Lithofacies Characterization and Sequence Stratigraphy of the Horn River Shale, Horn River Basin, British Columbia*

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Abstract

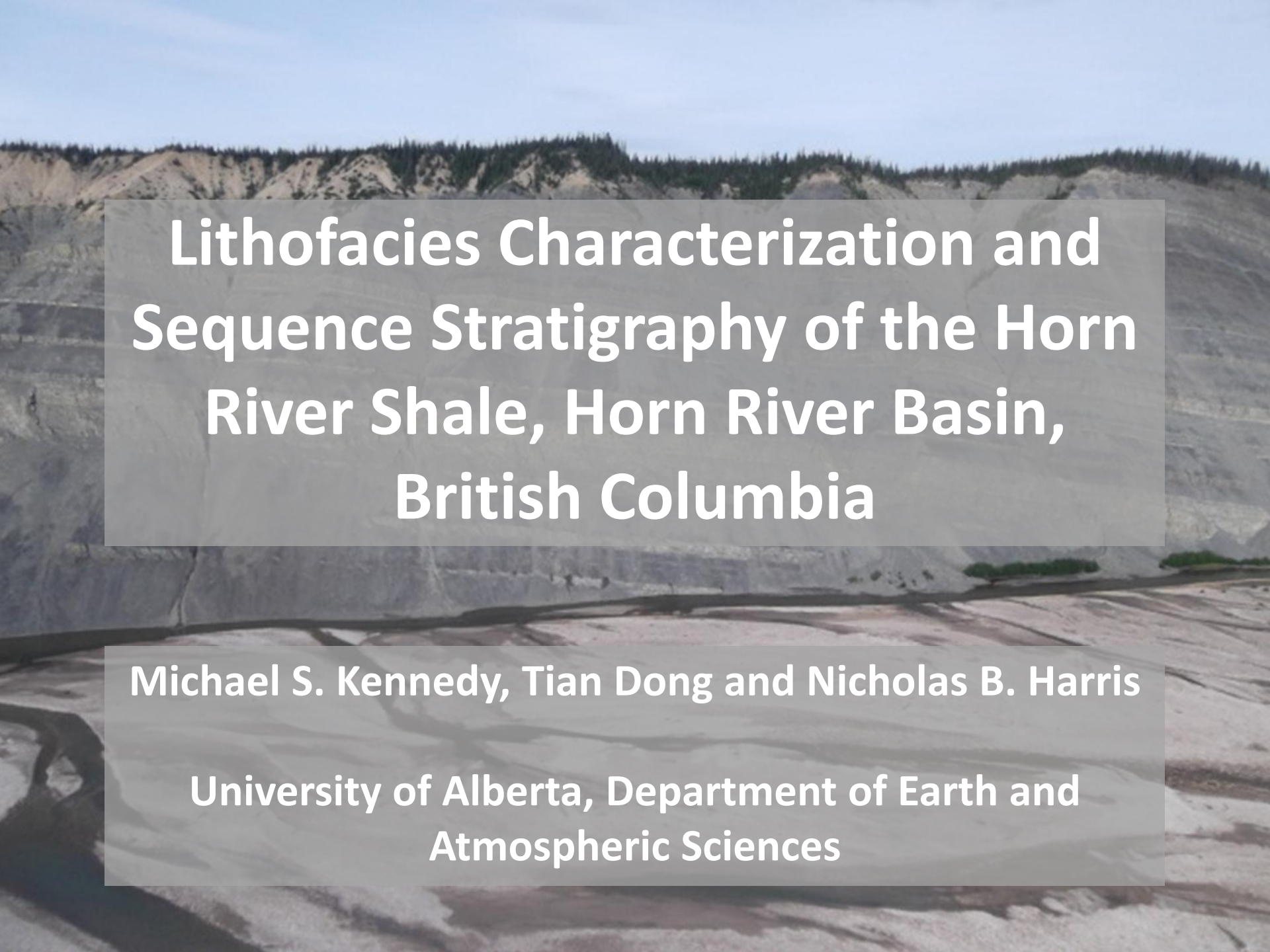
The Horn River Group of the Horn River Basin, northeastern British Columbia, is an Upper Devonian shale succession that has been targeted for its vast reserves of natural gas. This report is part of an ongoing study that aims to establish a sequence stratigraphic model for the Horn River Group, and to associate rock properties such as organic content, porosity, permeability, and brittleness with sequences and systems tracts. This study advocates a thorough integration of sedimentological, geochemical, and wireline log data from numerous long cores in the Horn River Basin and their shoreward equivalents, and cautions against an overreliance upon specific wireline logs.

The Horn River Group consists of the Evie, Otter Park, and Muskwa Formations overlying Keg River carbonates. Cores preserve two depositional phases that are lithologically and geochemically distinct. The first phase consists of gray calcareous mudstones and limestones, each containing numerous thin (1-2 cm) interbeds of bioclast-rich wackstones and packstones characteristic of carbonate shedding. These sediments comprise the Evie Formation, and were deposited under reducing ocean conditions based on elevated Mo/Al, V/Al, and U/Th ratios. The second depositional phase consists of black laminated silica-rich mudstones with abundant pyrite and no carbonate beds. These sediments comprise the Otter Park and the lower Muskwa Formations, and were deposited under less reducing ocean conditions based on a decrease of the same geochemical ratios mentioned above.

To the southeast, the shoreward equivalents of the Horn River units are two stacked reef complexes: the Presqu'ile Reef and the Slave Point Formation, both of which comprise the TSTs of two 3rd order sequences respectively within an overall 2nd order sea level rise. We correlate these two 3rd order sequences to the two depositional phases in the Horn River Basin. Therefore, the majority of carbonate shedding into the Horn River Basin originated from the Presqu'ile reefs and occurred during a 3rd order TST. Retrogradation of the Slave Point reefs due to the overall 2nd order sea level rise caused the shoreline to recede so that Slave Point shedding could not reach the basin during the second depositional phase, accounting for the absence of carbonate beds above the Evie Formation.

Selected Reference

Potma, K., R. Jonk, M. Davie, and N. Austin, 2012, A mudstone lithofacies classification of the Horn River Group: Integrated stratigraphic analysis and inversion from wireline log and seismic data: Presented at Sixth BC Unconventional Gas Technical Forum. Web accessed December 12, 2013. http://www.empr.gov.bc.ca/OG/oilandgas/petroleumgeology/UnconventionalGas/Documents/K%20Potma.pdf



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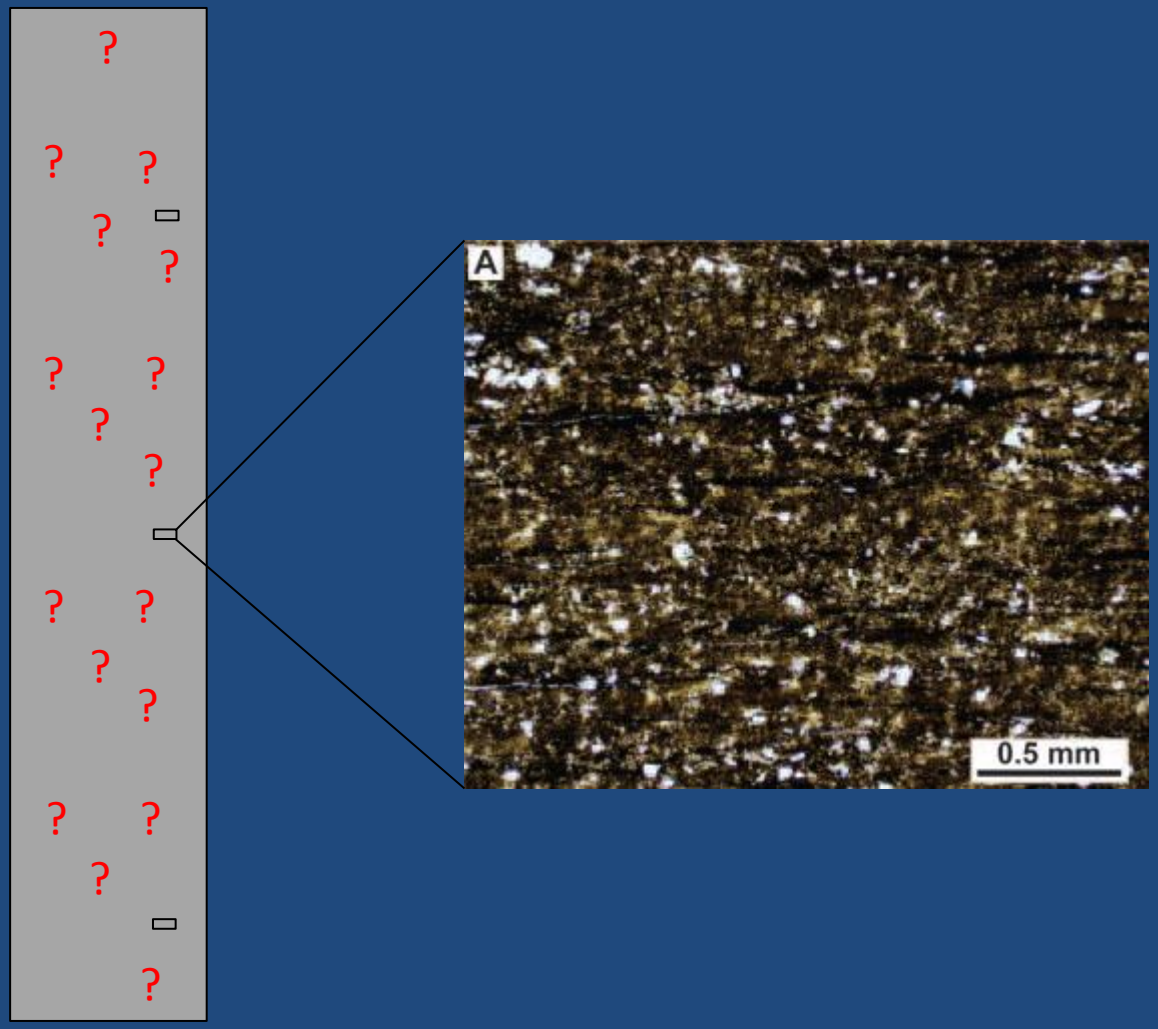
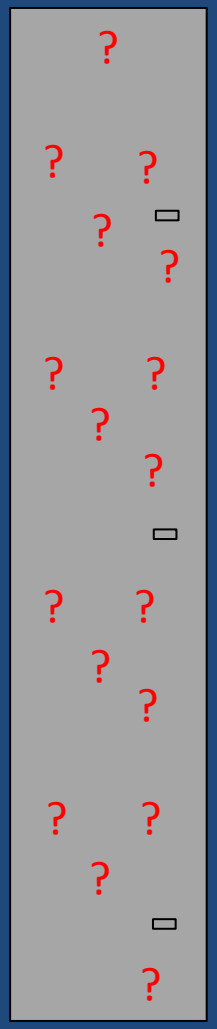
How to approach a shale lithofacies study?



Shale Core



Shale Core

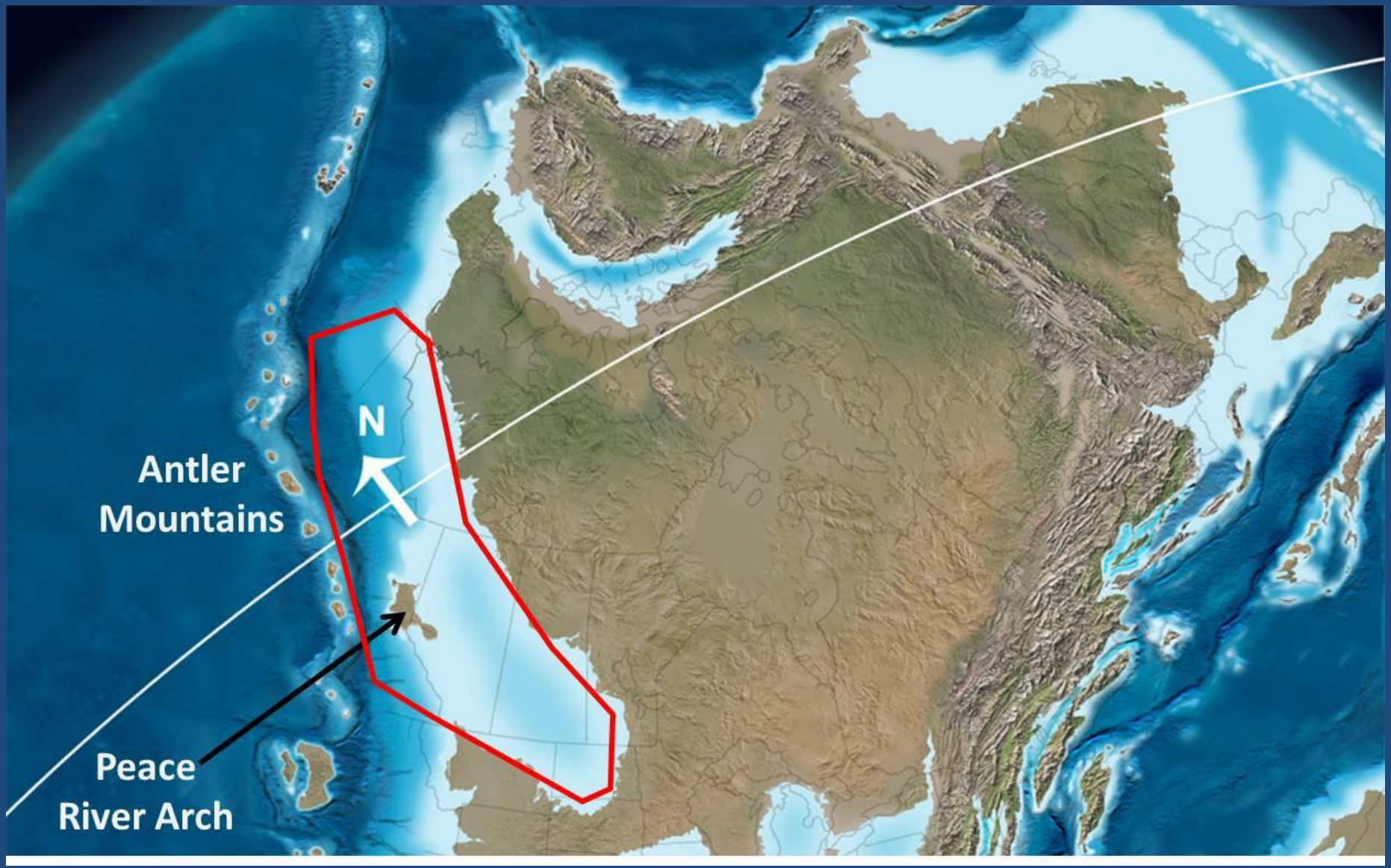
Our Approach:

- Identify meaningful **shale lithofacies** that can be identified with the human eye in cores, and link lithofacies to specific depositional environments
- Establish a **sequence stratigraphic model** for the Horn River Basin based on lithofacies distribution

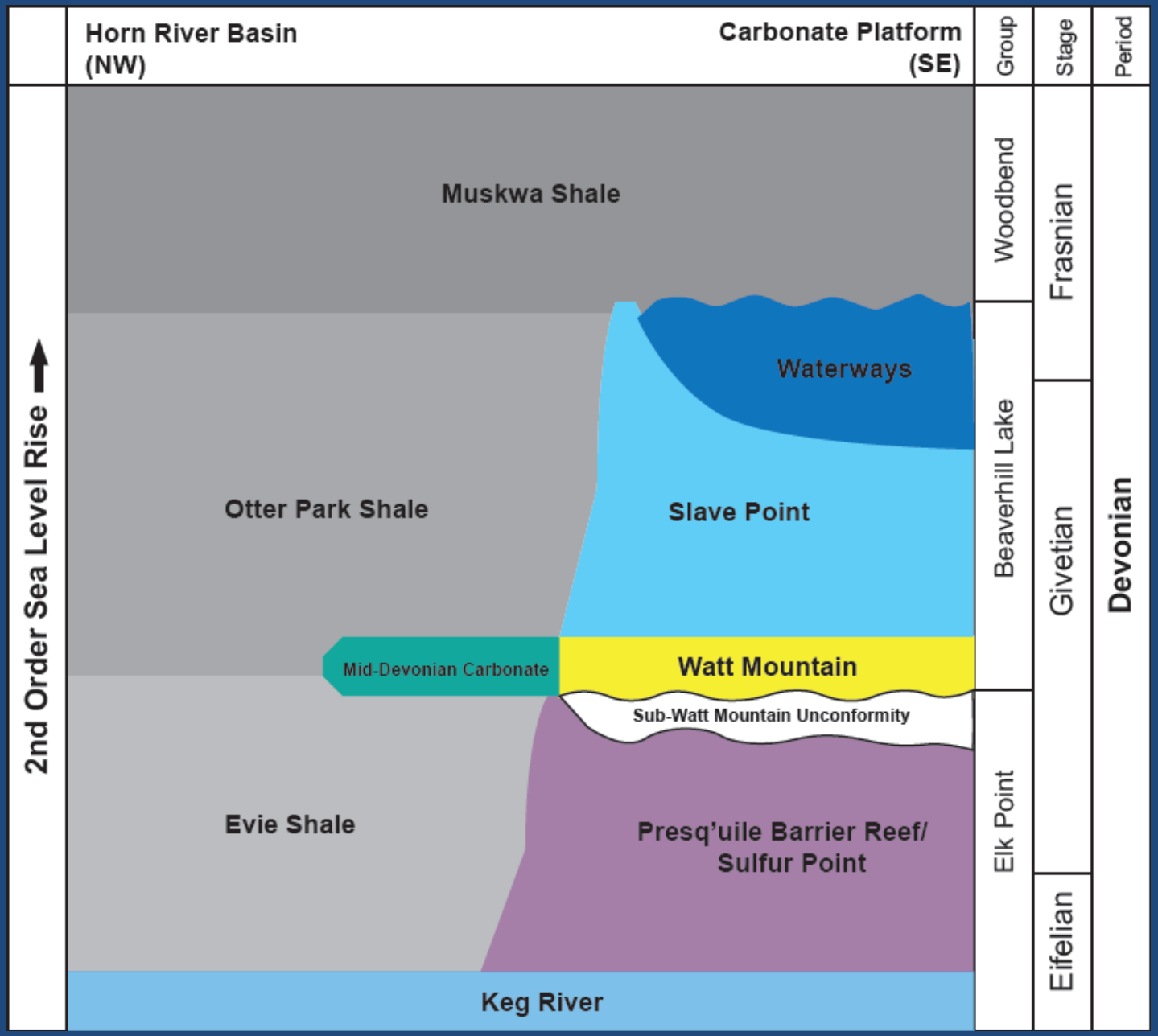
Horn River Shale

- Givetian-Frasnian (Middle Devonian)
- Deposited in the **Western Canada Sedimentary Basin**
- Includes the **Evie, Otter Park,** and **Muskwa** members
- **Natural gas estimates** (B.C. MEM, 2011):
  - **Ultimate Gas In Place**: 448 tcf
  - **Marketable:** 78 tcf

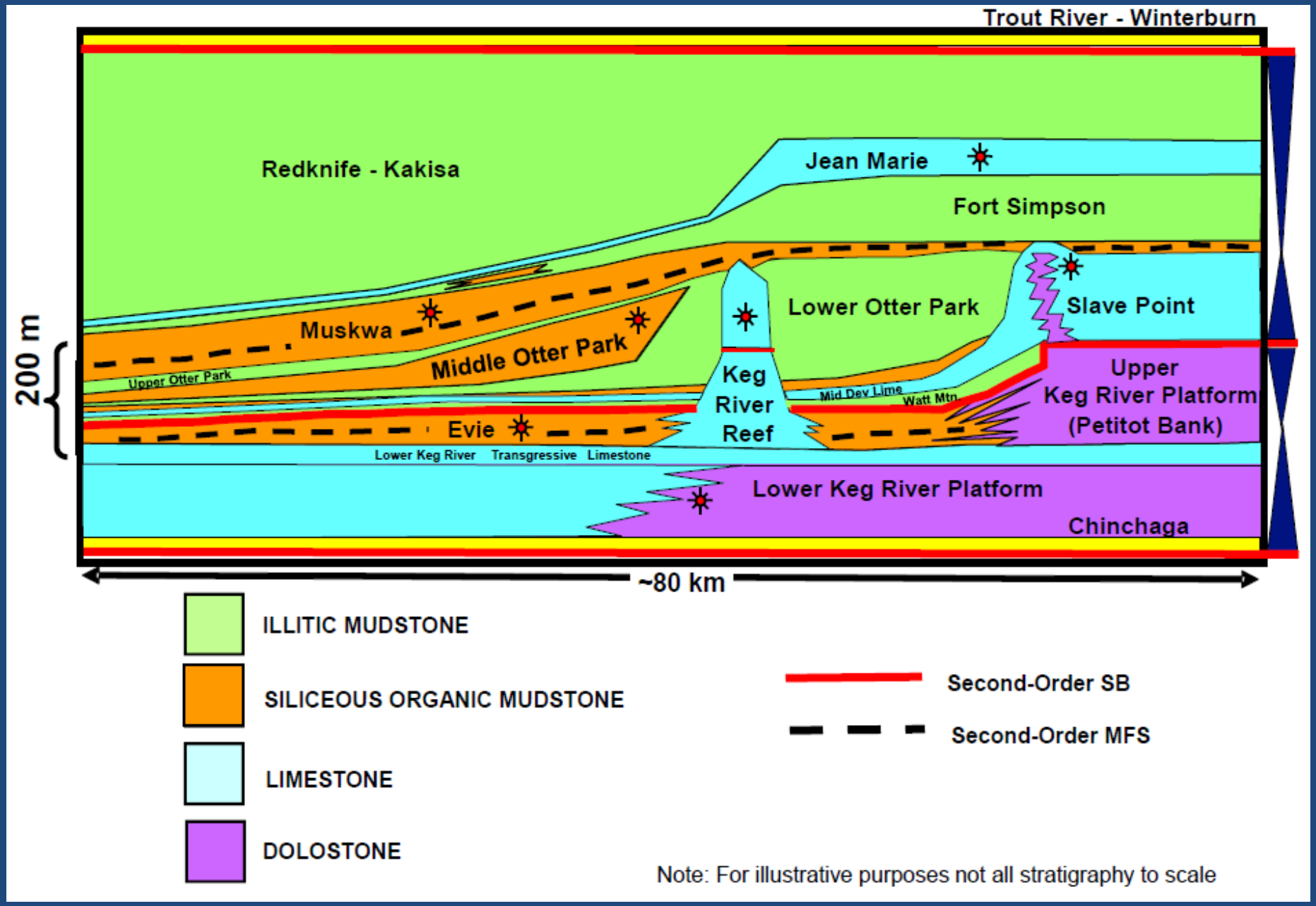
Figure 1.1 from B.C. MEM Oil & Gas Report, 2011



Western Canada Sedimentary Basin, Givetian-Frasnian Stages (~392 to 385 Ma). Taken from Hulsey 2011.



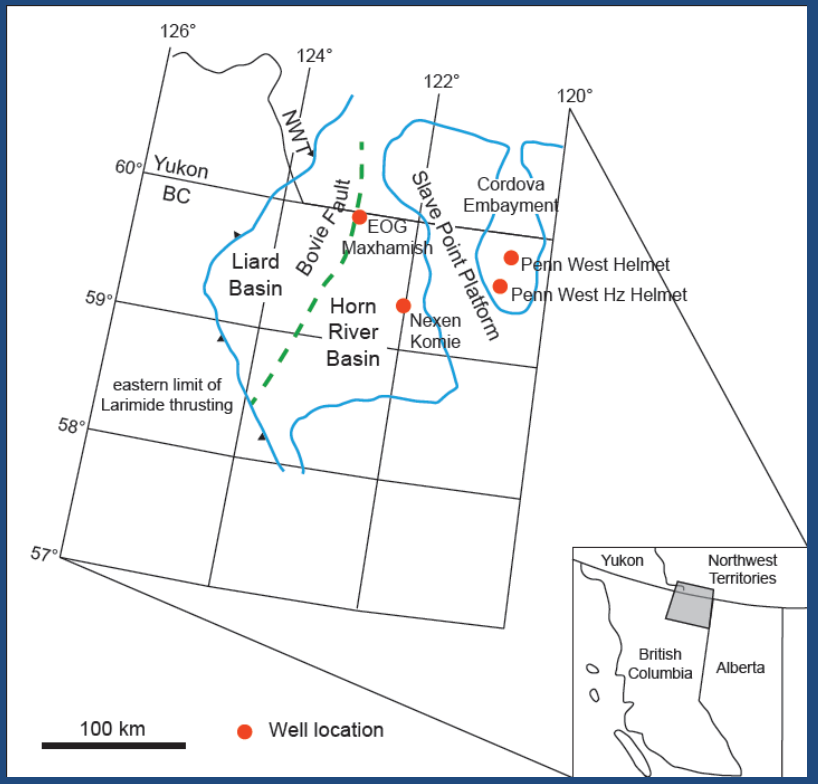
Stratigraphy of Horn River Shale units (Evie, Otter Park, Muskwa).



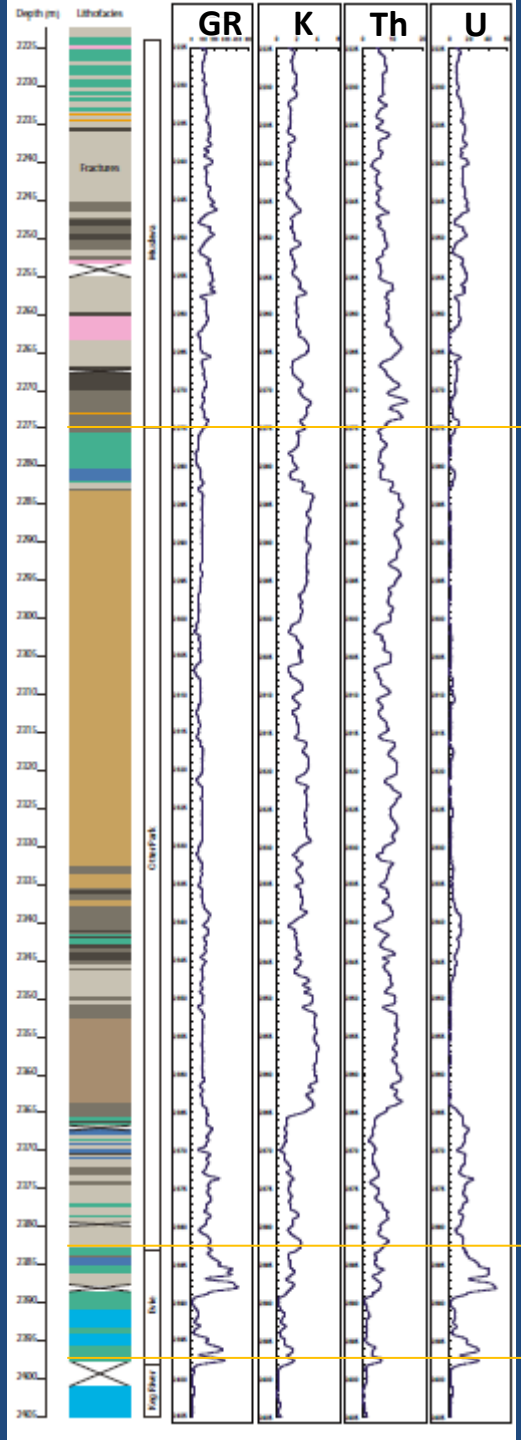
Schematic cross section illustrating platform-to-basin relationships. From Potma et al., 2012

Methods

- Four **Horn River cores** described lithologically
- Two of the cores sampled for bulk organic/inorganic geochemistry
- 90 thin sections
- 15 SEM and Micro-CT samples



10 lithofacies were identified



Muskwa Shale

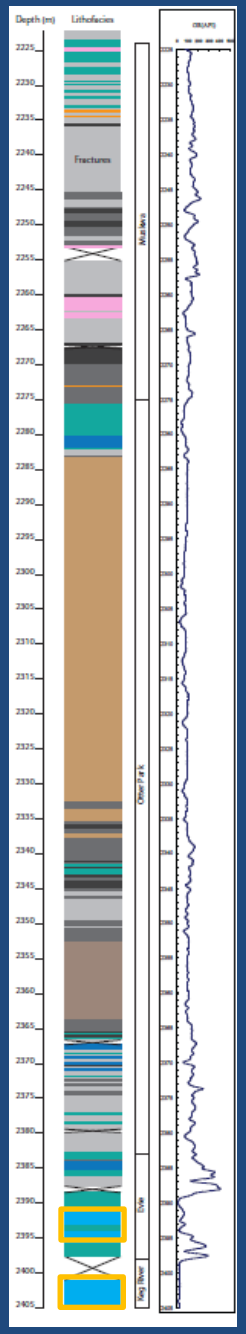
Otter Park Shale

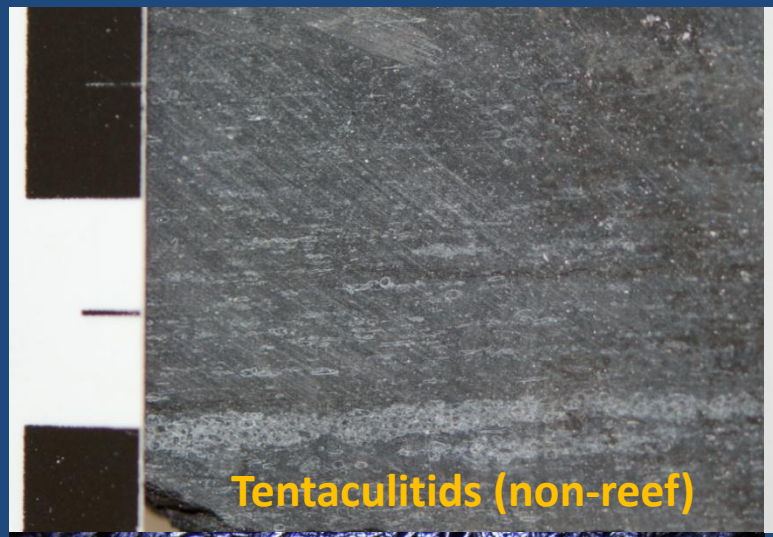
Otter Park Shale

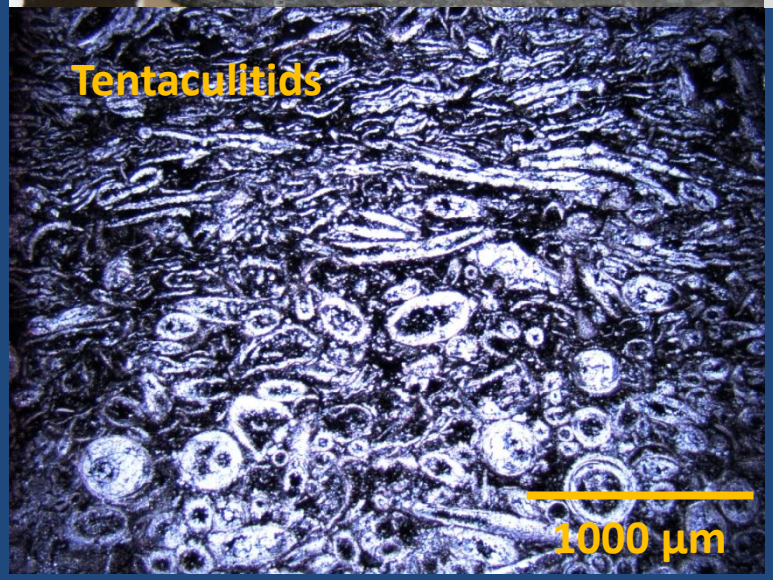
Evie Shale

Keg River (carbonates)

IOR Komie
D-069-K 094-O-02

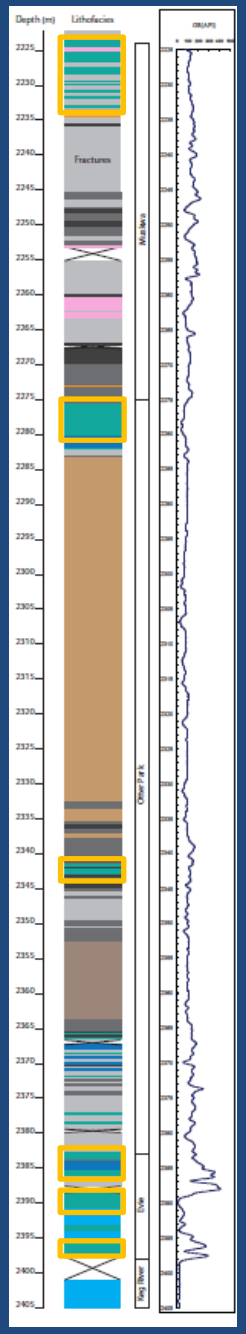


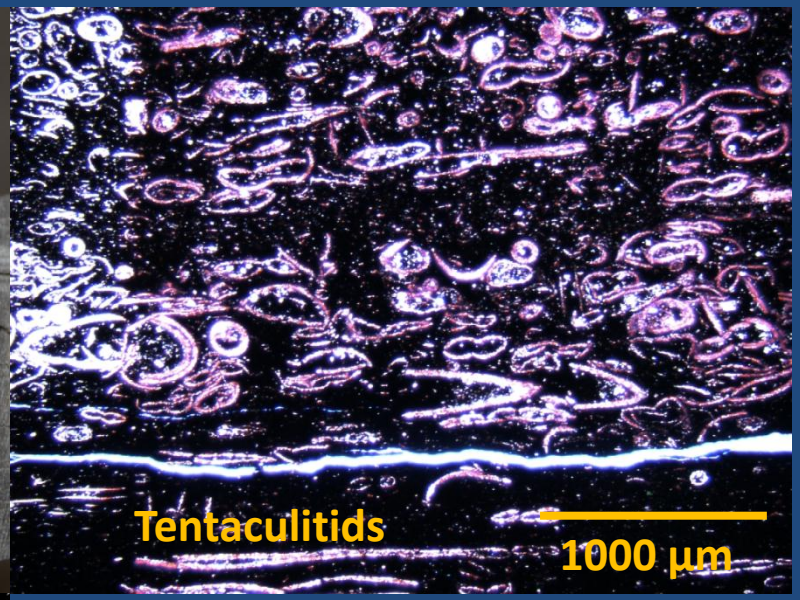


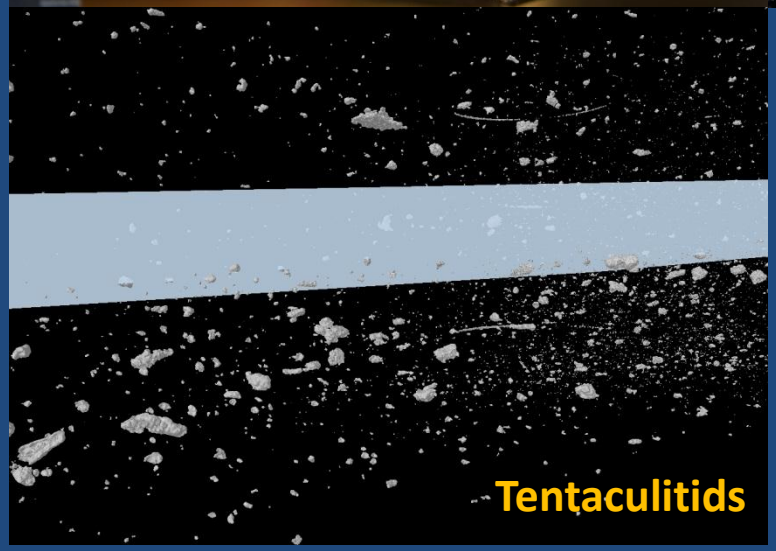


Limestone with skeletal fossils

Interpretation: denser accumulations of tentaculitids indicate shallower water. Less dense accumulations indicate relatively deeper water. Horizons are "die-out" events or gravity flows

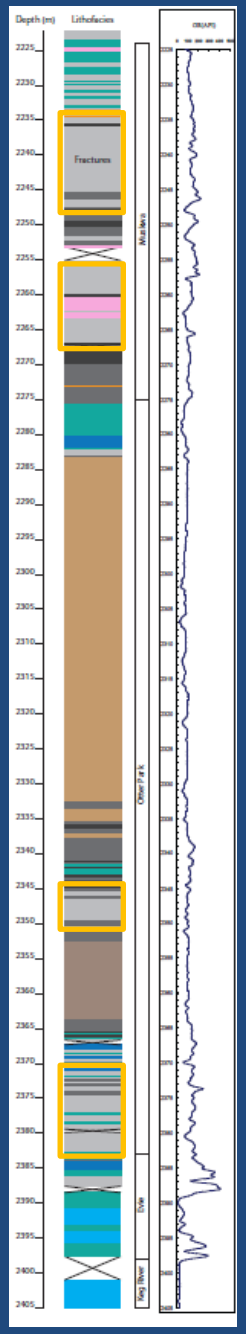


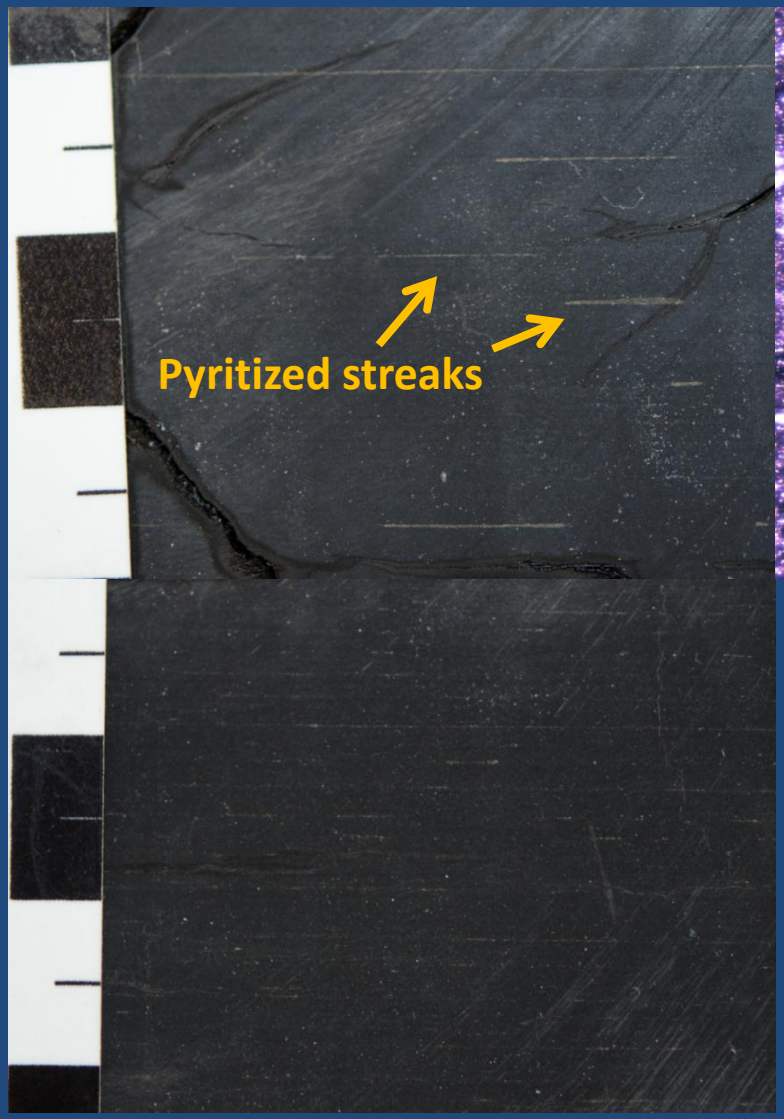


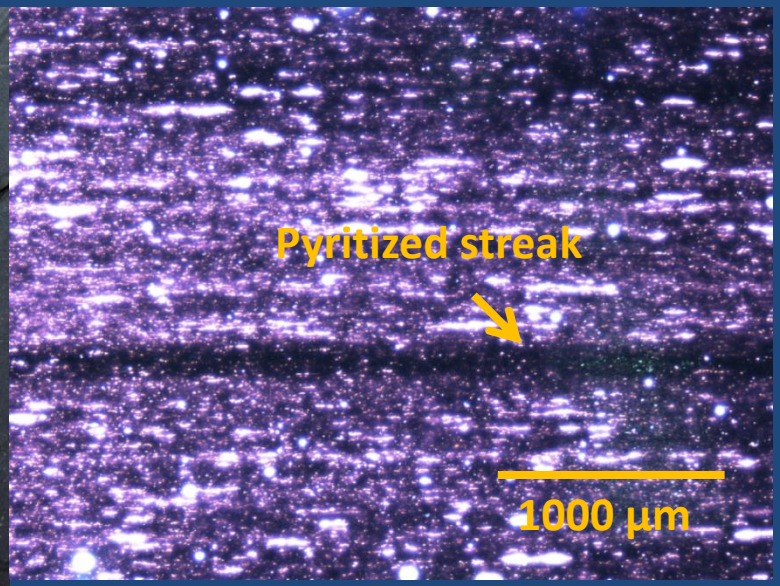


Calcareous mudstone with laminations defined by small crushed carbonate grains

Interpretation: carbonate grains are tentaclutids. Horizons of accumulation represent "die-out" events or gravity flows

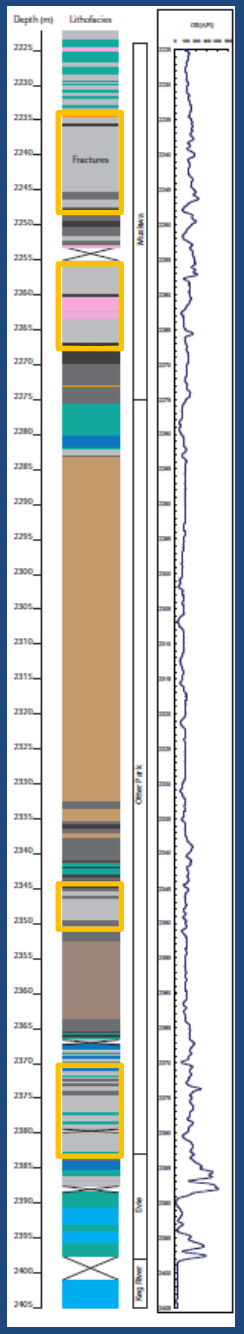


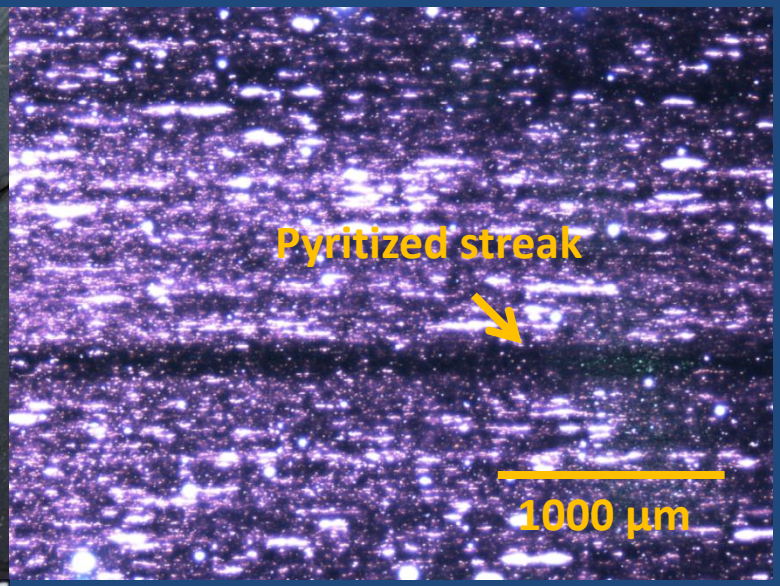


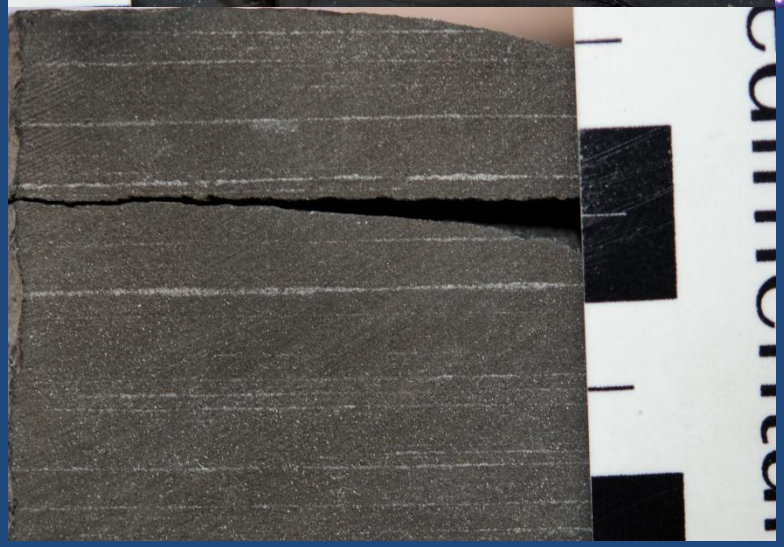


Siliceous mudstone defined by discontinuous grainy horizons or “silty streaks”

Interpretation: grainy horizons are sparse accumulations of dolomite, barite and pyrite grains. Structures are produced by weak bottom currents.







Siliceous mudstone defined by discontinuous grainy horizons or “silty streaks”

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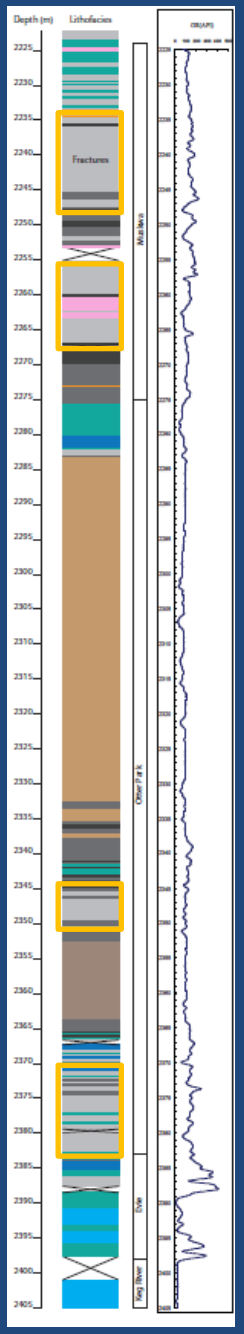

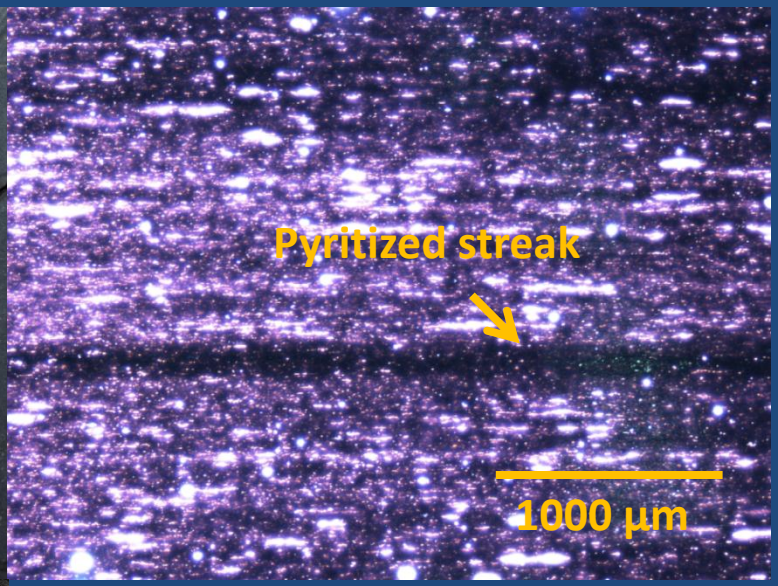

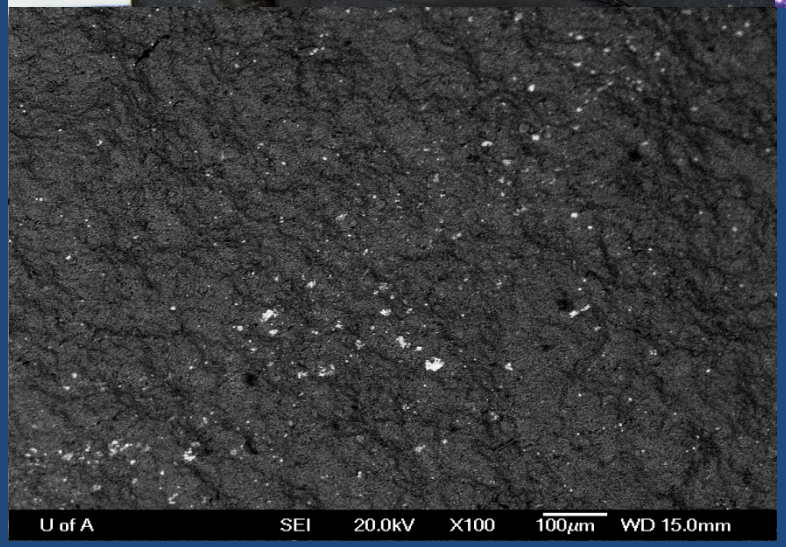

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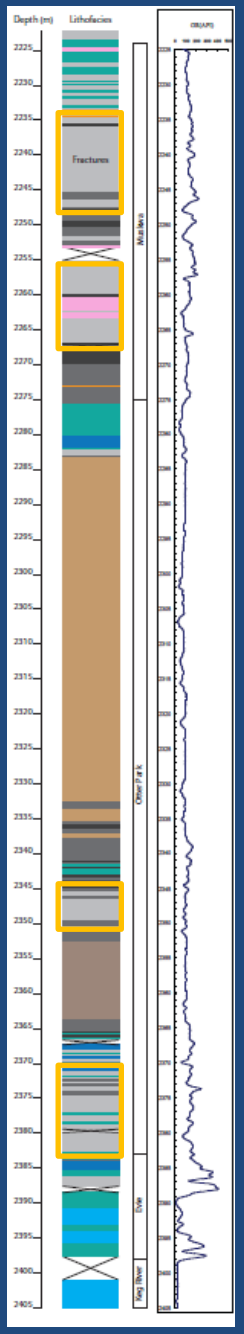

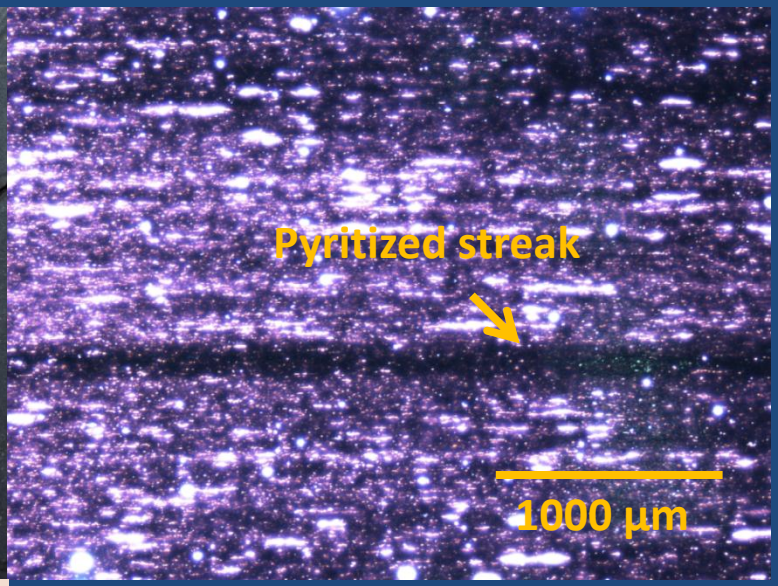

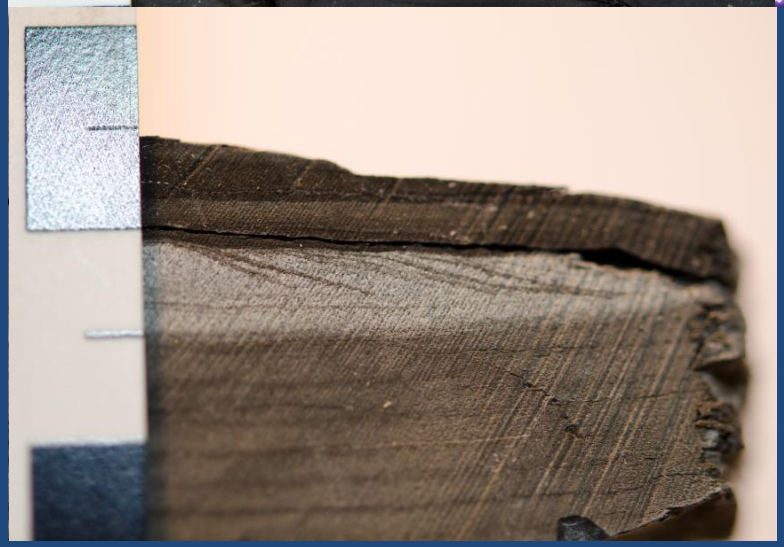

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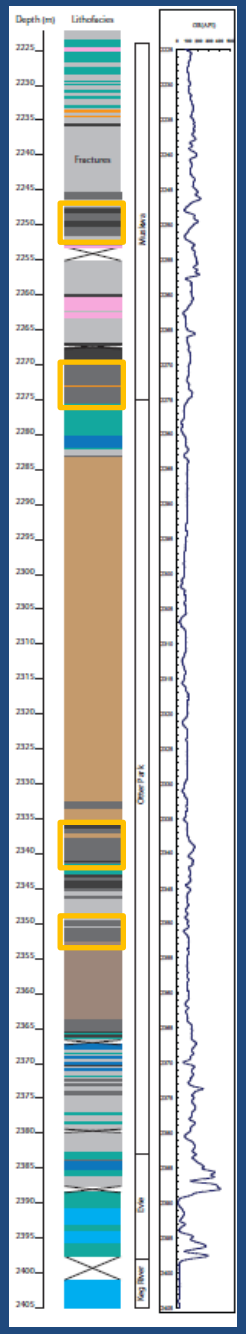
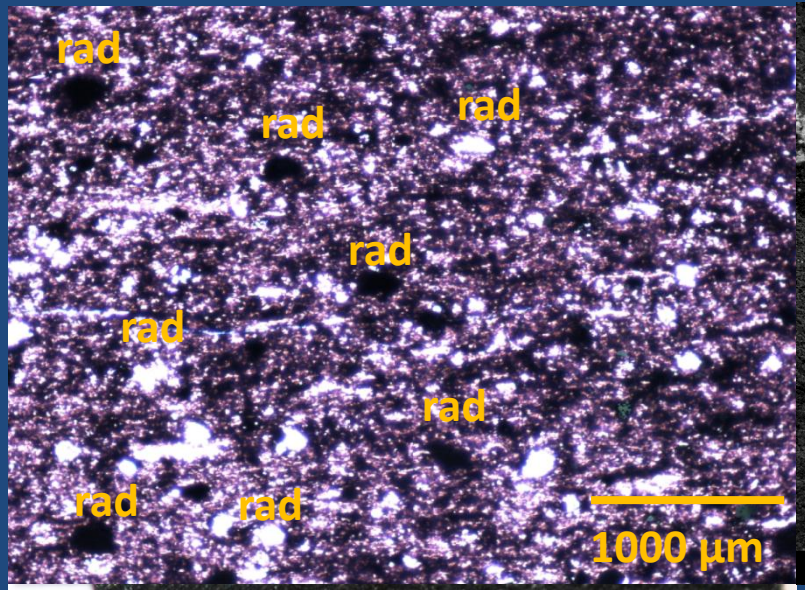
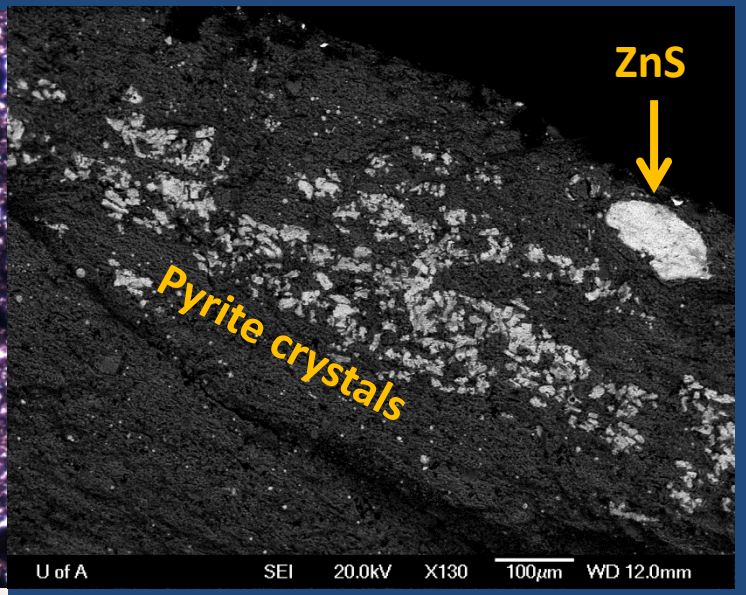
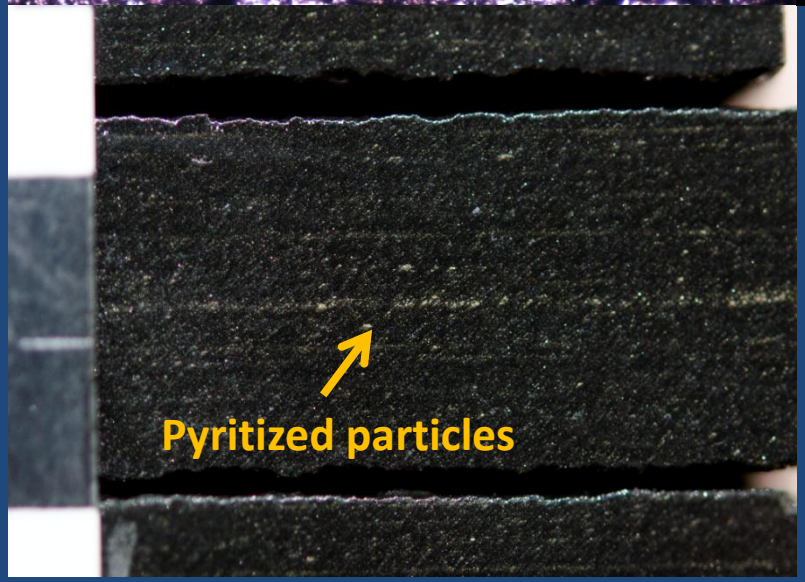


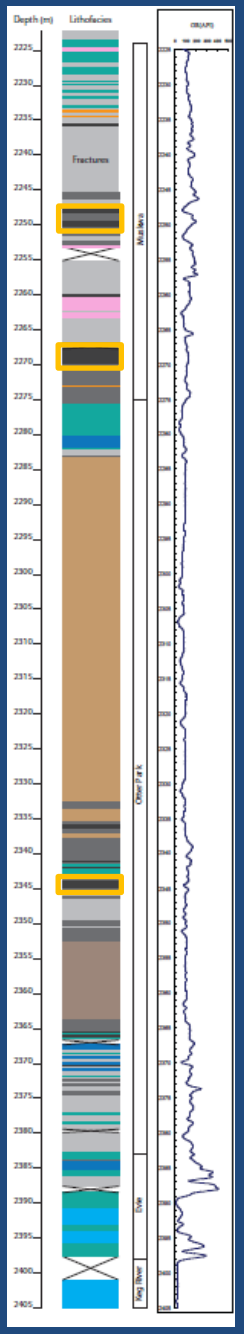


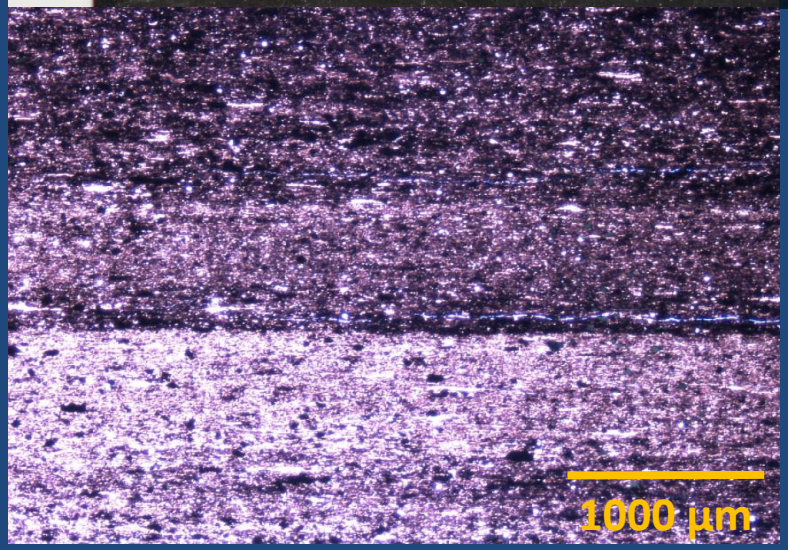


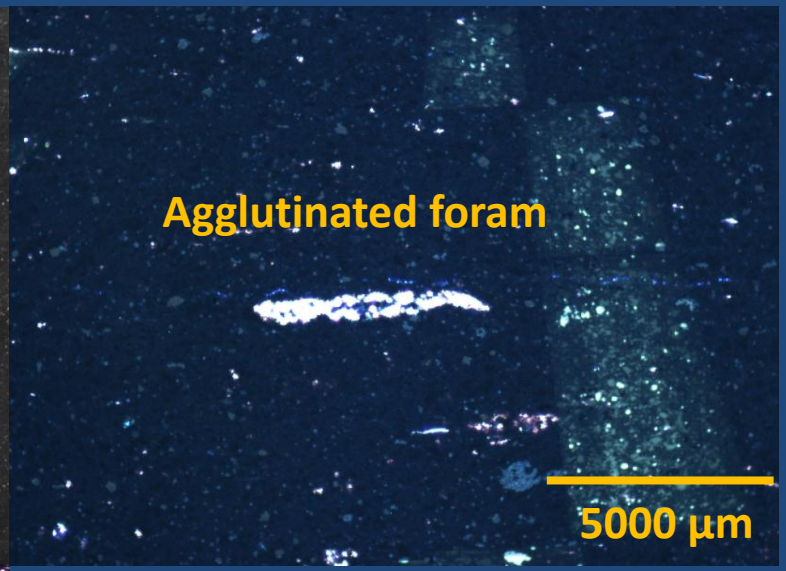


Siliceous mudstone defined by alignment of small pyritized particles

Interpretation: pyritized particles are small individual pyrite crystals. Larger particles are radiolarians and other fossils whose skeletons have been replaced with ZnS.

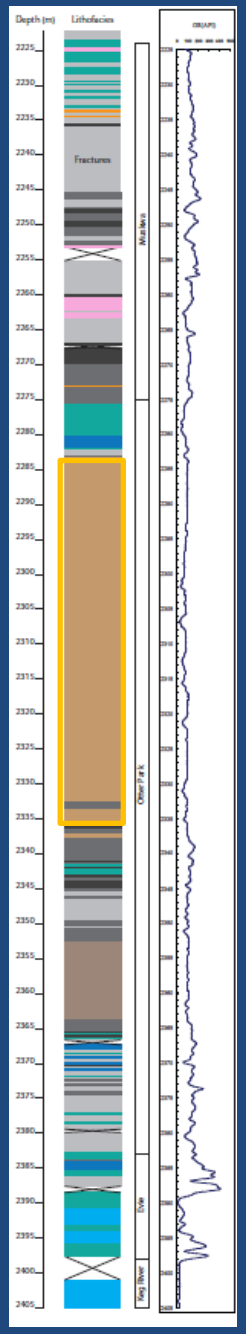


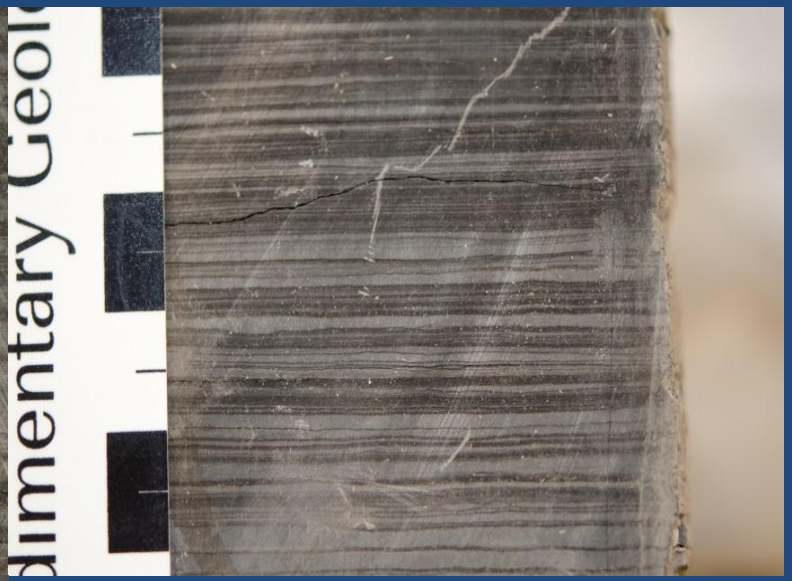


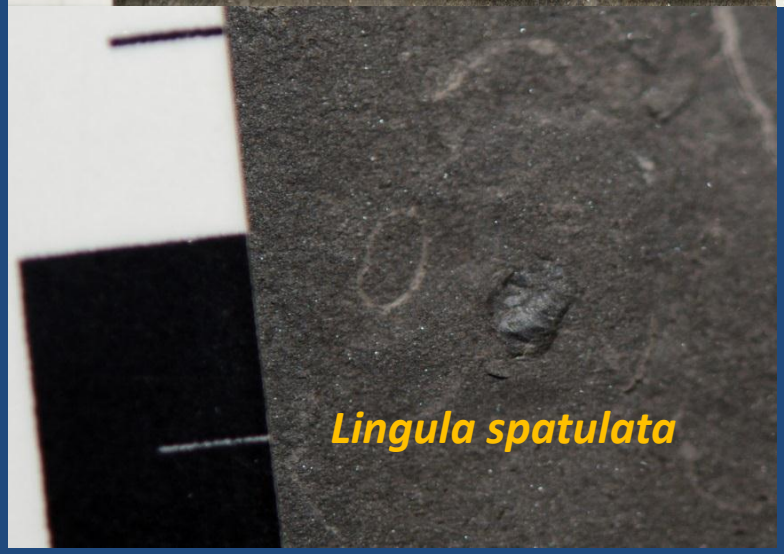


Siliceous mudstone with massive texture

Interpretation: homogenous texture results from a lack of pyrite, though some bedding occasionally presents in thin sections. Bedding is produced by the alignment of particles upon compaction.

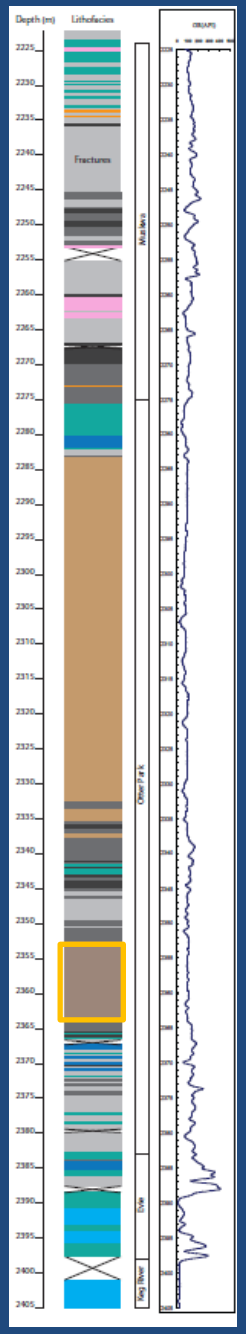


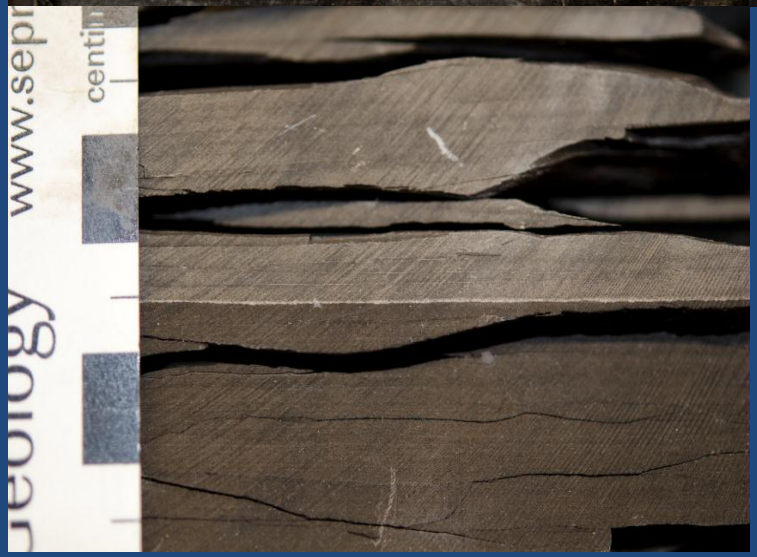




Thin (1-3 mm) alternating beds of dark clay/OM and gray lime mud

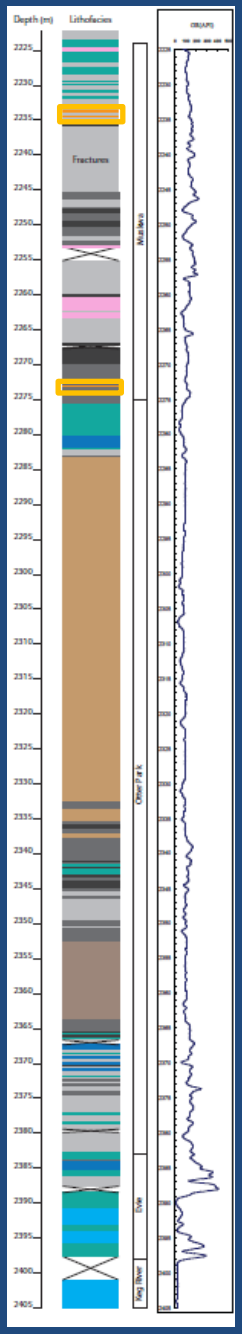
Interpretation: gray laminations are individual event beds triggered by storms. The lime mud is derived from intertidal zones, lagoons and shelf environments but there is no reef fauna

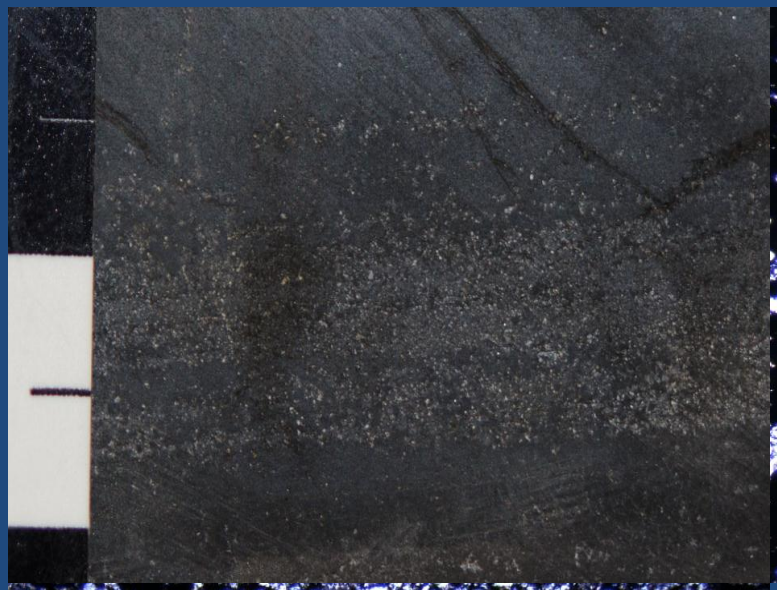


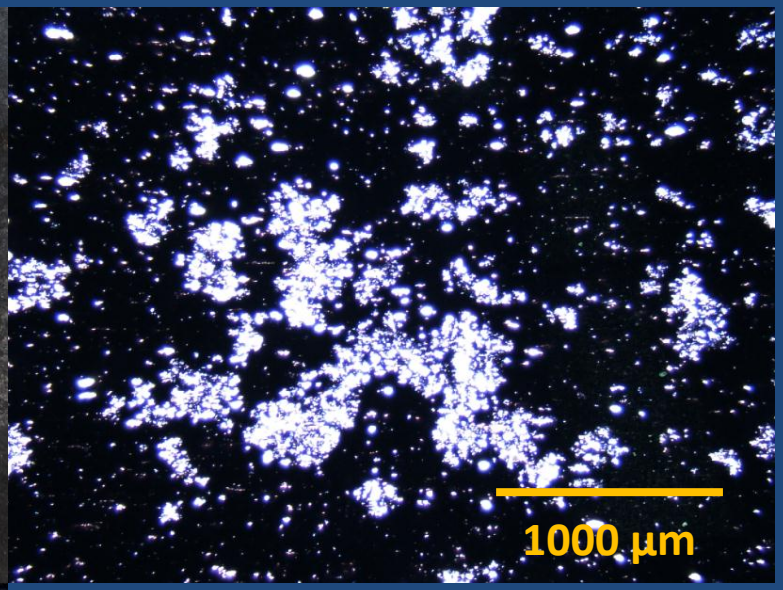


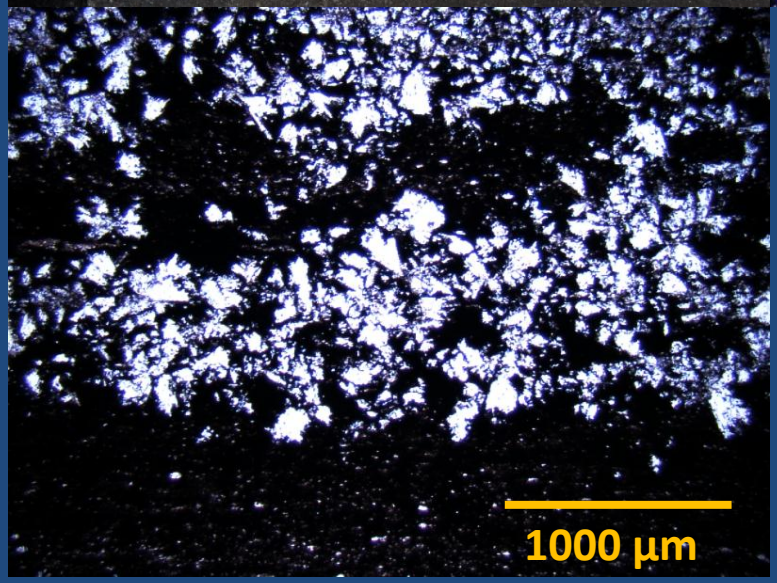
Thick (1-20 cm) alternating beds of dark clay/OM and gray dolomitic mud

Interpretation: dolomitic mud beds are individual event beds triggered by storms. Greater thickness is a product of a shallower depositional environment.









Apatite-rich cement zones

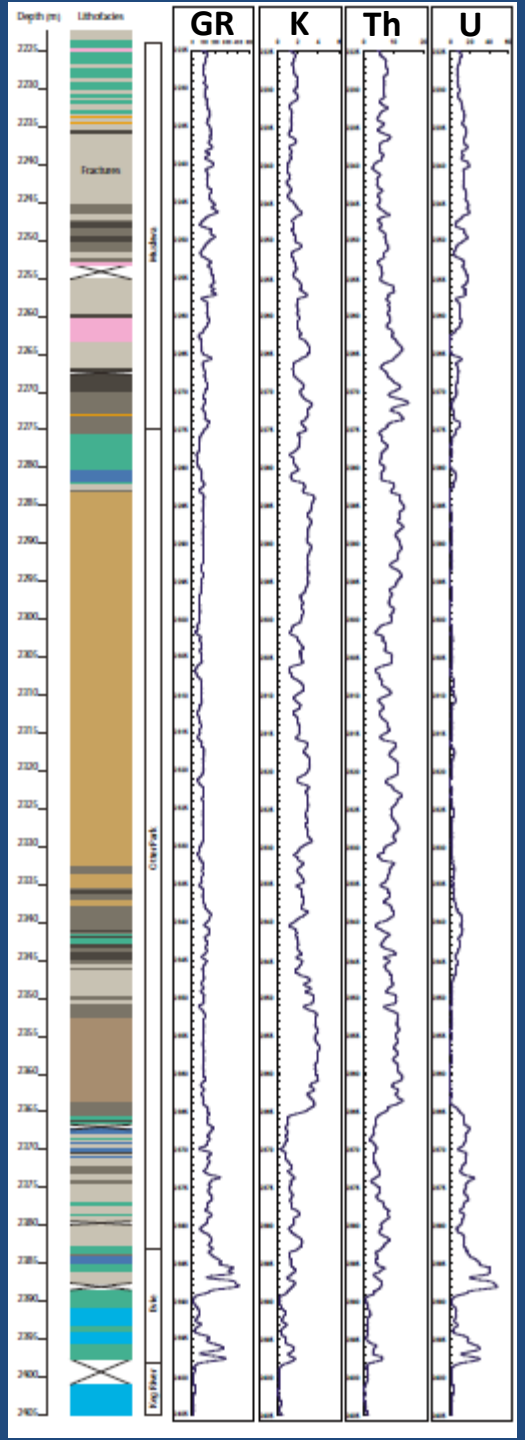
Interpretation: cement zones are the product of a hiatus in sedimentation due to transgression.

IOR Komie
d-069-K 094-O-02

LST

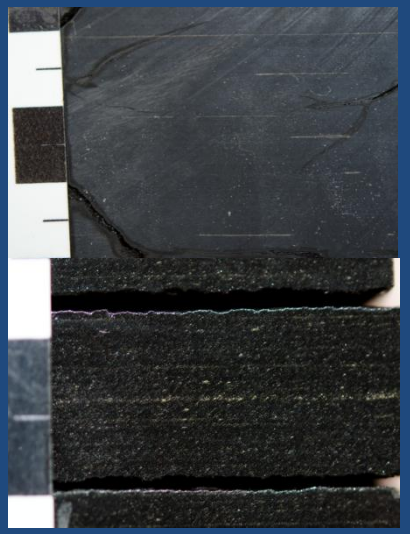
LST

LST



FSST

TST and HST



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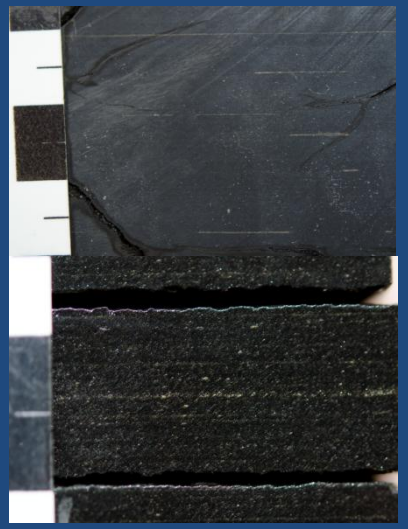

FSST

TST and HST

Conclusions

- Using **shale lithofacies** to establish sequence stratigraphy in shale basins is a promising approach
- The shale lithofacies are **repetitive** and **cyclical**, and represent cycles of sea level rise and fall
- **Transgressions** typically correlate to optimal drilling zones (siliceous, high organic matter, fractures)
- The Evie and Muskwa members offer the best reservoir zones, but the Otter Park should not be discounted completely