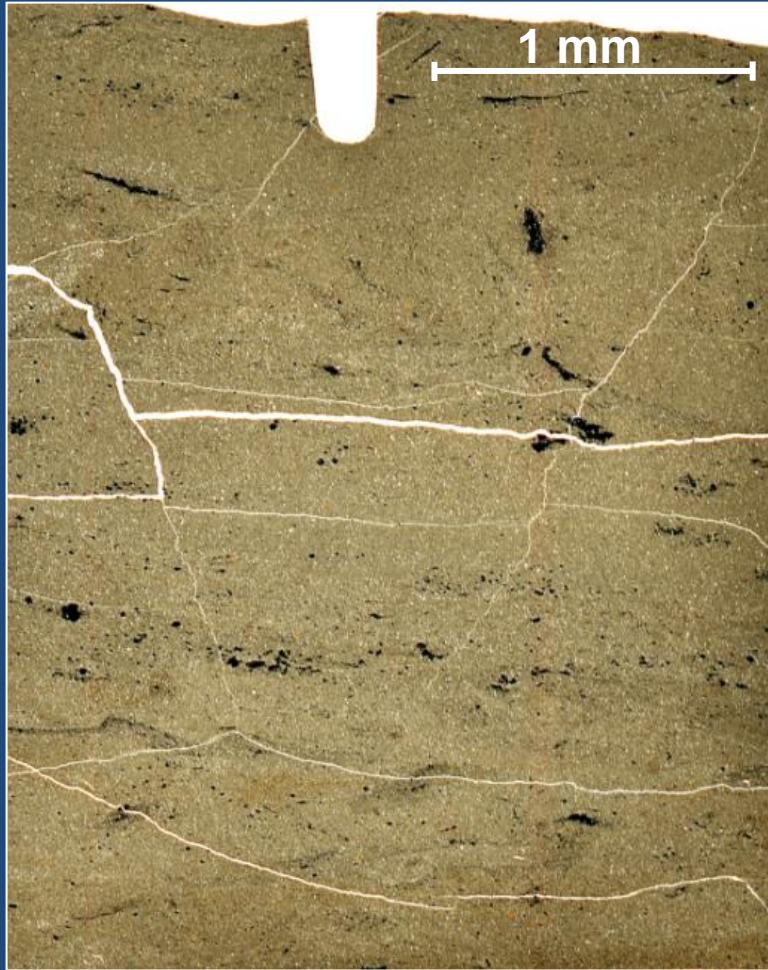
- I. Bioturbated gray shale (recessive weathering)
- II. Banded brownish-black shale (bioturbated, ledge forming)
- III. Thick and coarse silt lamina

Bioturbated gray shale

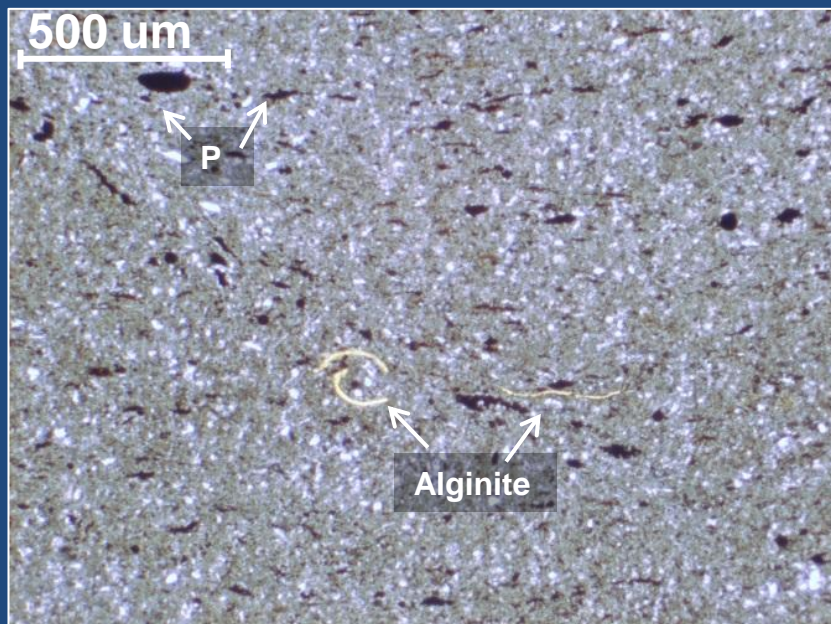
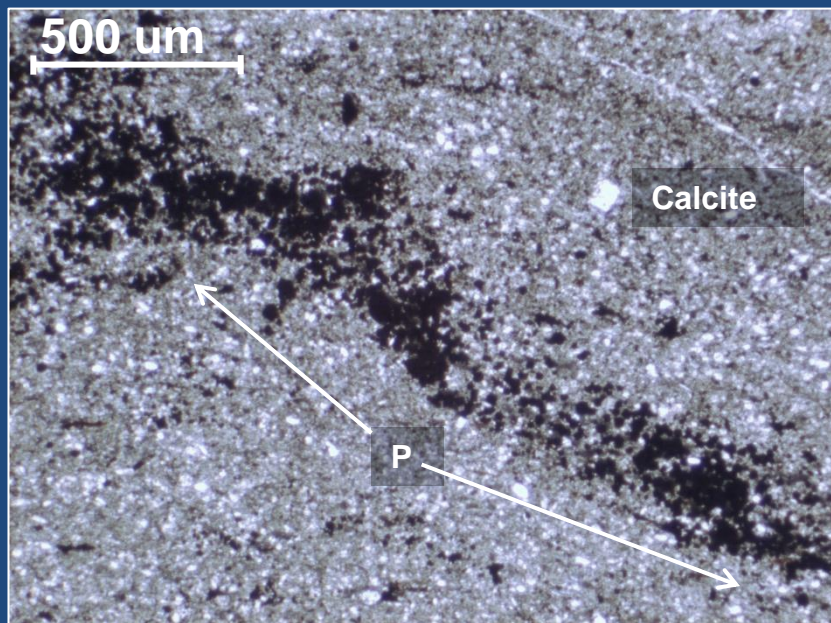
- Very little organic matter (TOC < 1%)
- Heavier and less marine stable carbon isotope signature ($\delta^{13}\text{C}$)

Quartz	Clays	Feldspars	Carbonates	Iron Sulfides
~31%-39%	~41%-49%	~12%	~6%	~1%

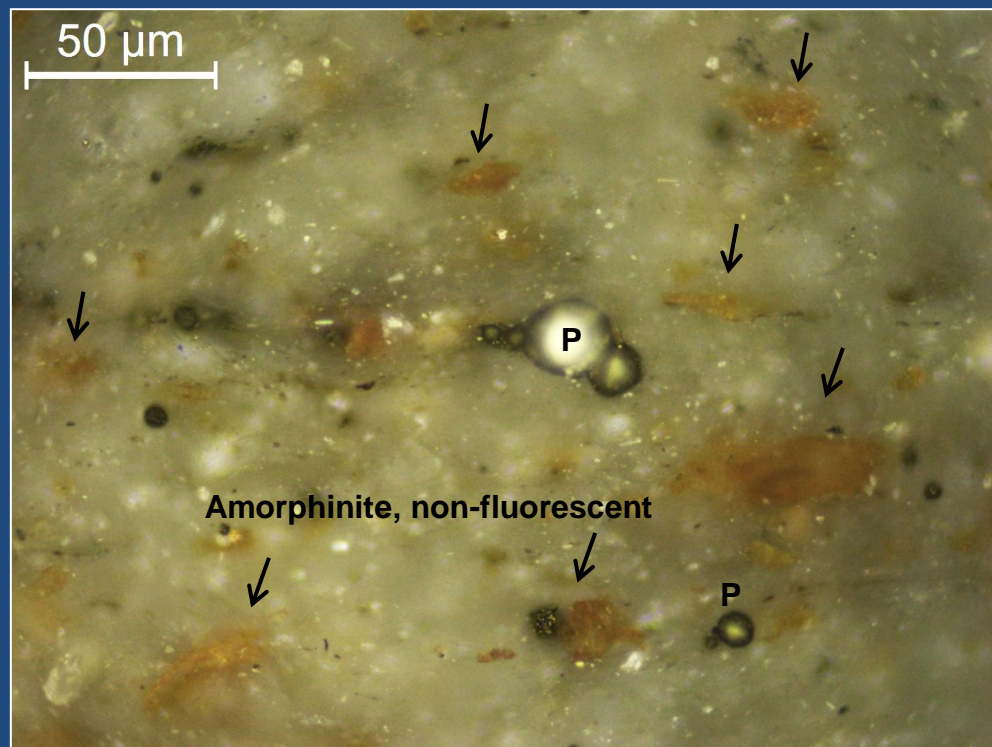
*Bulk mineralogy from Rietveld Refinement of digital powder x-ray diffraction patterns



Completely bioturbated gray shale with no sedimentary structures preserved due to complete reworking of the sediment, pyrite commonly in-fills burrows.



Transmitted light photomicrographs of completely reworked sediment with abundance of carbonate and pyrite grains and little organic matter.



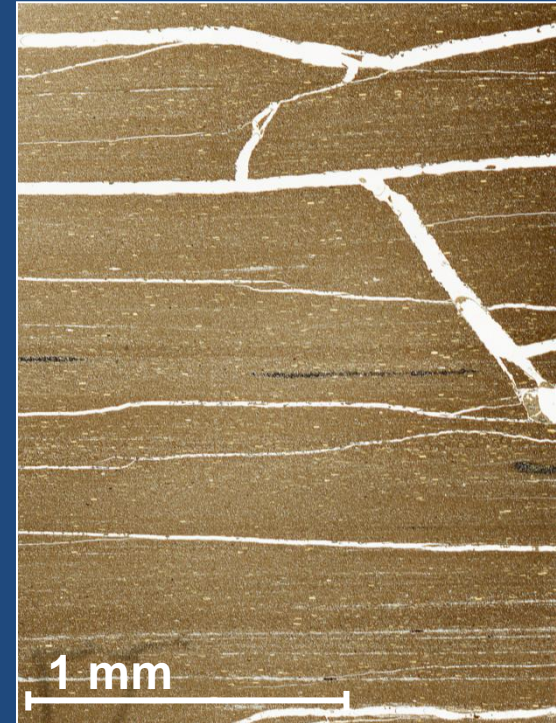
Reflected light photomicrograph, predominantly quartz and clay mineral matrix and organic matter present is mostly non-fluorescent amorphinite, P=pyrite, fluorescent light not shown as little to no fluorescence.

Banded brownish-black shale

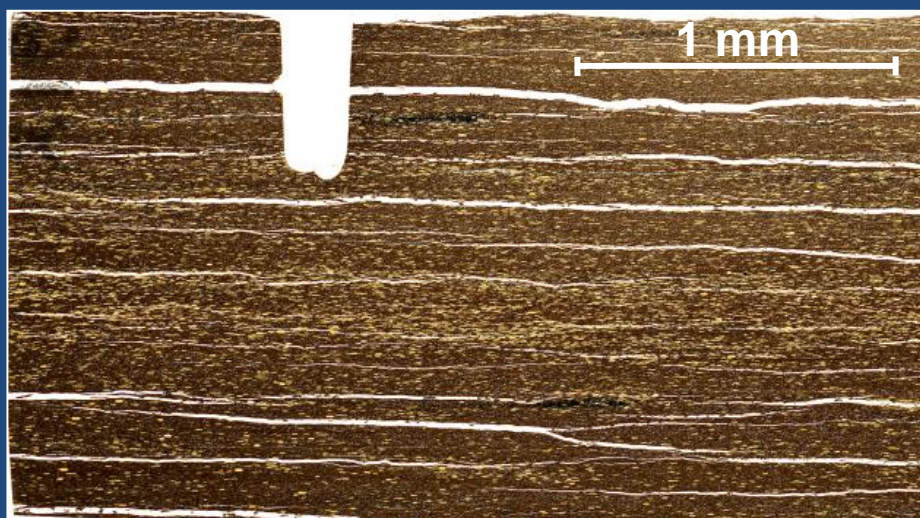
- TOC range ~6-13%
- Lighter and more marine stable carbon isotope signature ($\delta^{13}\text{C}$)
- Large variability in mineralogy and types of organic matter

Quartz	Clays	Feldspars	Carbonates	Iron Sulfides
~26%-45%	~36%-46%	~8%-16%	~1%-12%	~1%-5%

*Bulk mineralogy from Rietveld Refinement of digital powder x-ray diffraction patterns

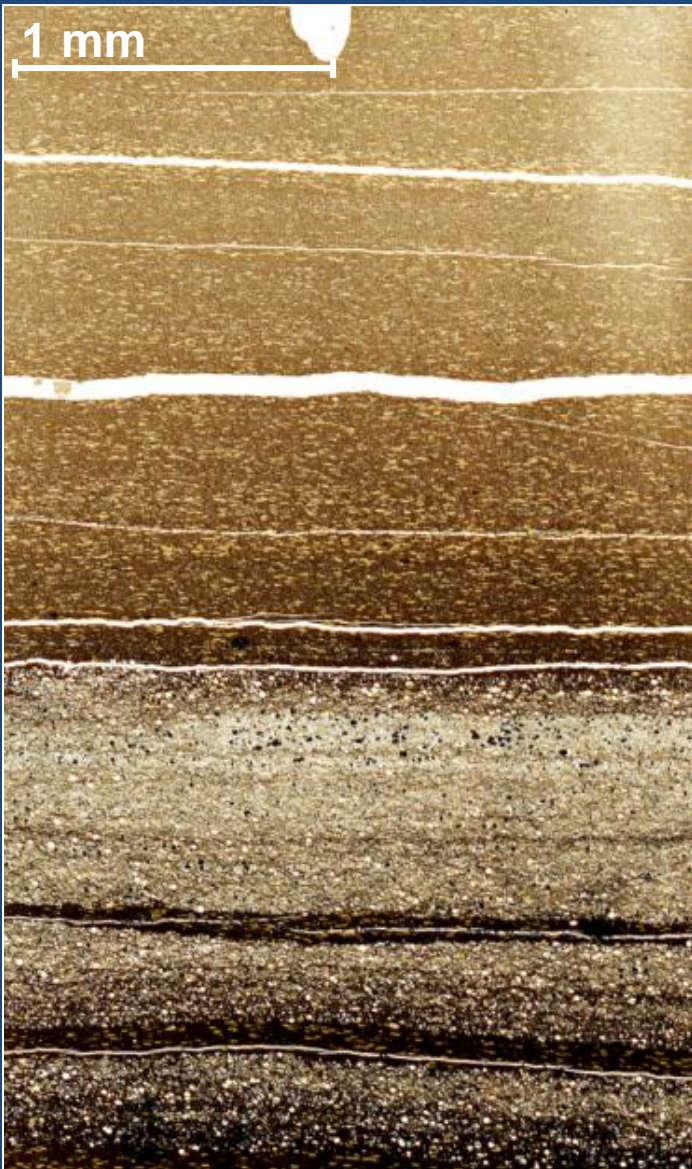


Light brown, low TOC (6.82%).



Dark brown, high TOC (12.97%), abundant alginite (type *tasmanites*). Distinct banding, TOC=6.12%.

Thick and coarse silt lamina



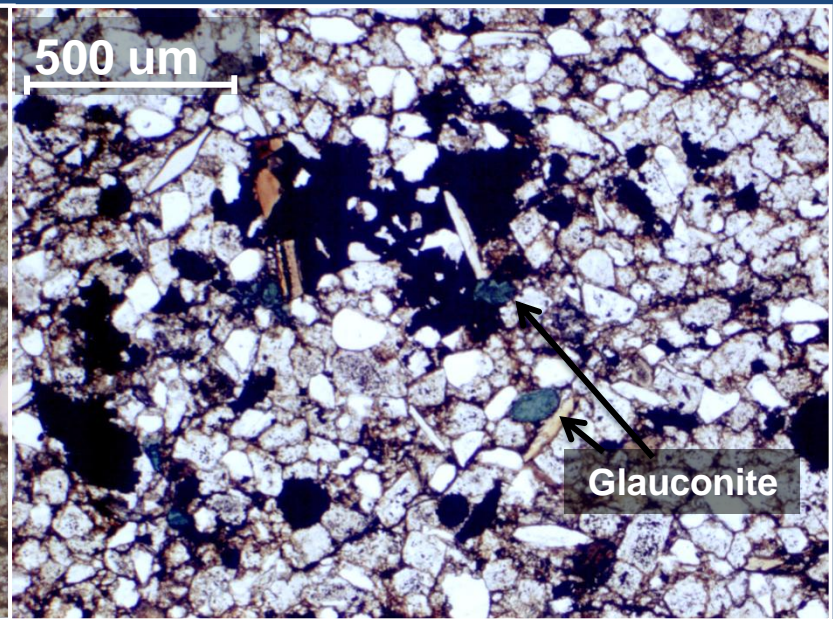
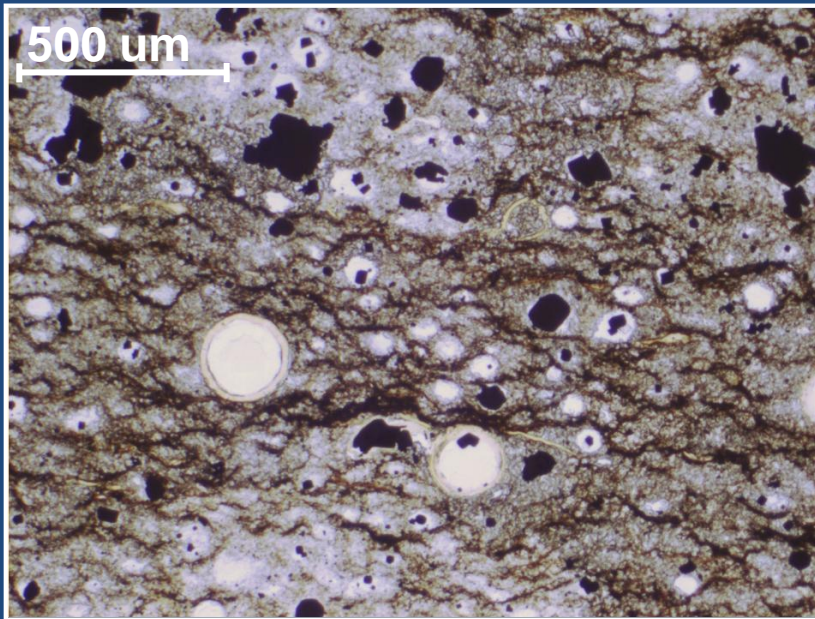
- Diagenetic cements (carbonate, iron sulfides, glauconite)
- Biogenic debris (conodonts, lingula, fish debris)
- Associated organic matter type and stable carbon isotope signature ($\delta^{13}\text{C}$) similar to that of banded brownish-black shale

Quartz	Clays	Feldspars	Carbonates	Iron Sulfides
~27%-49%	~25%-42%	~5%-12%	~7%-31%	~2.5%-5%

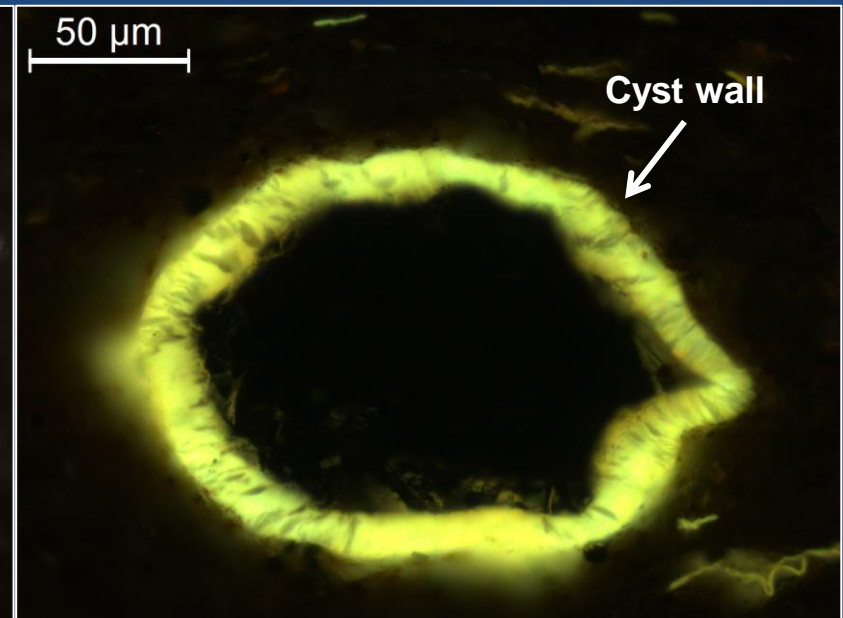
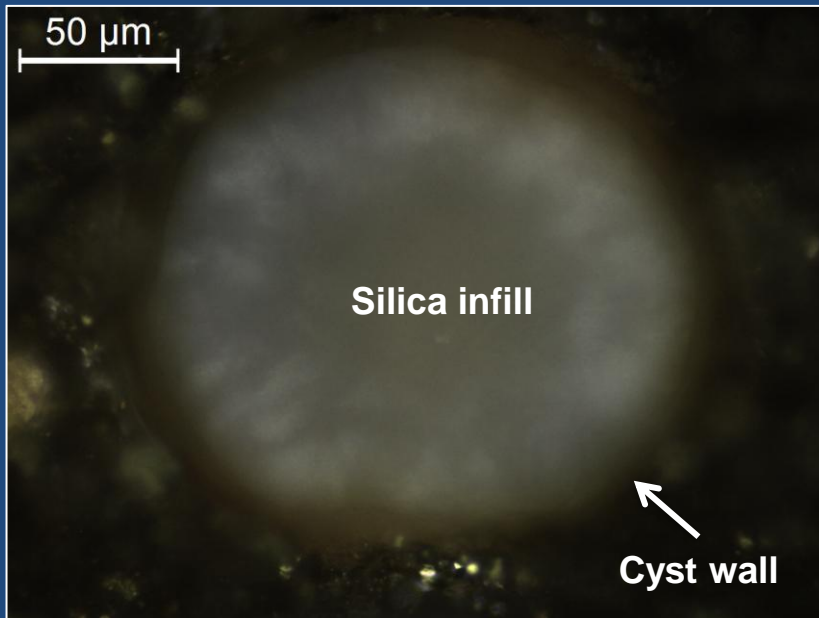
*Bulk mineralogy from Rietveld Refinement of digital powder x-ray diffraction patterns



Millimeter thick and coarse silt lamina inter-bedded with banded brownish-black shale



Transmitted light photomicrograph (left) has significant diagenetic mineral growth attributed to the formation of the silt layer whereas (right) silt is predominantly reworked detrital silts, glauconite indicates slow deposition and sediment starvation.

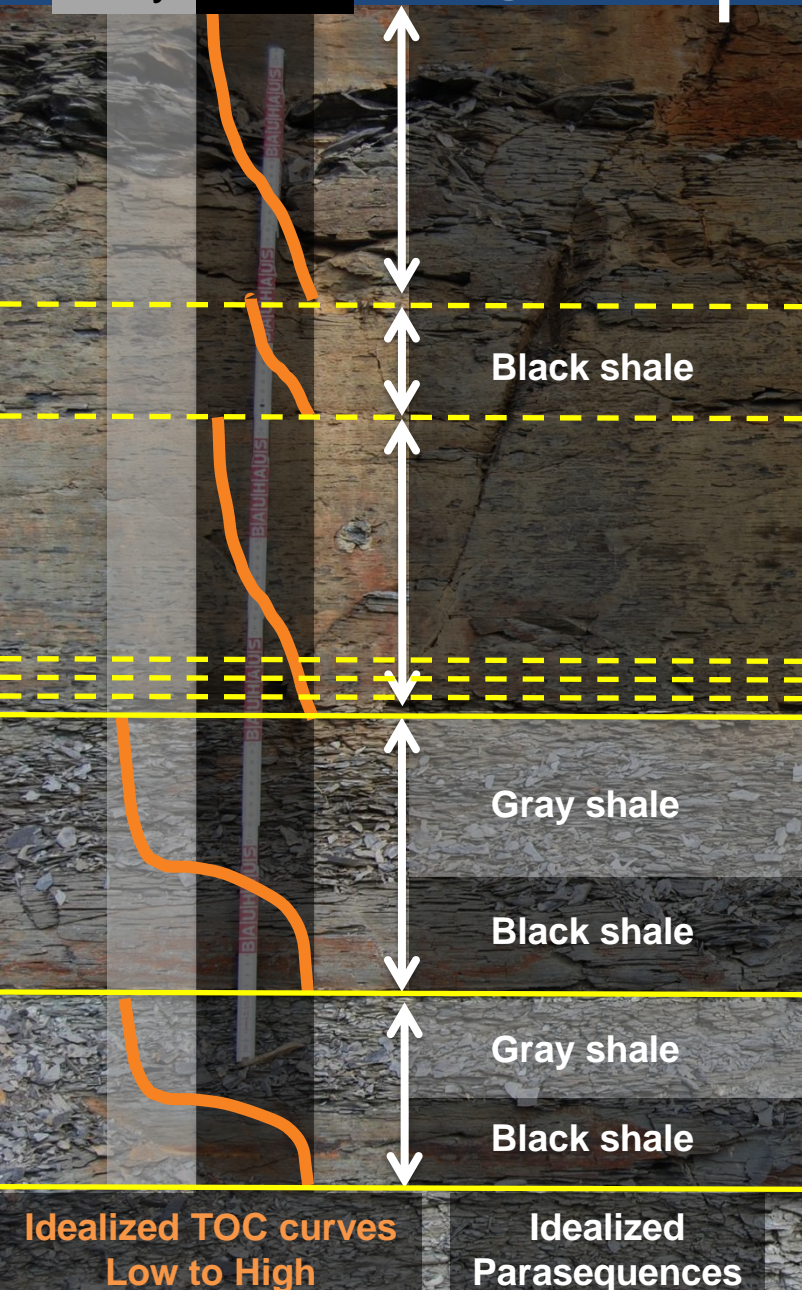


Reflected light photomicrograph of an algal cyst in-filled with chalcedony in a radial pattern indicating early diagenetic growth.

Fluorescent light photomicrograph of an algal cyst with pore space indicating pathway for mineral infill.

Camp Run Member

Gray Black



Three distinct facies:

- I. Bioturbated gray shale (recessive weathering)
- II. Banded brownish-black shale (bioturbated, ledge forming)
- III. Thick and coarse silt lamina

Silt

Silt

Silt

Sharp reworked contact

Silt

Silt

Flooding surface

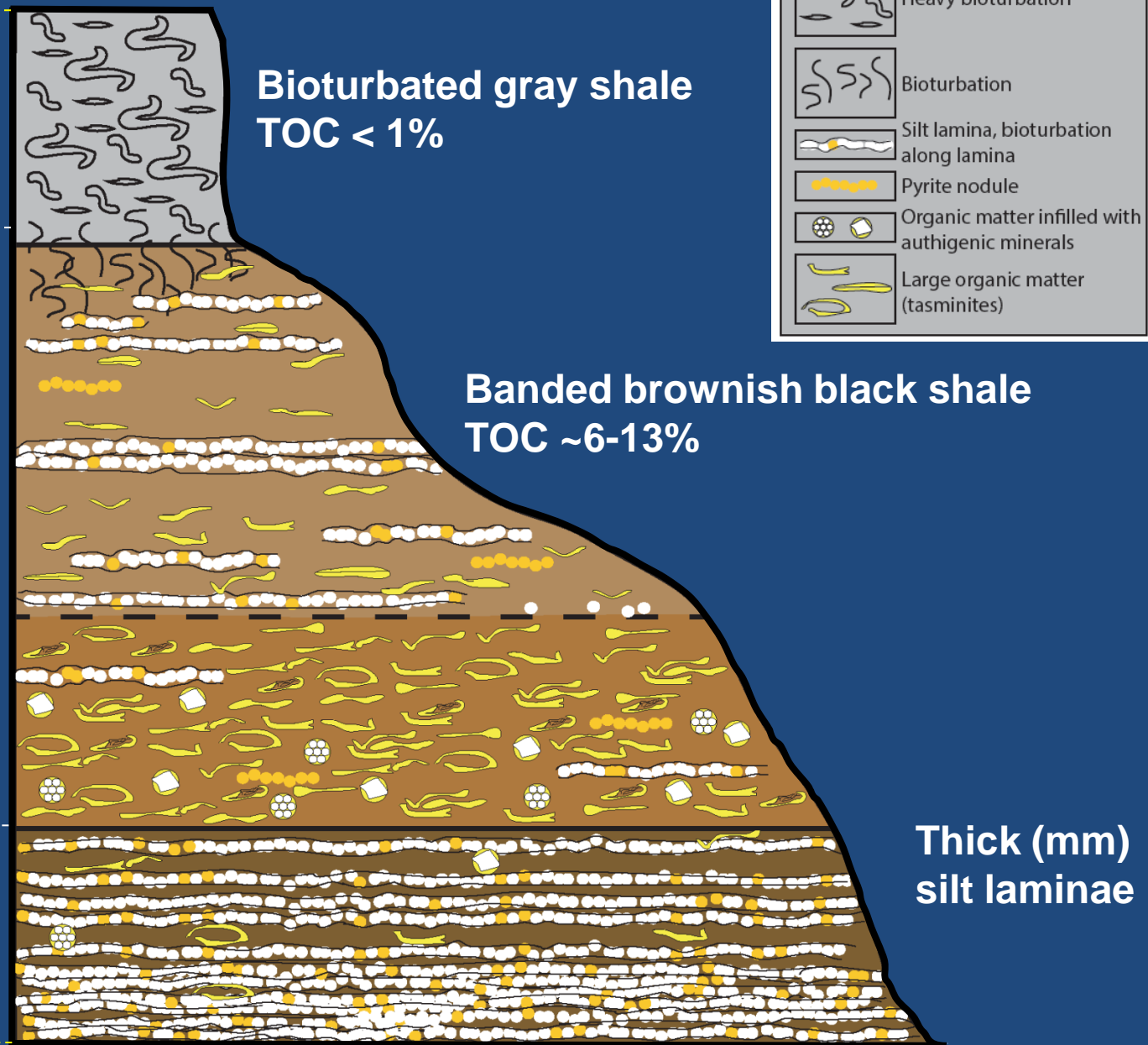
- Heavy bioturbation
- Sedimentary structures barely preserved

- Bioturbation by sediment feeders introduces improved ventilation that causes more microbial breakdown of organic matter

- Sedimentation rates creep up, organic matter dilution increases

- Gradual increase of detrital sedimentation improves preservation of labile organic materials

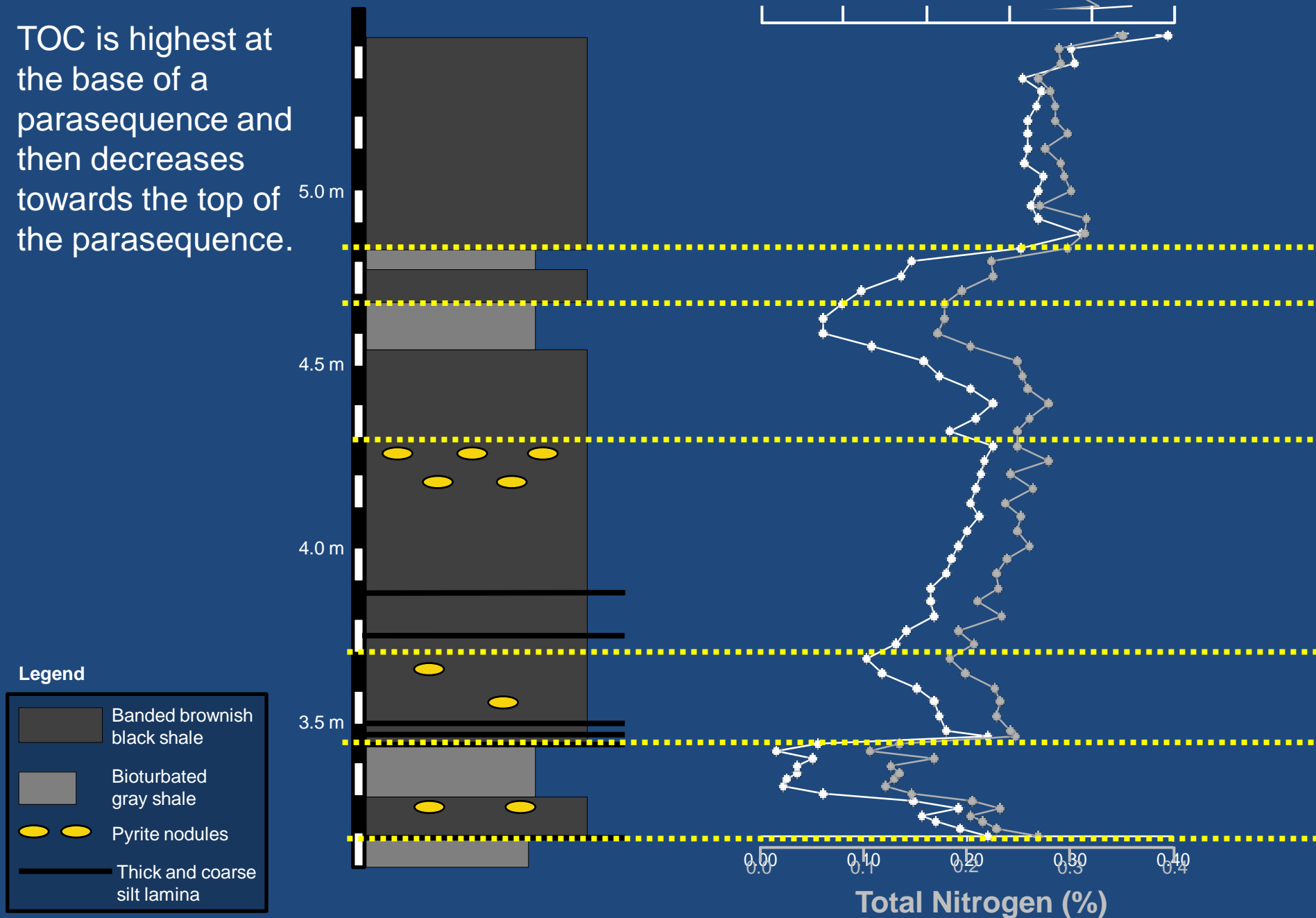
- Sediment starvation
- Increased diagenetic mineral precipitation (quartz and pyrite)



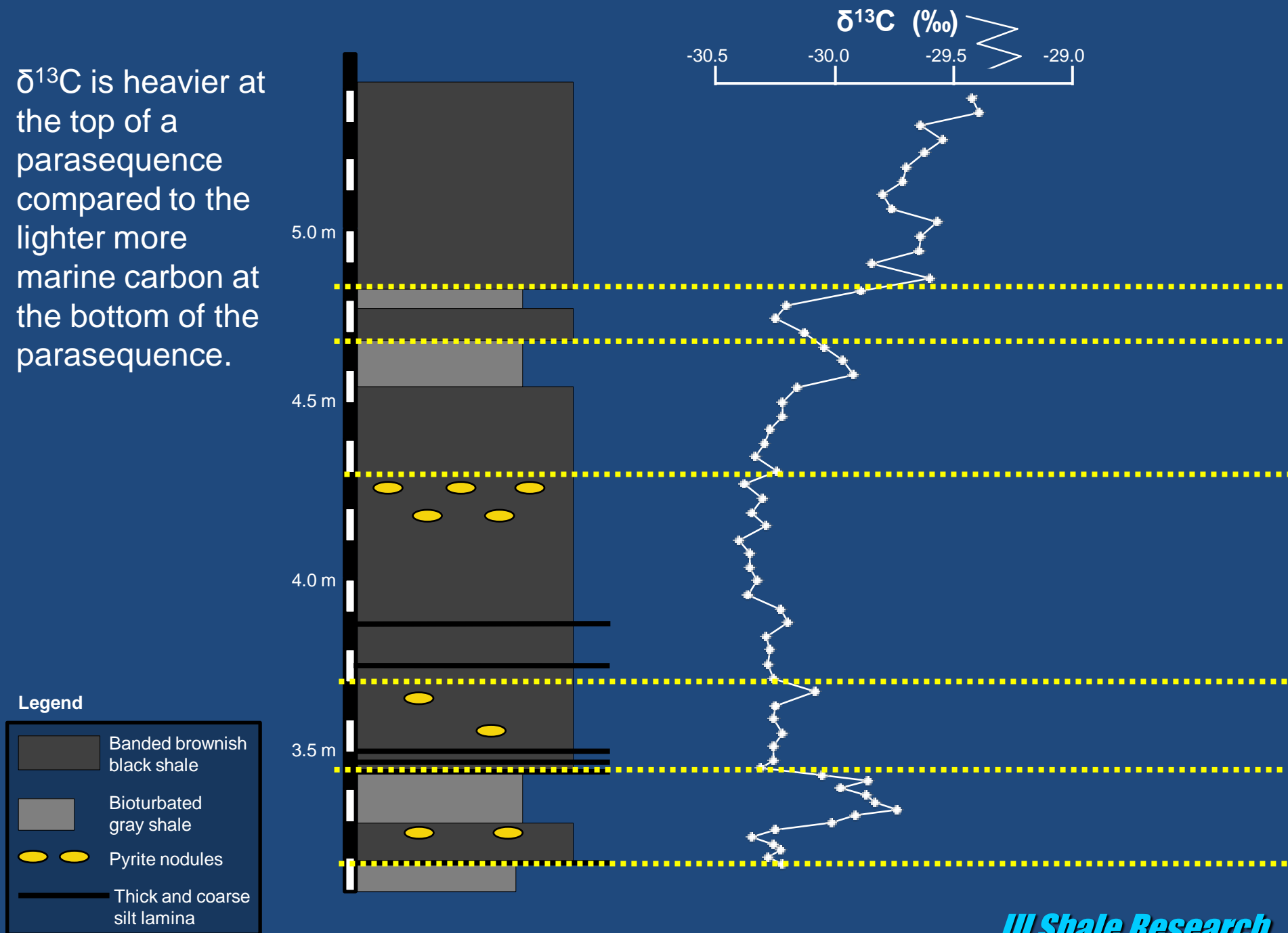
Flooding surface

Low ← Idealized TOC curve → High

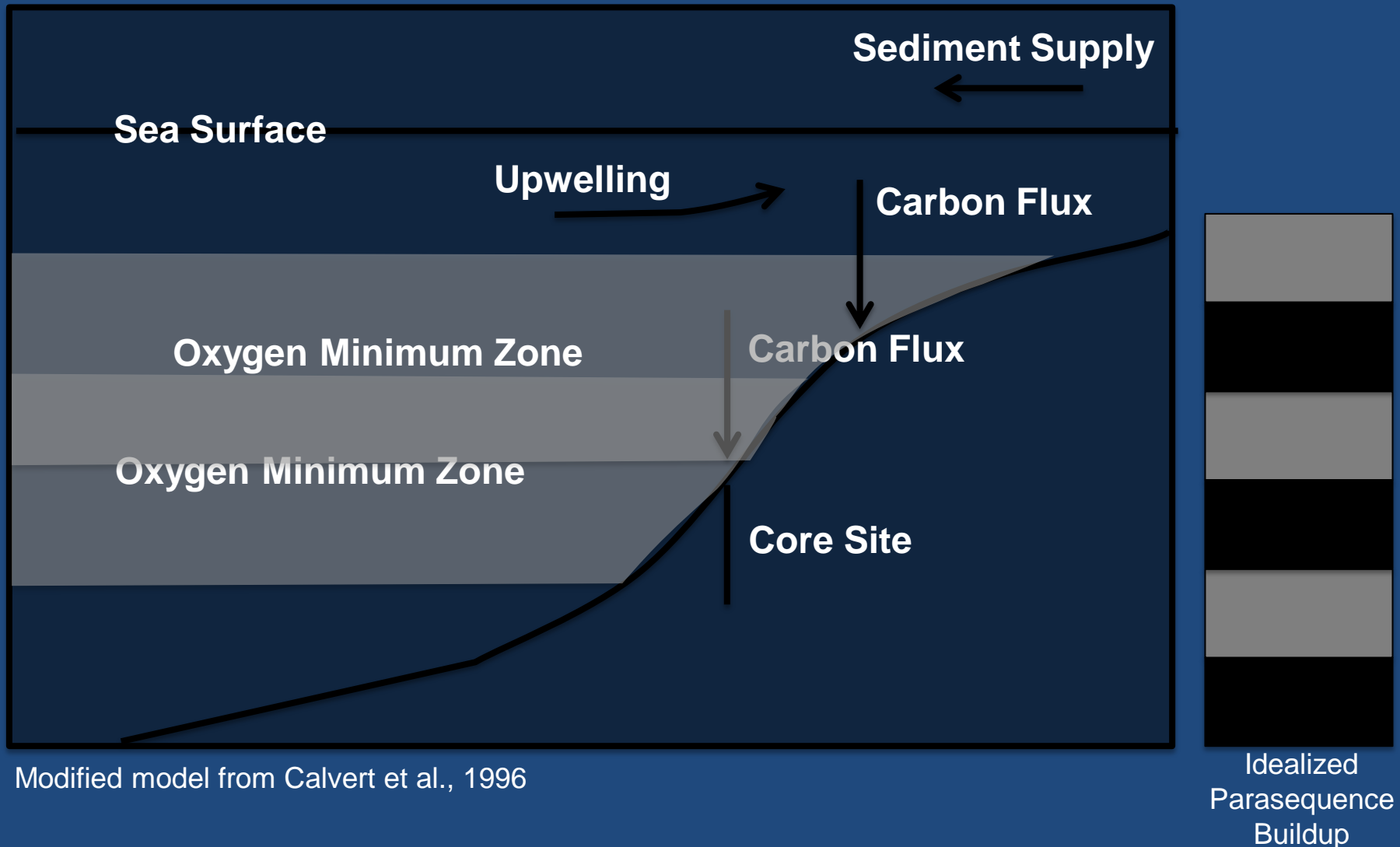
TOC is highest at the base of a parasequence and then decreases towards the top of the parasequence.



$\delta^{13}\text{C}$ is heavier at the top of a parasequence compared to the lighter more marine carbon at the bottom of the parasequence.

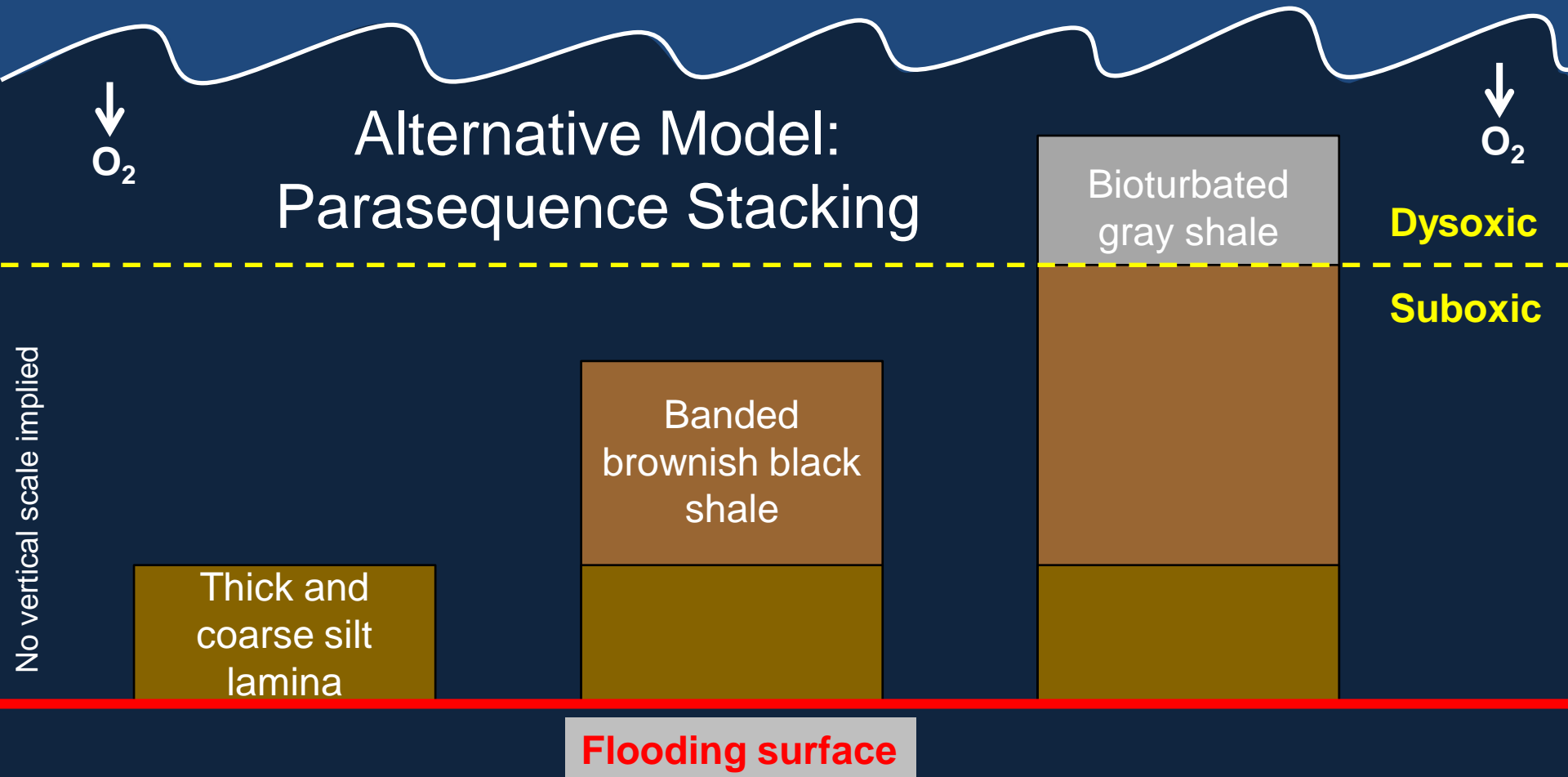


Previous Model



Modified model from Calvert et al., 1996

A fluctuating oxygen minimum zone does not align with current understanding of the paleogeography of the New Albany Shale and presence of benthic organisms.



- Over the course of a single parasequence ~1m sediment accumulates on the sea floor, enough to have the sea bed rise from suboxic to dysoxic conditions in our envisioned shallow water setting (10's of meters).
- TOC, stable carbon isotopes, mineralogy, and outcrop and petrographic characterization allow identification of subtle parasequences
- Continued work is targeted at laterally tracing parasequences of the Camp Run through outcrops and subsurface

Previous depositional models assumed cyclic changes of oxygen levels across large portions of the basin, with poorly defined drivers.

Interpreting the Camp Run Cycles as parasequences provides an internally consistent explanation of observed shale facies and sedimentary features, as well as their vertical successions and the stacking of cycles.

Acknowledgements

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As well as Dr. Abhijit Basu, Dr. Maria Mastalerz, Dr. David Bish, Dr. Peter Sauer, and Dr. Erika Elswick.

References

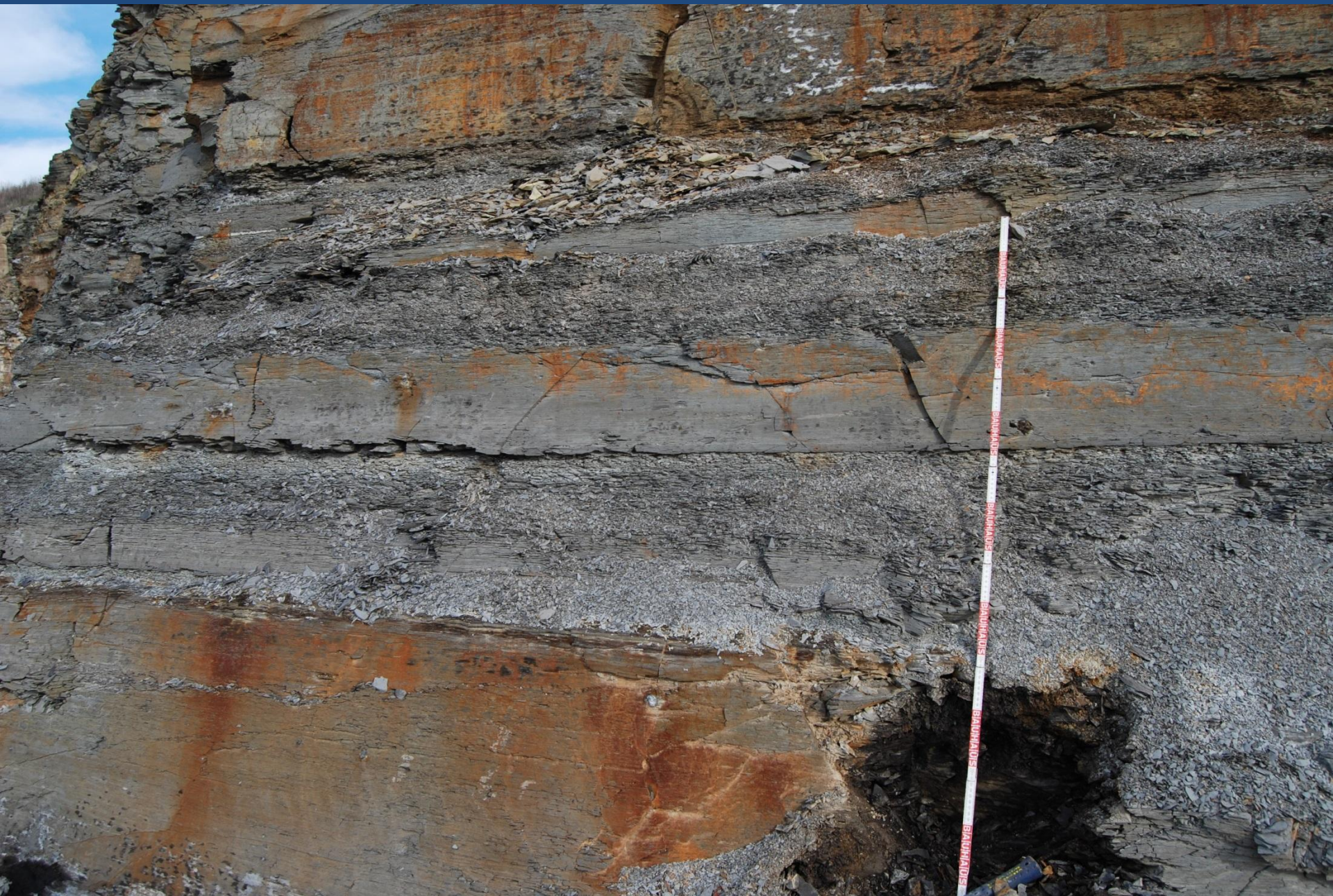
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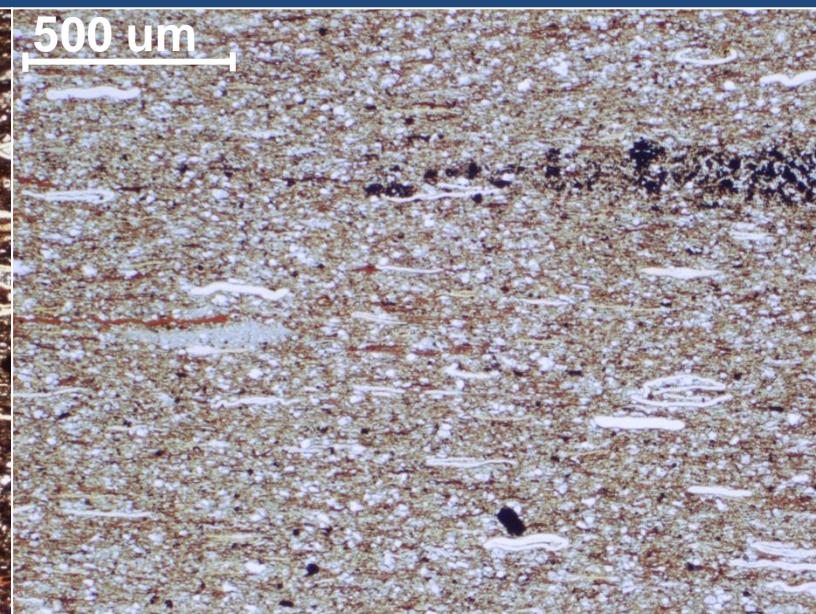
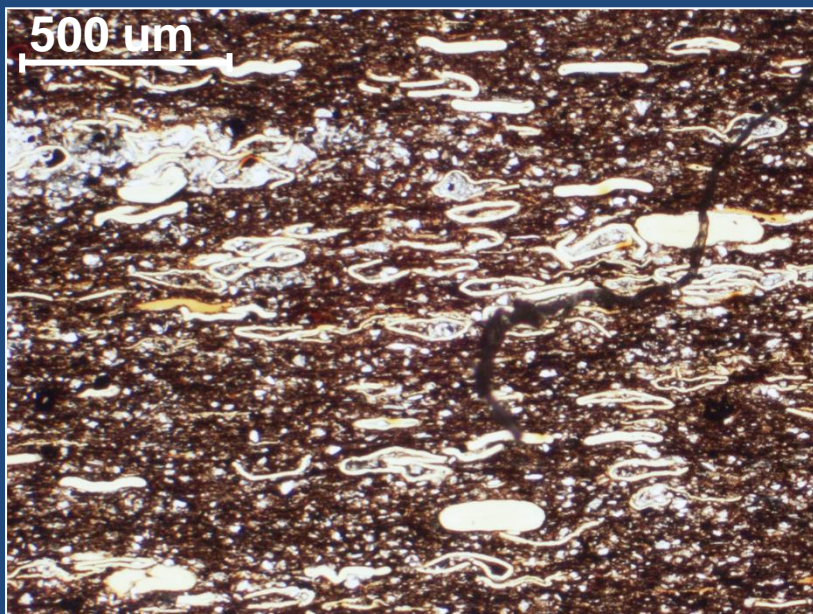
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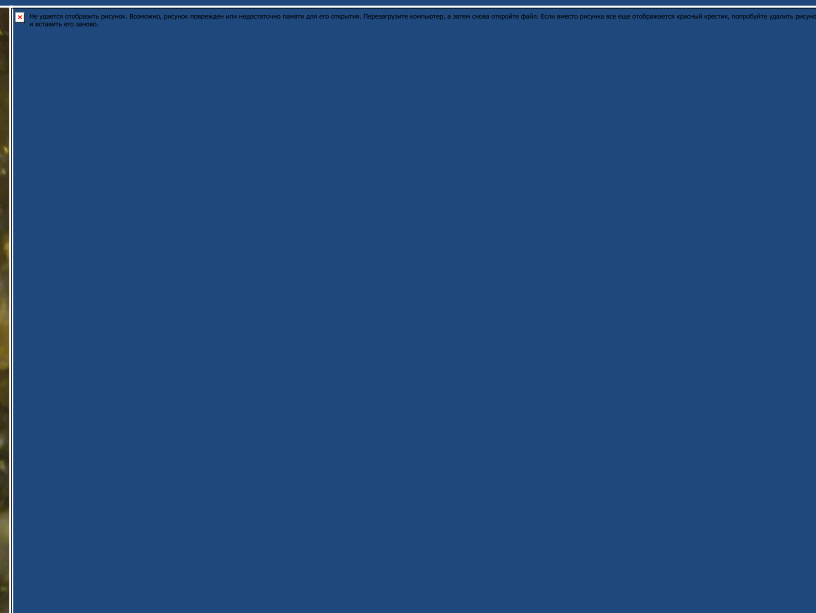
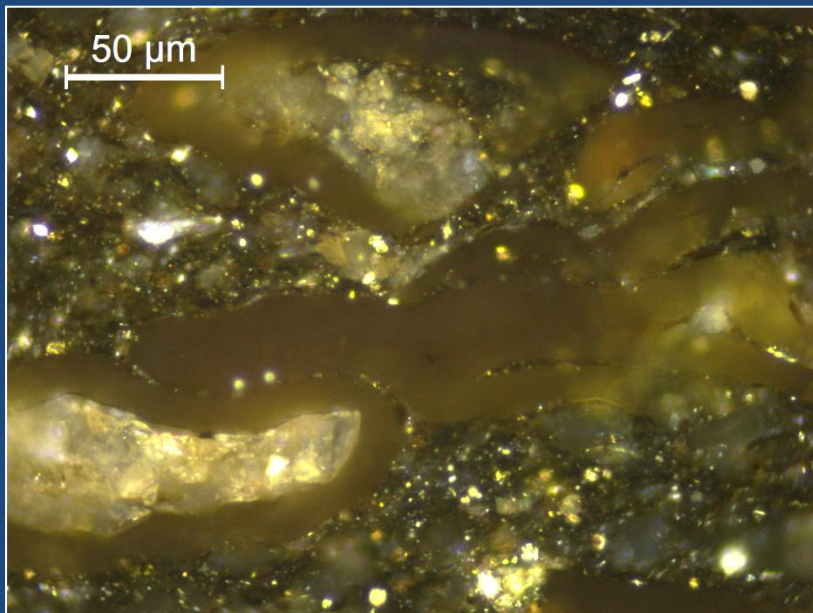
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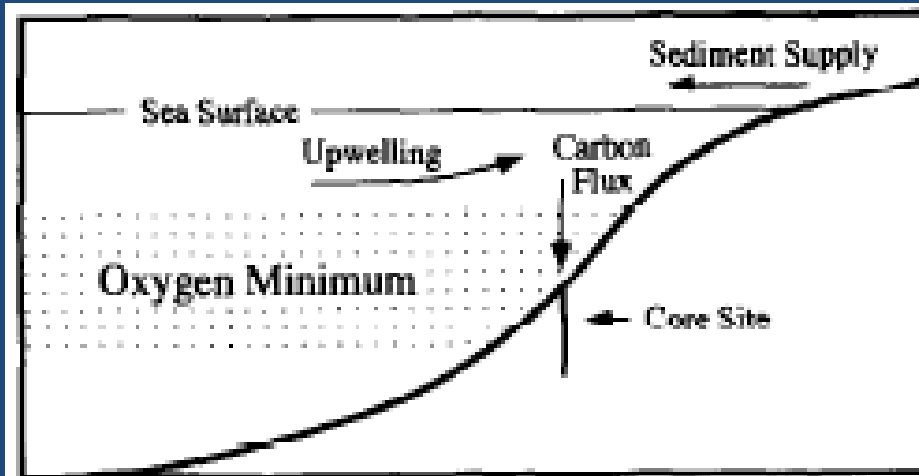


Transmitted light photomicrographs with abundant alginite (type *tasminites*) surrounded by a clay and silt mineral matrix with carbonates and iron sulfides, (left) TOC=12.97% and (right) TOC=9.6%



Reflected (left) and fluorescent (right) light photomicrographs with large yellow fluorescent alginite (type *tasmanites*) some with calcite infilling and preserving the structure of the cysts

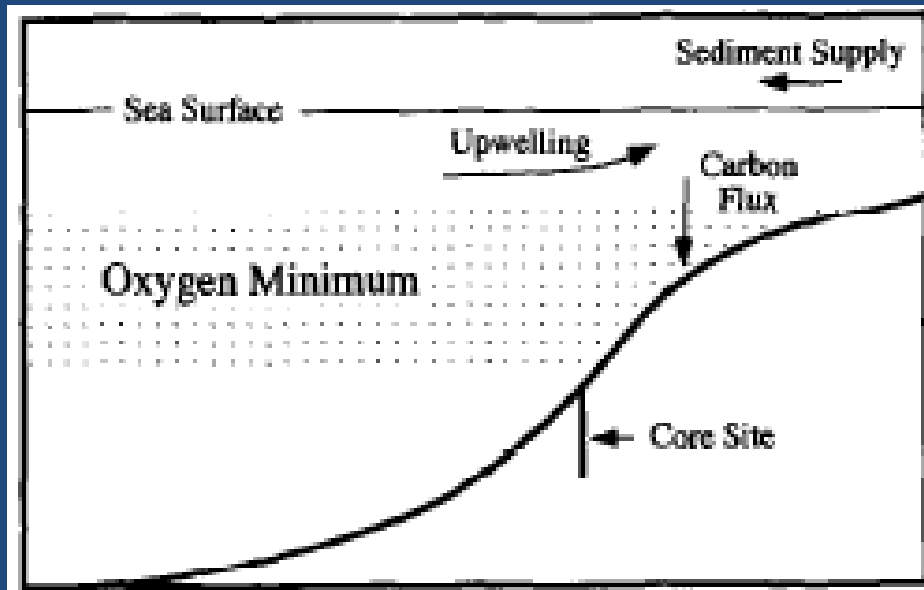
Previous model



Laminated shale facies:

- within the oxygen minimum during low relative sea level
- beneath a coastal upwelling cell
- close to clastic sediment sources

*Figures and descriptions as described by Calvert et al., 1996.



Bioturbated shale facies:

- deeper than the oxygen minimum zone during periods of high relative sea level
- beneath poorly productive waters
- a greater distance from clastic sediment sources