

Geochemical Characterization of Stratigraphic Sequences in the Horn River Shale, Middle and Upper Devonian, Northeastern British Columbia, Canada*

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Search and Discovery Article #50929 (2014)**

Posted February 17, 2014

*Adapted from oral presentation given at AAPG 2013 Annual Convention and Exhibition, Pittsburgh, Pennsylvania, May 19-22, 2013

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Abstract

Organic-rich shale and mudstone have long been recognized as primary sources of oil and natural gas. At elevated thermal maturities, they may contain large volumes of natural gas. Organic content is the major factor controlling gas generation and storage capacity of shales. Organic content is, in turn, controlled by organic productivity, organic matter preservation and sedimentation rate. A high-resolution geochemical dataset has been developed on continuous core from Horn River shale to investigate composition variation and effect of sea level fluctuation on productivity, redox condition and sedimentation rate.

Our research on the Middle and Upper Devonian Horn River shale (Horn River Basin, British Columbia), comprises the Muskwa, Otter Park, and Evie formations and underlying Lower Keg River formation. We report here on a large suite of samples, taken at dense sample spacing from a long Horn River core. Samples were analyzed by ICP and ICP-MS for major, minor and trace elements and Leco and Rock-Eval analysis for organic carbon.

According to stacking pattern of mudstone lithofacies, a second order scale sequence stratigraphic framework has been established. The Lower Keg River member is interpreted as an early transgressive system tract, then the Evie member forms a transgressive-highstand system tract and the overlying Otter Park through Muskwa sequence forms a transgressive system.

TOC content is highest in the Evie and Muskwa Formations, averaging 3.5 to 4.0%, and 2.5% in the Otter Park. It seems that TOC is richest in the late stage transgressive system tract and early stage of highstand system tract, in contrary, lowest in late stage of high system tract and early stage of transgressive system tract. This pattern correlates to some extent with the strongest enrichment in the redox sensitive elements Mo, U and V, suggesting that redox conditions were related to organic carbon deposition. However, to some extent, TOC variation is reversely with redox sensitive element concentration, demonstrating that other factors like productivity and dilution may play a more important role in organic matter enrichment. Statistical analysis of the inorganic geochemical data shows no correlation between SiO₂ and other elements associated with feldspars and clays. SiO₂ is strongly and inversely related to carbonate content. We interpret the SiO₂ data as a

biogenic silica signal. Major elements indicate a trend of increasing biogenic silica and decreasing carbonates upward, while the clay-rich Otter Park formation may represent a shorter-term sea level low stand.

References Cited

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Ross, D.J.K., and R.M. Bustin, 2008, Characterizing the shale gas resource potential of Devonian-Mississippian strata in the Western Canada Sedimentary Basin; application of an integrated formation evaluation: AAPG Bulletin, v. 92/1, p. 87-125.



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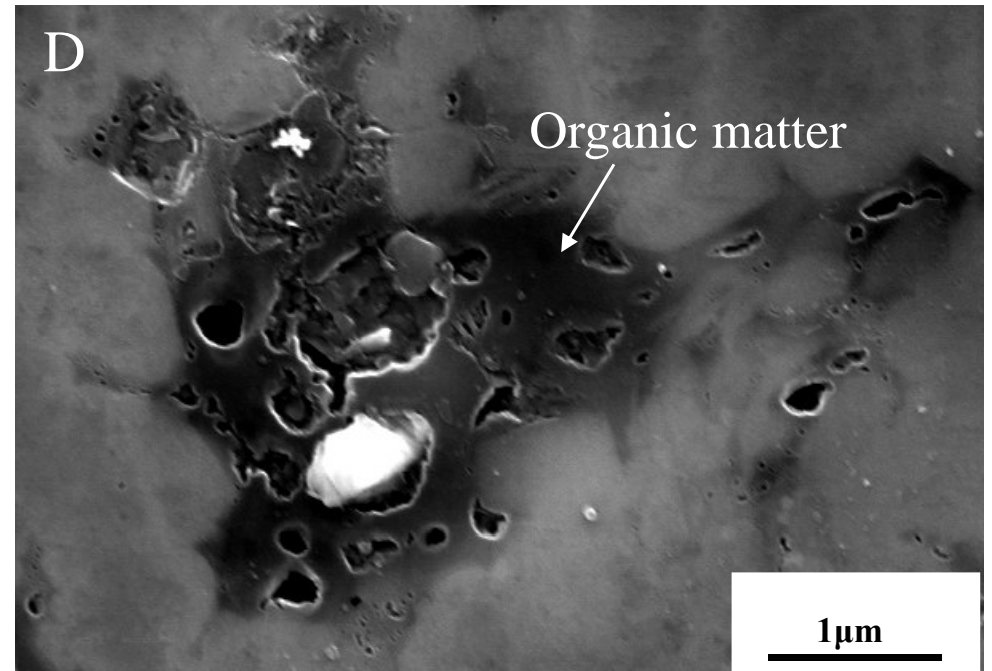
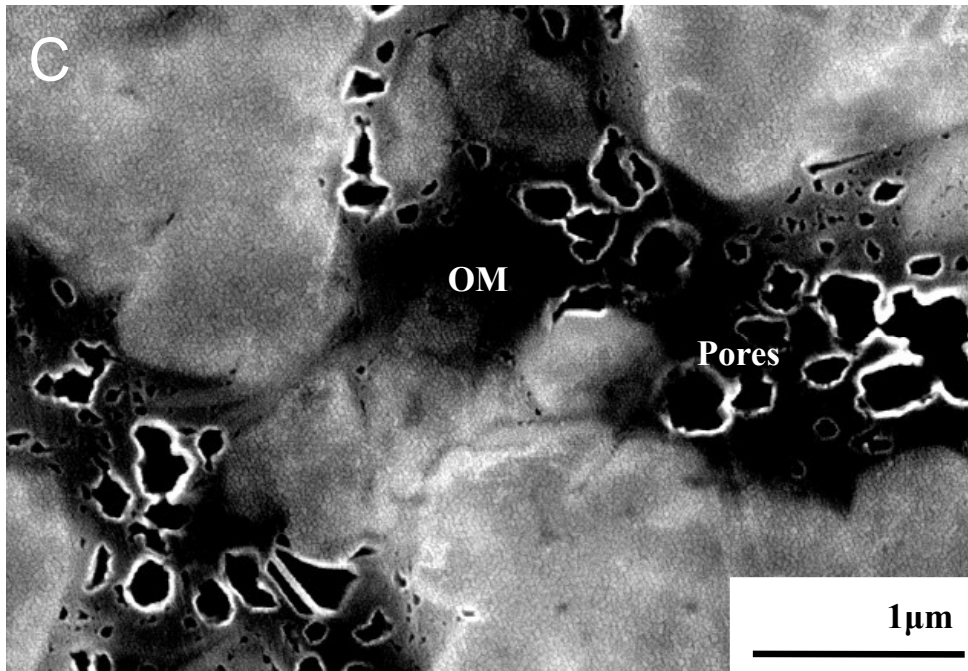
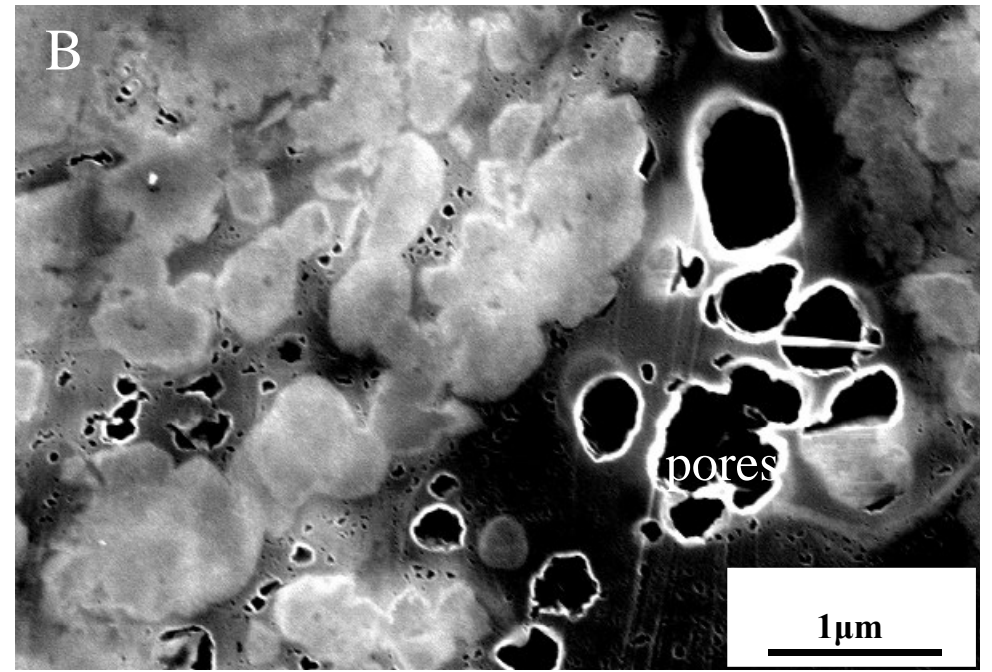
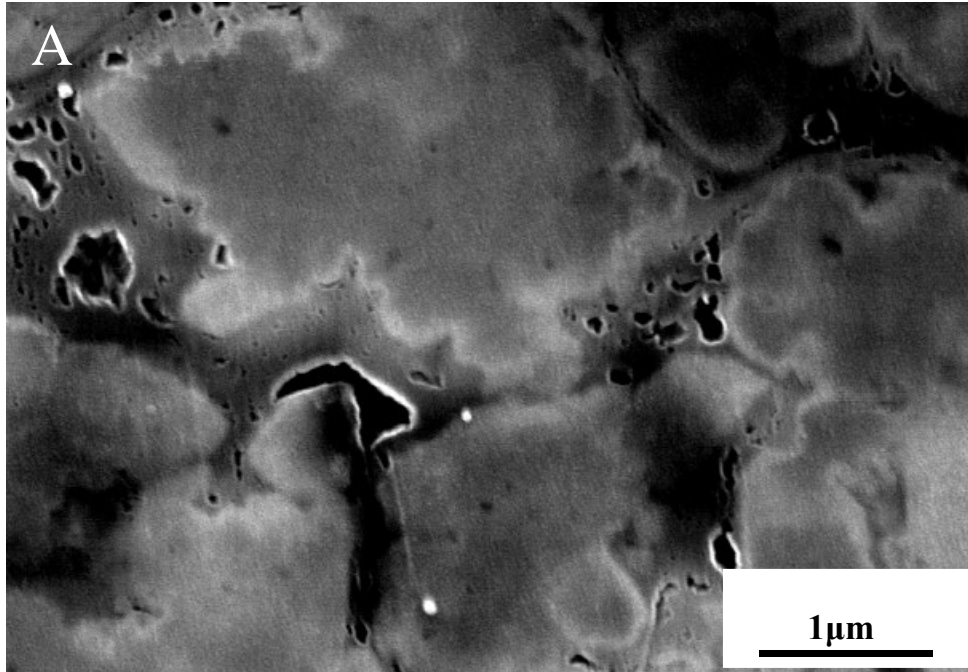
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How to do sequence stratigraphy in shales ?

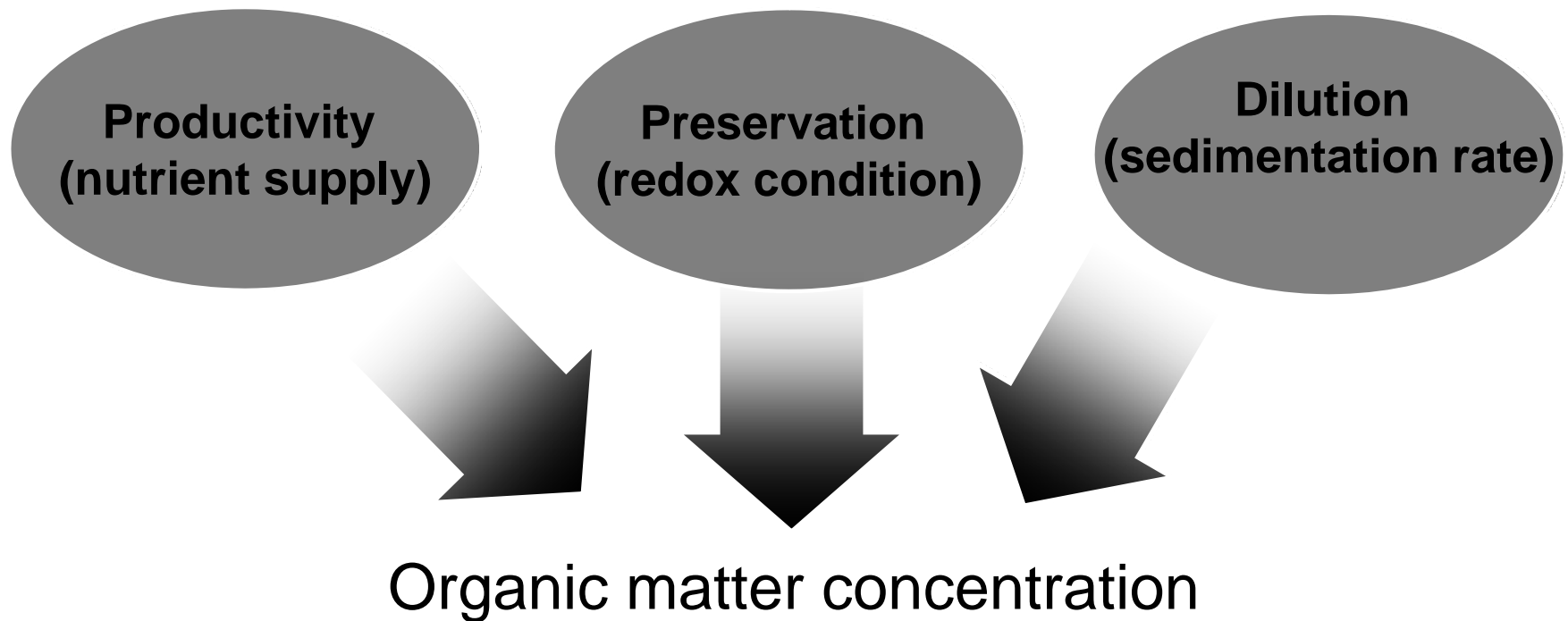


Sea level cycles may be expressed in well logs, geochemical data and mineralogy.

SEM image examples from Horn River shale

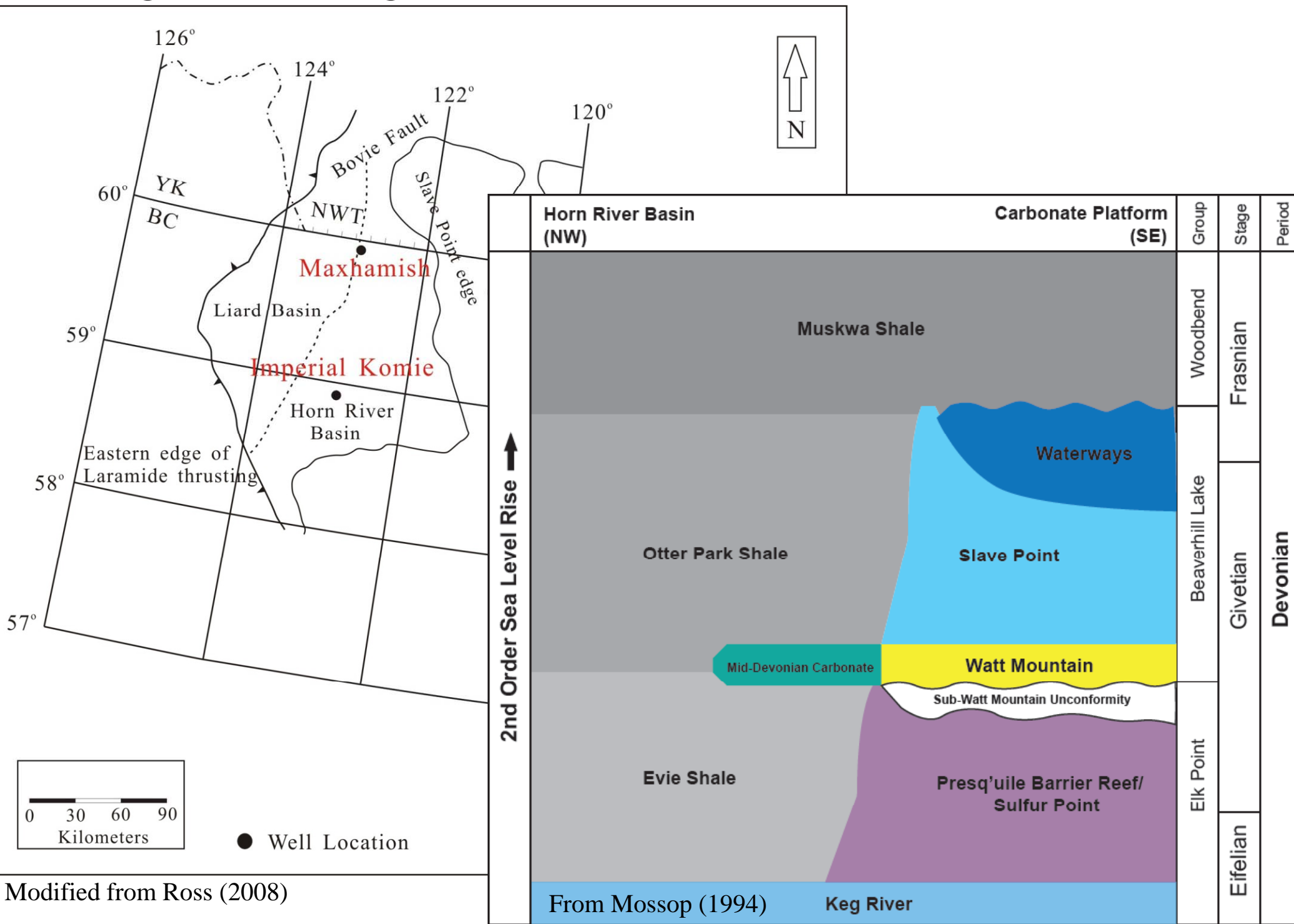


How does sea level fluctuation control organic matter deposition?



Sea level change will exert an effect on productivity, preservation and dilution

Geological setting



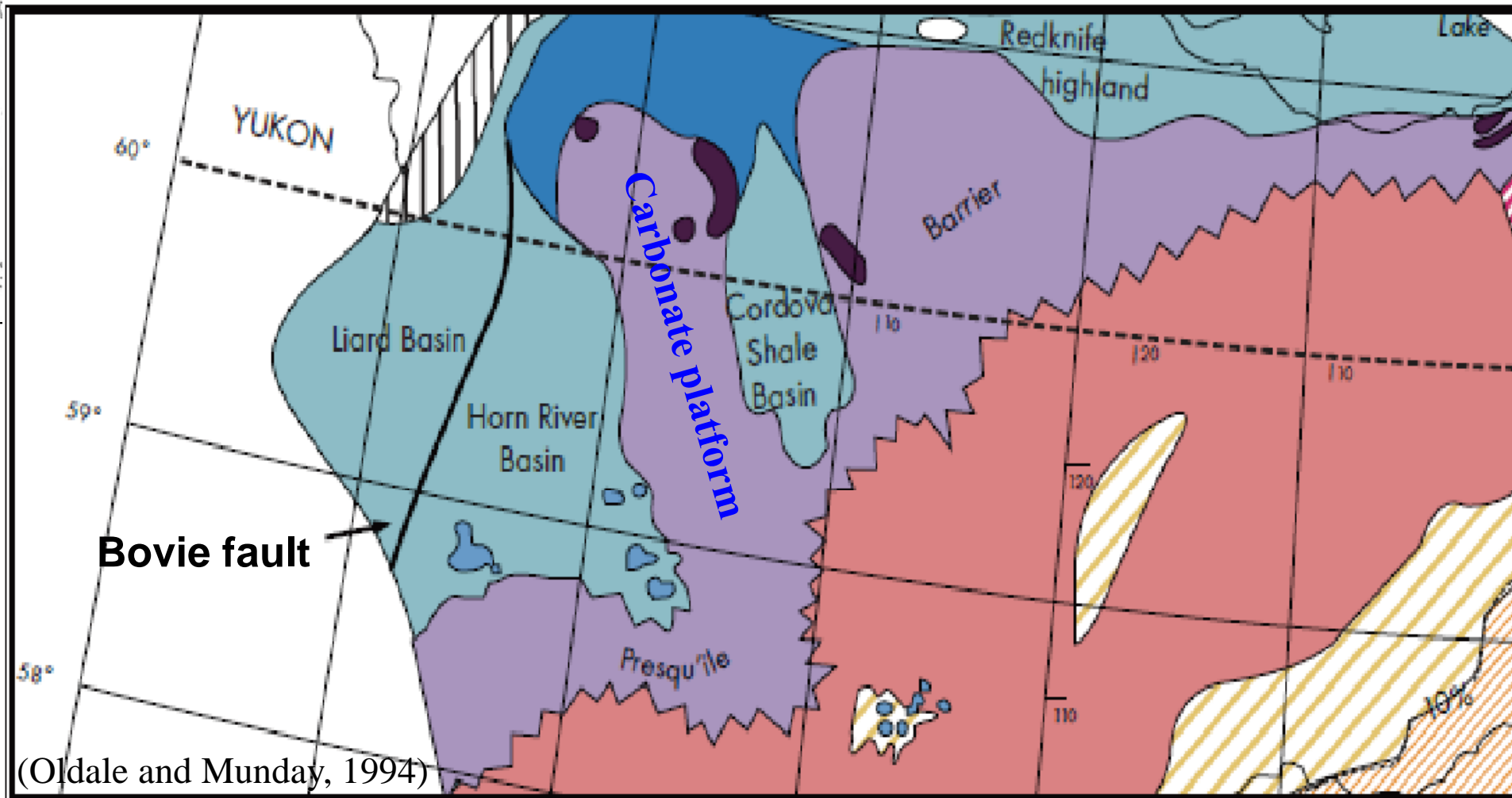
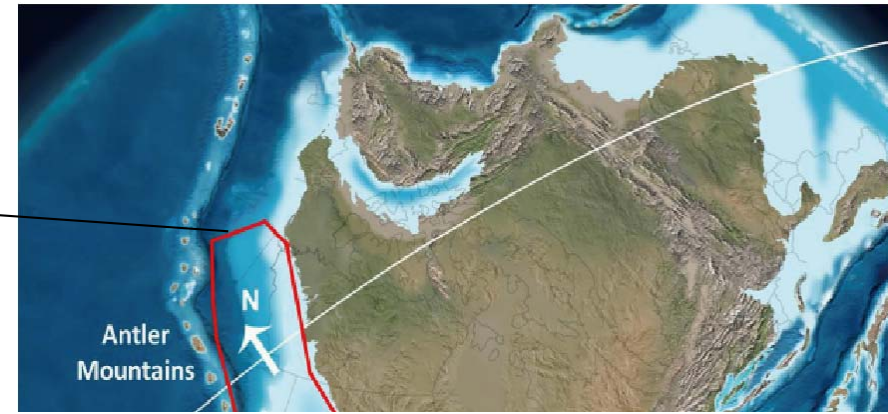
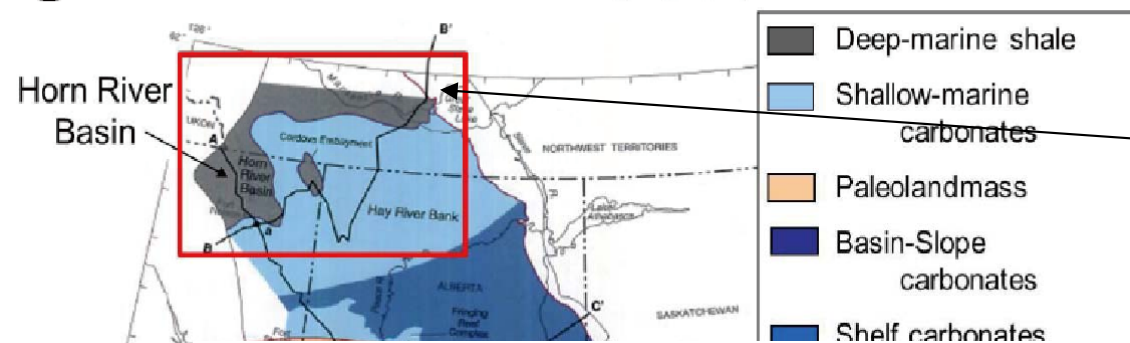
Modified from Ross (2008)

Paleogeography

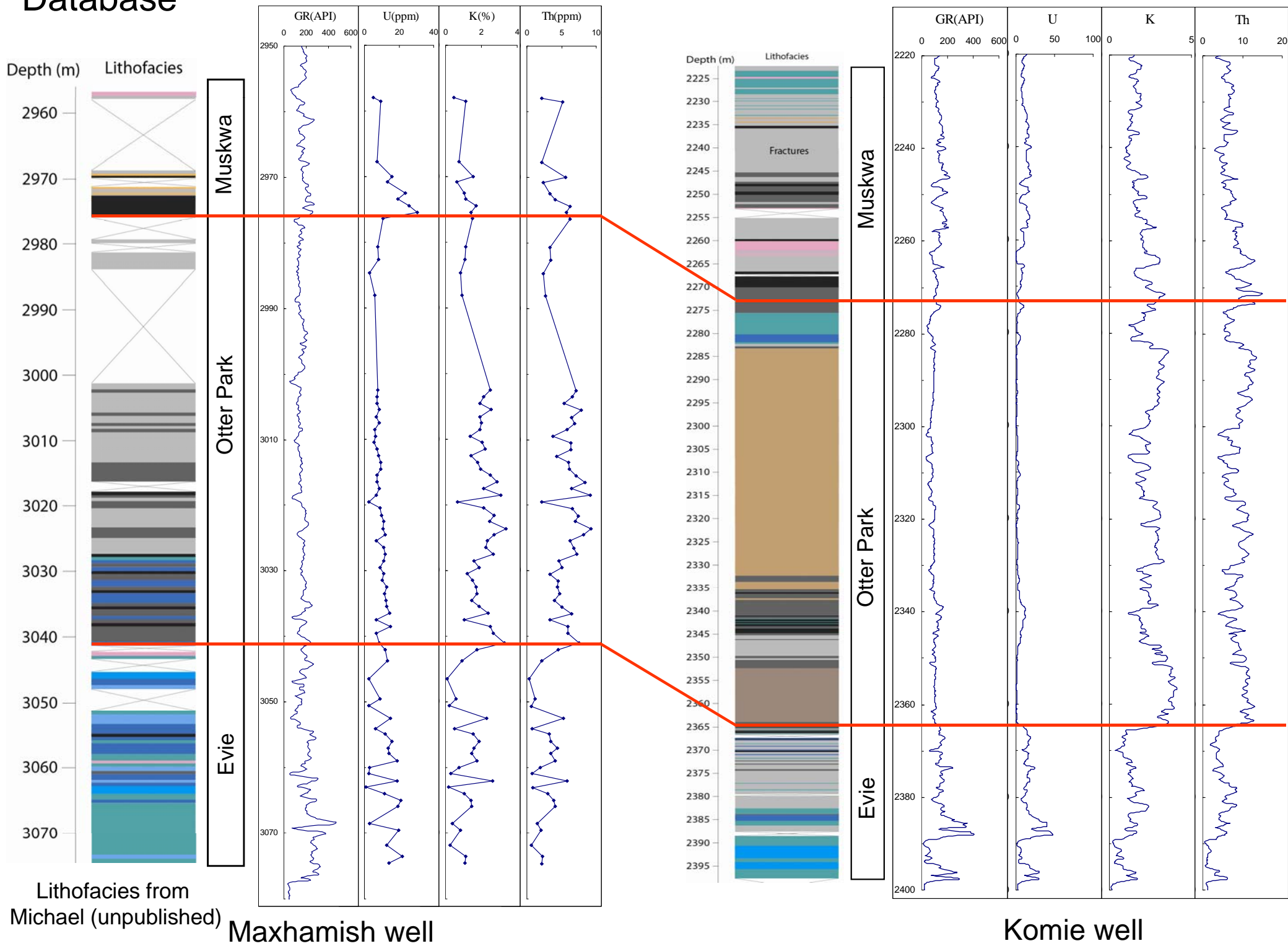
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Western Canadian Sedimentary Basin

Middle Devonian Paleogeography



Database



Lithofacies from
Michael (unpublished)

Maxhamish well

Komie well

Factor analysis-Maxhamish well

Factor1	36.9%	Factor2	17.7%	Factor3	10.4%	Factor4	8.5%	Factor5	3.8%	Factor6	2.9%	Factor7	1.9%
Stotal	0.611	TOC	0.526	V	0.926	SiO2	0.827	MgO	0.935	Tl	-0.879	P2O5	0.885
Al2O3	0.927	U	0.681	Mo	0.599	Ba	0.556	MnO	0.96				
Fe2O3	0.597	Y	0.949	Zn	0.936	Ctotal	-0.774						
Na2O	0.727	Gd	0.756	Ag	0.593	Inorganic C	-0.764						
K2O	0.921	Tb	0.782	Ni	0.649	CaO	-0.737						
TiO2	0.928	Dy	0.769	Cd	0.945	LOI	-0.783						
Cr2O3	0.722	Ho	0.839	Sb	0.88	Sr	-0.59						
Sc	0.869	Er	0.825	Se	0.709								
Co	0.92	Tm	0.823										
Cs	0.933	Yb	0.769										
Ga	0.921	Lu	0.807										
Hf	0.907												
Rb	0.939												
Sn	0.785												
Ta	0.799												
Th	0.936												
Zr	0.905												
La	0.807												
Ce	0.929												
Pr	0.863												
Nd	0.821												
Sm	0.766												
Eu	0.619												
Cu	0.628												
Pb	0.844												
Bi	0.792												

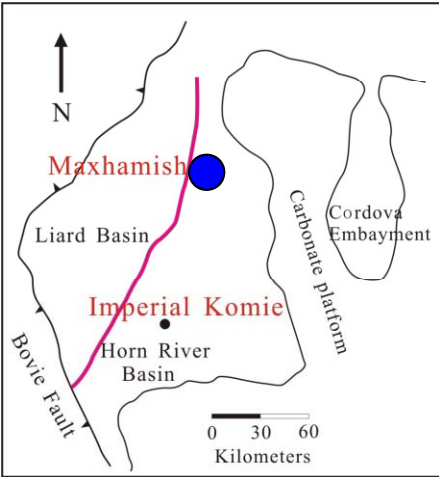
Factor1: associated with siliciclastic minerals: clay+feldspar

Factor2: TOC is moderately correlative to U

Factor3: redox-sensitive elements

Factor4: associated with carbonates, quartz is strongly positively correlated with this factor and decoupled from siliciclastic minerals. Both Si and Ba are positive with this factor

Factor7: Phosphorus behaves independently



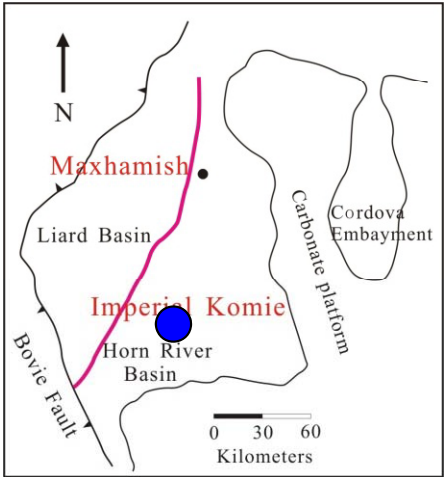
Factor analysis-Imperial Komie well

Factor1	53.20%	Factor2	10.10%	Factor3	9.30%	Factor4	4.10%	Factor5	3%	Factor6	2.20%	Factor7	1.80%
Ctotal	-0.827	SiO2	0.615	V	-0.878	MgO	-0.912	Stotal	-0.918	Au	-0.972	P2O5	0.811
CaO	-0.698	U	0.914	Zn	-0.98	MnO	-0.898						
LOI	-0.723	Mo	0.901	Cd	-0.986								
Al2O3	0.956	Ni	0.751	Sb	-0.874								
Fe2O3	0.556	As	0.722	Ag	-0.835								
Na2O	0.726	Hg	0.629										
K2O	0.946												
TiO2	0.976												
Cr2O3	0.813												
Sc	0.968												
Ba	0.8												
Co	0.915												
Cs	0.938												
Ga	0.961												
Hf	0.934												
Nb	0.938												
Rb	0.949												
Sn	0.624												
Ta	0.883												
Th	0.982												
W	0.735												
Zr	0.954												
Y	0.719												

Factor1: associated with siliciclastic minerals: clay+feldspar,
Carbonates has a opposing trend with clastic minerals.

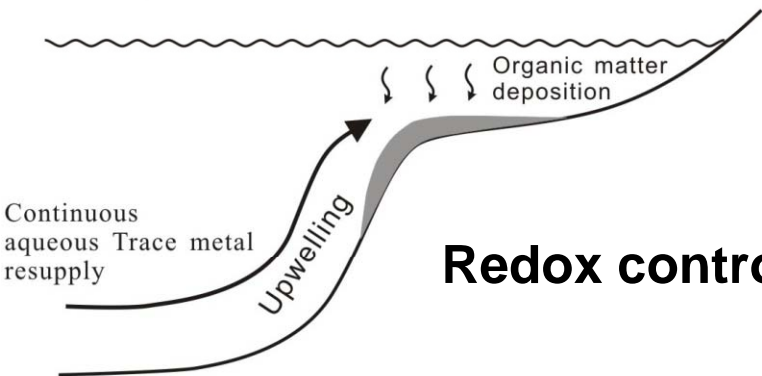
Factor2: redox-sensitive elements, Si behaviors differently
from clastic input

Factor7: Phosphorus behaves independently



Basin restriction proxy - Mo/TOC

Upwelling zone

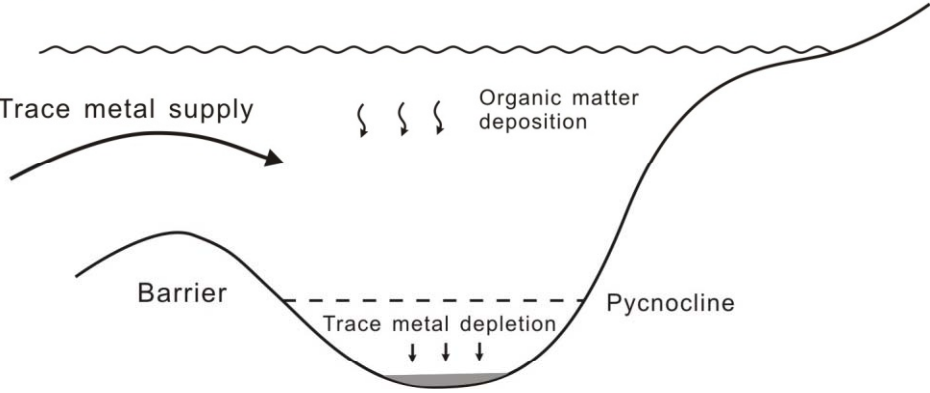


Redox controlling

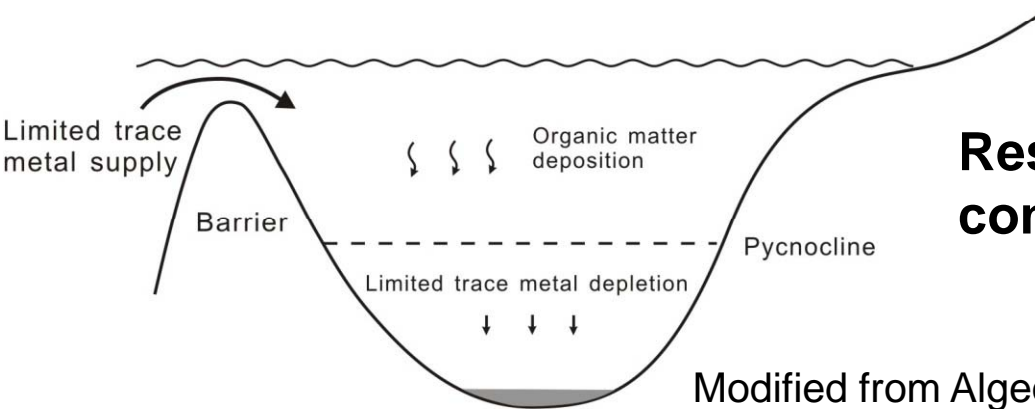
Mo behavior

Concentrated in reducing condition;
Recharge from global sea and varies with degree of basin restriction.

Weak restriction



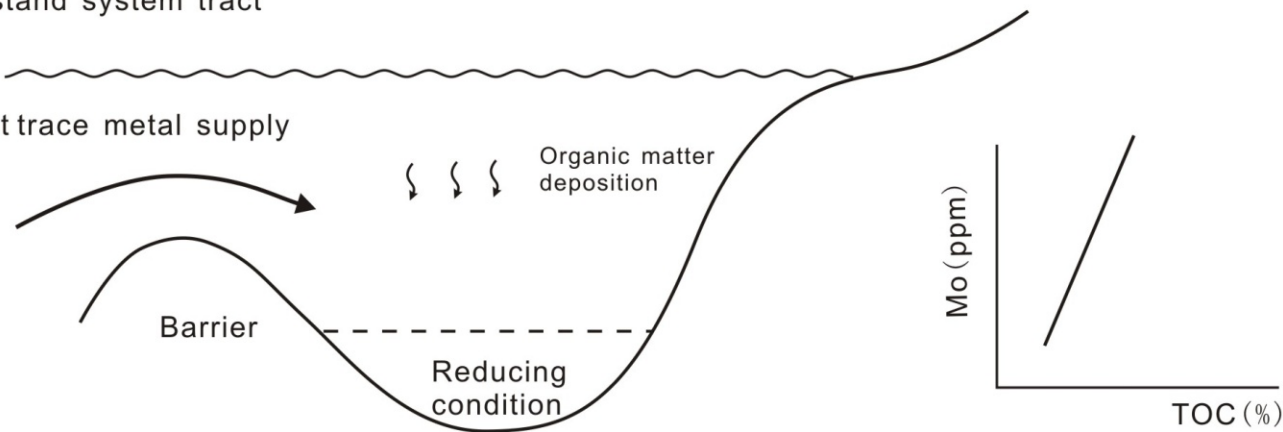
Strong restriction



Restriction degree controlling

Highstand system tract

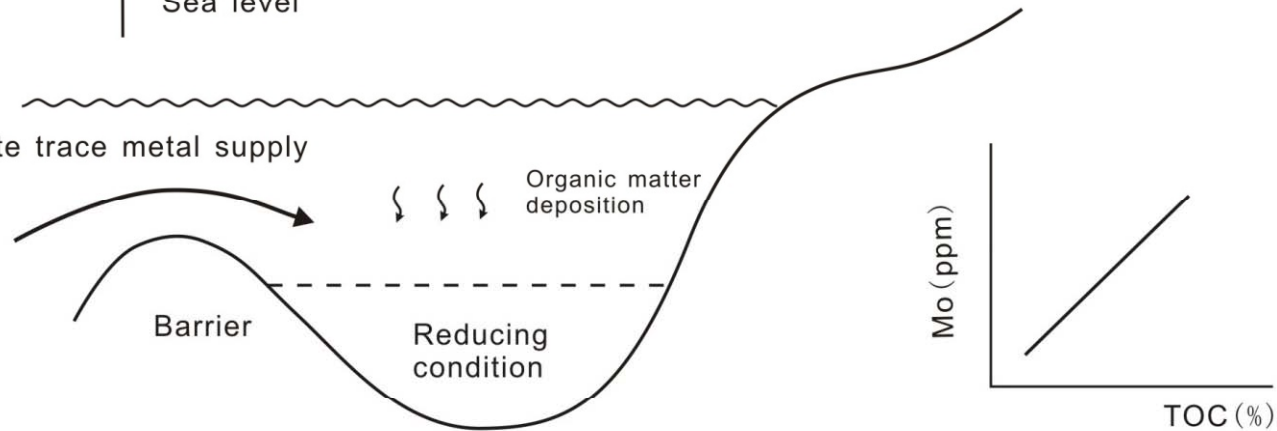
Sufficient trace metal supply



Transgressive system tract

↑ Sea level

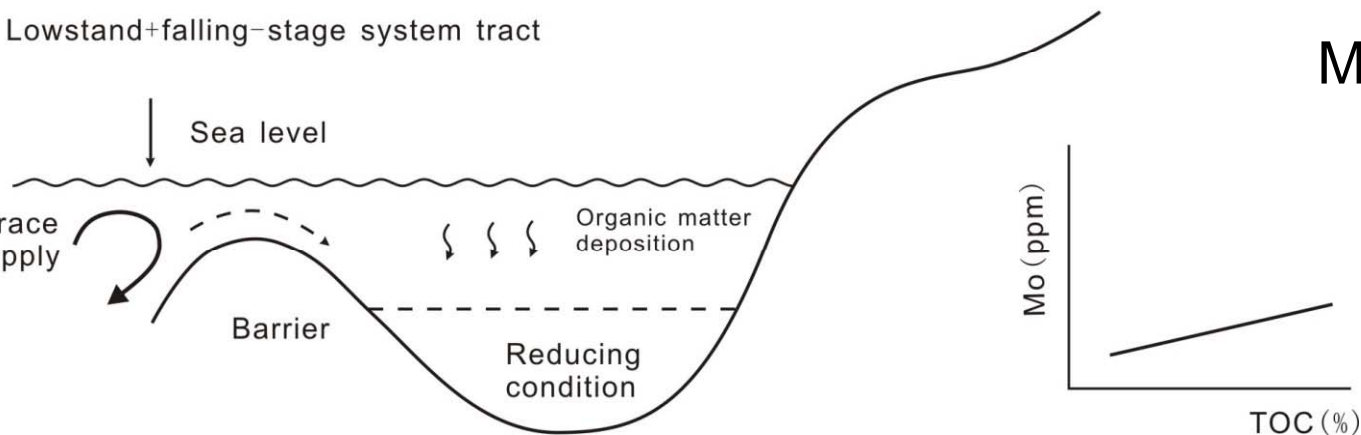
Moderate trace metal supply



Lowstand+falling-stage system tract

↓ Sea level

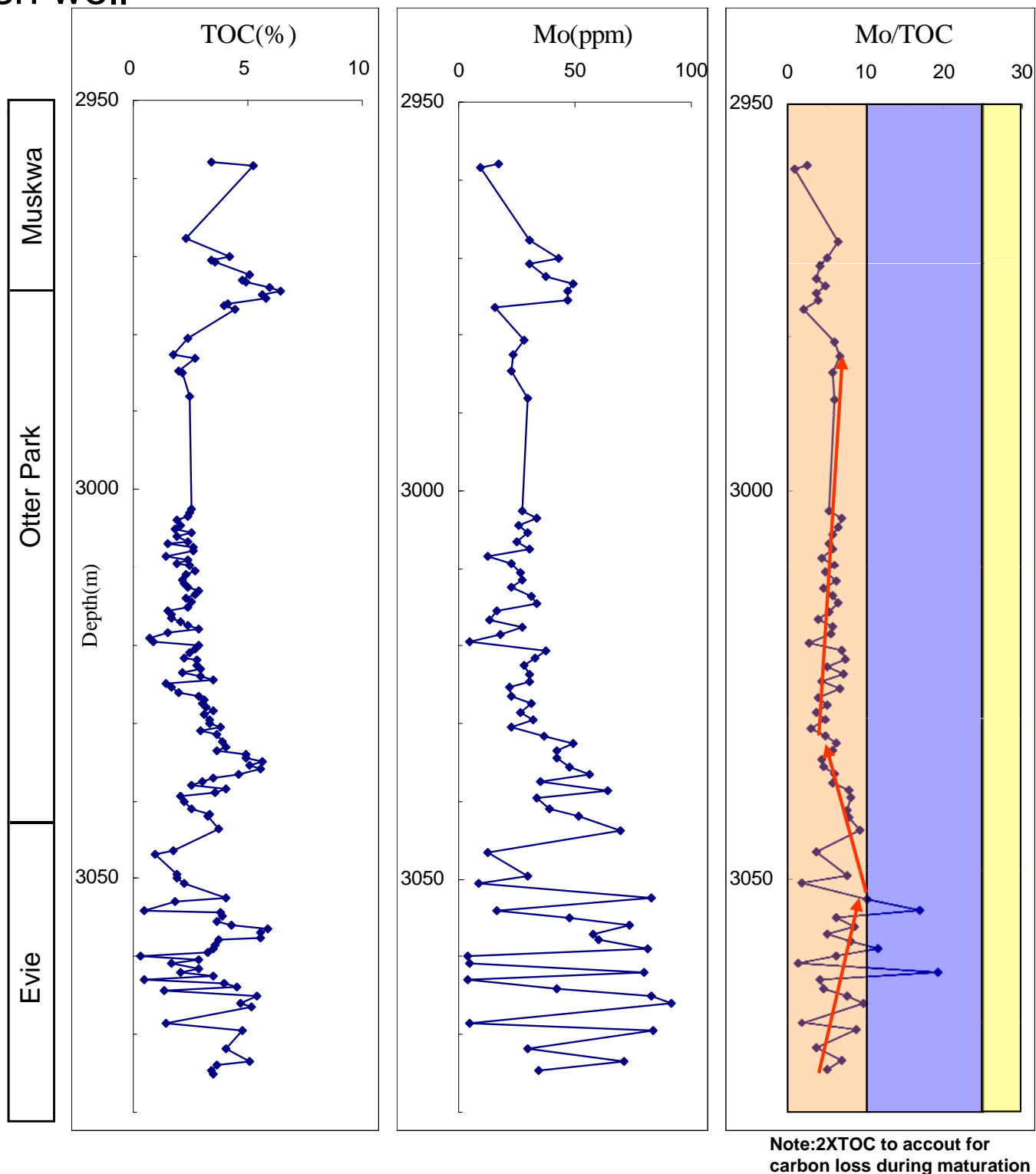
Limited trace metal supply



$\text{Mo}_{\text{aqueous}}$
concentration
should vary with
sea level and
redox condition

$$\text{Mo}_{\text{aqueous}} = \frac{\text{Mo}_{\text{sediment}}}{\text{TOC}}$$

Maxhamish well

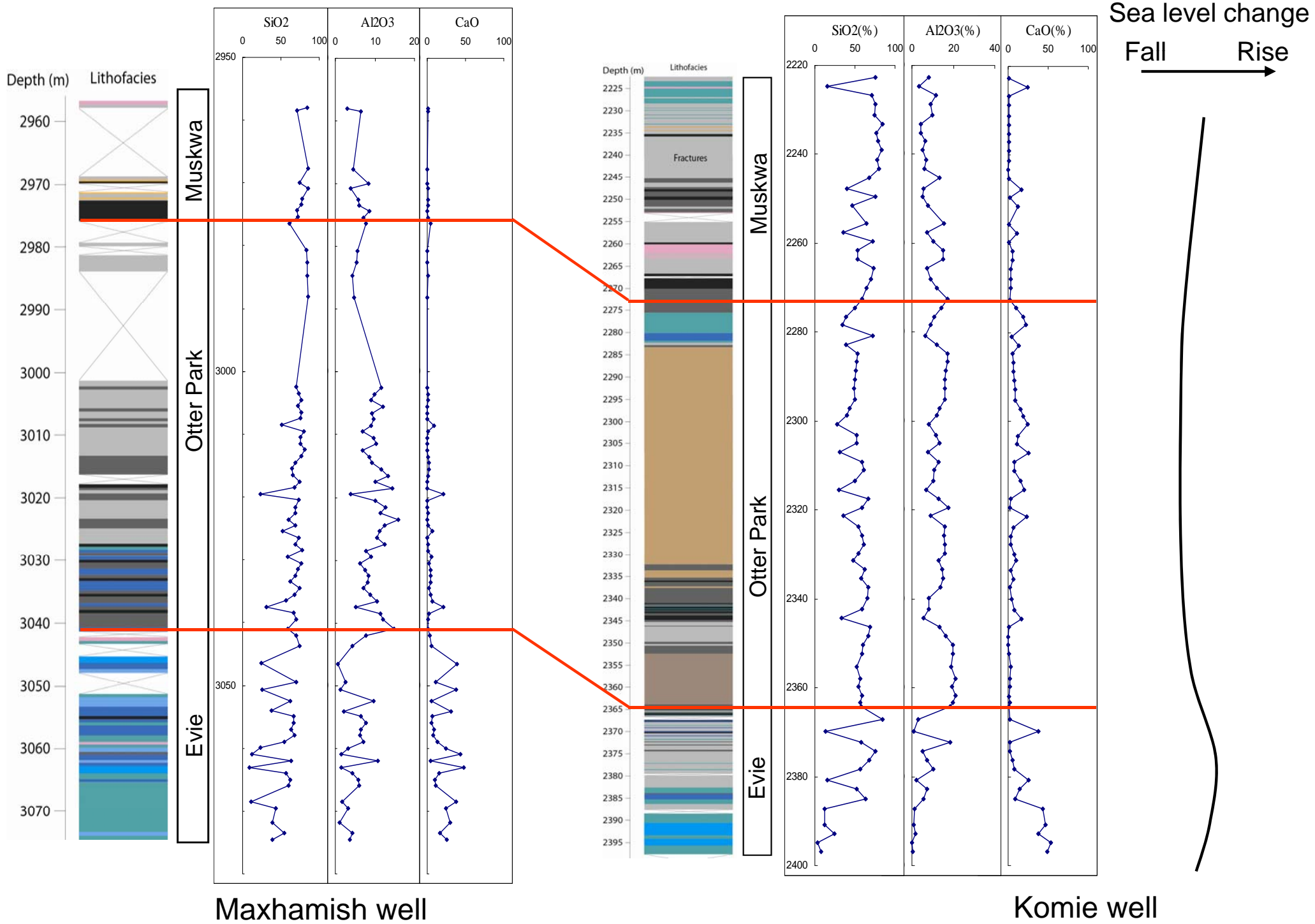


Sea level change

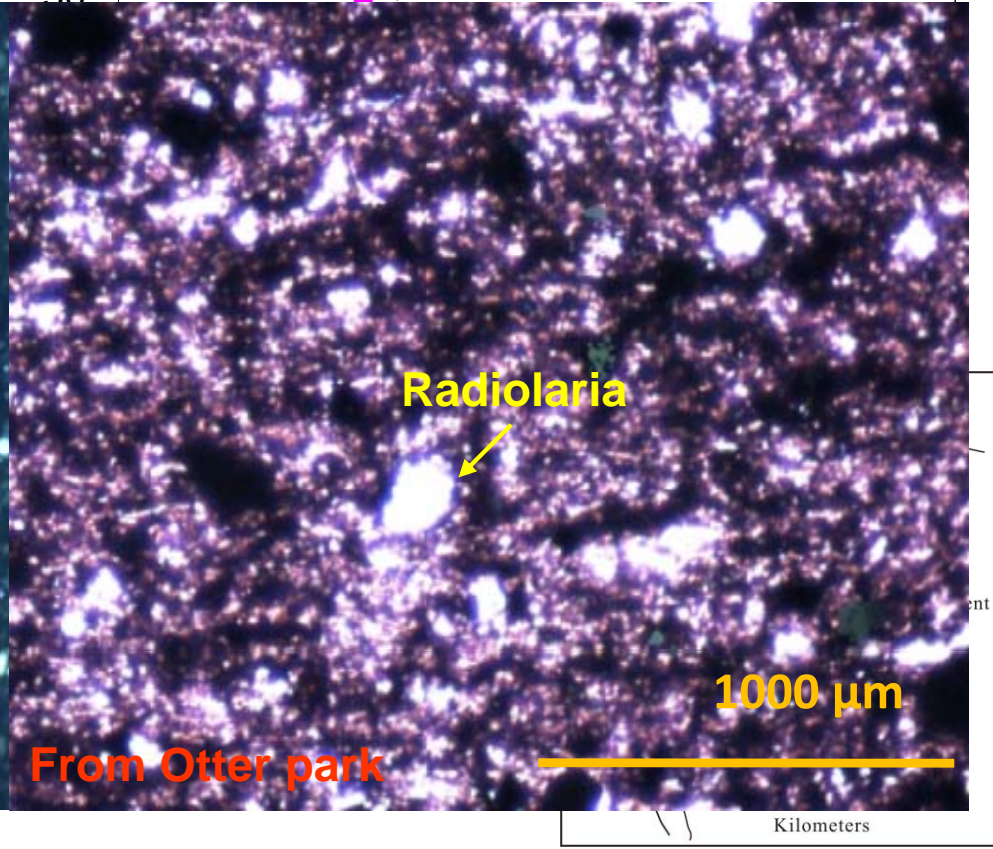
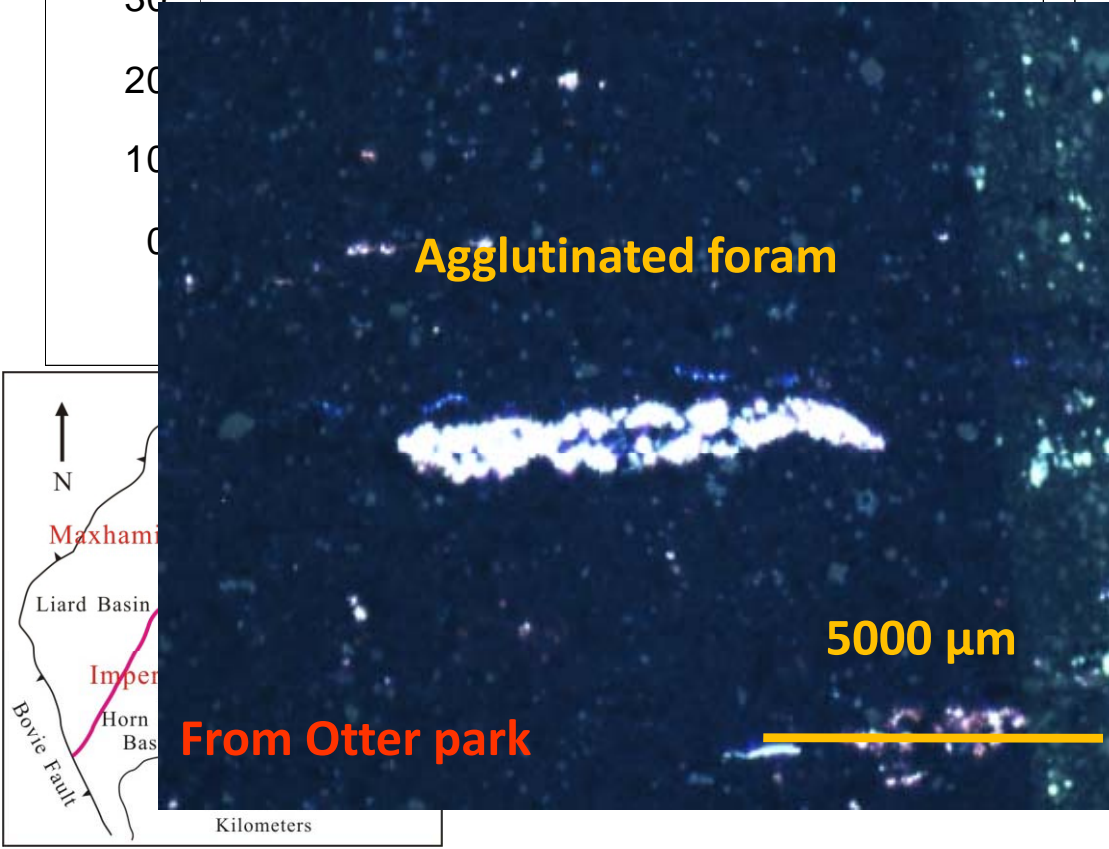
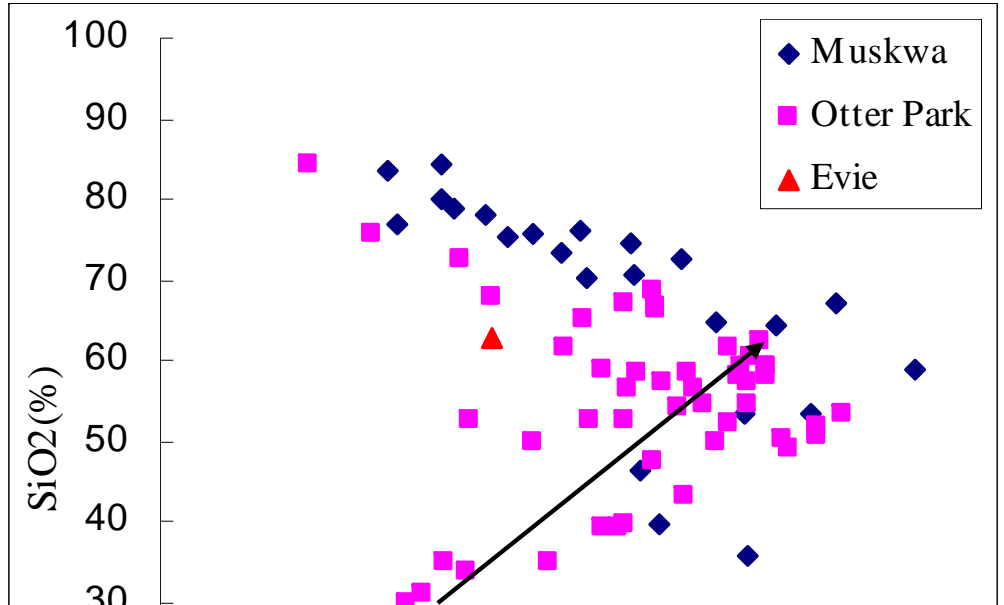
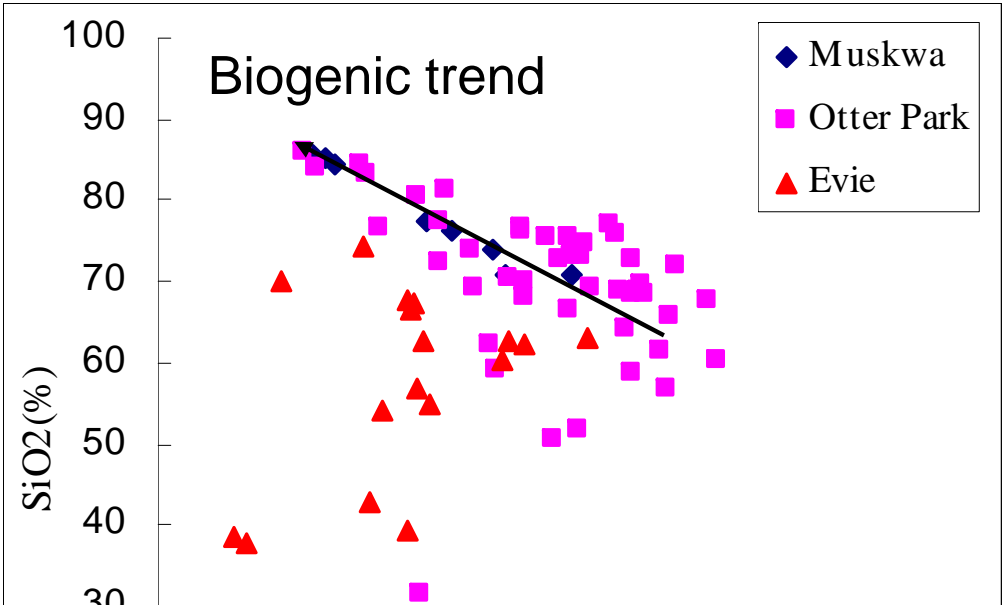
Fall → Rise



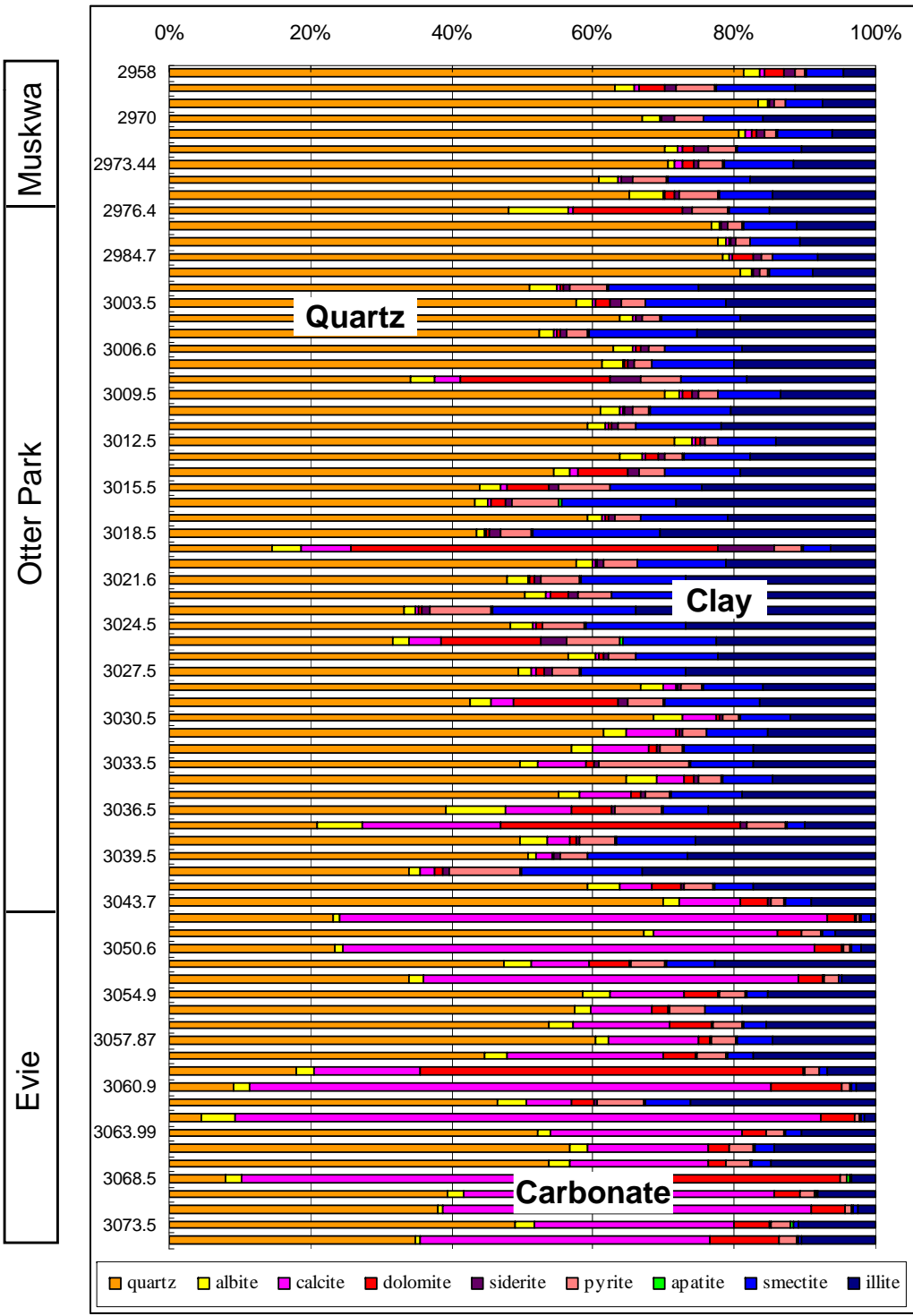
Major elements



Zr vs SiO2 binary plots



Mineralogy -Maxhamish well



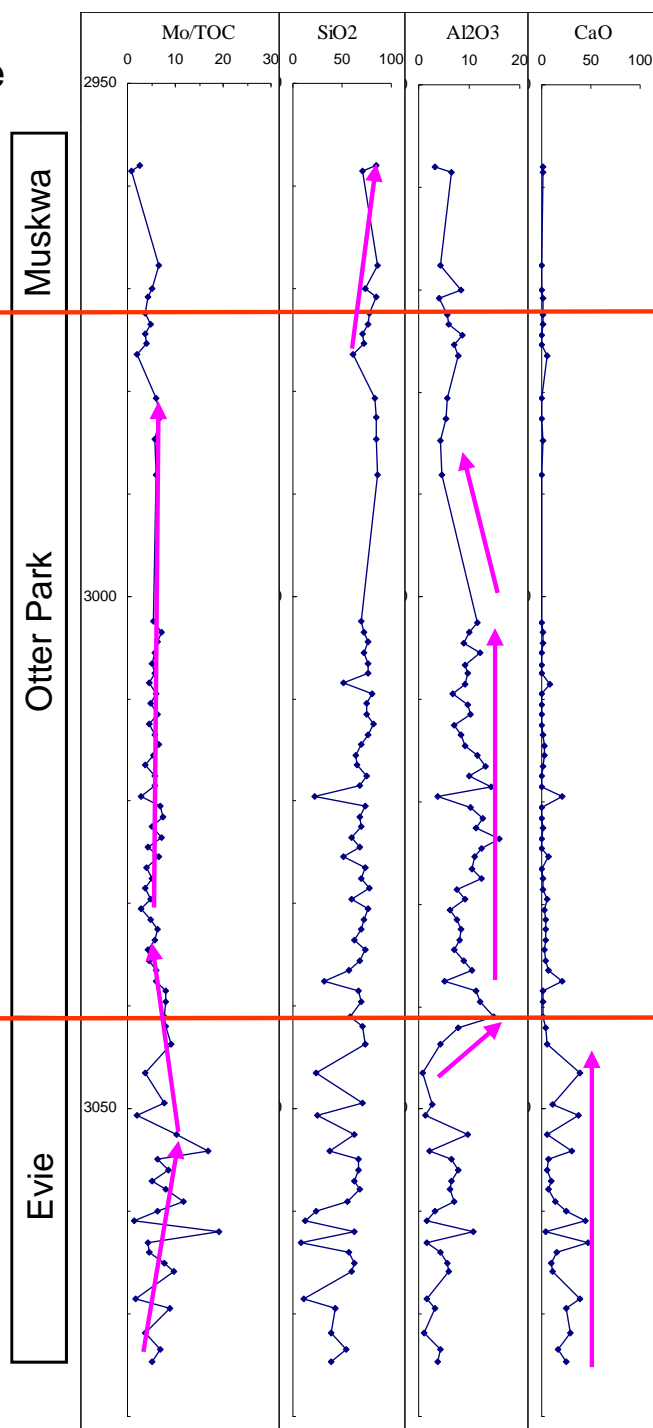
Sea level rise produces increased biogenic silica

Sea level fall triggers Increased clay deposition

Carbonate shedding - sea level highstand

Sea level change interpretation

Fall → Rise

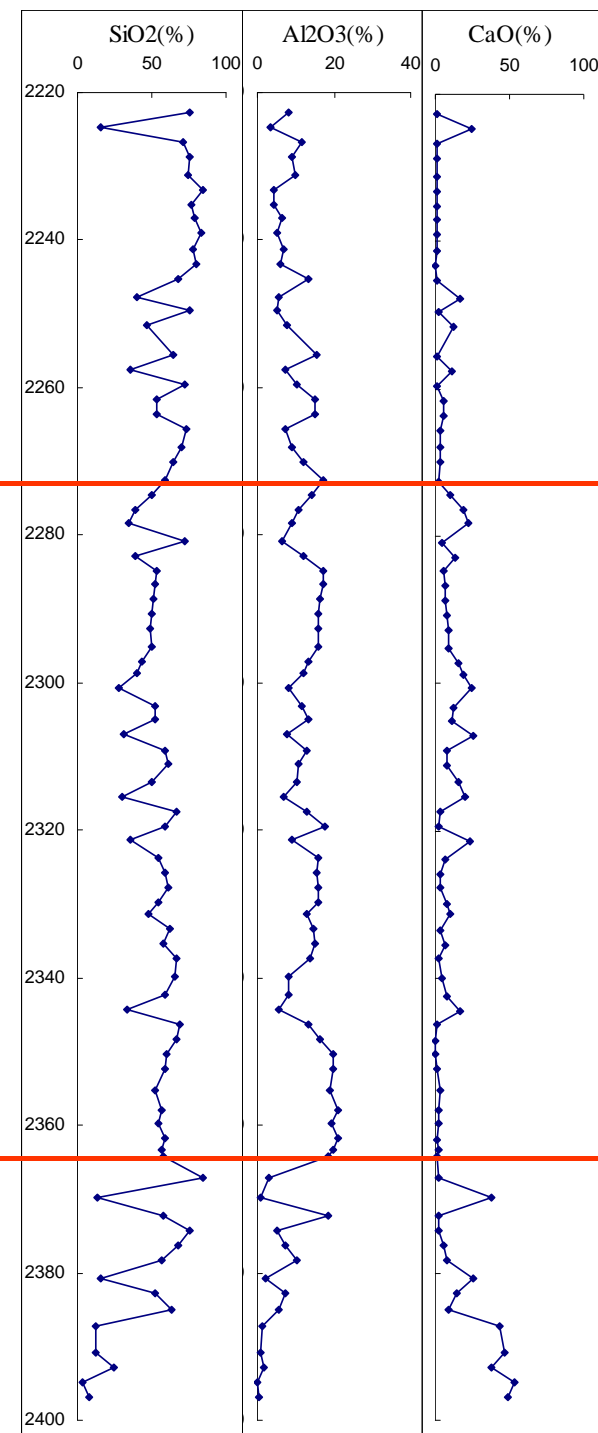


Maxhamish well

Transgressive
system tract

Lowstand
system tract

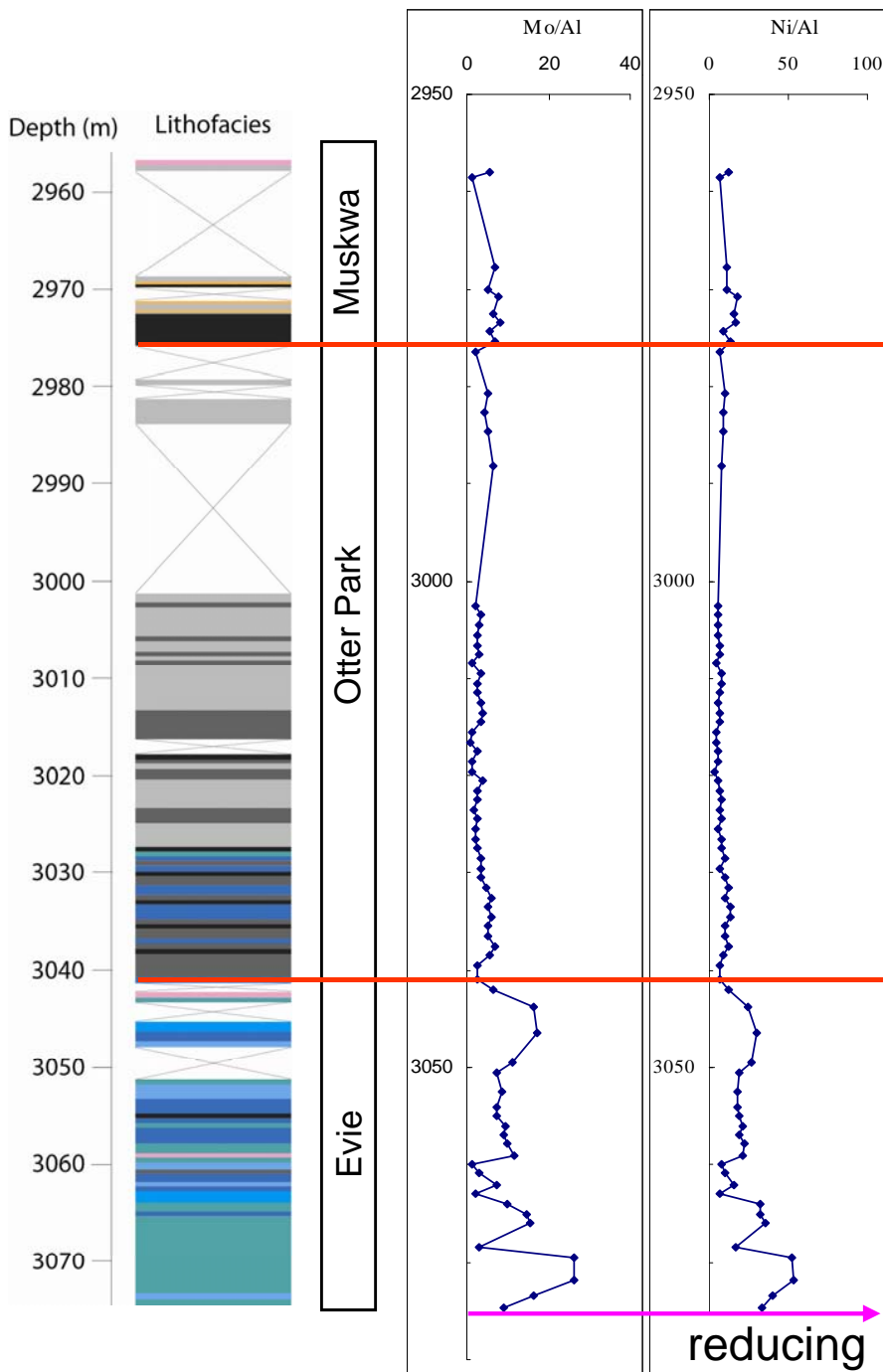
Highstand
system tract



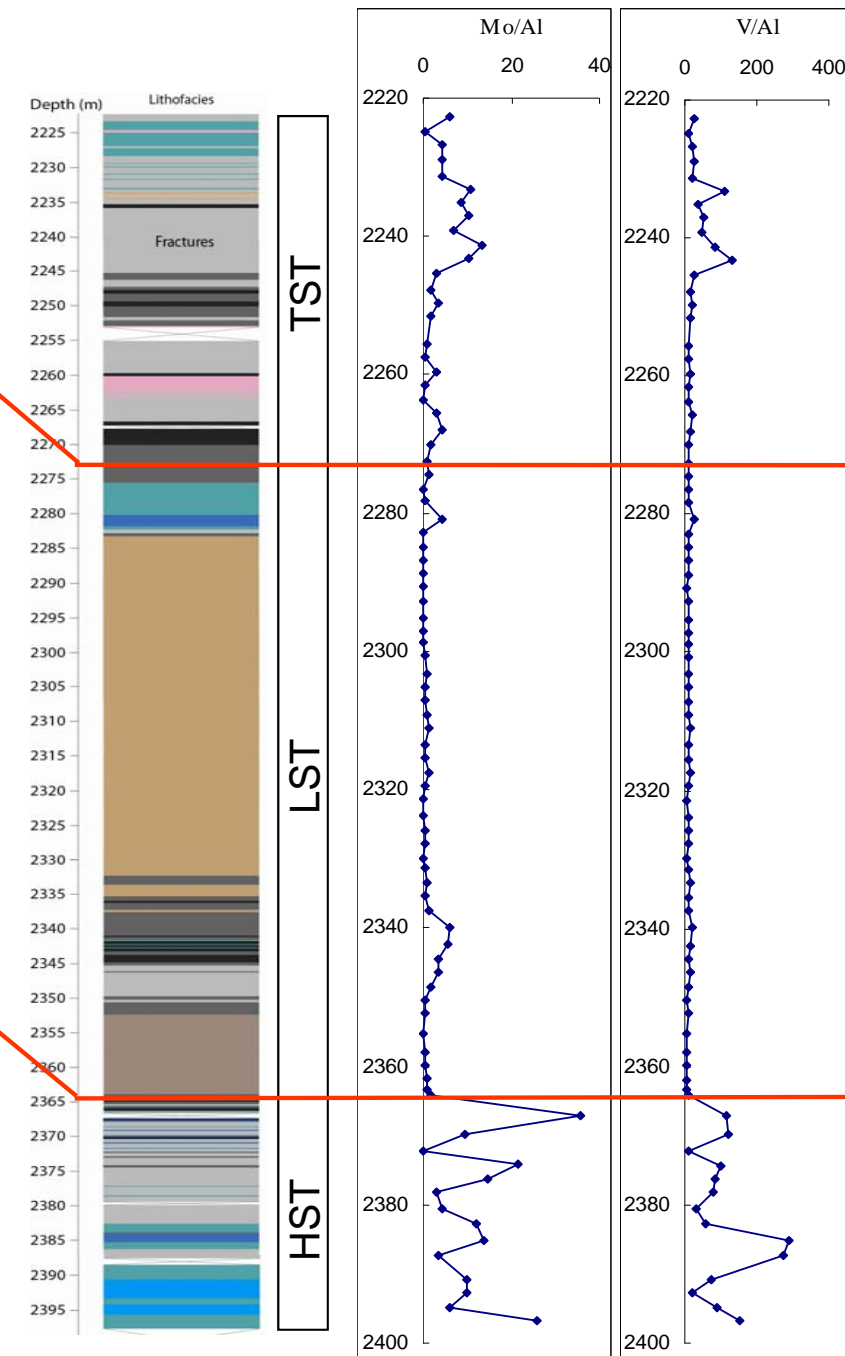
Komie well

Paleoredox proxy

Fall Rise
→

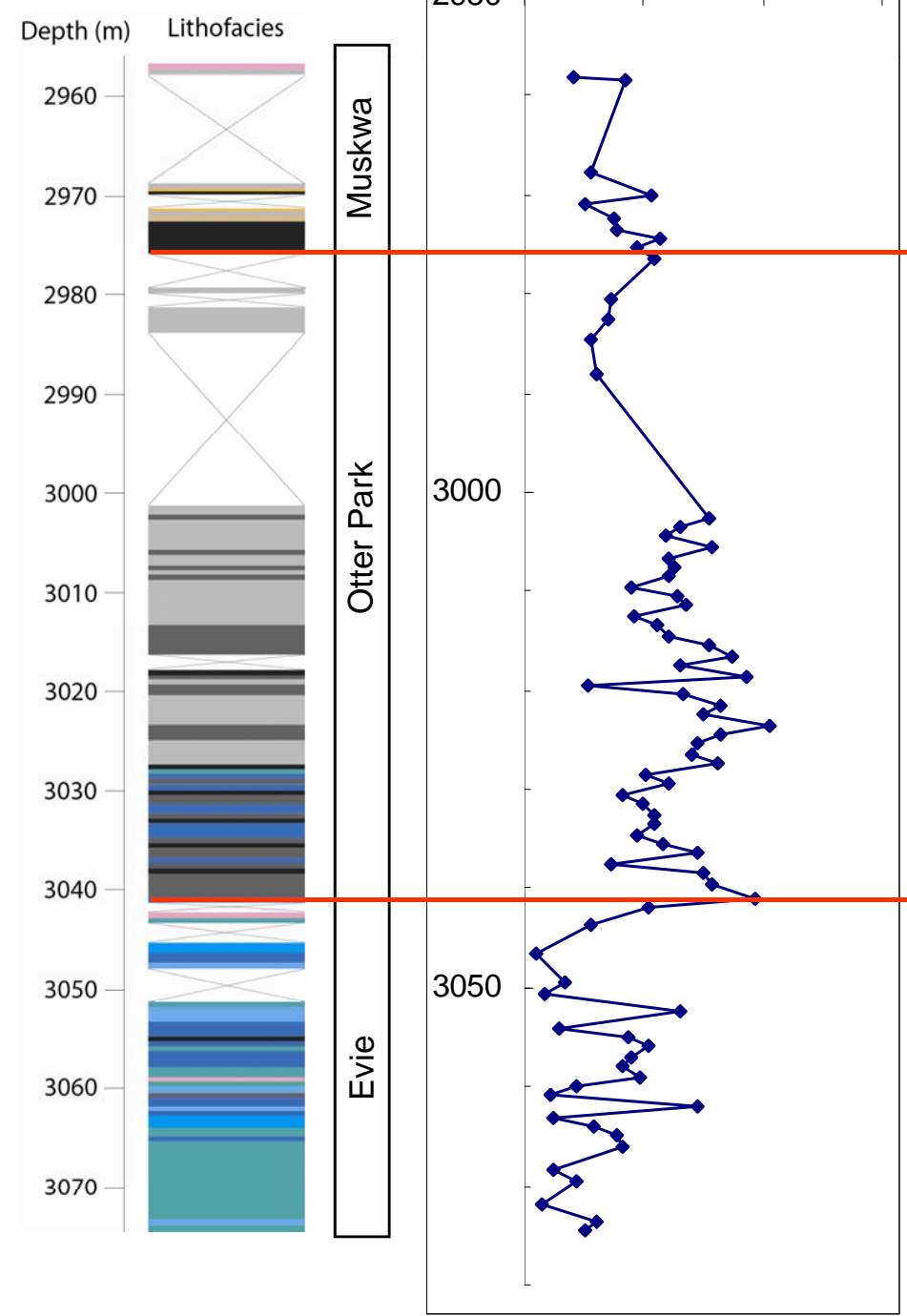


Maxhamish well

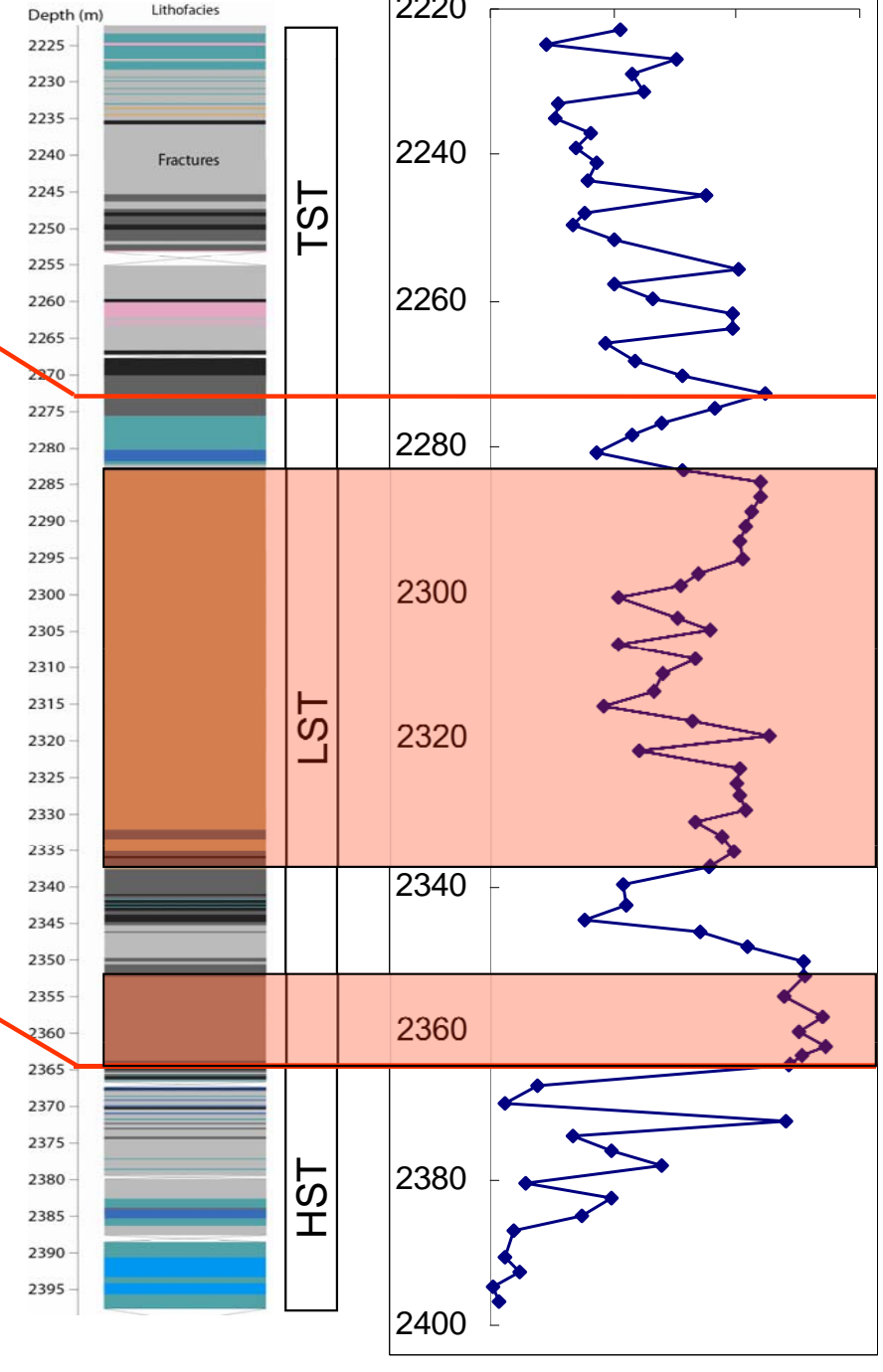


Komie well

Detrital flux



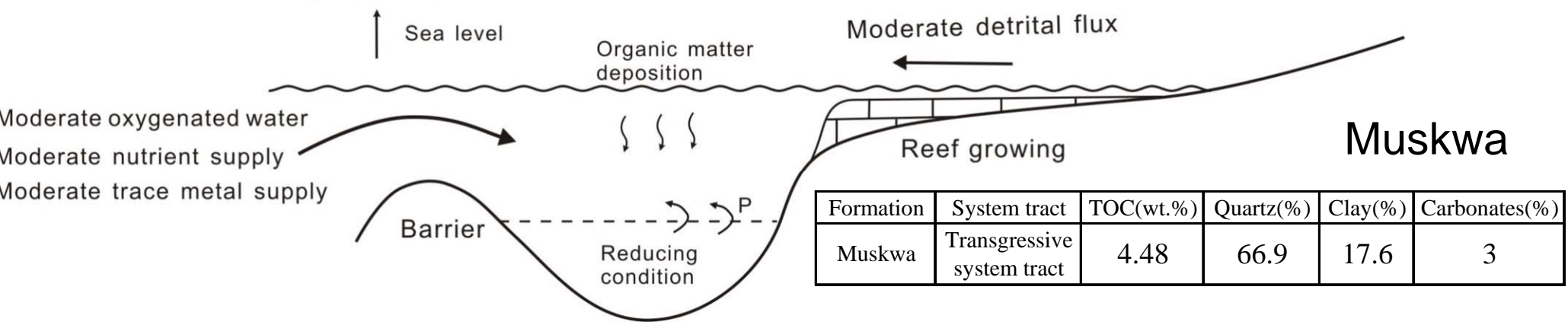
Maxhamish well



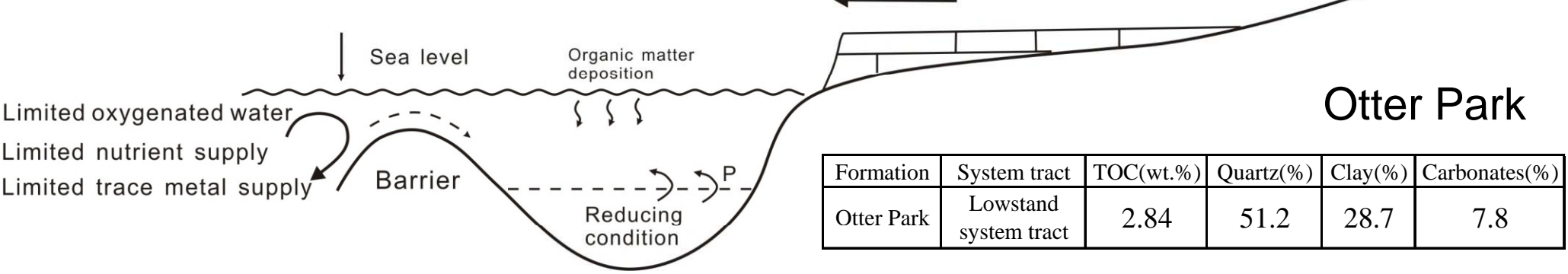
Komie well

Discussion

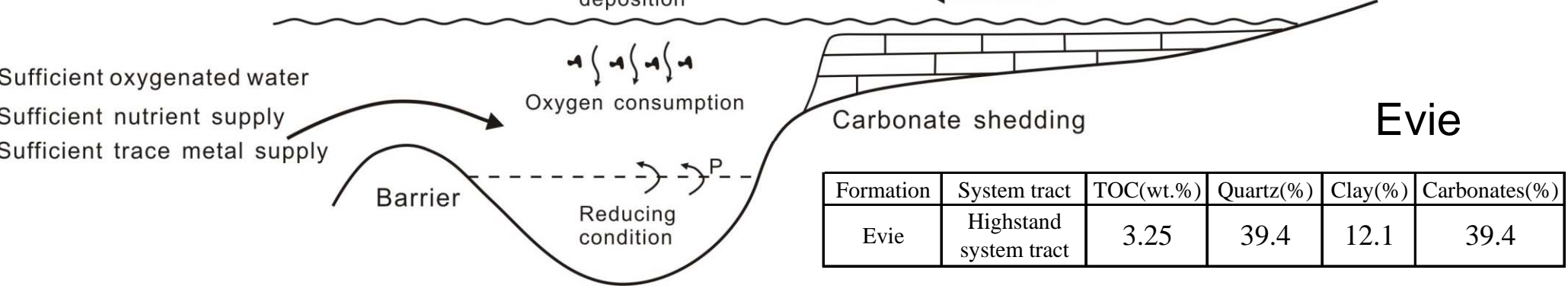
Transgressive system tract



Lowstand system tract



Highstand system tract



Conclusion

- Horn River shale was deposited in a restricted basin;
- Basin restriction proxy Mo/TOC can be a good expression of 2nd order and 3rd cycles of sea level;
- Probably mineralogy, especially clay content versus quartz concentration can be used to indicate sea level fluctuation;
- Factors controlling organic matter deposition, preservation and dilution are generally controlled by sea level variation.
- Muskwa and Evie formation assigned to transgressive and highstand system tract, having relatively high TOC and high brittle minerals (quartz and carbonate), which is favorable for shale gas production.

Acknowledgements

