

Factors Controlling Organic-Richness in Upper and Lower Bakken Shale, Williston Basin: An Application of Inorganic Geochemistry*

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Abstract

Organic-richness in shale is controlled by the interplay between the three factors viz., organic productivity, preservation and dilution. This study is focused on identifying the effect of these factors in the context of upper and lower (U&L) Bakken shales in the Williston Basin. Lithologically, the U&L shales are siliceous mudstones with the Total Organic Carbon (TOC) varying between 3 to 20 weight percent. X-ray fluorescence results, TOC information, X-ray diffraction mineralogy and stable isotope data (C, O and S) collected from 10 well cores are used to determine the influence of detrital sediment influx, paleoproductivity and paleoceanographic conditions in controlling organic content in the U&L shales. The mineralogical composition of the U&L shales may vary as follows: 30-45% of biogenic, detrital and authigenic quartz silt, 20-30% clay, 5-10% feldspar, 2-11% detrital and authigenic dolomite and 3-9% pyrite. So, to distinguish biogenic silica-rich intervals from detrital sediment-rich intervals, inorganic geochemical proxies (Si/Ti and Al/Ti ratios) are used. The vertical profiles show positive covariance between TOC-rich and the detrital sediment-rich intervals, which demonstrate the beneficial effect of detrital sediment input in the organic matter (OM) accumulation. Therefore, an optimum sedimentation rate, instead of creating a dilution effect, appears to have helped in quick preservation of OM.

Paleoproductivity and paleonutrient utilization was determined by using stable Nitrogen isotope data as a proxy. In U&L shales, the covariance between lighter values of δN_{15} and higher TOC reveals that OM accumulation relies on increased nutrient supply for a higher organic productivity. The nutrients required to sustain the organic productivity was supplied by the detrital sediment influx and the surface water currents within the basin. Anoxic-euxinic basin condition results in higher preservation of OM. Enrichment of redox-sensitive trace elements (like Mo, V, U, Ni and Cu) and their relation with TOC, values of C/S ratio and degree of pyritization suggests that the Bakken shales were deposited in an anoxic-euxinic basin with higher OM preservation potential. Therefore, this study concludes that higher paleoproductivity driven by critical nutrient supply, optimum detrital sedimentation rate and anoxic-euxinic basin condition resulted in higher accumulation and better preservation of the OM within the Bakken shales.

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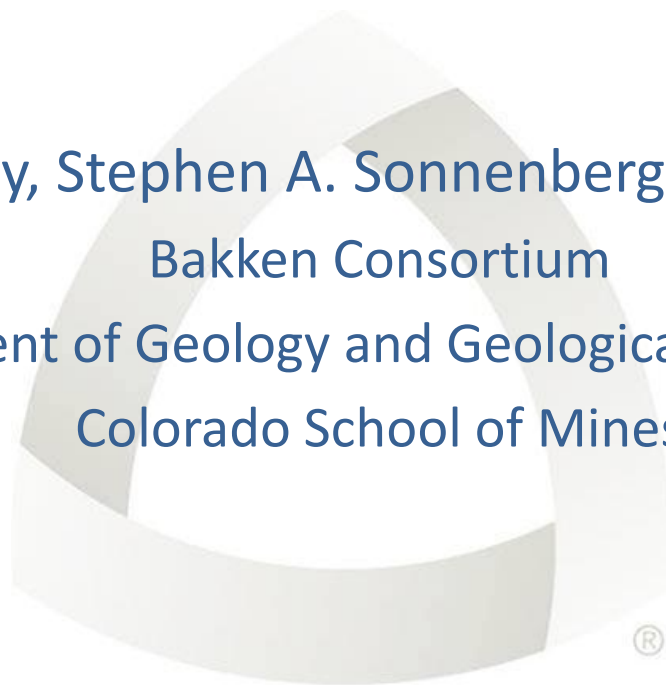
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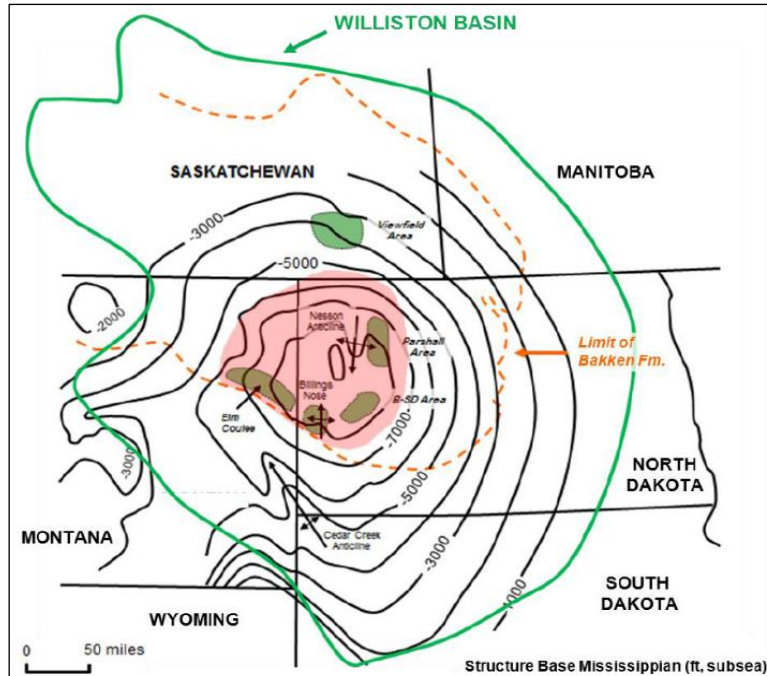
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Outline

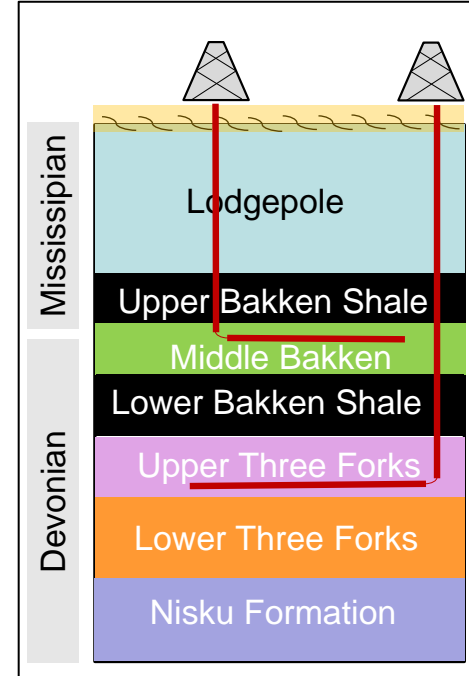
- ✓ Introduction
- ✓ Objectives
- ✓ Workflow
- ✓ Results
- ✓ Key Takeaways

Introduction

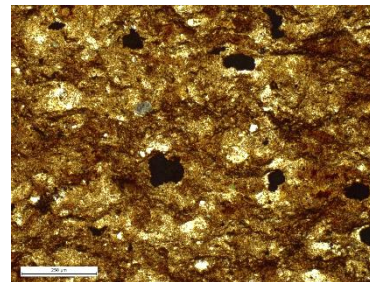
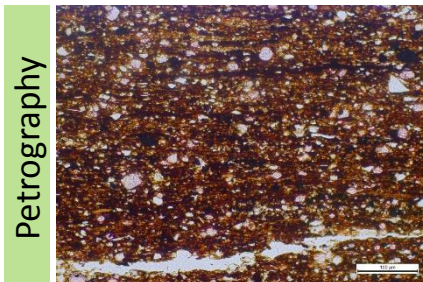
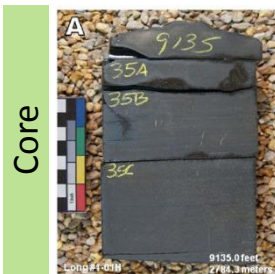
Williston Basin Map



Stratigraphy



Bakken Shale Key Points



- TOC range: 3-20 wt%
- Vertical heterogeneity

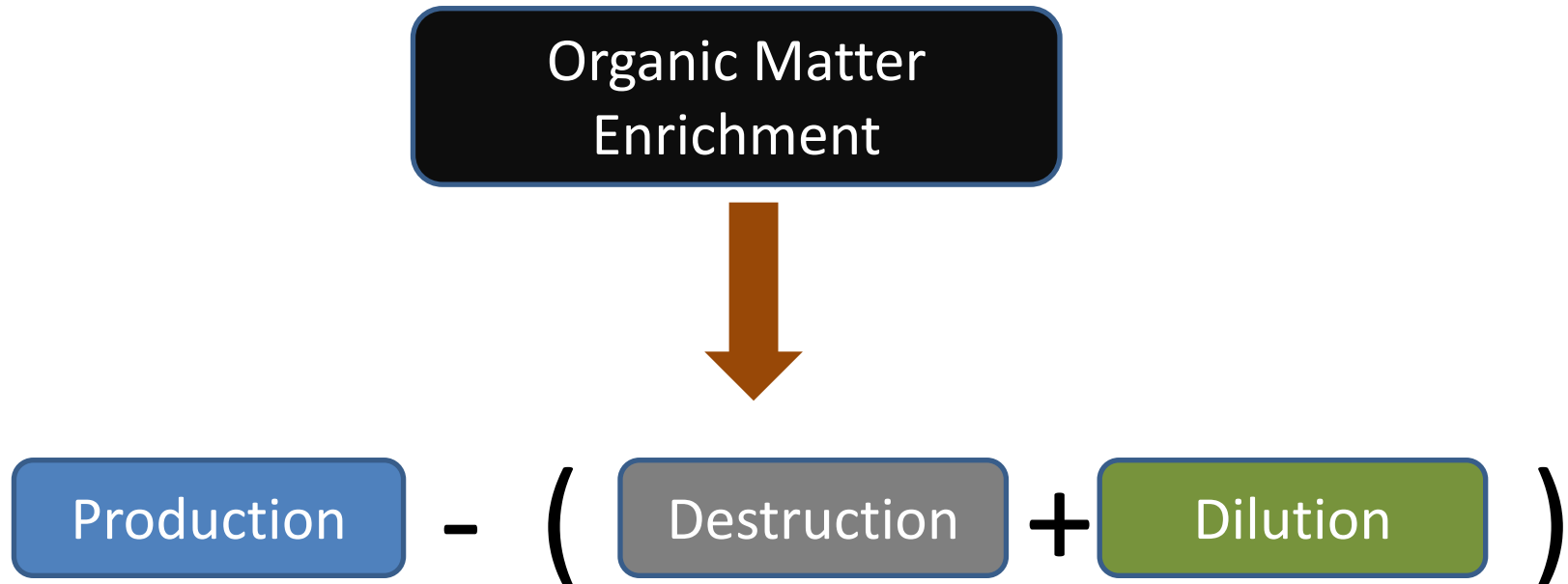
Objectives

- Understand the factors that controls the organic richness within the Bakken shales
 - Dilution of OM
 - Destruction of OM
 - Organic productivity

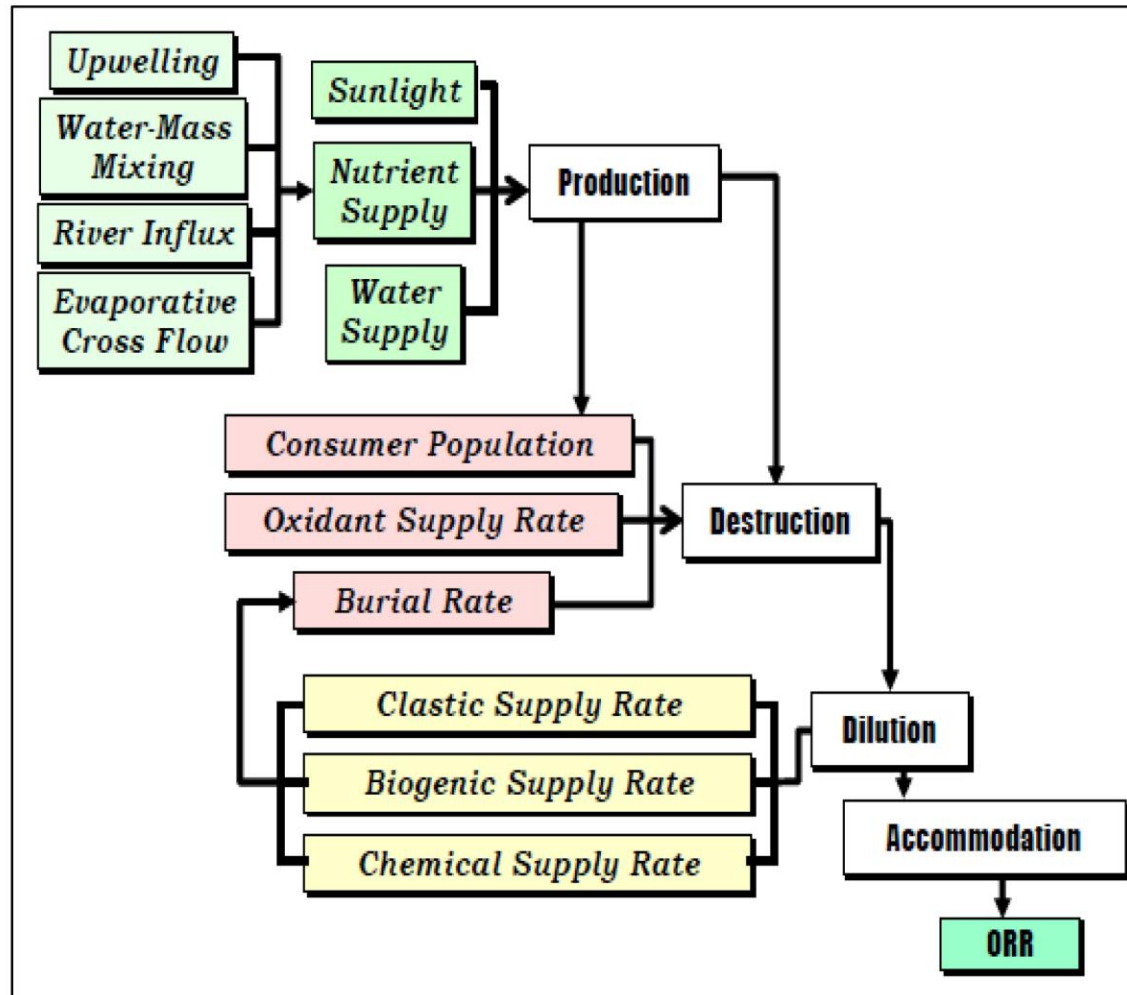
- Use a multi-proxy approach to interpret the role of each one of the above mentioned factors for high TOC in the Bakken shales

Factors Controlling Organic Richness

What controls organic richness?



Controls on Organic Richness



Passey et al., 2010

Presenter's notes: To understand these factors we have used various proxies.

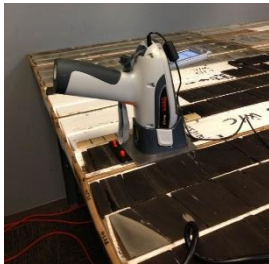
Workflow

Dataset

- No of Cores: 10
- Source Rock Data: TOC
- Stable Isotope Data: $\delta^{15}\text{N}_{\text{org}}$, $\delta^{13}\text{C}_{\text{org}}$, $\delta^{32}\text{S}$
- Portable X-Ray Fluorescence (XRF) Element concentration



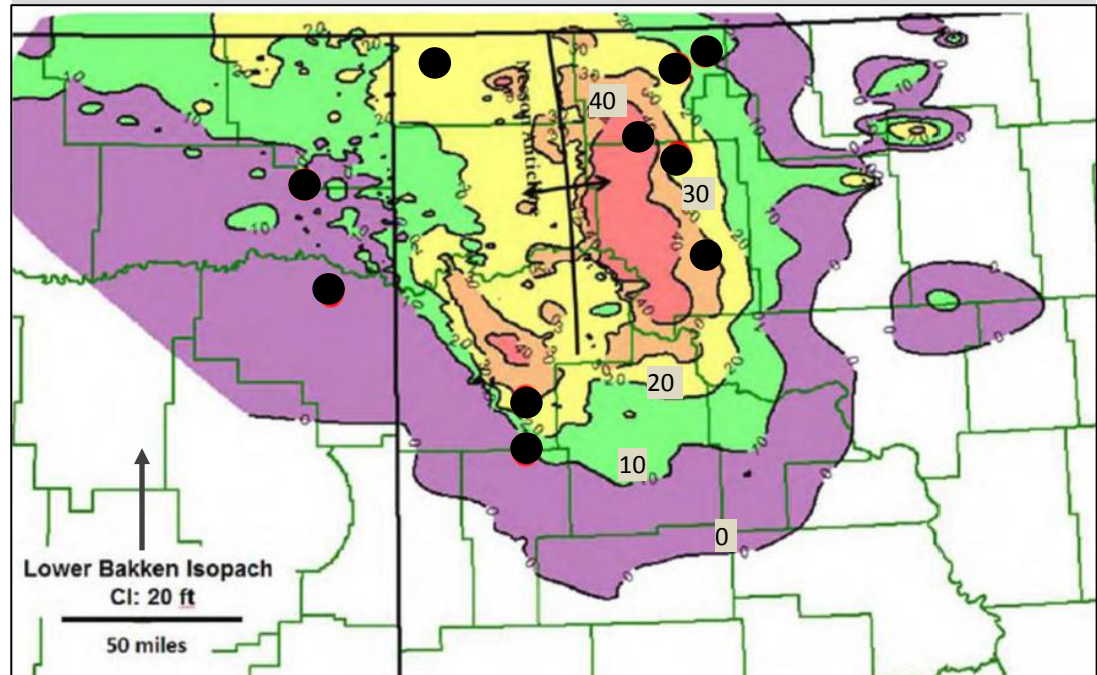
XRF Measurement



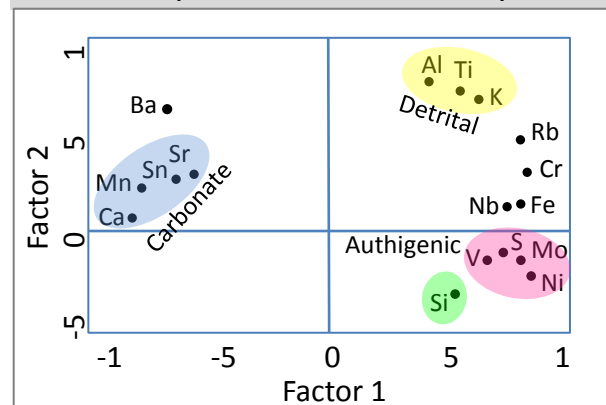
- Measurement time: 180 seconds
- No of elements considered: 24
- Sampling rate: 6" interval
- Calibration with Inhouse Standard Reference



Core Locations in Lower Bakken Shale Isopach



Cross-plot from Factor Analysis



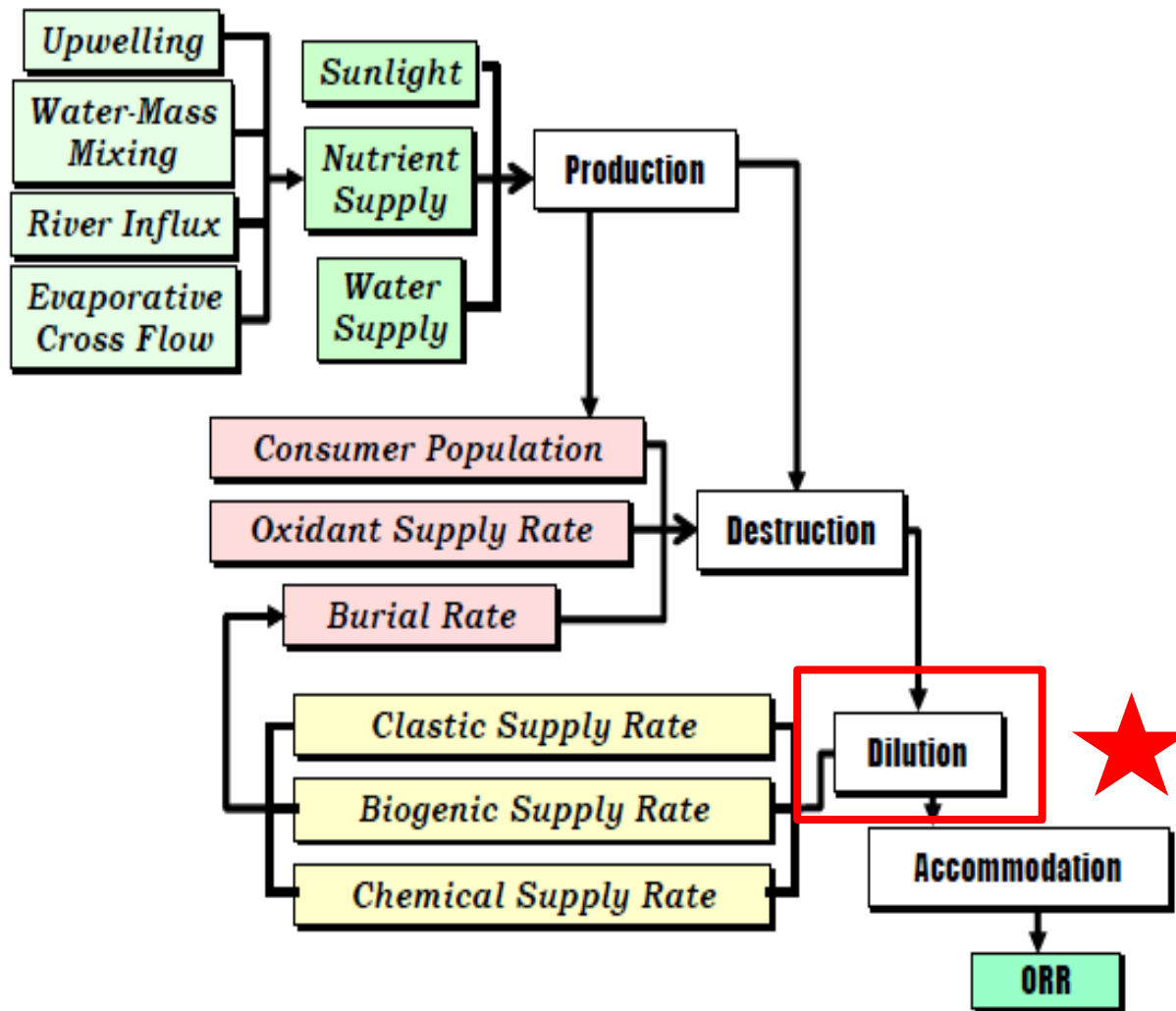
TOC

+

$\delta^{15}\text{N}_{\text{org}}$
 $\delta^{13}\text{C}_{\text{org}}$
 $\delta^{32}\text{S}$

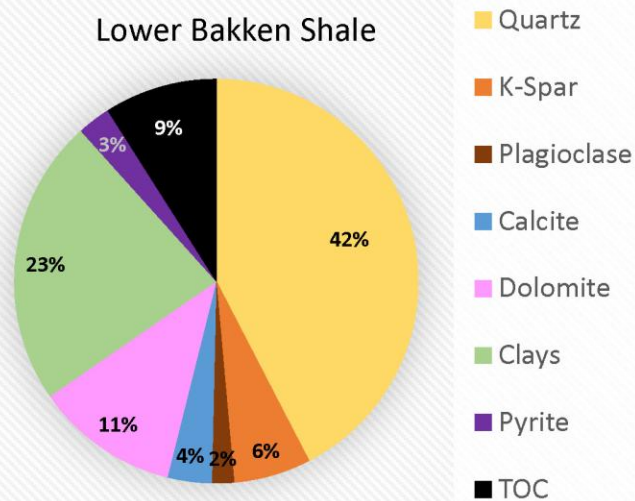
Source : Modified from Jin, 2014

Controls on Organic Richness



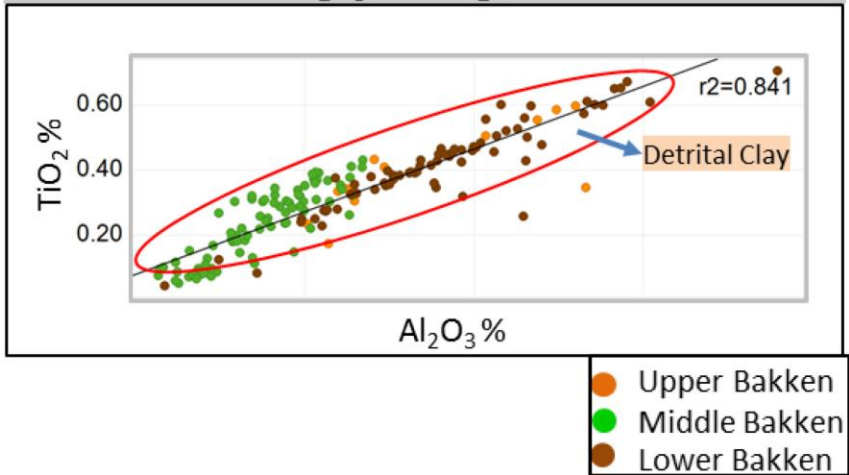
Sediment Composition

Mineralogy and TOC (Wt %)

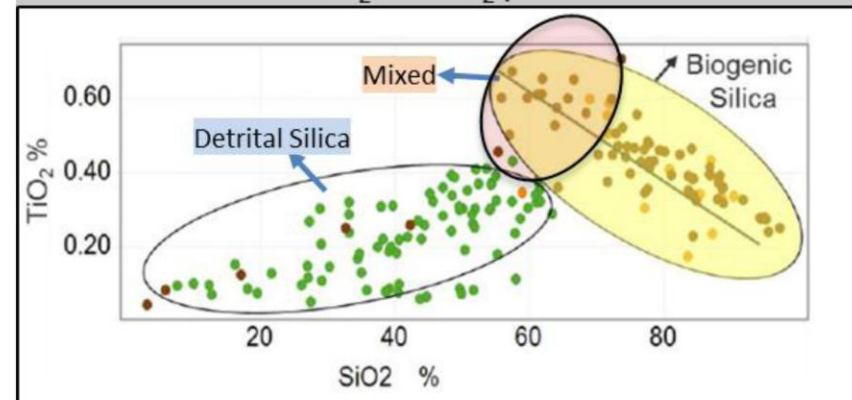


- Al can be used as a proxy for clay and other aluminosilicate minerals.
- Positive or negative covariance between Al or Si with Ti indicates detrital or biogenic origin of sediments.

Al_2O_3 vs TiO_2 plot

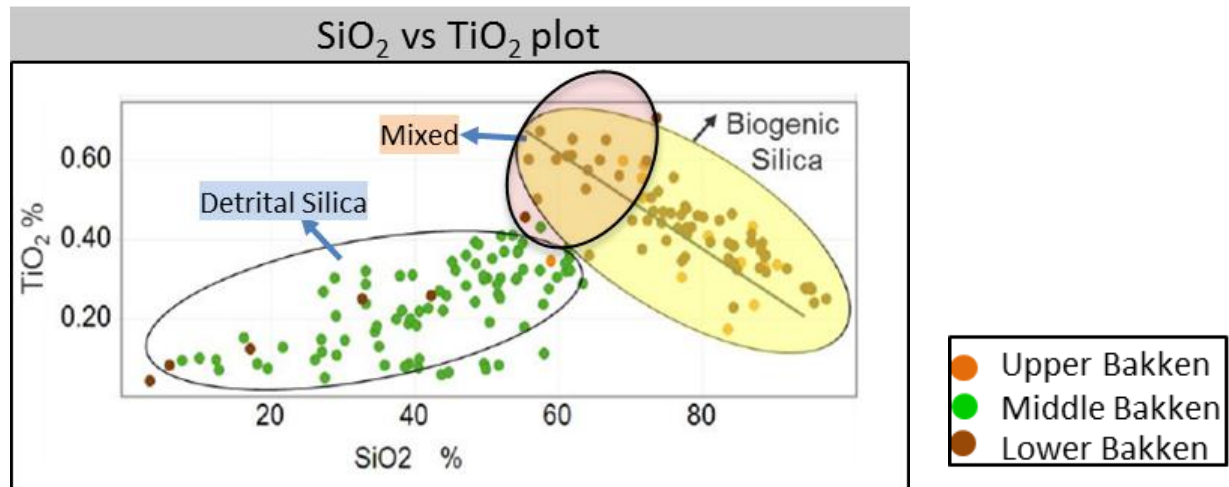


SiO_2 vs TiO_2 plot

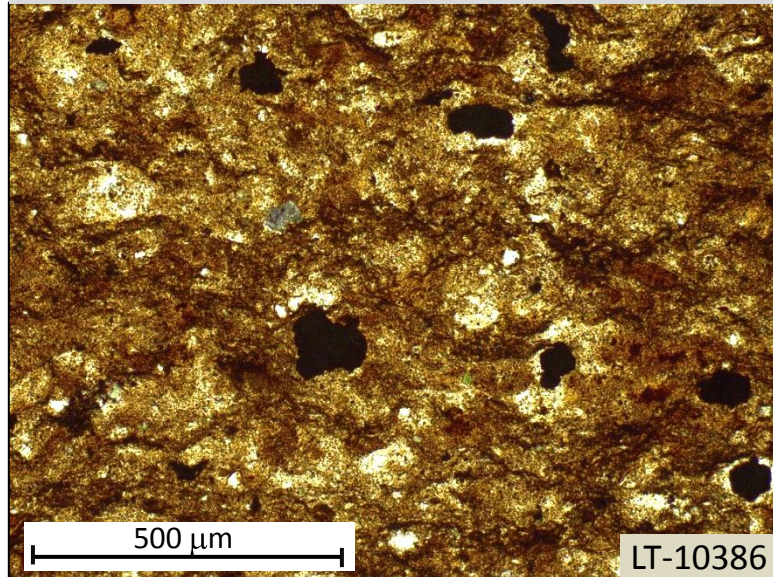


Presenter's notes: Apart from the organic matter, let us see what the composition of the Bakken shale sediments looks like.

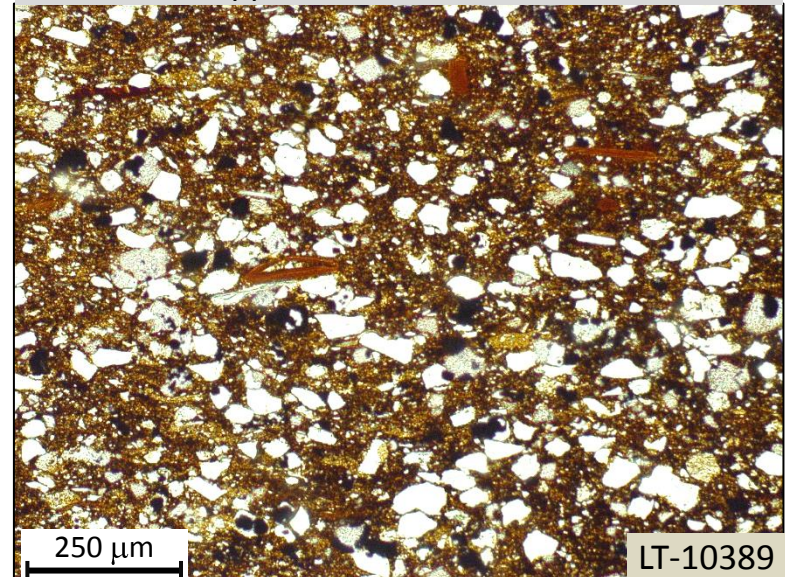
Biogenic vs Detrital Silica



Upper Bakken Shale

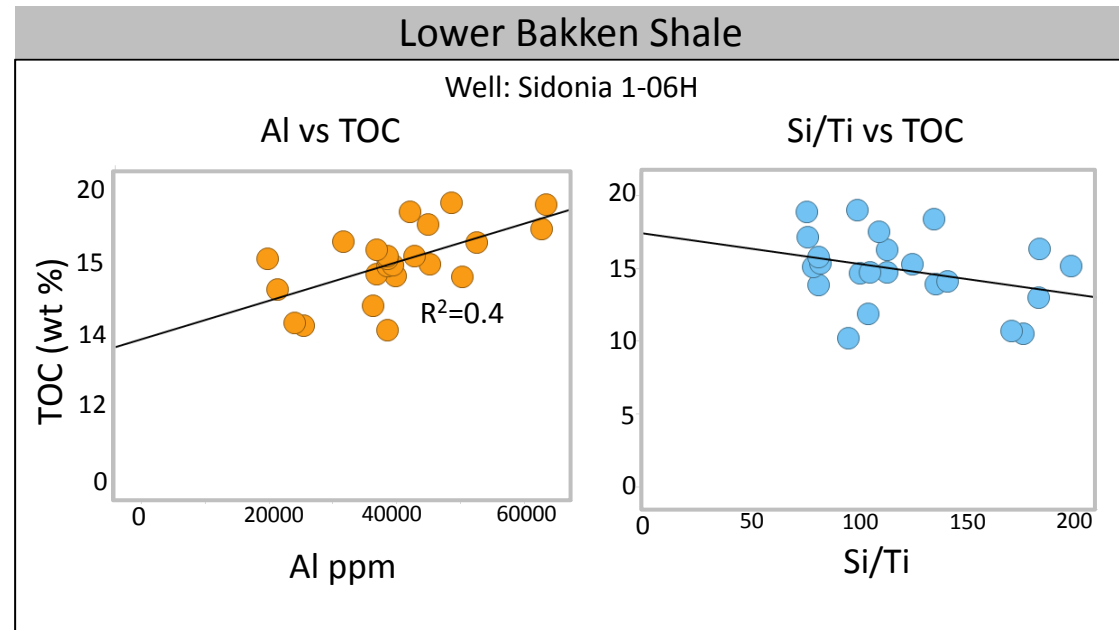
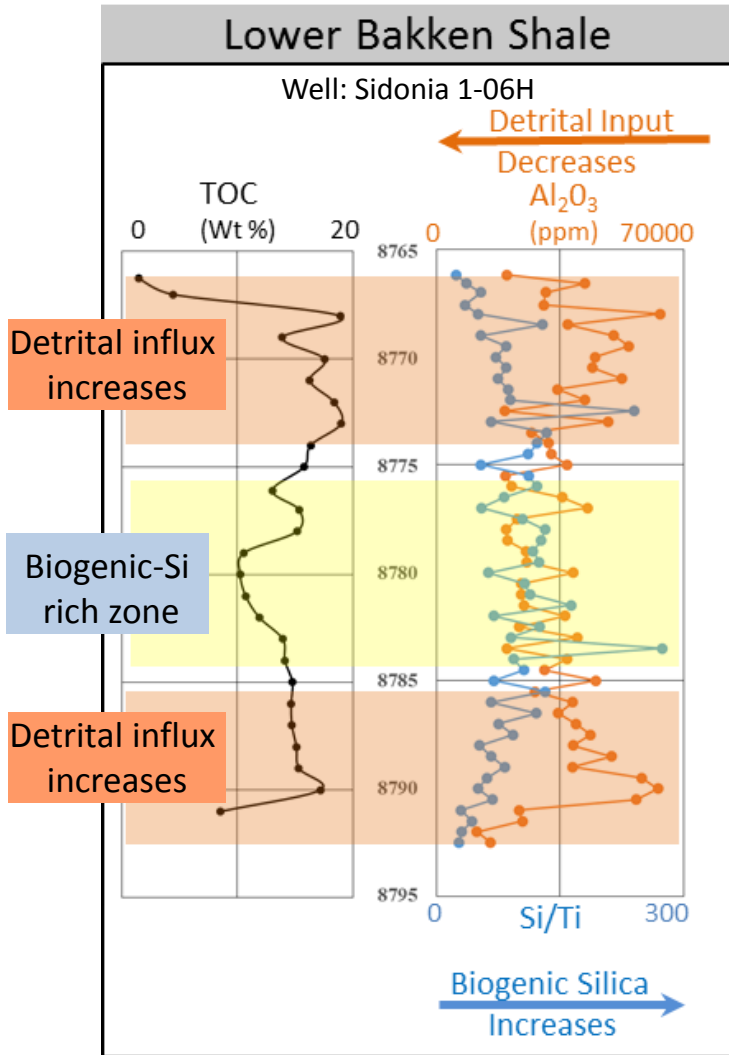


Upper Bakken Shale



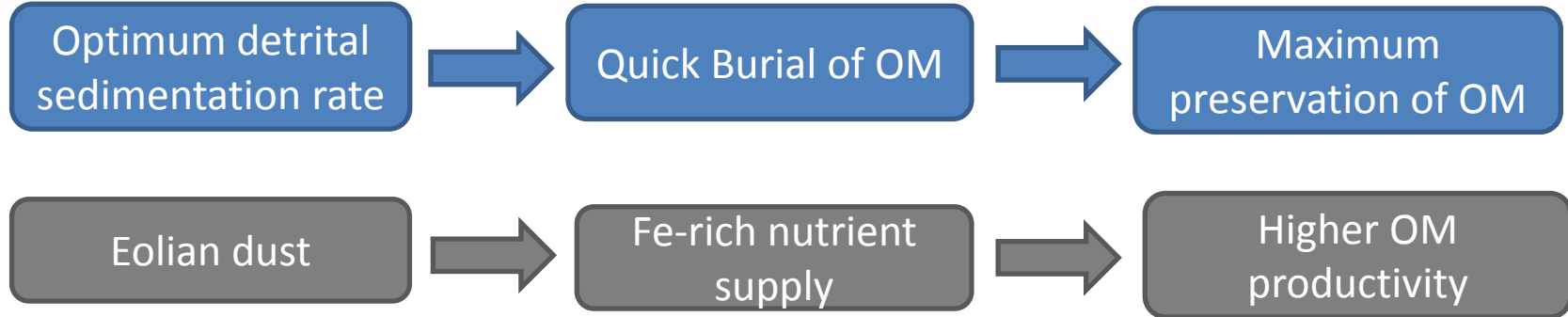
Effect of Detrital Sediment Influx

- Highest TOC interval has more detrital sediment influx.

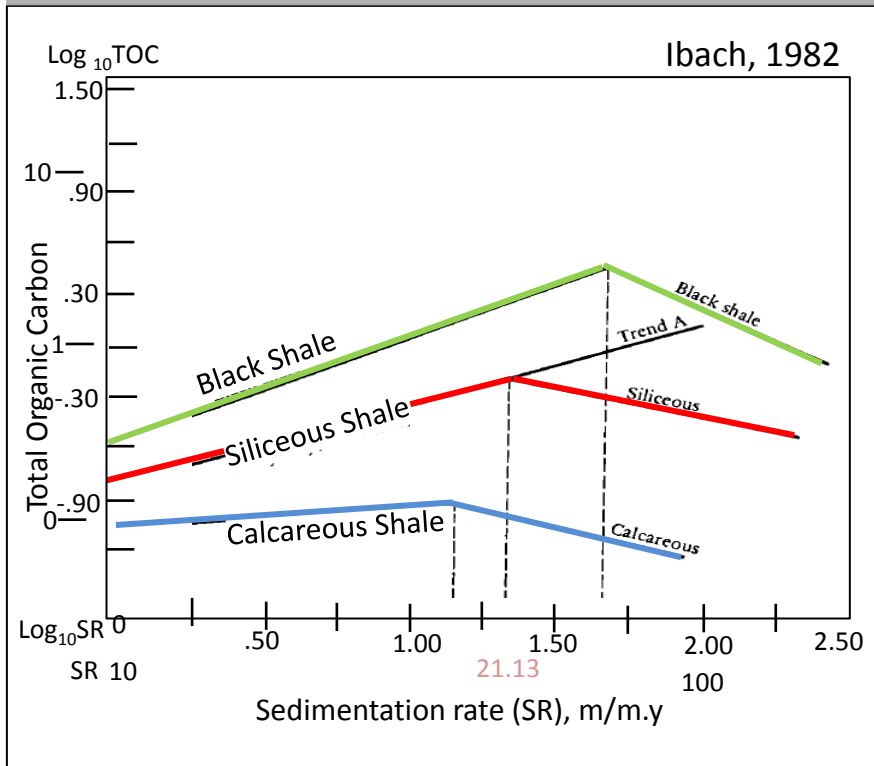


- Weakly positive correlation between Al and TOC.
- This indicates detrital sediment influx has no dilution effect on organic content.
- But biogenic silica supply causes slight dilution of organic matter.

Effect of Detrital Sediment Influx

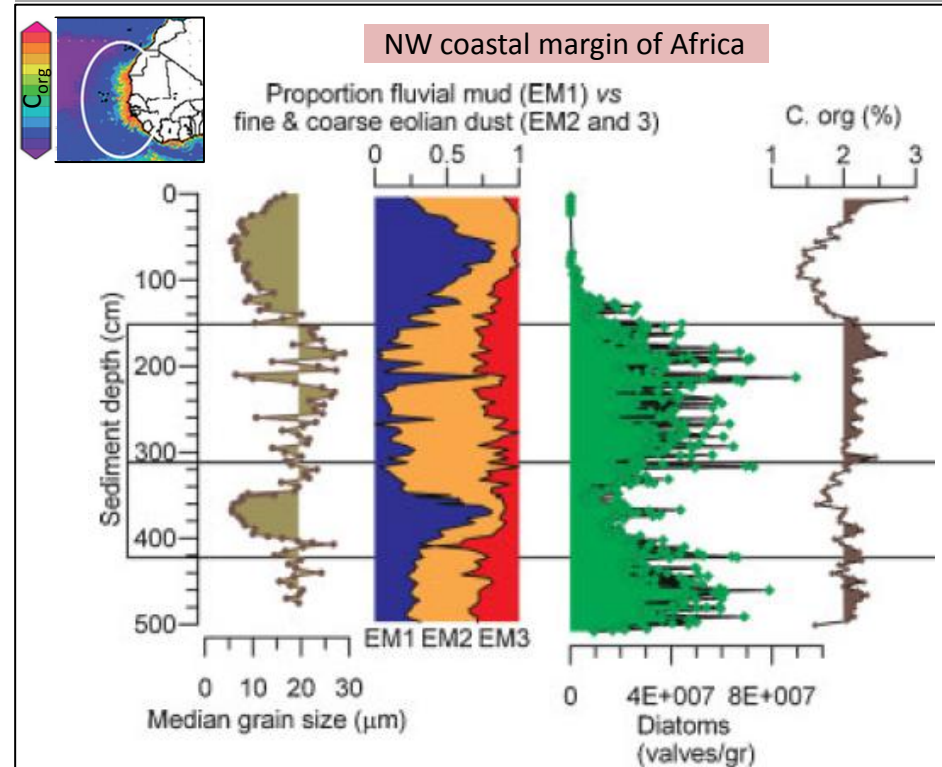


TOC vs Sedimentation rate



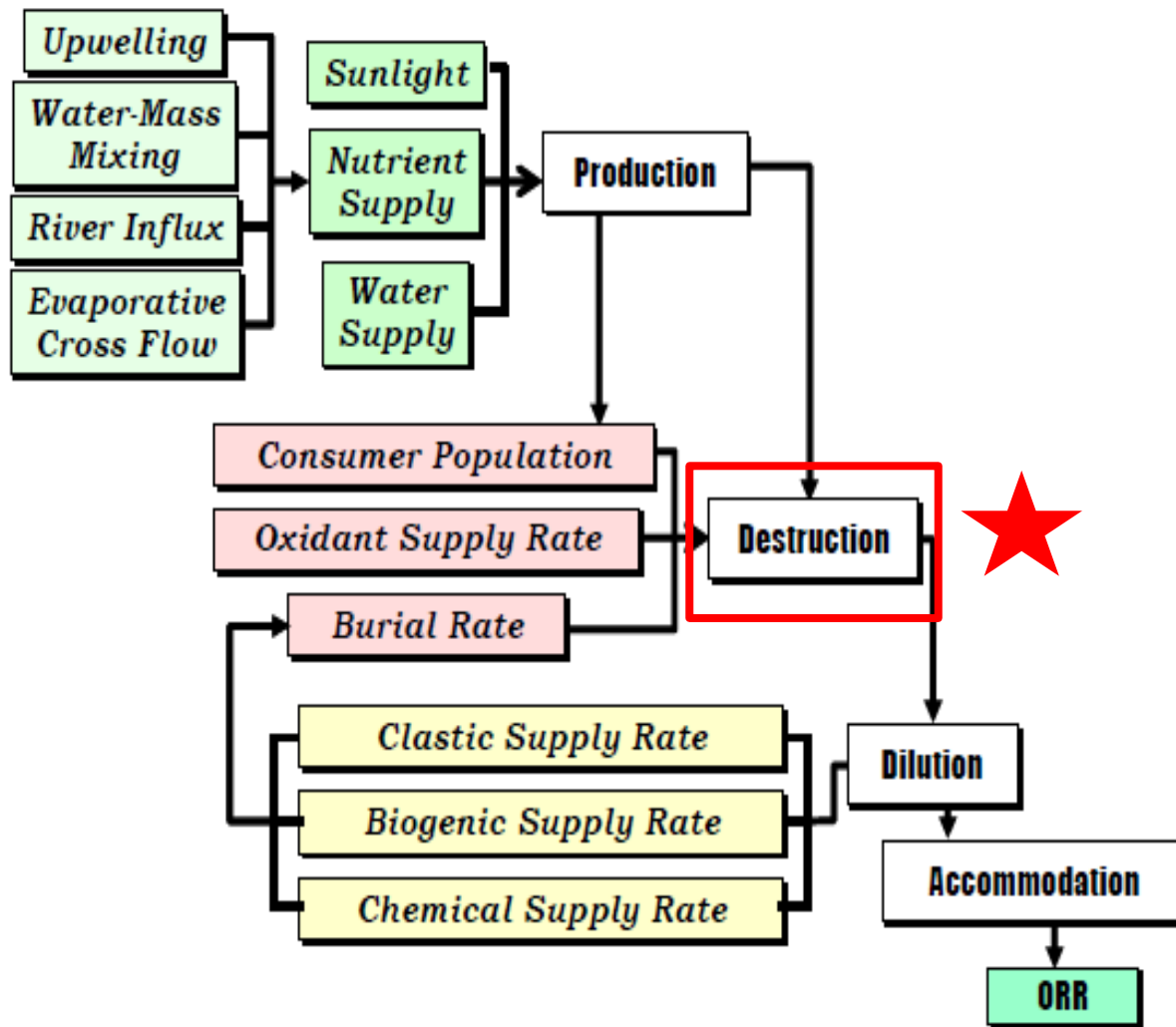
Jurassic to Recent sediments from Deep Sea Drilling Cores

Impact of eolian dust in TOC



Filipsson et al., 2011

Controls on Organic Richness



Preservation Potential of Organic Matter

Quick Burial of
OM



Redox
condition

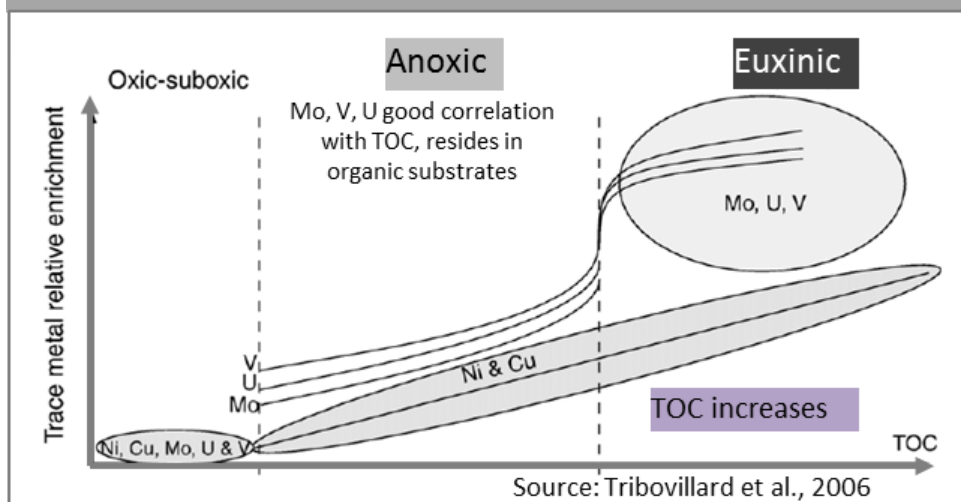


OM Preservation
Potential

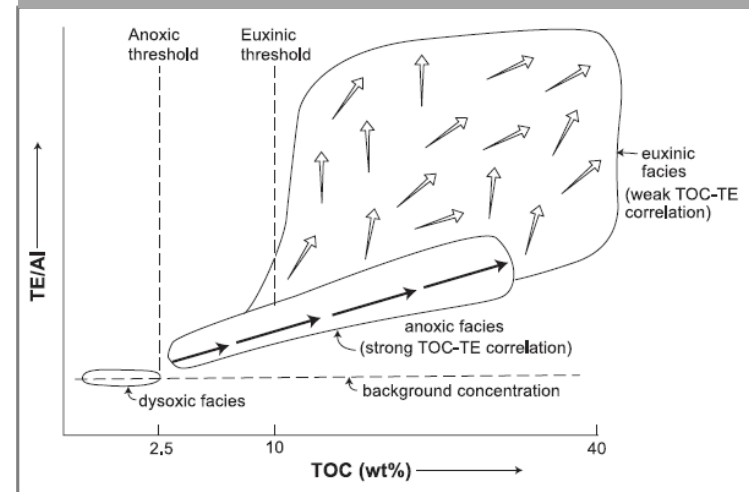
Proxy for Redox Condition

- Authigenic enrichment of redox-sensitive trace elements like **Mo, U, V, Ni, Cr** and **Cu**.
- Lighter values of $\delta^{34}\text{S}$ isotope
- **Fe-S** relationship and Degree of Pyritization (**DOP**)

TOC and Trace Element Correlation



TOC and Trace Element Correlation



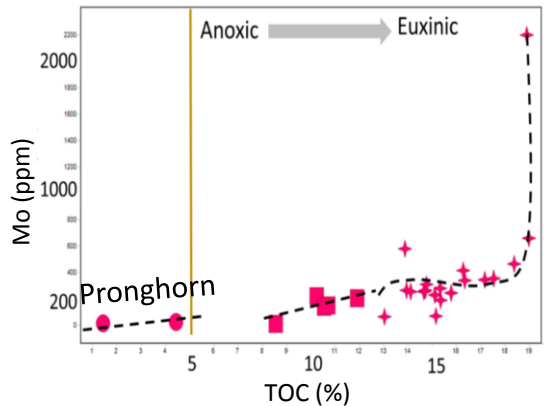
Algeo and Maryland, 2004

TOC-Trace Element Relationship

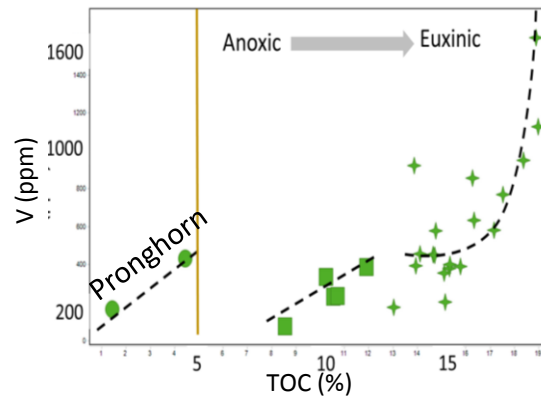
Well: Gunnison State 44-36H

Lower Bakken Shale

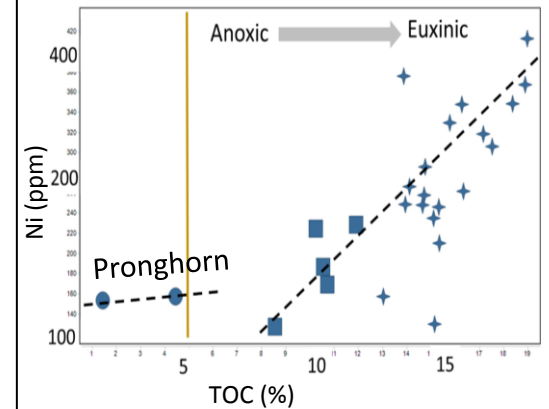
TOC vs Mo



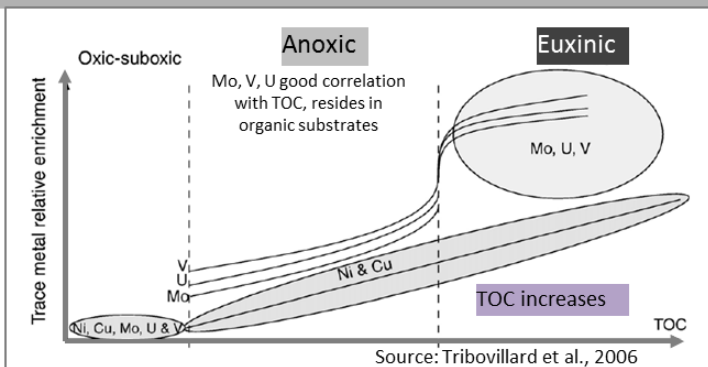
TOC vs V



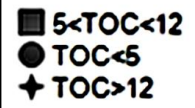
TOC vs Ni



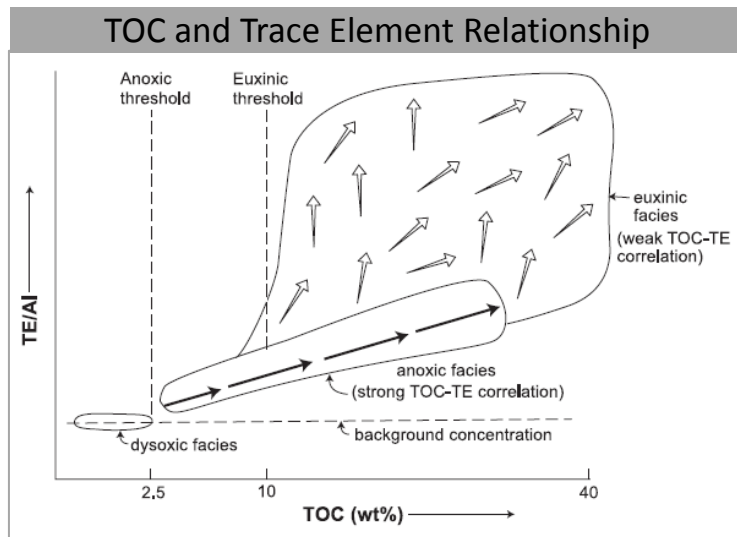
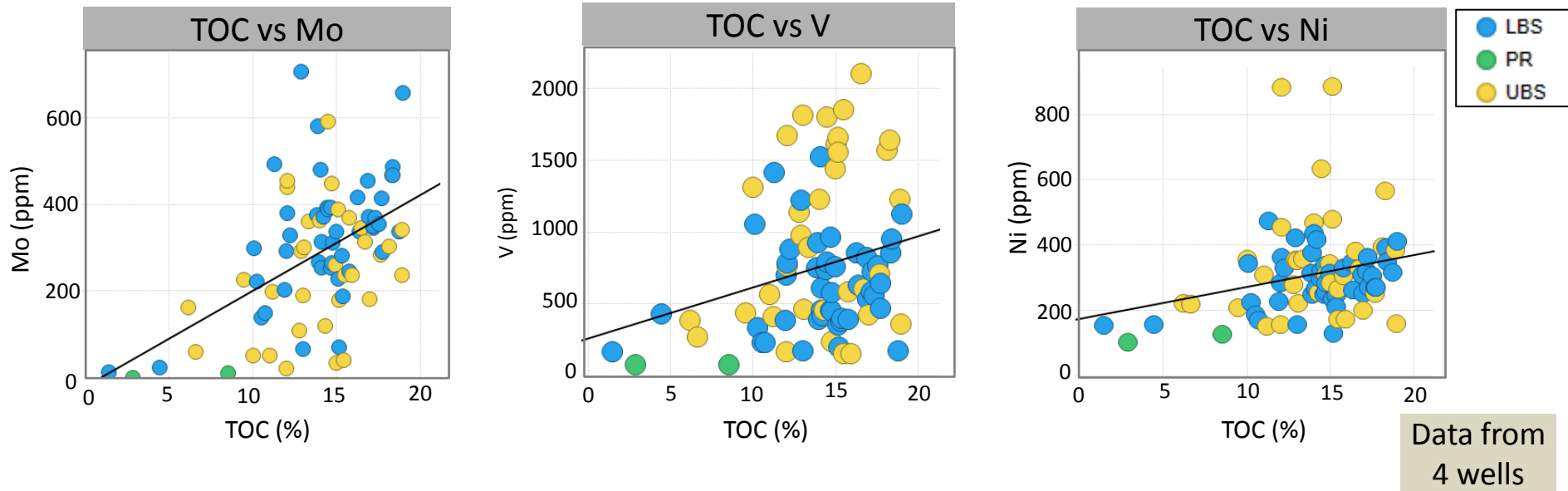
TOC-Redox-Sensitive Elements



- Redox-condition of basin varied from anoxic-euxinic.



TOC-Trace Element Relationship

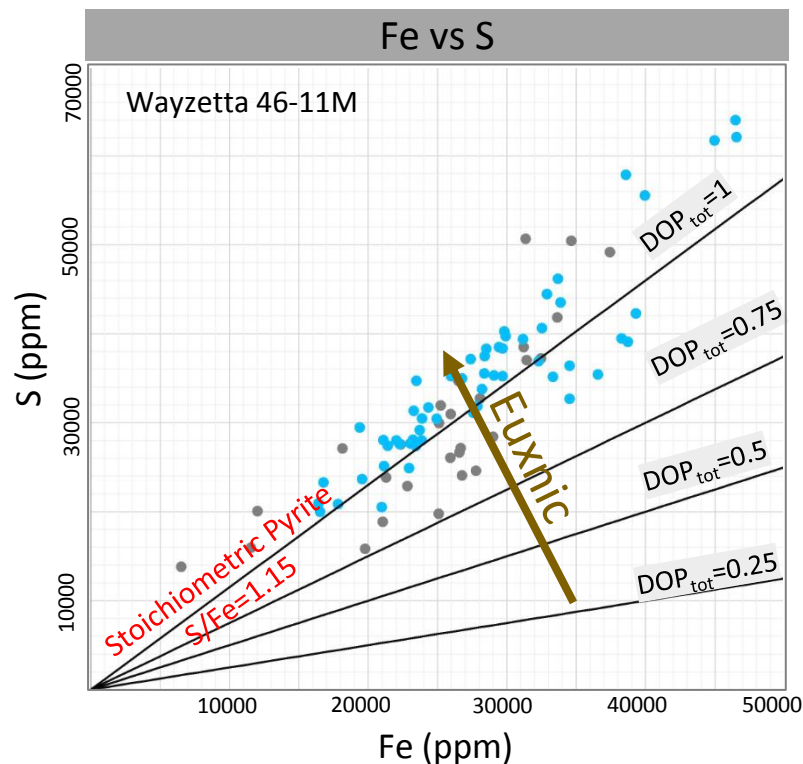


Algeo and Maryland, 2004

- Bakken Shales highly enriched in redox-sensitive trace elements.
- Weak correlation TOC-TE plot indicates redox-condition of basin varied from anoxic-euxinic.
- High preservation potential during Bakken shale deposition.

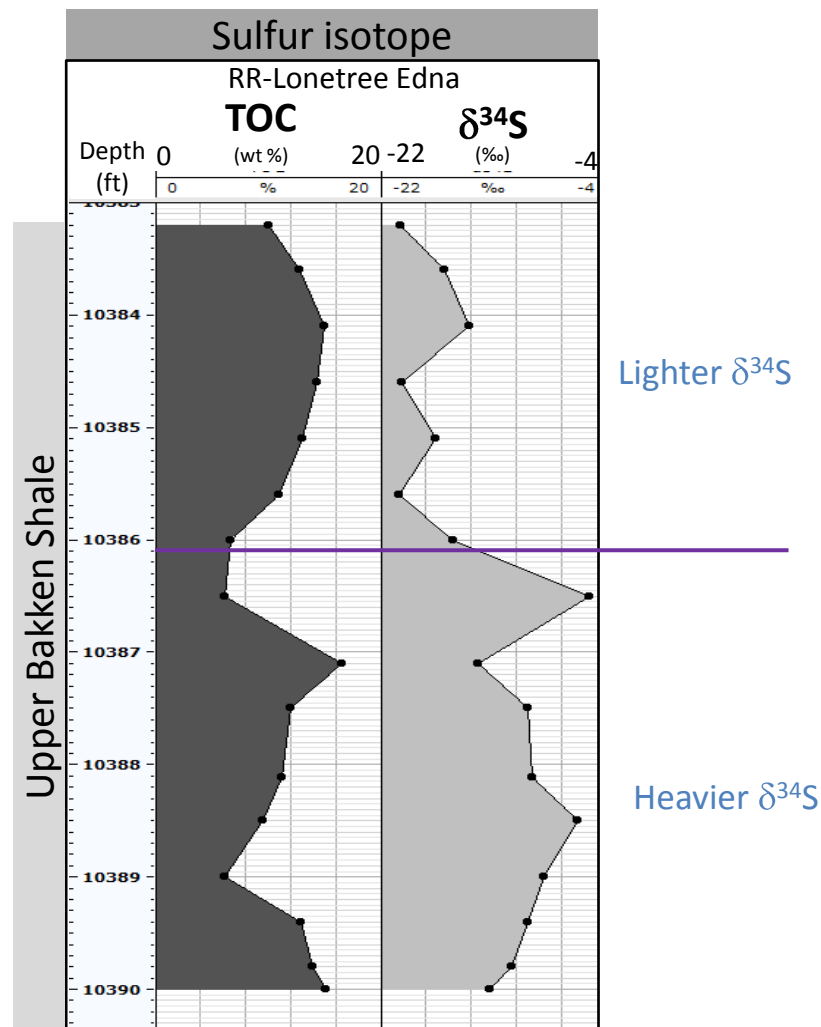
Fe-S Relationship

- Fe-S relationship: When DOP_{tot} is more than 0.75 then the redox-condition is euxinic.
- Sulfur isotope: Significant depletion of $\delta^{34}S$ is indicative of prolonged euxinia.



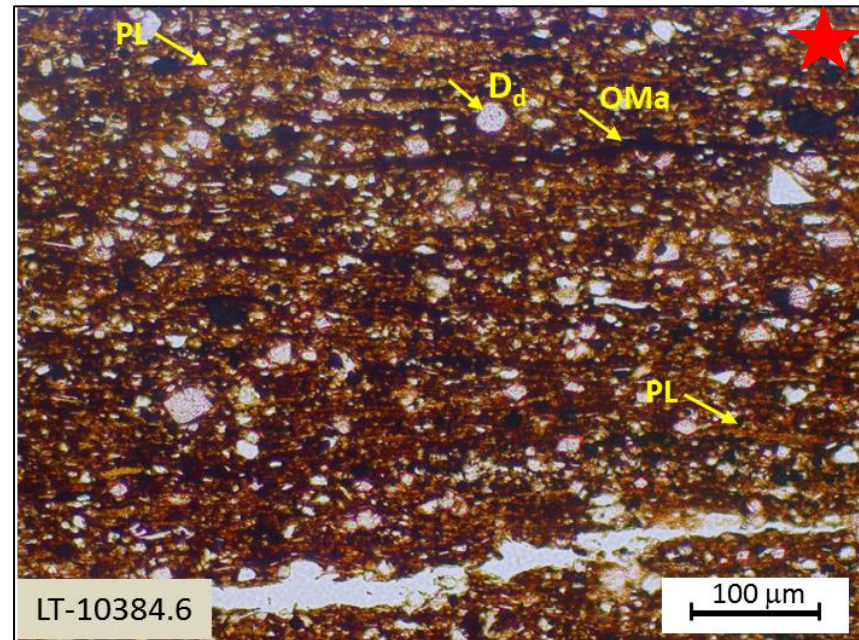
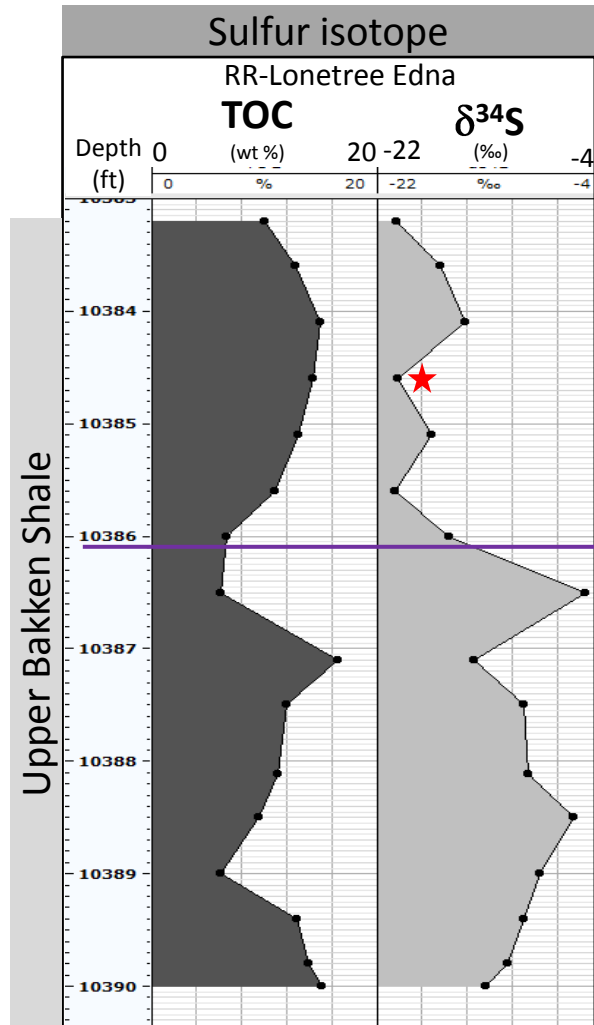
(Based on Algeo and Maryland, 2004)

- Upper Bakken Shale
- Lower Bakken Shale



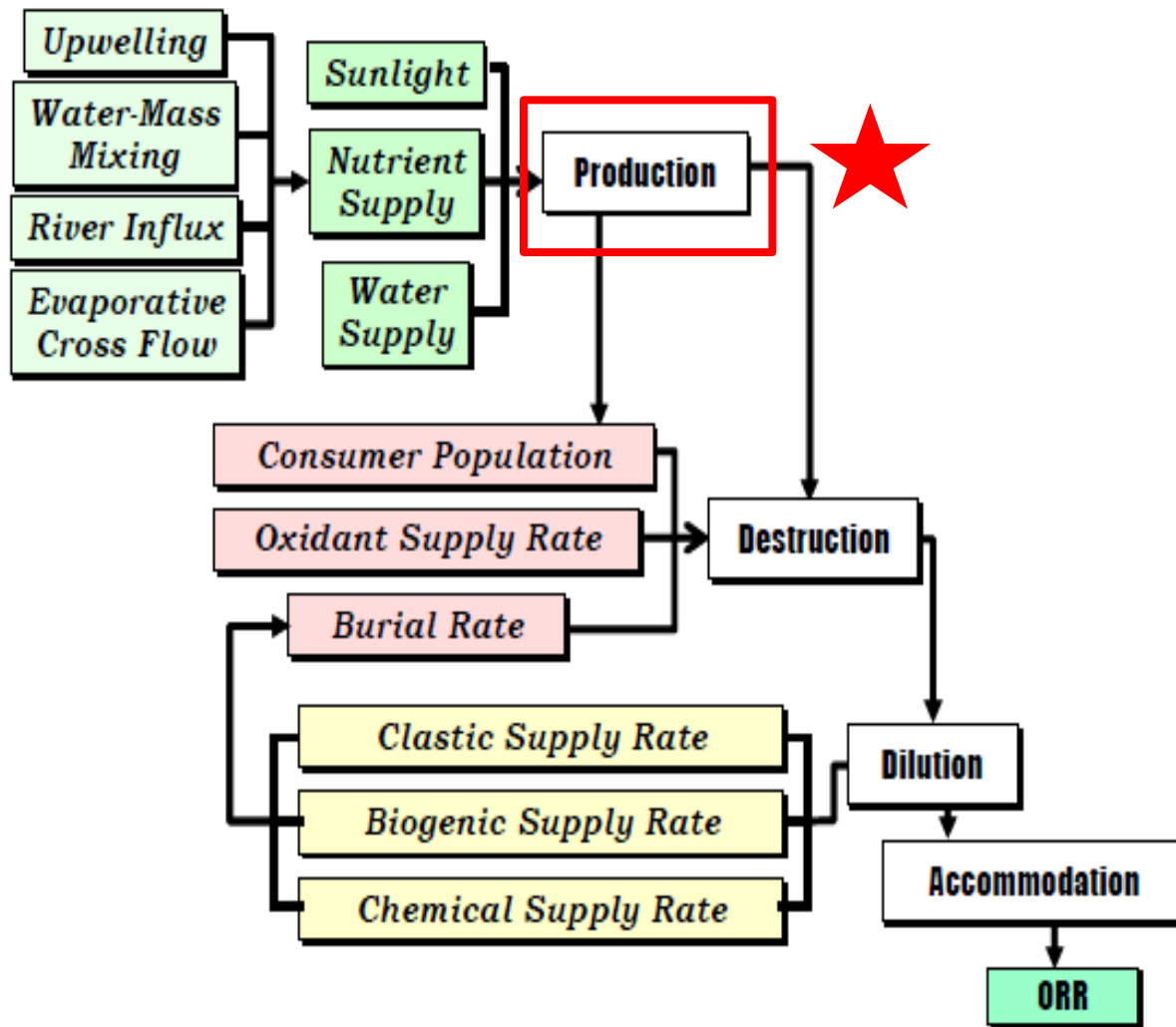
Bottom Water Anoxia/Euxinia

- Lighter $\delta^{34}\text{S}$ indicates prolonged euxinia.
- Presence of squashed pellets and lighter $\delta^{34}\text{S}$ indicates only bottom water euxinia.

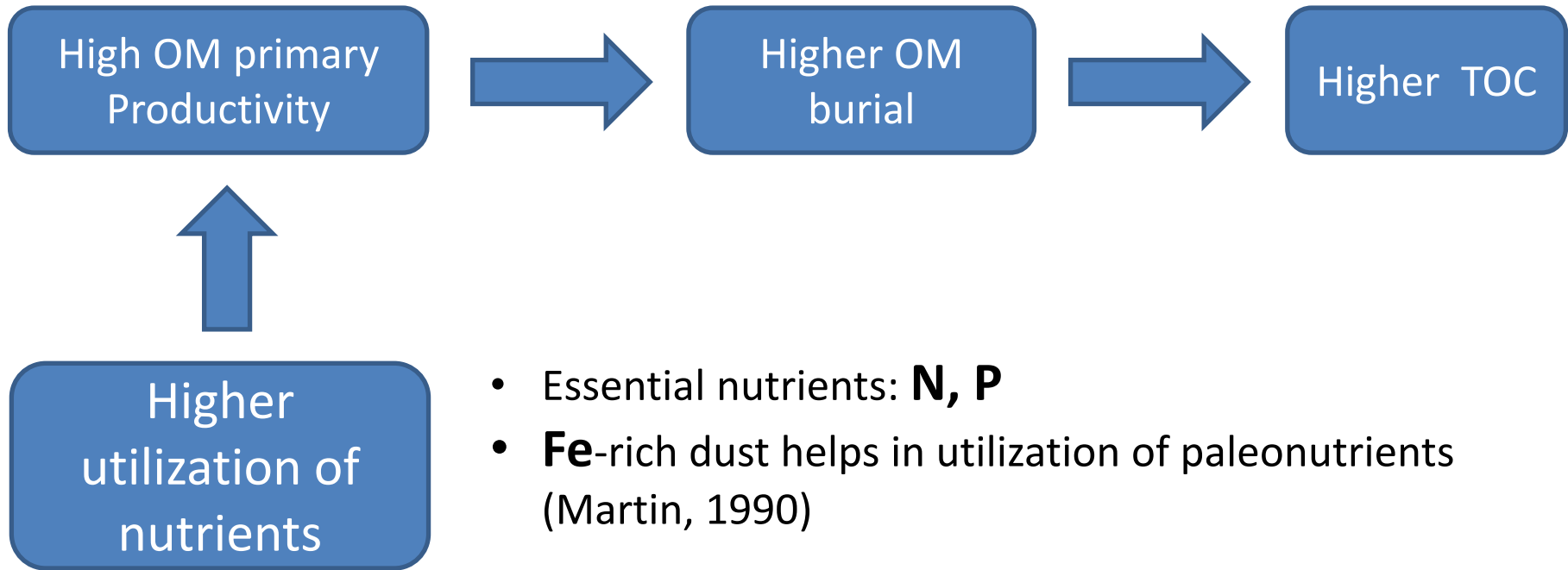


Oma- Organomineralic aggregate
PL-squashed pellet
Dd- Detrital domite

Controls on Organic Richness



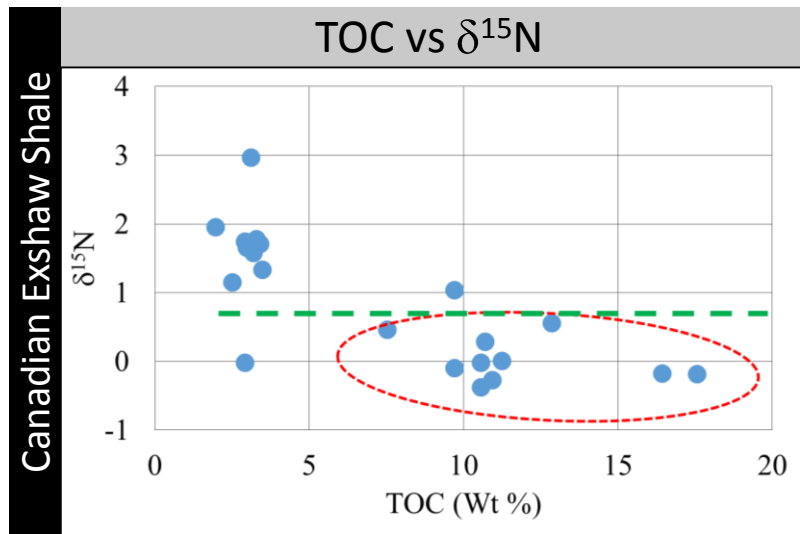
Paleoproductivity



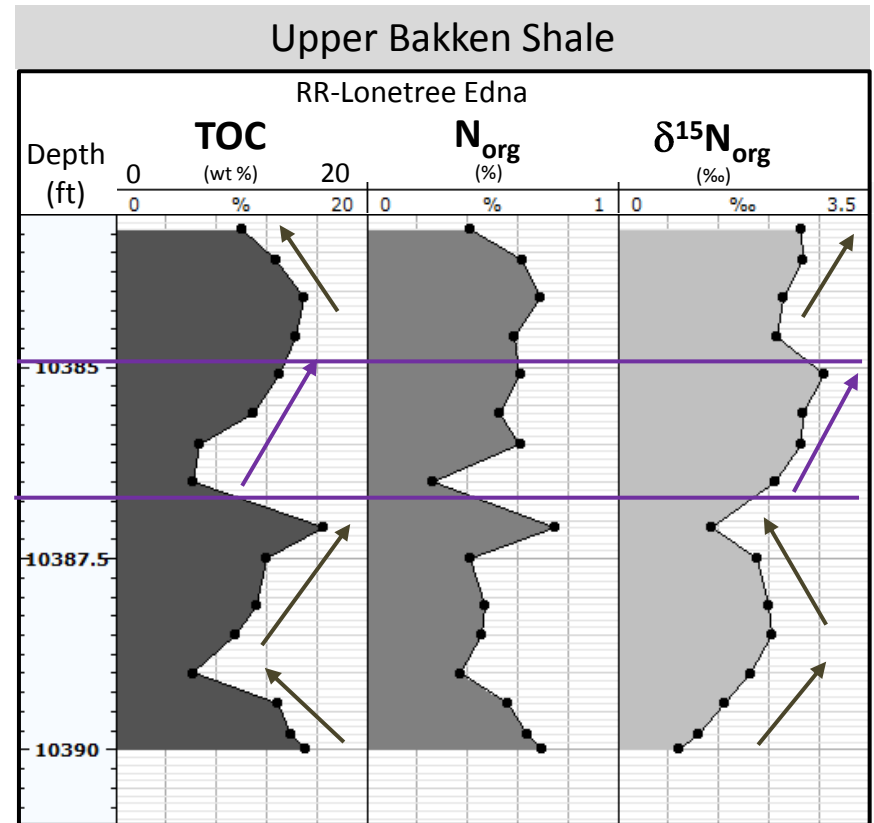
Proxy for Paleonutrient

- $\delta^{15}\text{N}$: Lighter values of $\delta^{15}\text{N}$ indicates higher nutrient utilization and therefore higher rate of organic paleoproductivity.
- Positive covariance between TOC and Al content

TOC and $\delta^{15}\text{N}$

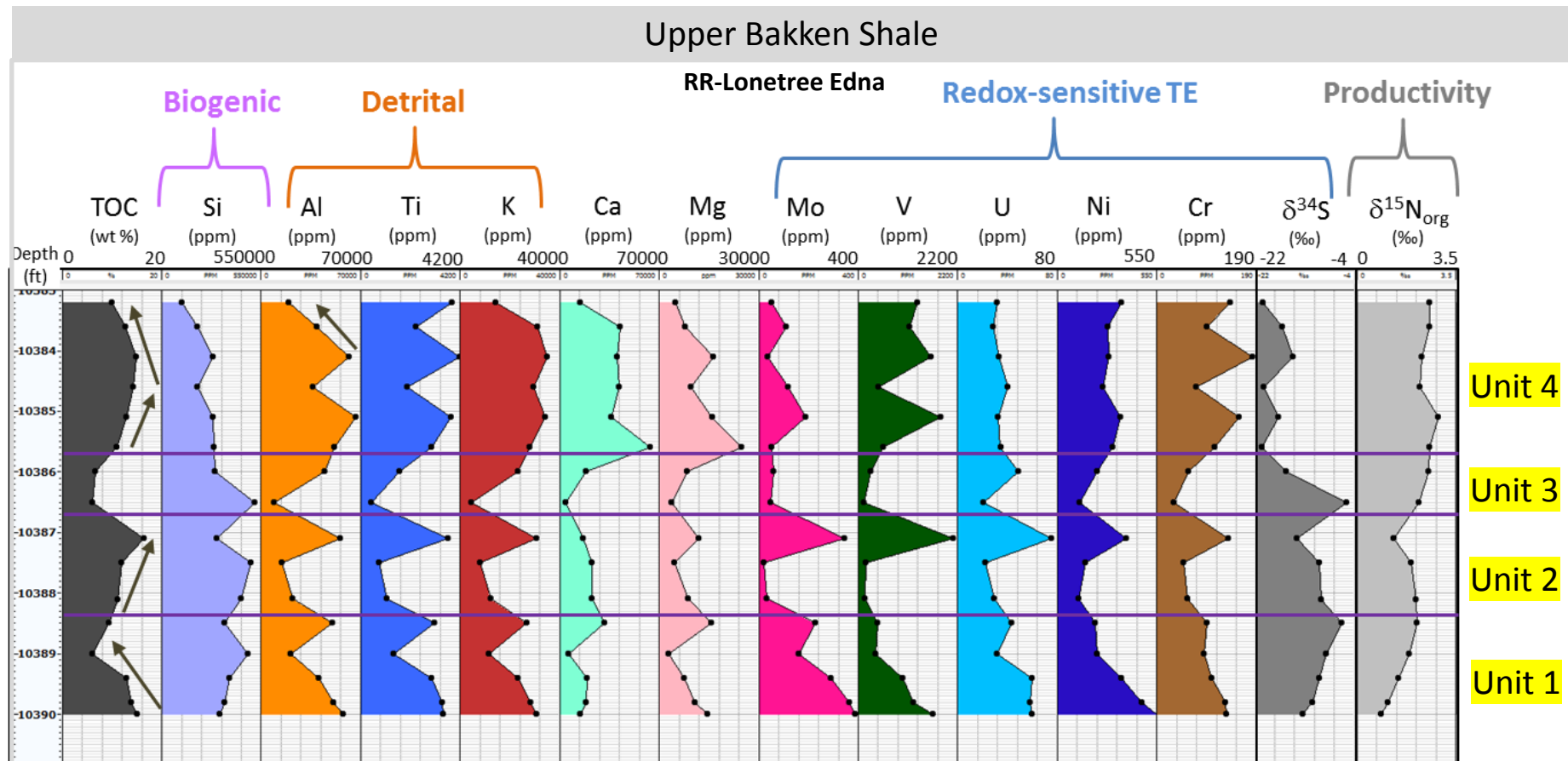


Data Source : Caplan and Bustin, 1998



- Initially, greater utilization of ^{14}N isotope-bearing nitrate by marine algae.
- This indicates higher concentration of nutrients and an increased rate of organic productivity in basin surface water at the onset of deposition.
- Gradually, less utilization of nutrients, indicates less productivity, but higher TOC related to euxinic condition.

Multiproxy Approach



- **Unit 4:** Preservation potential high, prolonged euxinic condition, higher detrital sediment influx leads to quick burial of OM, productivity rate less than Unit 1 and 2, lower utilization of nutrients.
- **Unit 3:** Highest biogenic silica/ radiolarian causing dilution, less anoxic.
- **Unit 2:** High nutrient utilization, high OM productivity rate, increasing anoxic/euxinic, good preservation potential
- **Unit 1:** High nutrient utilization, high OM productivity rate, decreasing anoxia/euxinia, good preservation potential

Key Takeaways

- Optimum detrital sedimentation rate helped in quick burial of OM and thereby helped in preservation of OM.
- Detrital sediment influx may have helped in bringing Fe-rich nutrients thereby influencing primary productivity.
- High enrichment of redox sensitive trace-elements like Mo, V, U, Ni and Cr indicates anoxic to euxinic bottom water condition.
- Lighter values of $\delta^{34}\text{S}$ and Fe-S relationship indicates anoxic to euxinic condition.
- Variation in paleoproductivity through time.
- Good preservation potential and higher paleoproductivity both controlled the organic-richness of the Bakken Shales.

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Kathy Emme



Colorado School of Mines Bakken Consortium 2015



WHITE EAGLE
EXPLORATION



THE ENERGY OF
enerPLUS



Schlumberger

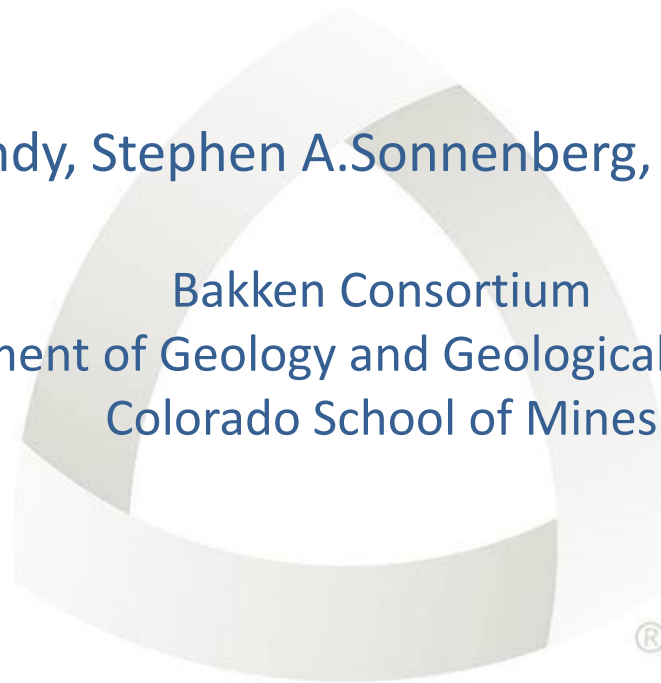


Mike Johnson &
Associates

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