

Trace Elements and Basin Processes: Woodford Shale, Permian Basin, West Texas*

Nicholas B. Harris¹

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Abstract

The trace and minor element geochemistry of the Upper Devonian Woodford Shale, Permian Basin, are analyzed in order to gain insights into paleoceanographic conditions and processes during deposition of this formation, which is a major source of hydrocarbons in the basin and an analog for many other Upper Devonian shales in North America and elsewhere. Stratigraphic relationships suggest that the Woodford was deposited during a second-order sea level fall, culminating in the deposition of cherts and organic-poor, highly bioturbated mudstones.

The Woodford lacks enrichment in many trace metals, in contrast to many organic-rich shales. Only Mo, U, S, and Se are significantly enriched. Other redox sensitive elements are depleted or similar to average shale composition, including Pb, Bi, Cr, Ti, Cu, Zn, Co, and V. Multivariate factors analysis identified associations between elements, including groupings of: rare earth elements; elements enriched in granitic crust; silica, varying antithetically with elements in carbonate minerals; organic carbon, Mo and U; V; phosphate; Fe and S. Noteworthy among the results are the different behavior of redox-sensitive element V in comparison to Mo and U, suggesting different precipitation mechanisms or varying dependence on reservoir effects. A strong basin reservoir effect is noted among several redox-sensitive elements, including Mo, Cu, and Ni, which likely accounts for the depletion of Cu and Ni.

A strong redox effect is noted in the TOC/P_{tot} ratio at the same depth where Mo/TOC ratios indicate a short-term significant fall in sea level. This is interpreted to approximate the Frasnian - Famennian boundary, which was marked by an abrupt long-term transition to an anoxic water column, based on the TOC/P_{tot} data. This suggests that anoxia was induced by isolation of the basin from the global ocean; somewhat surprisingly, there is little change in organic carbon content at this boundary. Re-Os geochronology for the Woodford section is similar to correlative sections of the Appalachian and Peace River Basins of North American and the Rhenohercynian basin of Europe. This indicates that although the Permian Basin became restricted during the upper Devonian and early Mississippian, ocean connectivity remained between regional and global basins.

Reference Cited

Comer, J.B., 1991, Stratigraphic analysis of the Upper Devonian Woodford Formation, Permian Basin, West Texas and Southeastern New Mexico: Report of Investigations No. 201, Bureau of Economic Geology, University of Texas at Austin, Austin, Texas, 66 p.



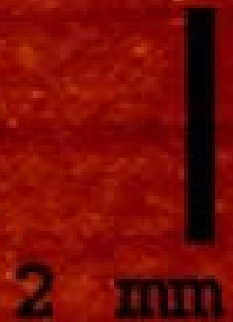
Trace elements and basin processes: Woodford Shale, Permian Basin, West Texas

Nicholas B. Harris

Earth & Atmospheric Sciences

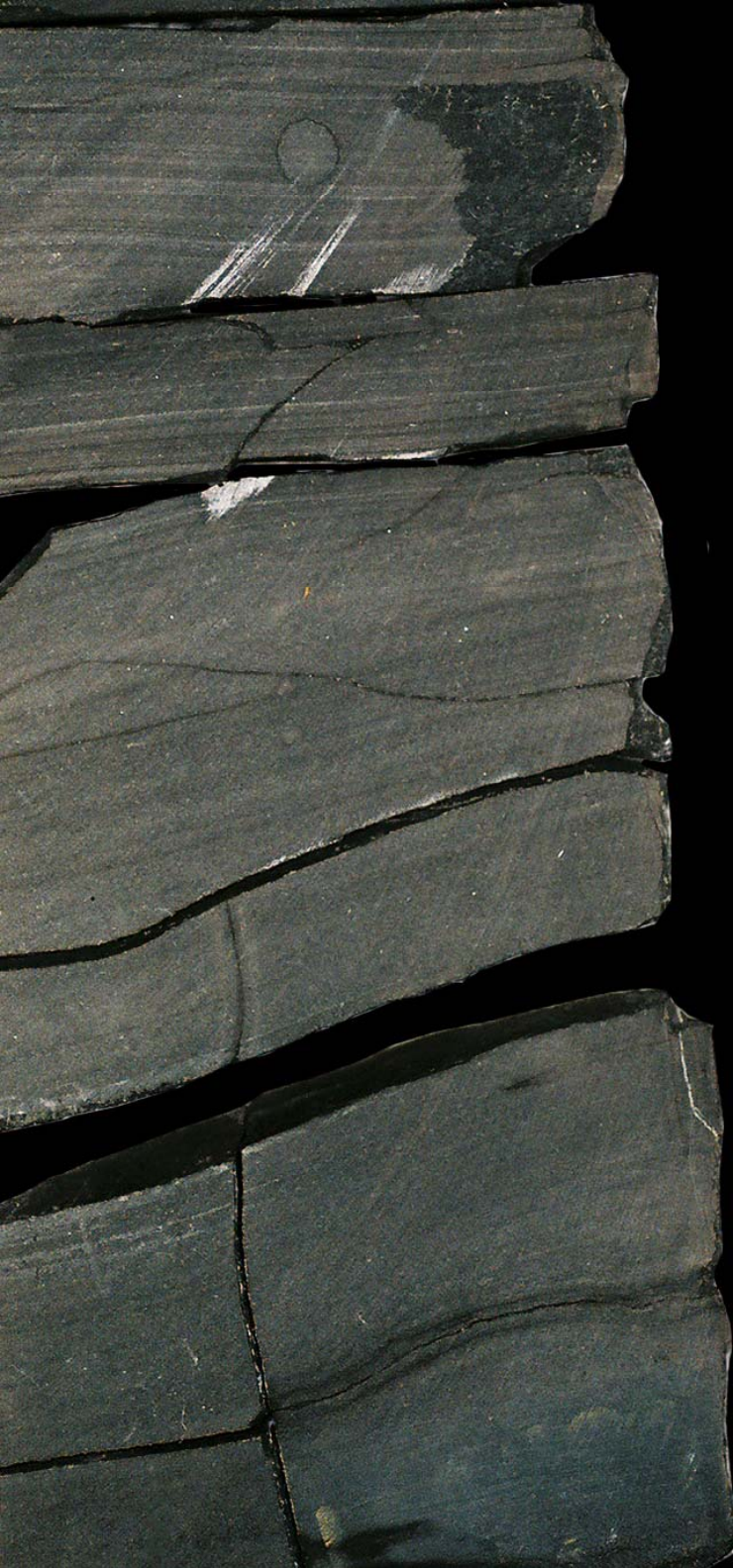
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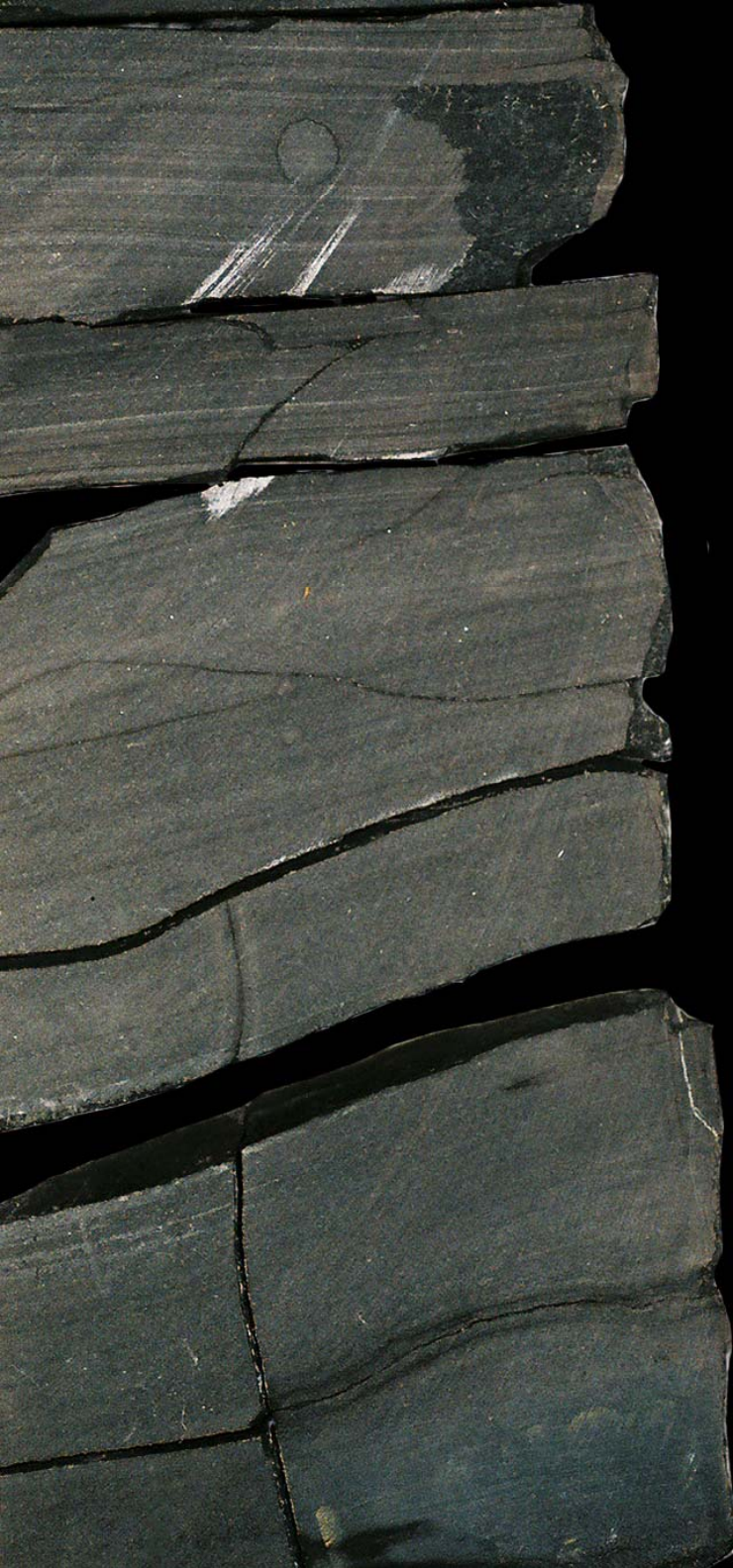


When shale textures are hard to read, what can you learn from trace element data?



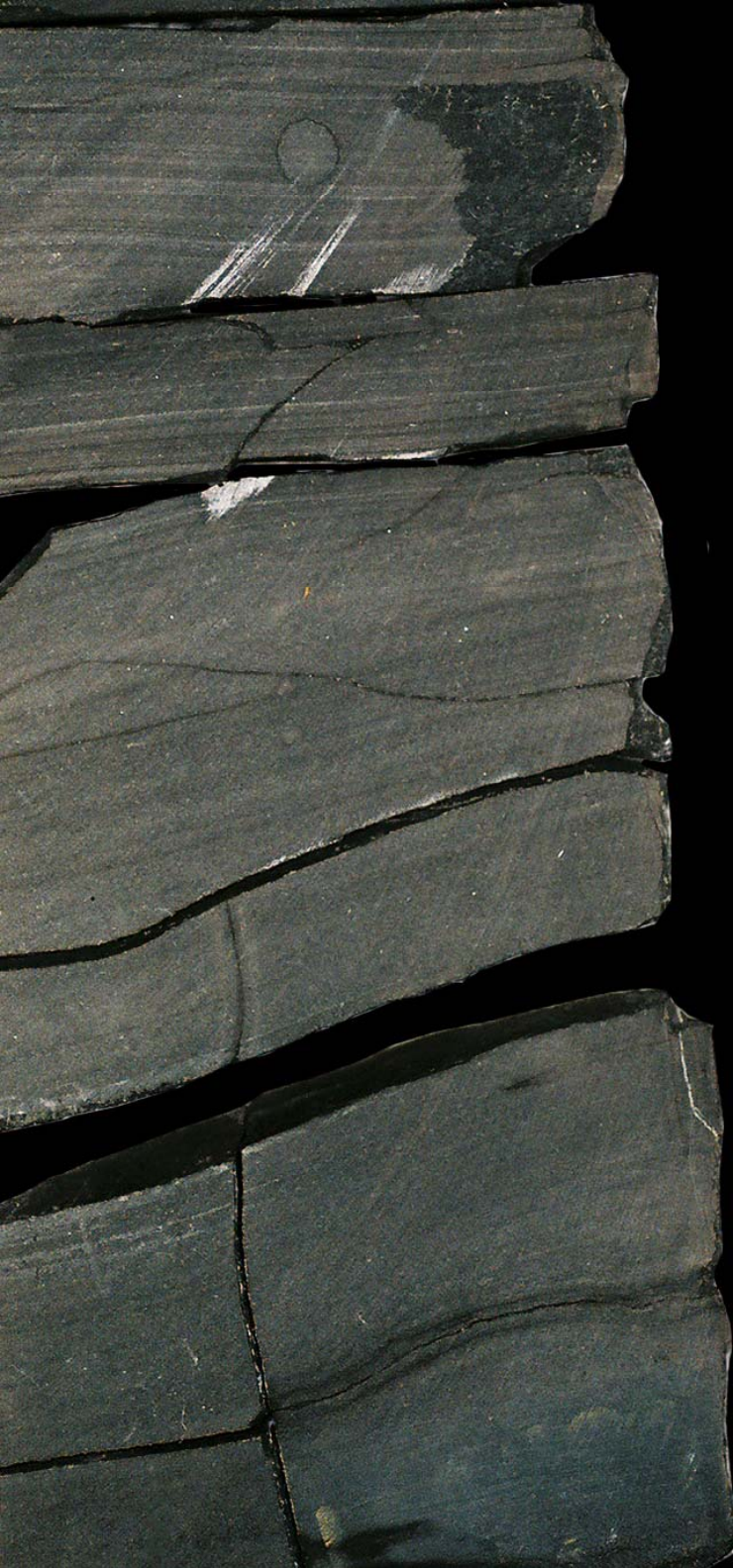
When shale textures are hard to read, what can you learn from trace element data?

- 1) Paleooceanographic conditions (water body circulation, redox conditions)
- 2) Mechanisms of organic matter accumulation
- 3) Correlations
- 4) Sources of sediment



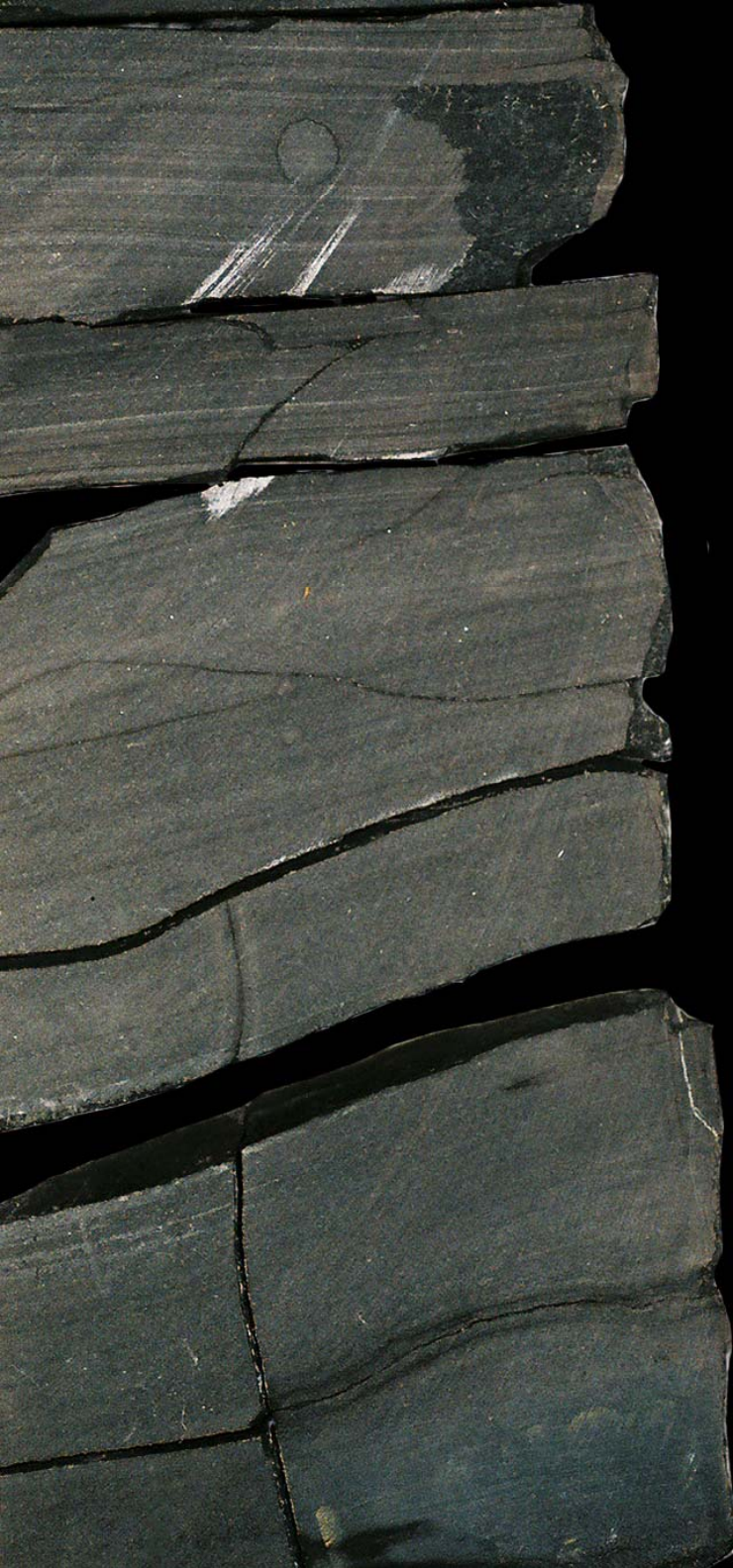
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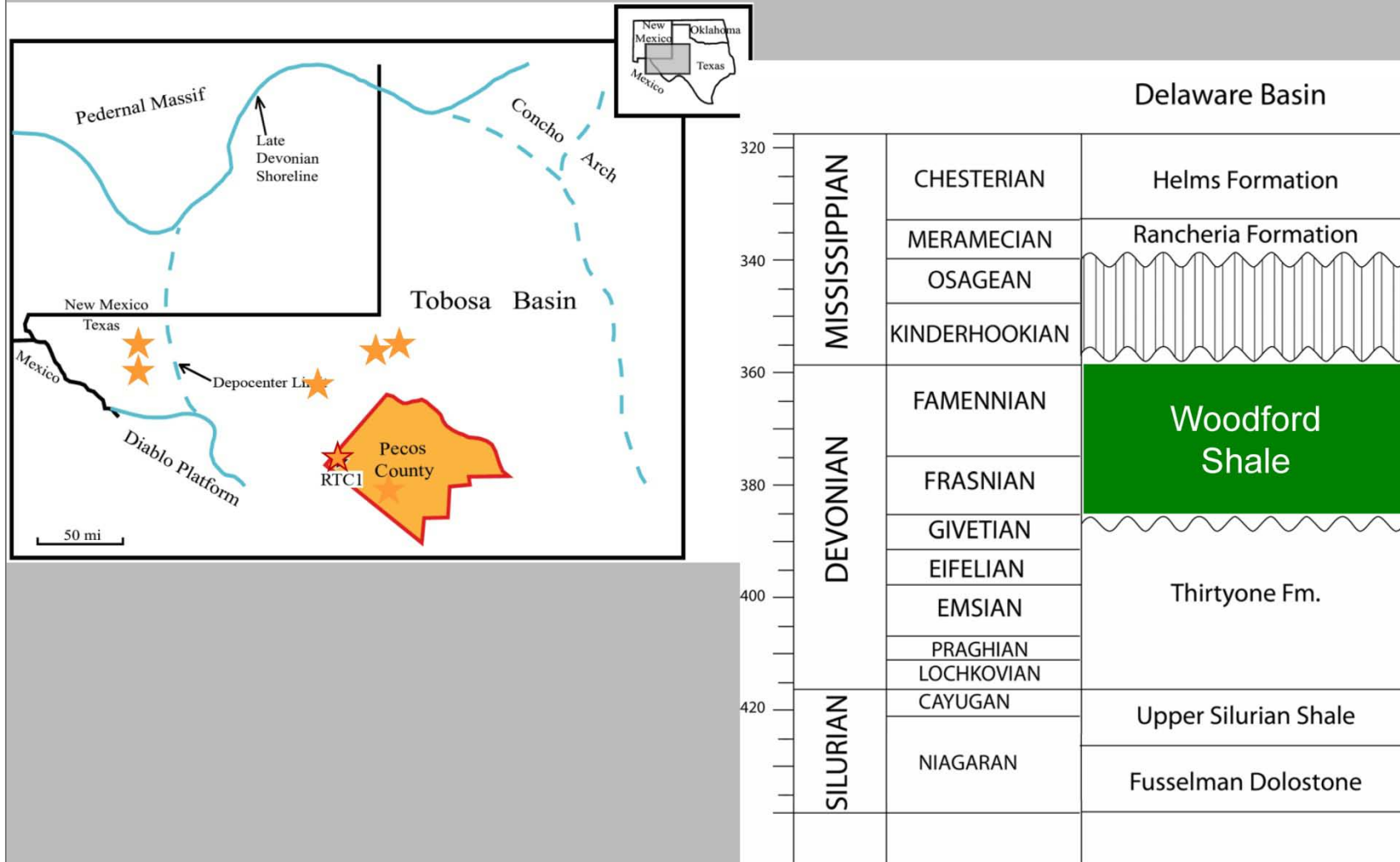
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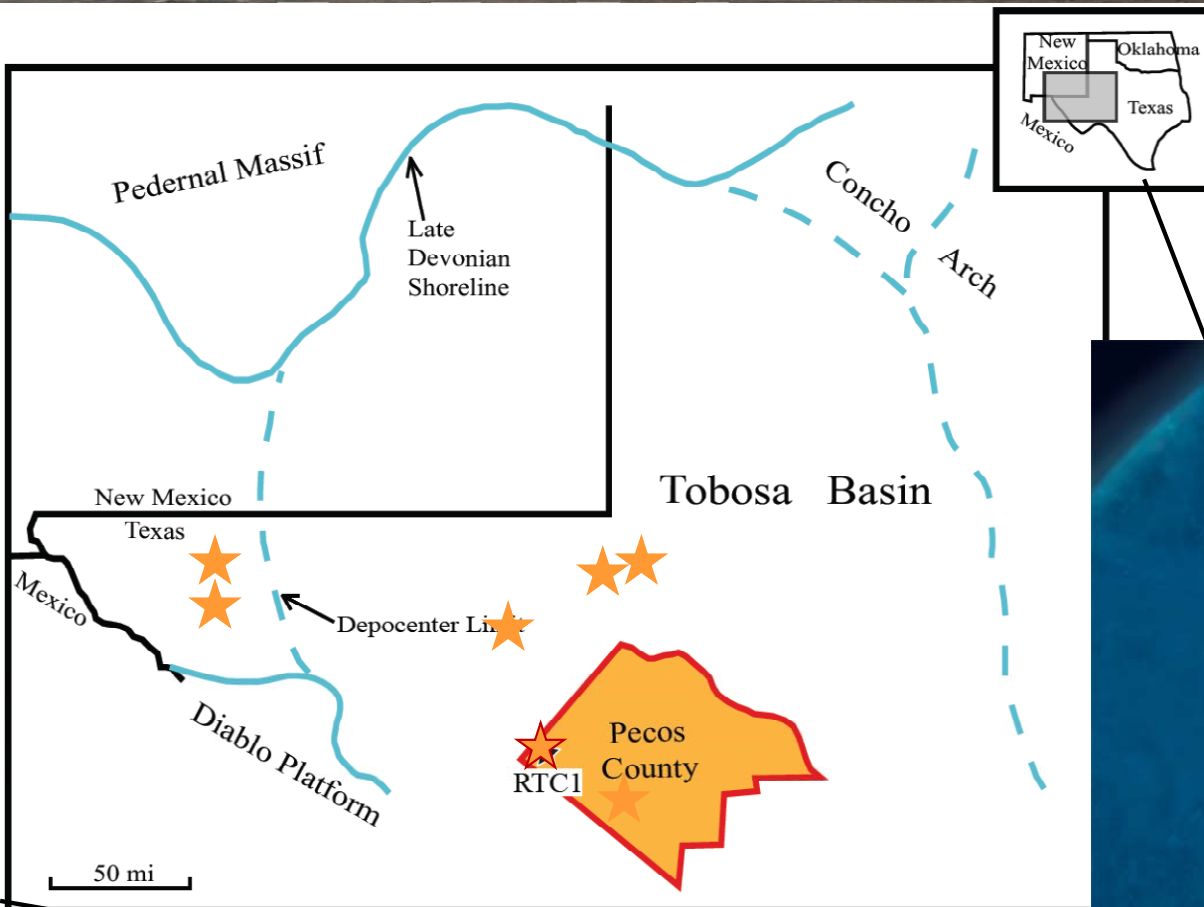
Geologic Setting



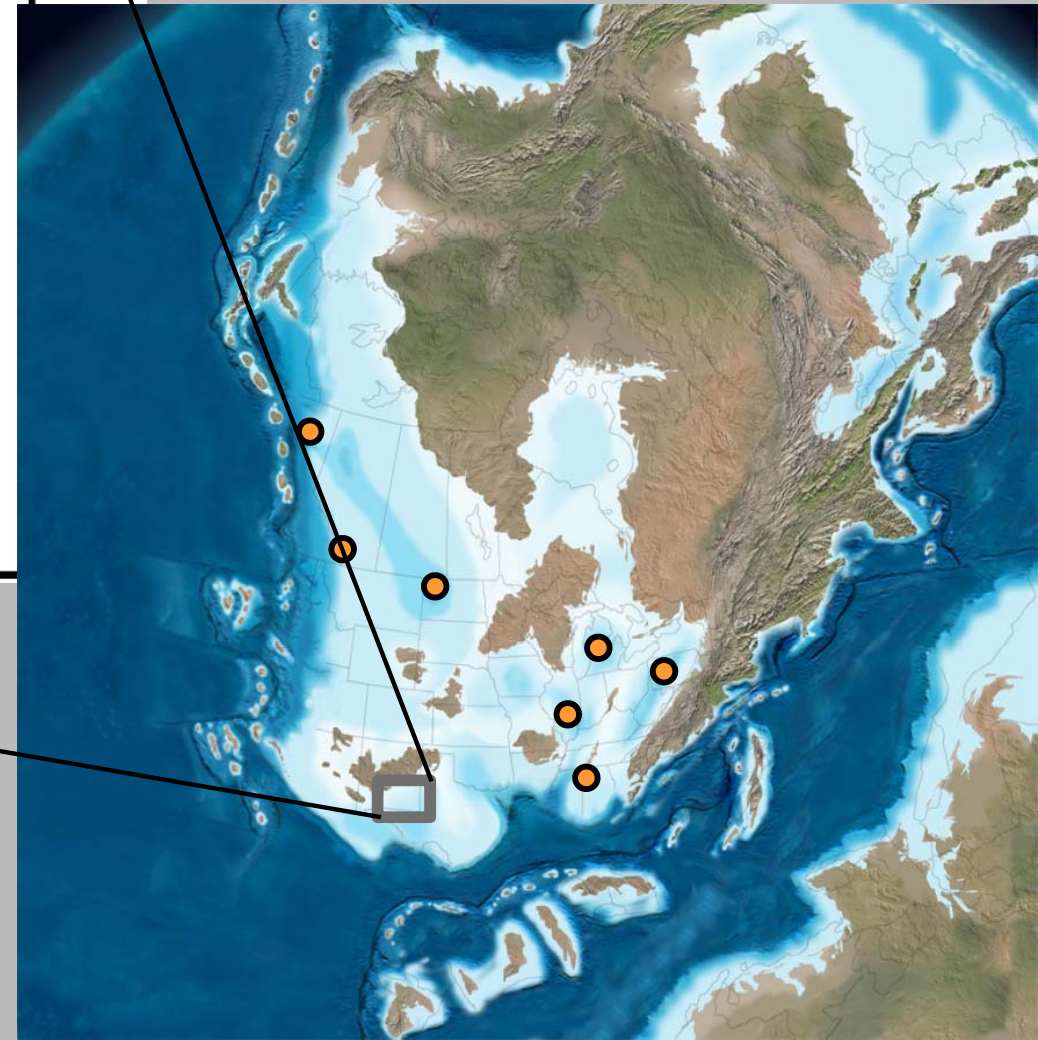
Presenter's notes: Our focus area is the Permian Basin in west Texas. For this study, we've been given access to a number of long cores by operators in the basin, indicated by the stars. In this talk, I'll be describing our observations in the RTC 1 core.

Paleogeography

Woodford Shale
Consortium



Late Devonian paleogeography

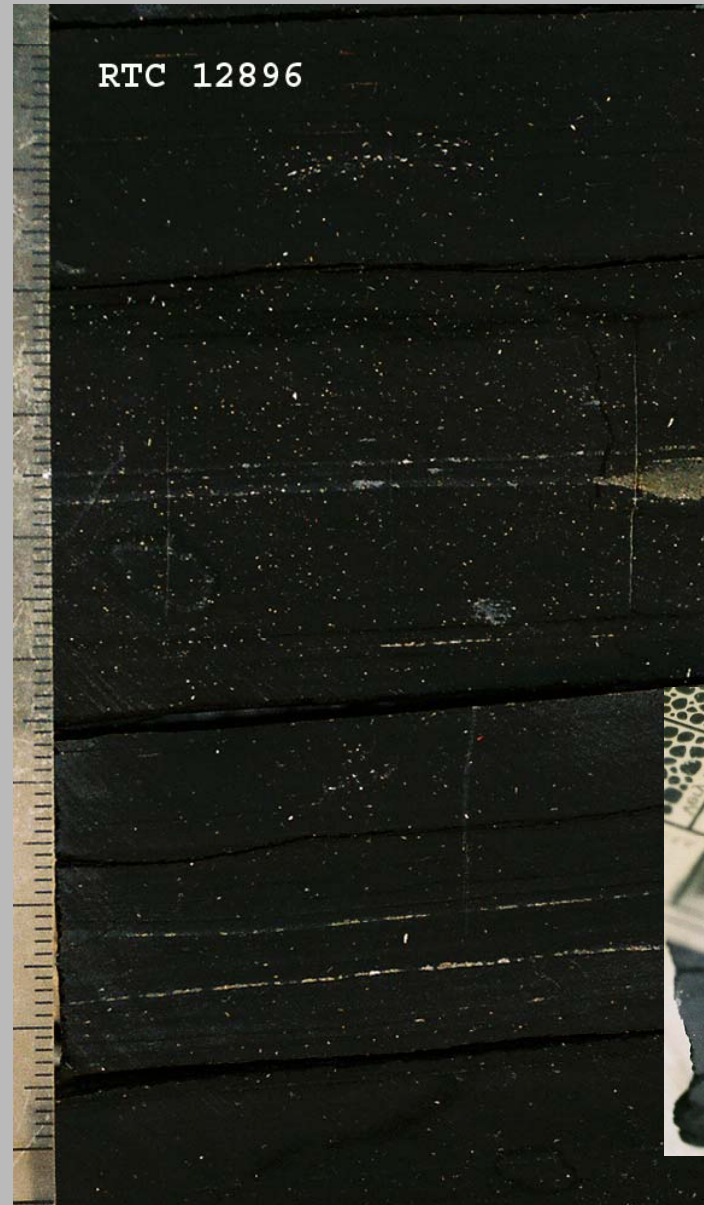
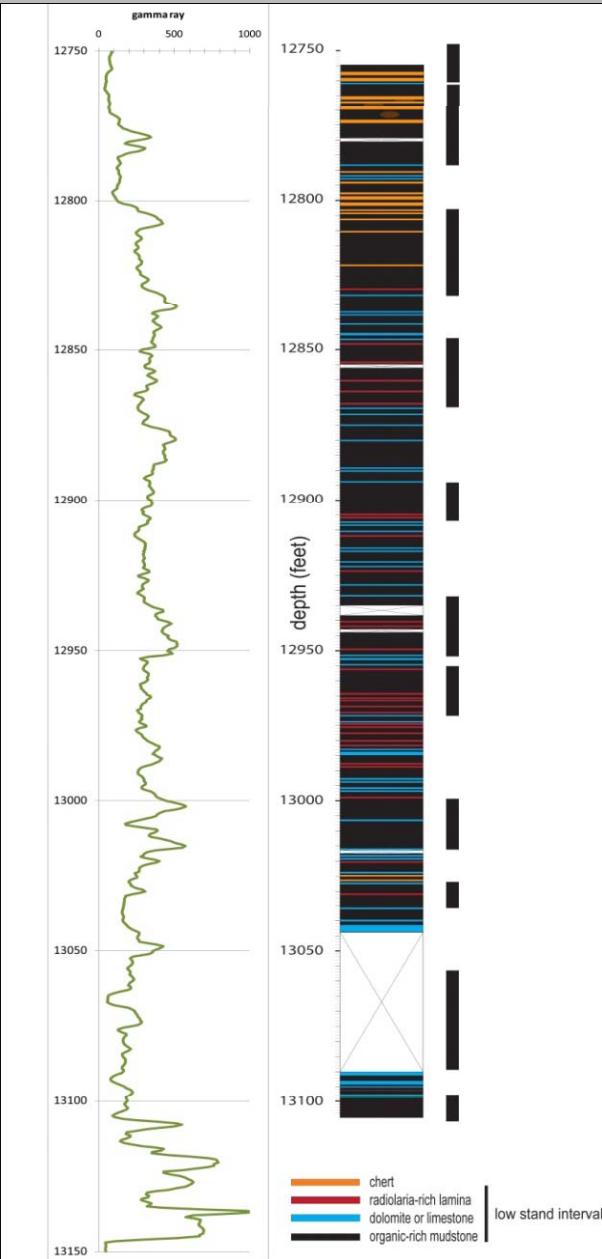


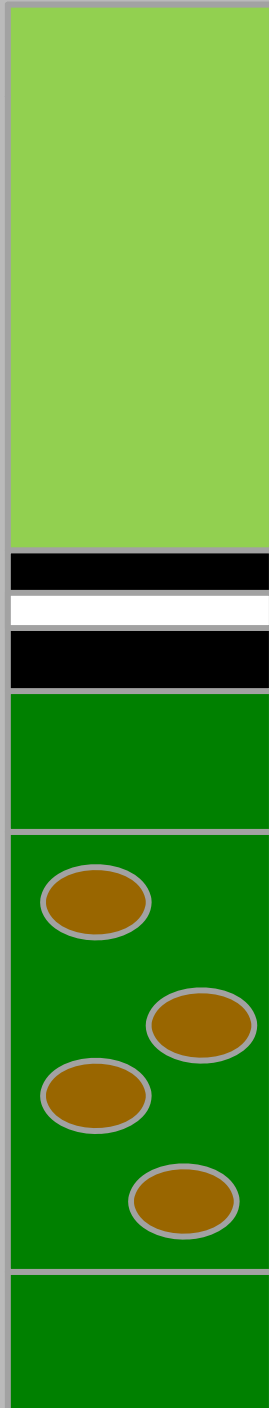
Modified from
Comer (1991)

Reliance Triple Crown #1

Woodford Shale
Consortium

Black Mudstone Lithofacies



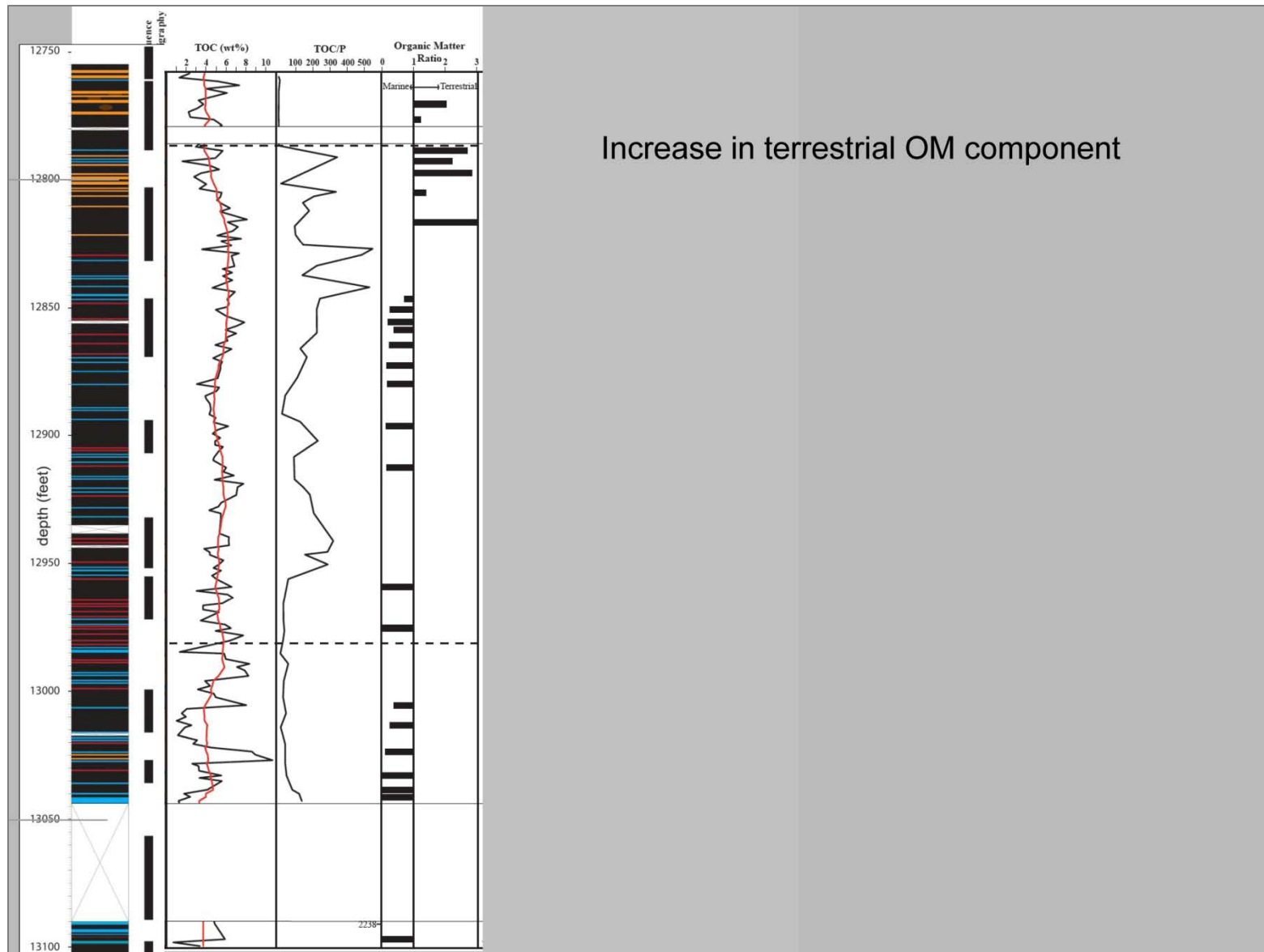


organic mudstone with
phosphate nodules

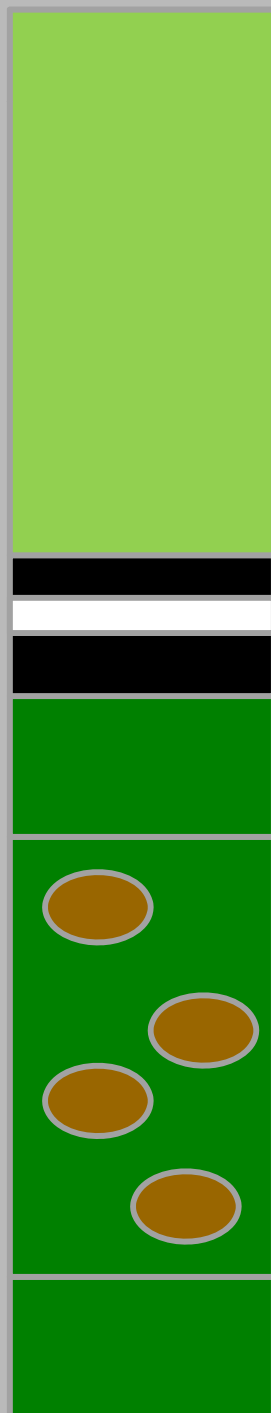


Upper Woodford

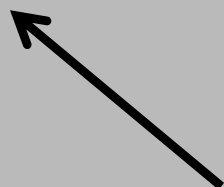
Middle Woodford



Presenter's notes: Finally, we see a change in the type of organic matter present in the Woodford. That is represented by the bars on the right hand side of the figure. Throughout most of the Woodford, the dominant form of organic matter is marine, shown by bars projecting to the left. But in the upper part of the Middle Woodford, there's a distinct change in the organic assemblage, with the upper part of the formation dominated by terrestrial, plant-derived organic matter. You can see the bars projecting to the right here. This is also consistent with the model of falling sea level. As sea level drops, sources of terrestrial organic matter move closer to the basin center, so that begins to dominate the organic assemblage.

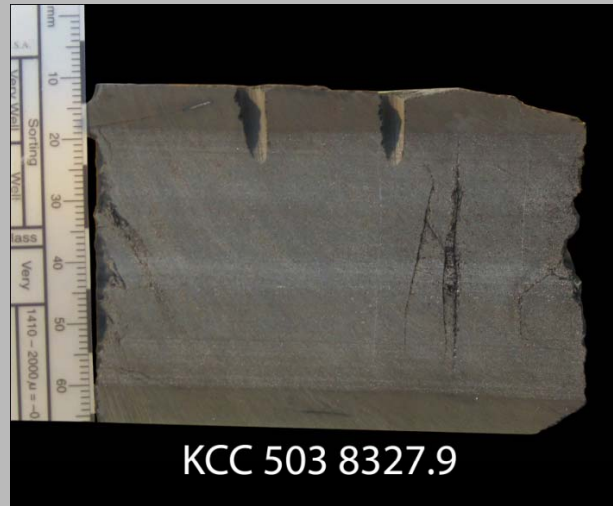
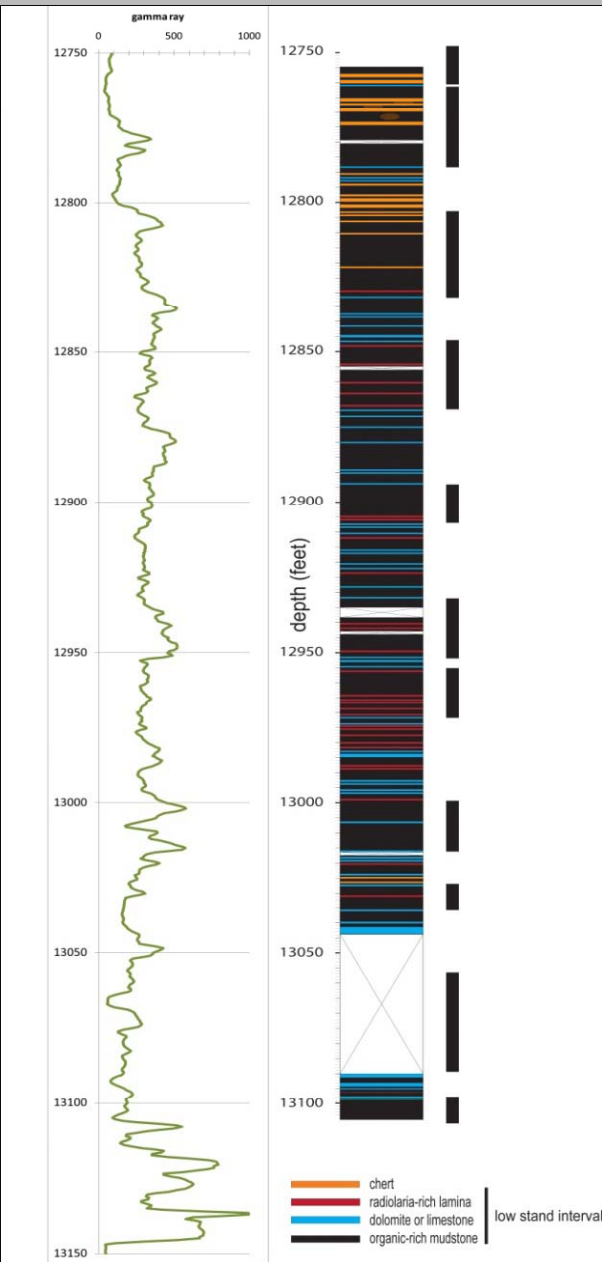


bioturbated
mudstone



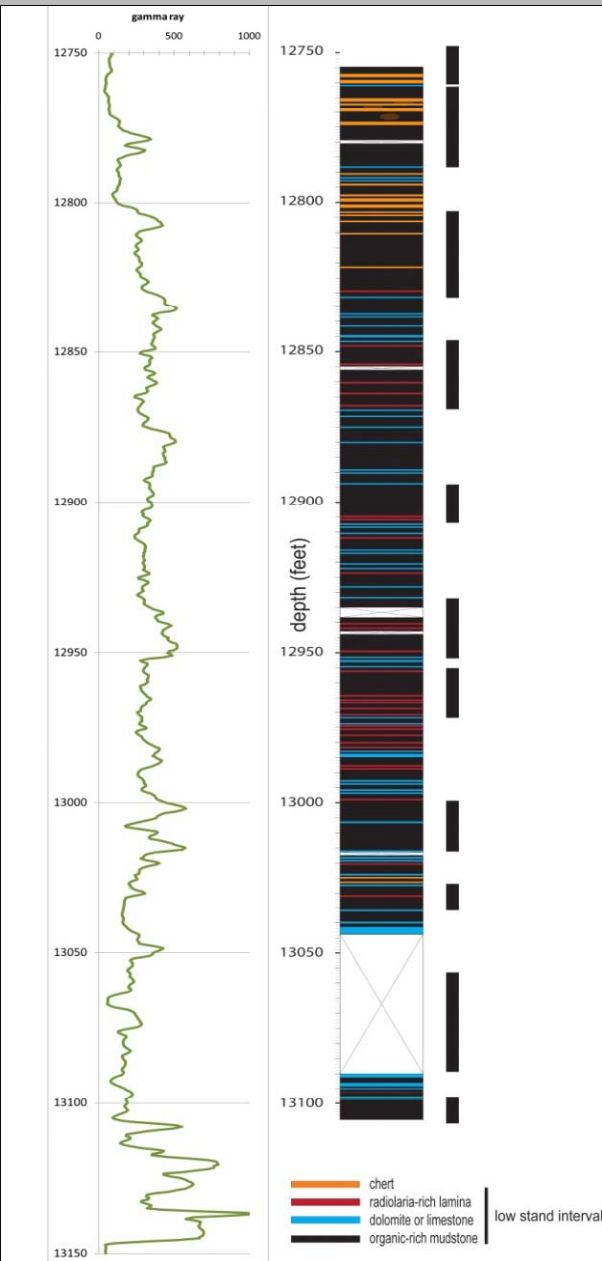
novaculite

Minor lithofacies within the organic mudstone



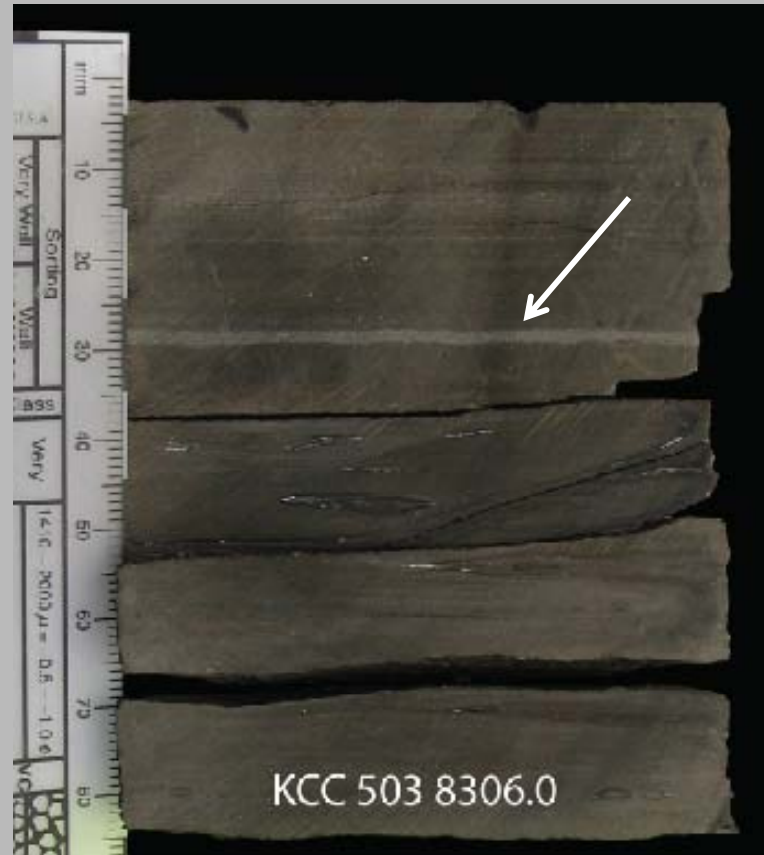
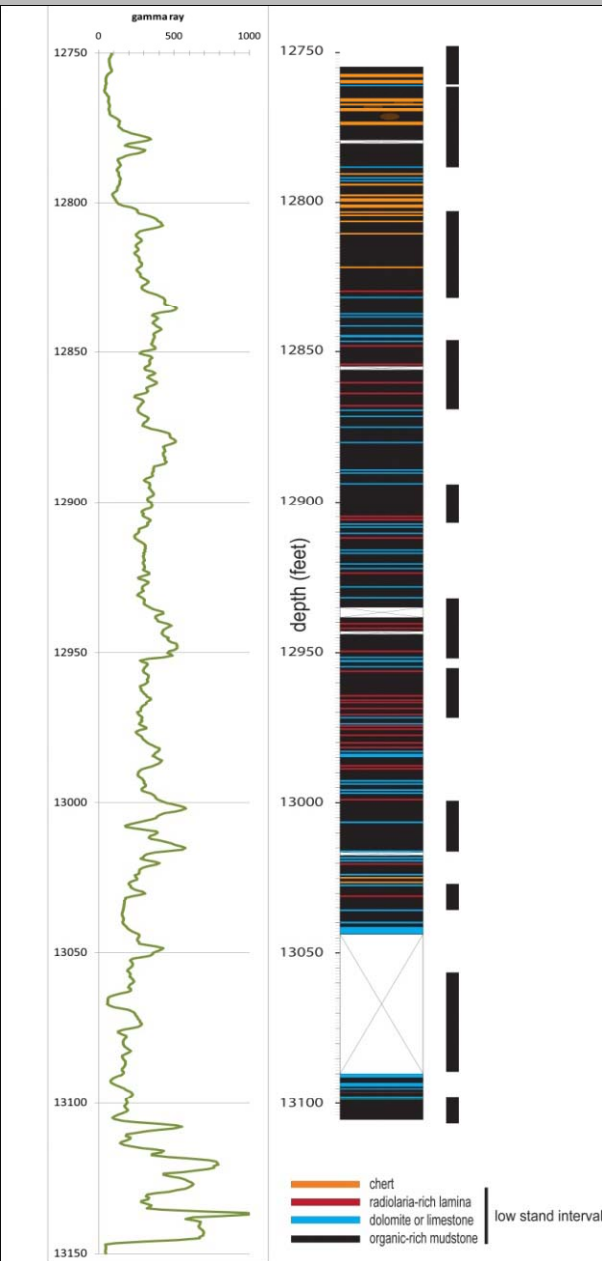
Chert beds
(orange)

Minor lithofacies within the organic mudstone



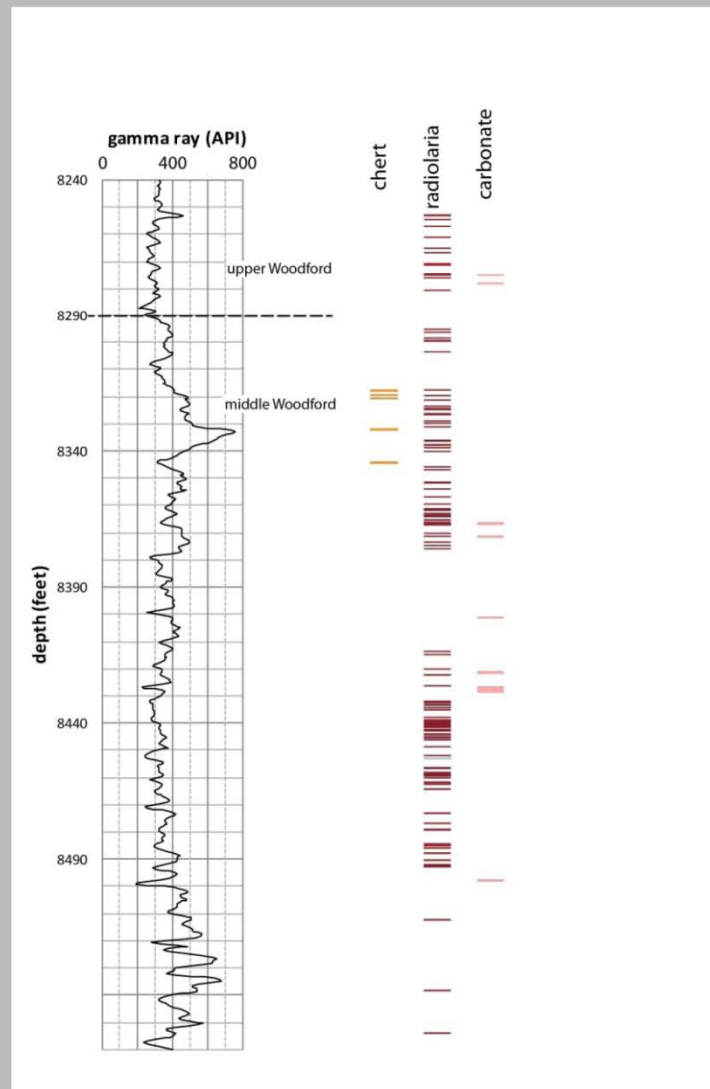
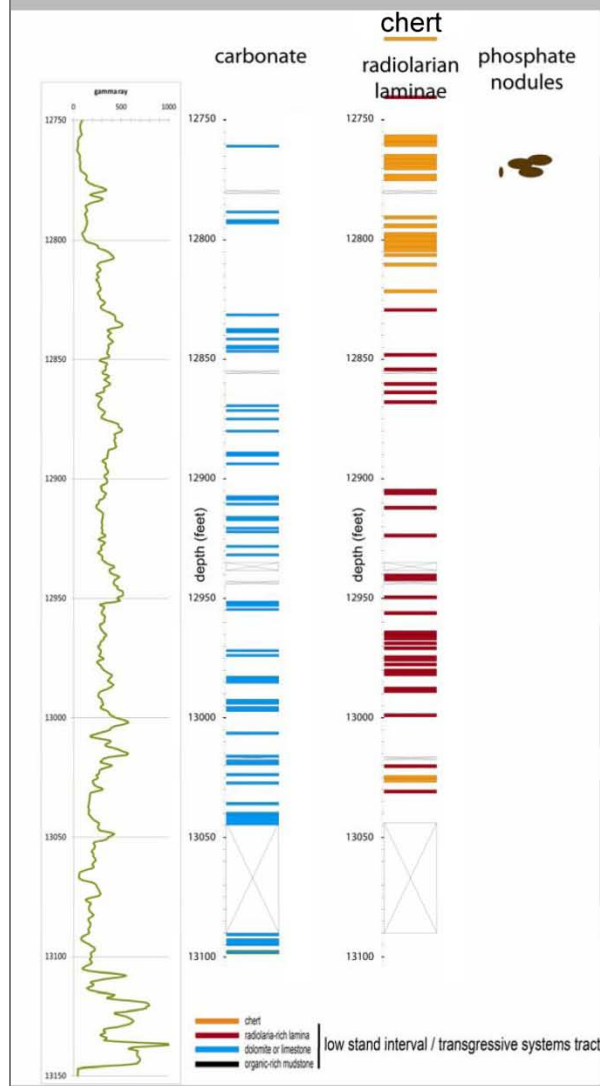
Dolomite beds
(blue)

Minor lithofacies within the organic mudstone



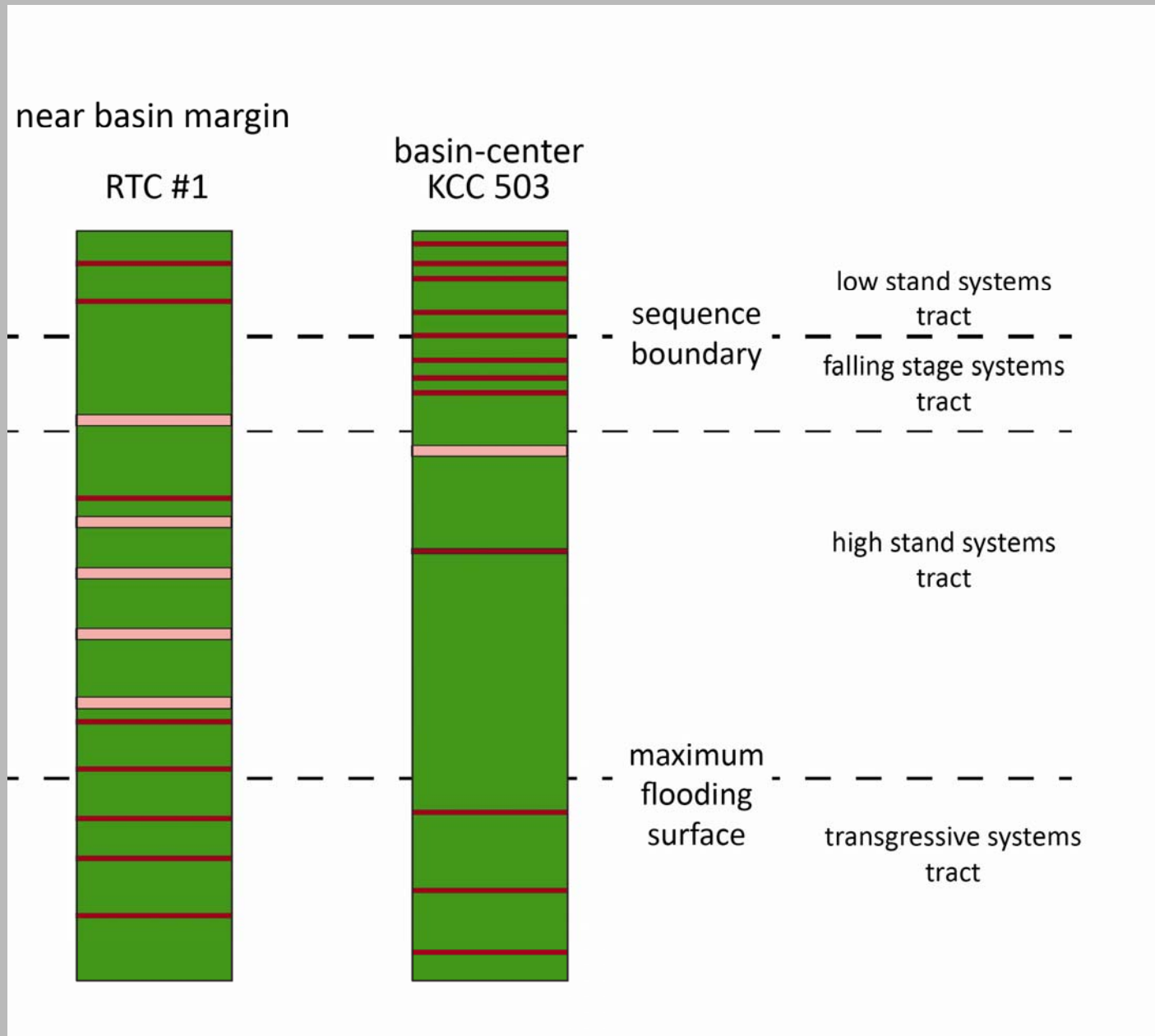
Radiolarian
laminae

(dark red)



Presenter's notes: But we also see longer-term variations in the Woodford. Look, for example, at the distribution of the exotic beds. These clearly become more abundant upward, starting near the Middle Woodford – Upper Woodford contact. The simplest interpretation is that we're seeing a long-term fall in sea level, bringing the carbonate platform closer to the center of the basin during deposition of the Upper Woodford.

The style of bundling depends on where you are ...



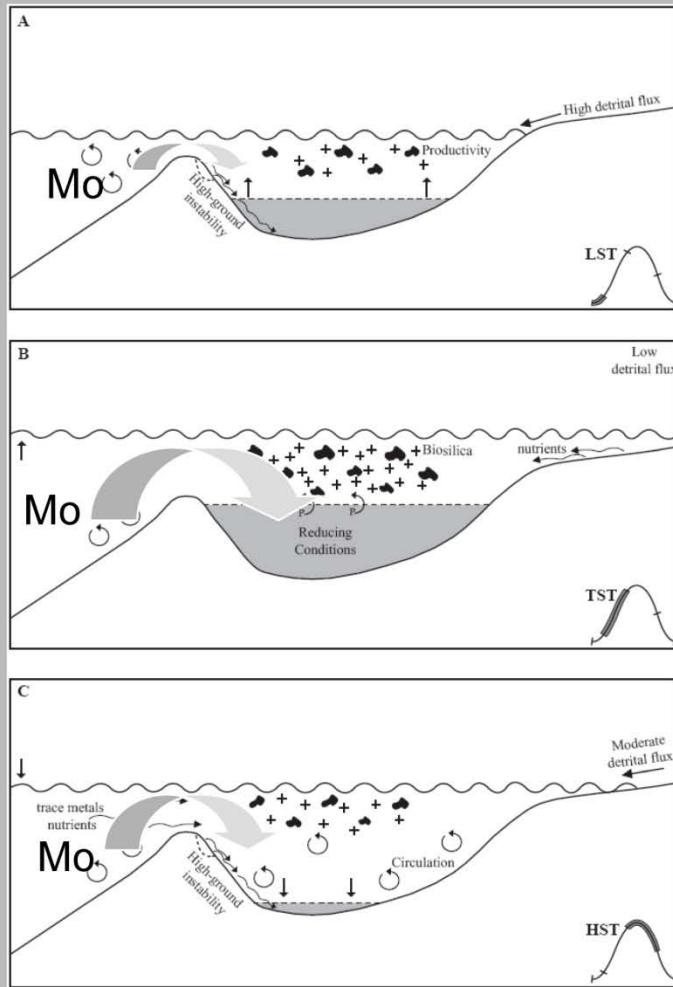


When shale textures are hard to read, what can you learn from trace element data?

- 1) Paleooceanographic conditions (water body circulation, redox conditions)

→ Sea level

Silled Basins – The ‘Basin Reservoir’ Effect



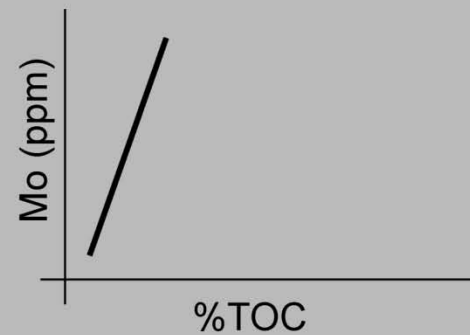
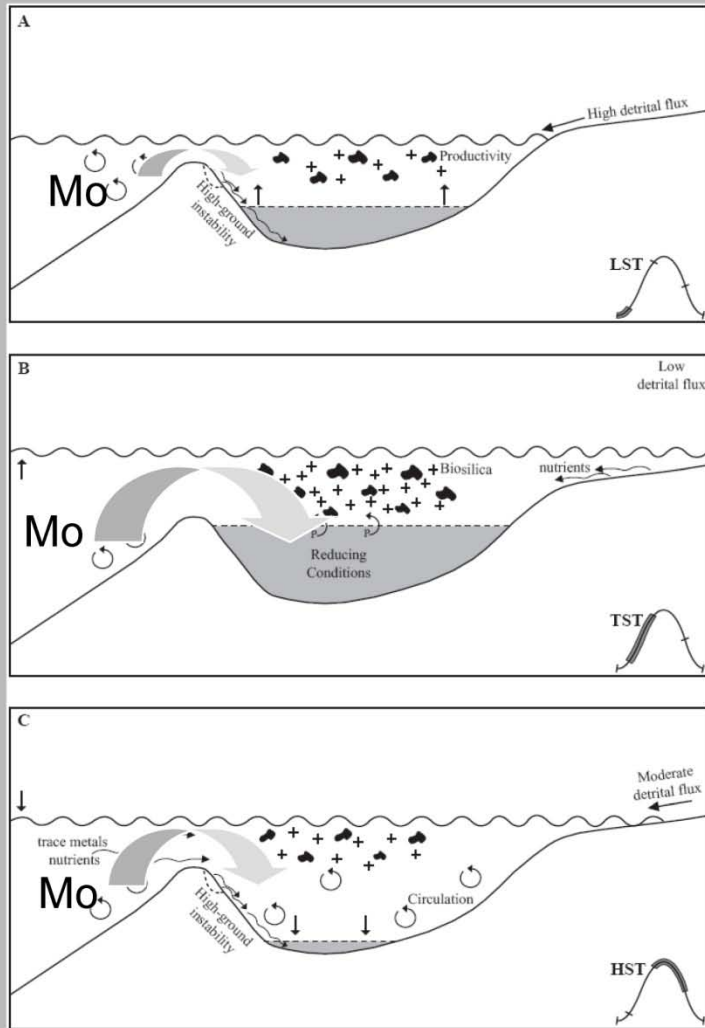
Mo behavior

Mo recharge from global ocean varies with degree of restriction across barrier.

Mo concentration should vary with sea level AND redox conditions.

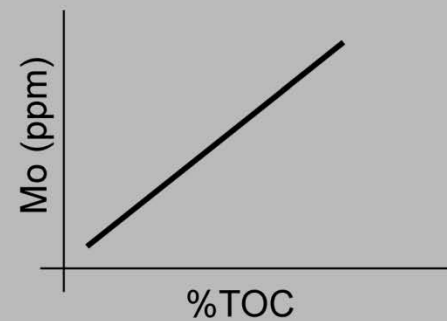
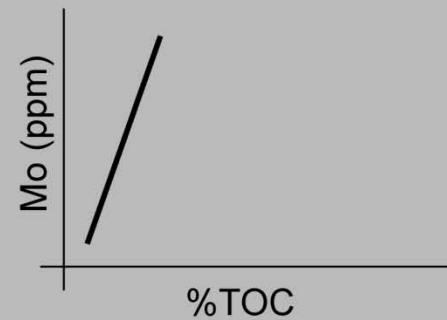
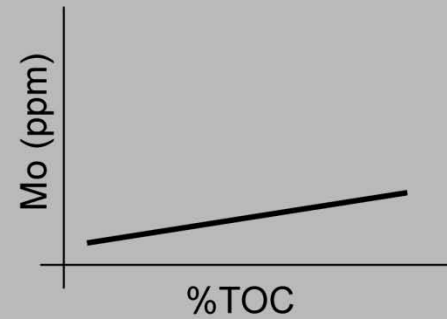
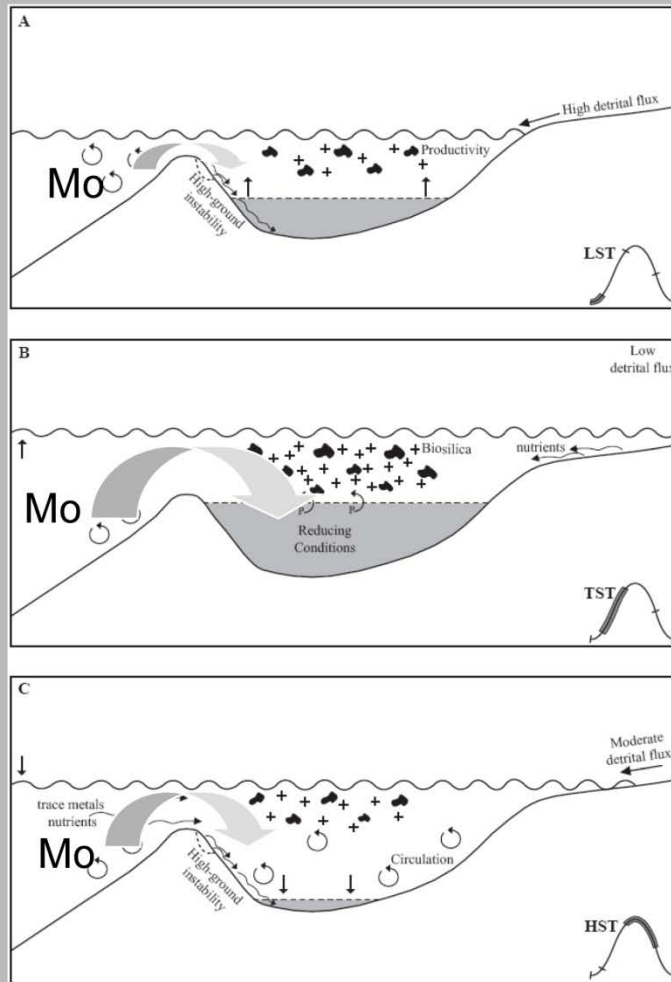
Presenter's notes: Molybdenum is a really interesting element, telling us a lot about ocean circulation in a restricted basin. Moly deposition is controlled by redox conditions, so we generally see a correlation between total organic carbonate content. But moly is also supplied from the global ocean, so the degree of restriction becomes very important.

Silled Basins

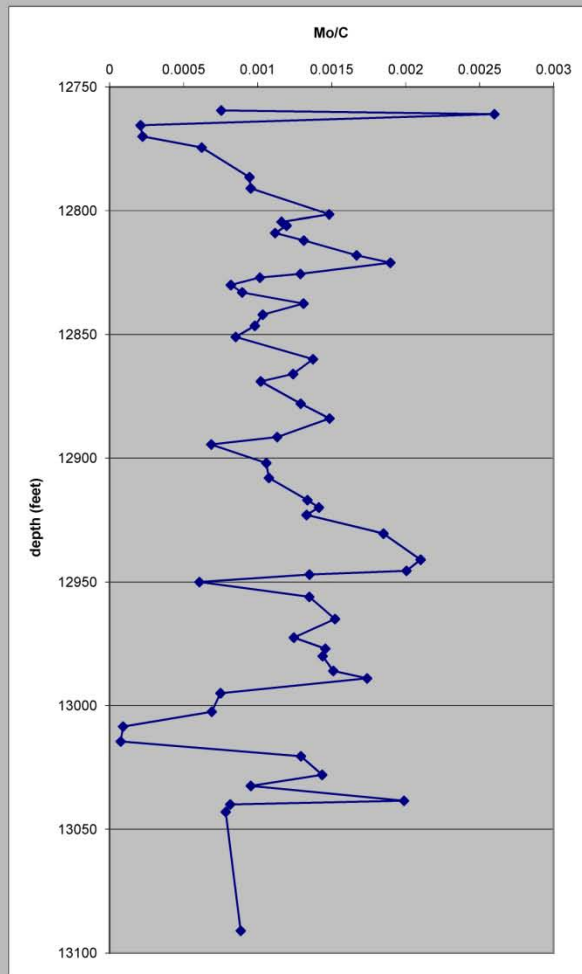


Presenter's notes: If you look at one particular basin, you generally see a linear relationship between Mo and TOC; as TOC increases, the Mo content of the shale also increases.

Silled Basins



Presenter's notes: But if you look at several basin, something interesting emerges. Some very good work by Tom Algeo at the University of Cincinnati has shown that the ratio of Mo to TOC is sensitive to the degree of restriction, which you see in the slope of the line on a Mo-TOC cross plot. When a basin is restricted, the slope of the line, the ratio of Mo to TOC, is low. When the ratio is high, the ratio of Mo to TOC is high.

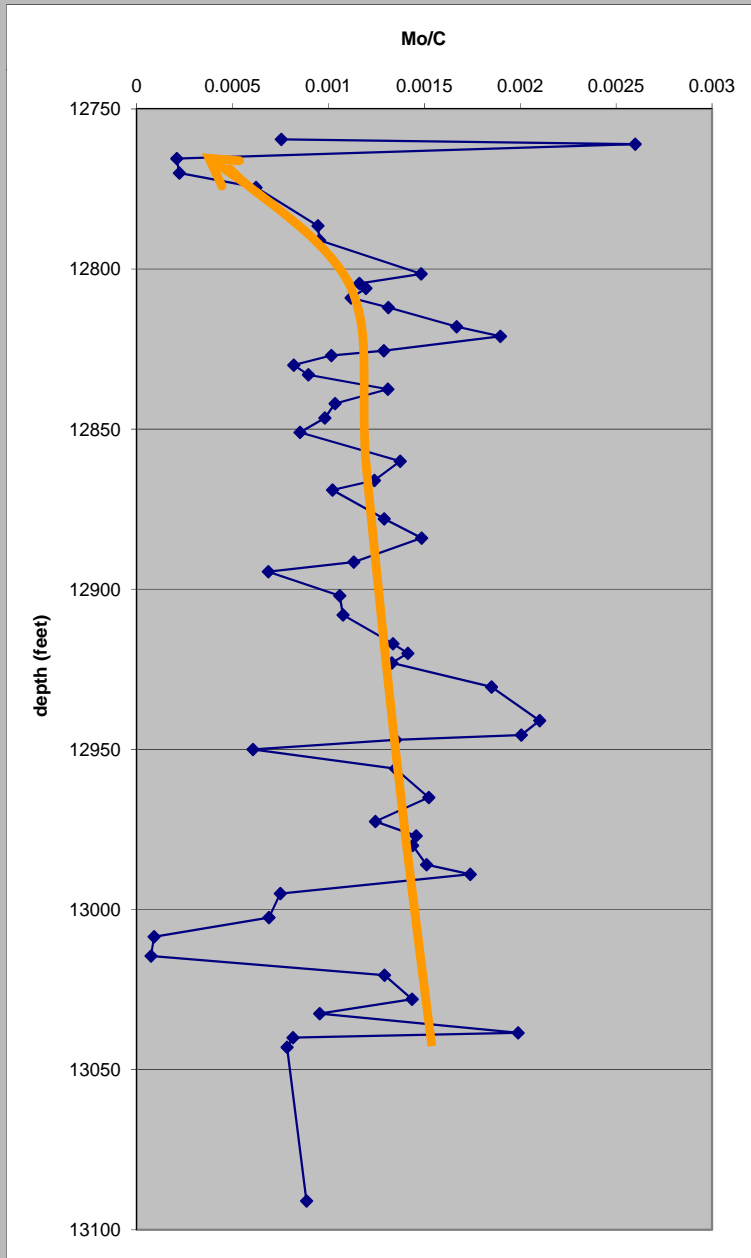


Mo / C ratios decrease systematically to the top of the formation

- A proxy for sea level

very restricted  open

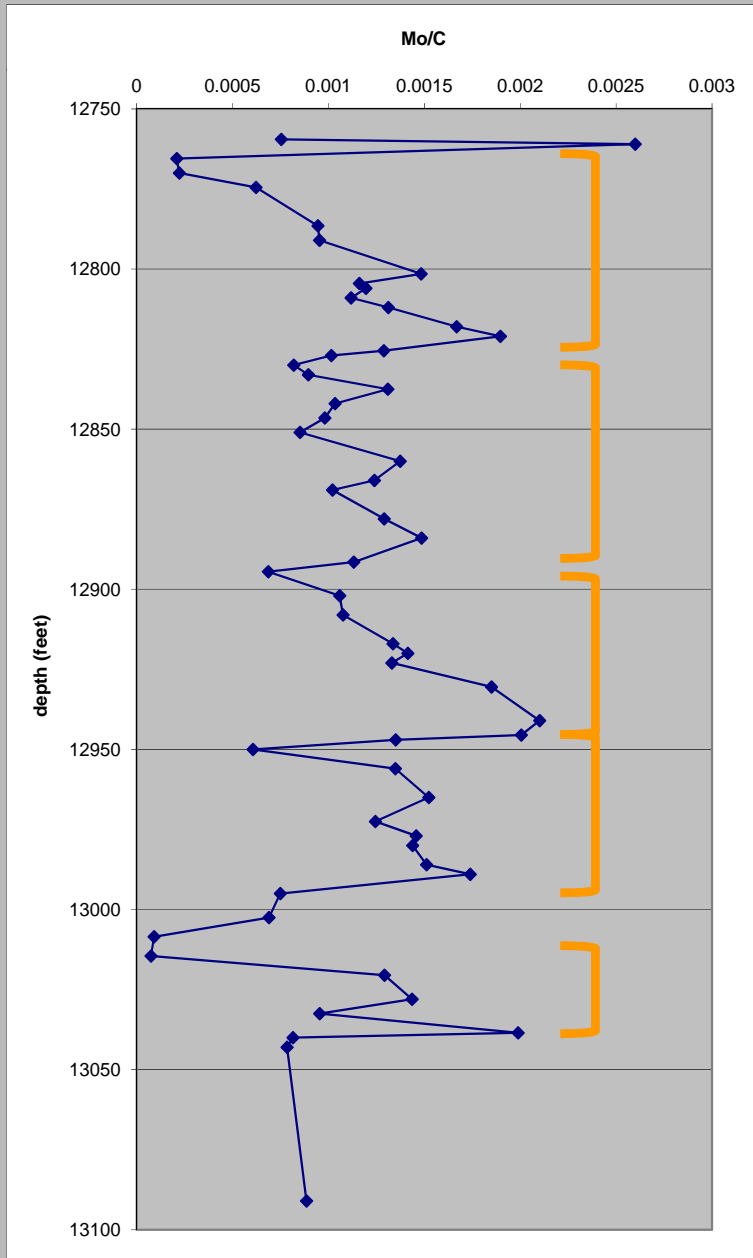
Presenter's notes: We think that this relationship can be applied stratigraphically. In other words, if you look at the ratio of Mo to TOC vertically through Woodford section, you would have a measure of the degree of restriction in the Permian Basin and therefore a proxy for sea level. What you see is an overall decrease in Mo/TOC upward through the Woodford section; this corresponds to the 2nd order sea level fall that we know occurred in the Late Devonian. The smaller scale variability in Mo/TOC corresponds to the 3rd and 4th order sea level cycles.



Mo / C ratios decrease systematically to the top of the formation

- A proxy for sea level

very restricted ← → open



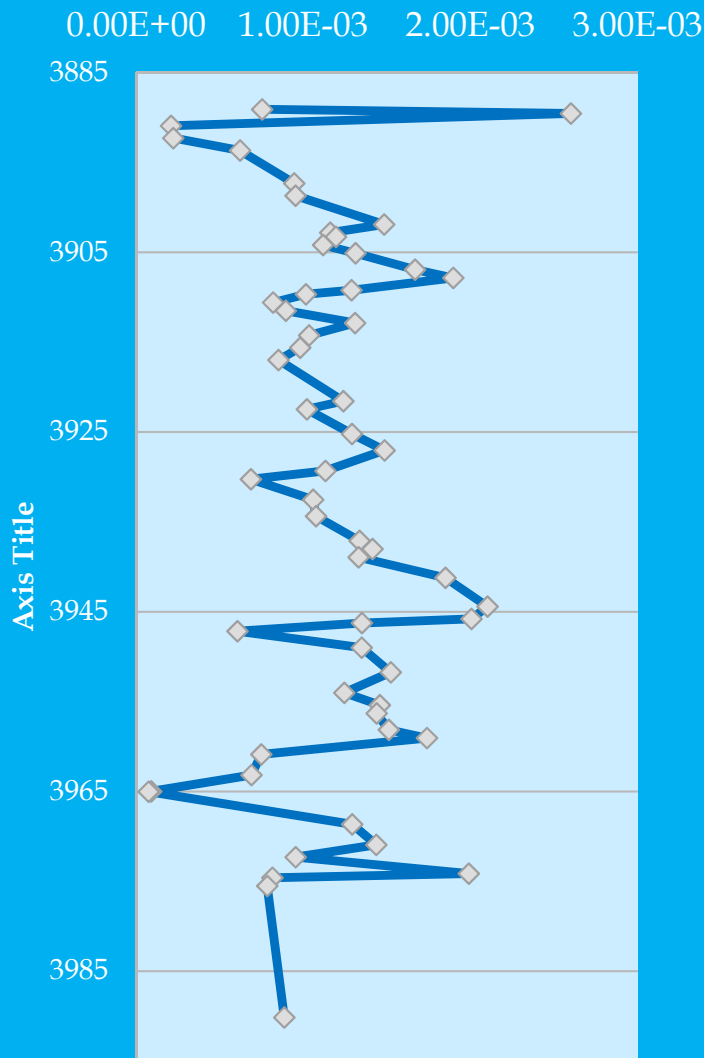
Smaller Mo / TOC

- Reflect 3rd order sea level cycles

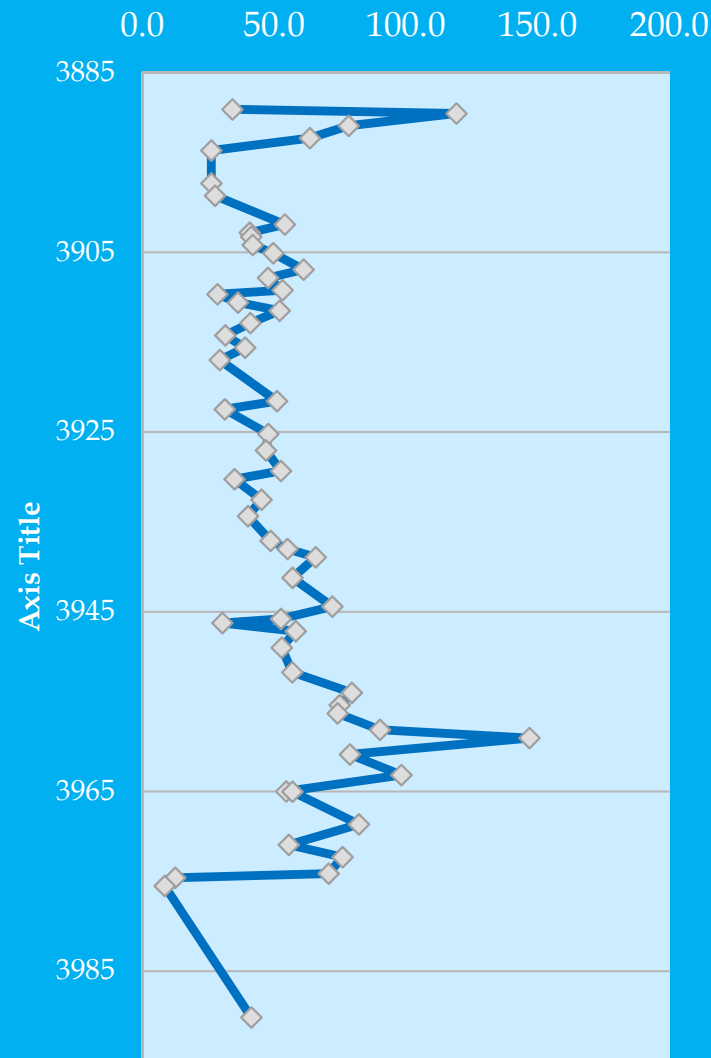
very restricted ← → open

Basin Reservoir Effect in Mo and Cu

Mo/TOC

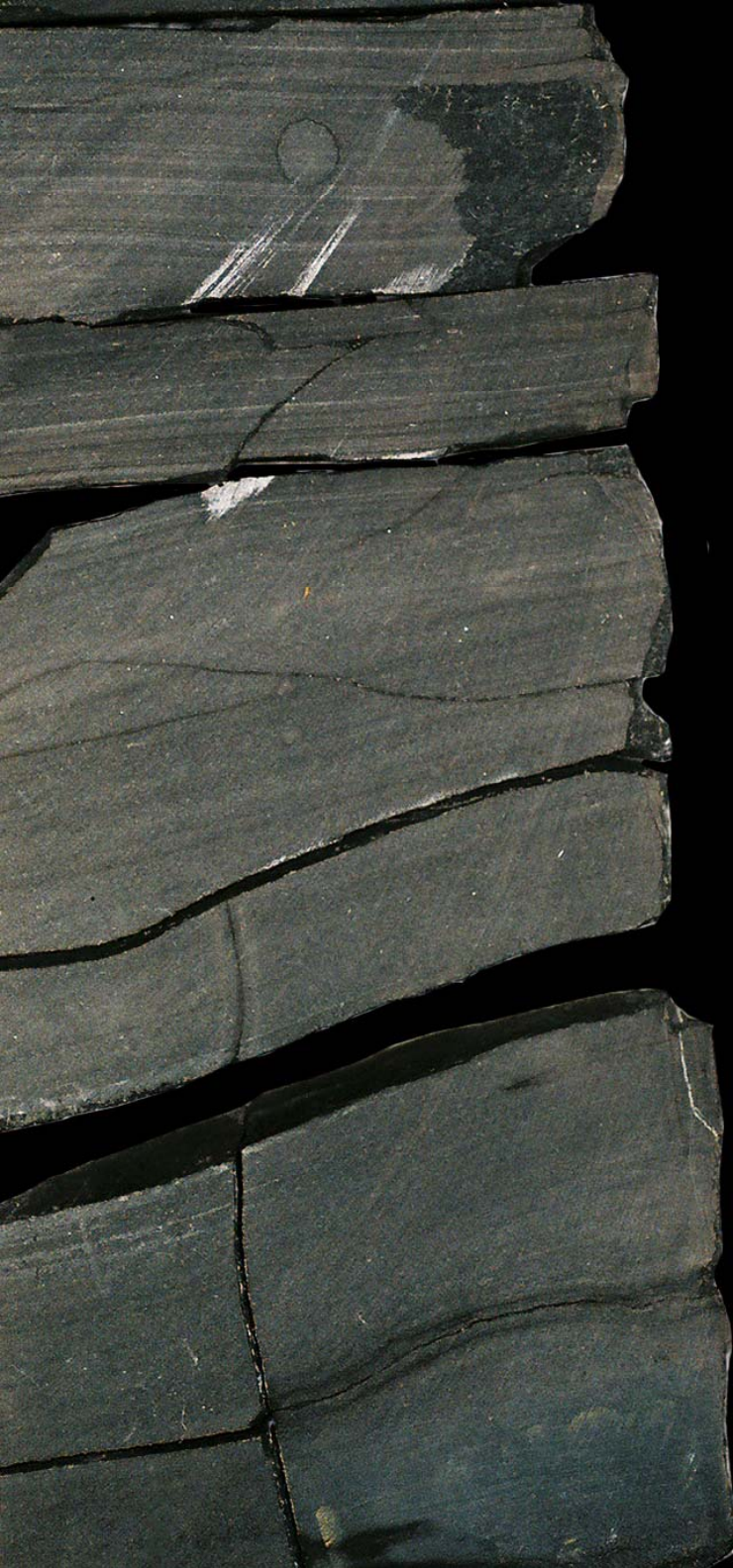


Cu/TOC



Both Mo and Cu appear to reflect the basin reservoir effect.

Both elements that are (1) redox-sensitive and (2) derived from the global ocean.



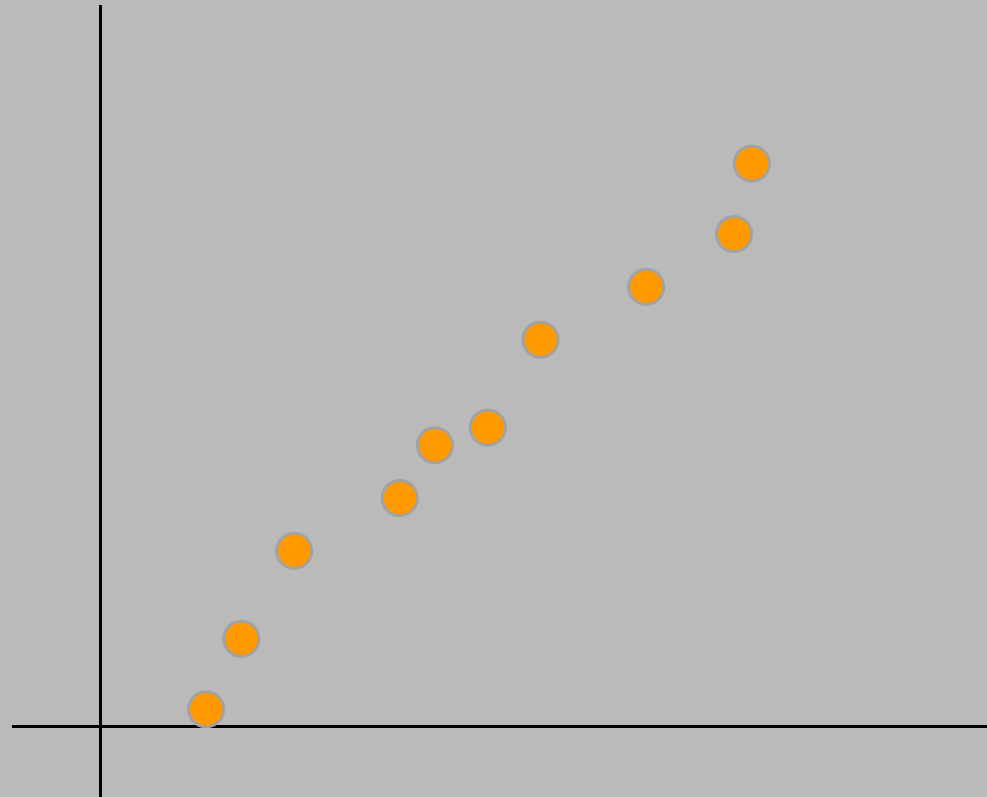
When shale textures are hard to read, what can you learn from trace element data?

- 1) Paleooceanographic conditions (water body circulation, redox conditions)

→ Redox conditions

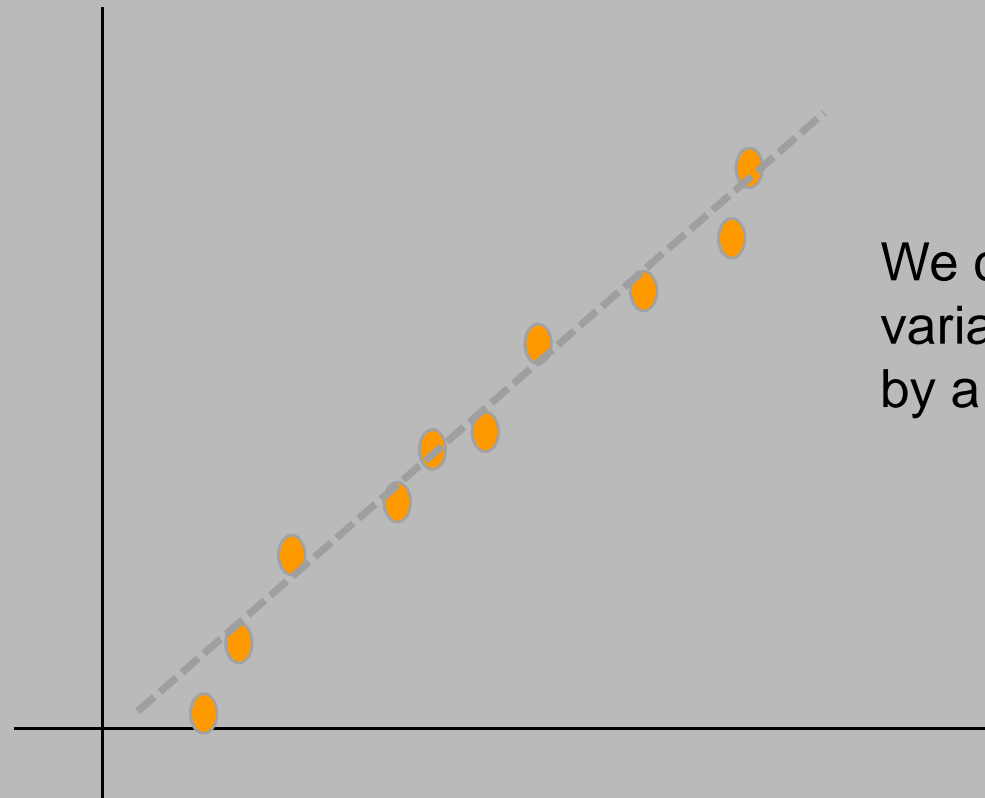
Factor analysis: Identifies groupings among elements (variables) with

- Technique looks for correlations among variables to reduce the variance in a data set.
- Related to correlation coefficient matrices



Identifying groupings among elements (variables) with factor analysis

- Technique looks for correlations among variables to reduce the variance in a data set.



We can explain the variance in this data set by a single variable

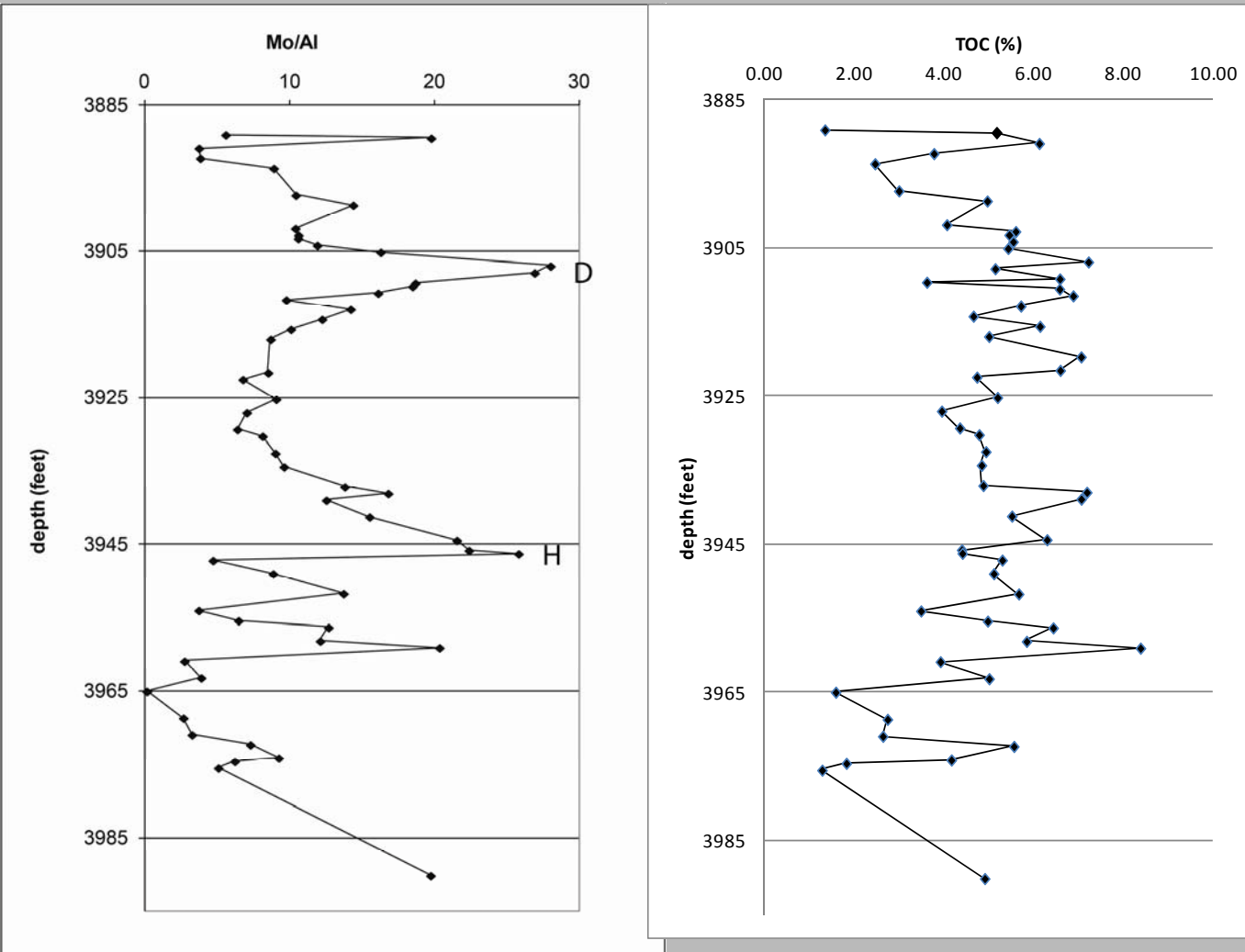
	Factor														
	1		2		3		4		5		6		7		8
%age of total variance	39.00%		13.00%		11.00%		7.90%		6.30%		3.60%		3.60%		2.20%
Al2O3	.945	Y	.935	TOC	.817	SiO2	-.923	V	.813	Fe2O3	.970	P2O5	.838	Sn	.849
Na2O	.828	La	.692	Ni	.787	MgO	.934	Cd	.921	TOTAL S	.963	Ag	.643		
K2O	.937	Ce	.504	Co	.675	CaO	.883	Sb	.759	As	.563	Se	.553		
TiO2	.952	Pr	.720	U	.860	MnO	.853	Ag	.683	Hg	.575				
Cr2O3	.547	Nd	.733	Mo	.830	LOI	.898	Se	.701						
Cs	.805	Sm	.834	Ni	.827	Sr	.583								
Ga	.920	Eu	.886	As	.729	inorganic C	.880								
Hf	.921	Gd	.941	Hg	.615										
Nb	.931	Tb	.944	Tl	.716										
Rb	.918	Dy	.931												
Ta	.900	Ho	.925												
Th	.930	Er	.894												
Zr	.915	Tm	.863												
La	.575	Yb	.817												
Ce	.680	Lu	.798												
Pr	.577														
Nd	.541														
Pb	.628														
Bi	.779														

A strong association between TOC and some redox sensitive elements (U, Mo, Ni)

	Factor														
	1		2		3		4		5		6		7		8
%age of total variance															2.20%
	39.00%		13.00%		11.00%		7.90%		6.30%		3.60%		3.60%		
Al2O3	.945	Y	.935	TOC	.817	SiO2	-.923	V	.813	Fe2O3	.970	P2O5	.838	Sn	.849
Na2O	.828	La	.692	Ni	.787	MgO	.934	Cd	.921	TOTAL S	.963	Ag	.643		
K2O	.937	Ce	.504	Co	.675	CaO	.883	Sb	.759	As	.563	Se	.553		
TiO2	.952	Pr	.720	U	.860	MnO	.853	Ag	.683	Hg	.575				
Cr2O3	.547	Nd	.733	Mo	.830	LOI	.898	Se	.701						
Cs	.805	Sm	.834	Ni	.827	Sr	.583								
Ga	.920	Eu	.886	As	.729	inorganic C	.880								
Hf	.921	Gd	.941	Hg	.615										
Nb	.931	Tb	.944	Tl	.716										
Rb	.918	Dy	.931												
Ta	.900	Ho	.925												
Th	.930	Er	.894												
Zr	.915	Tm	.863												
La	.575	Yb	.817												
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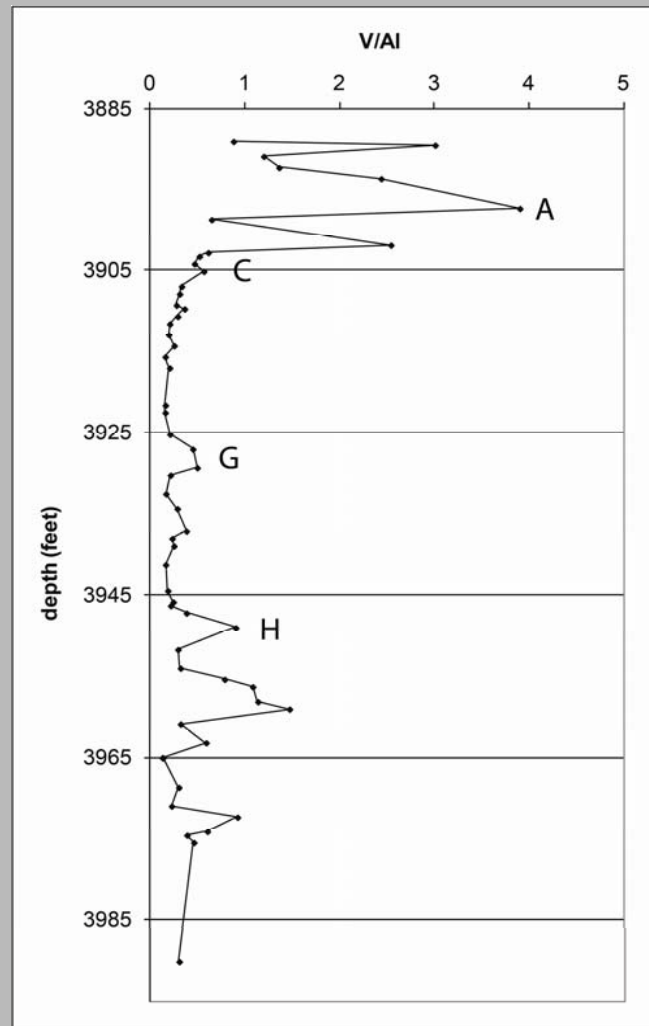
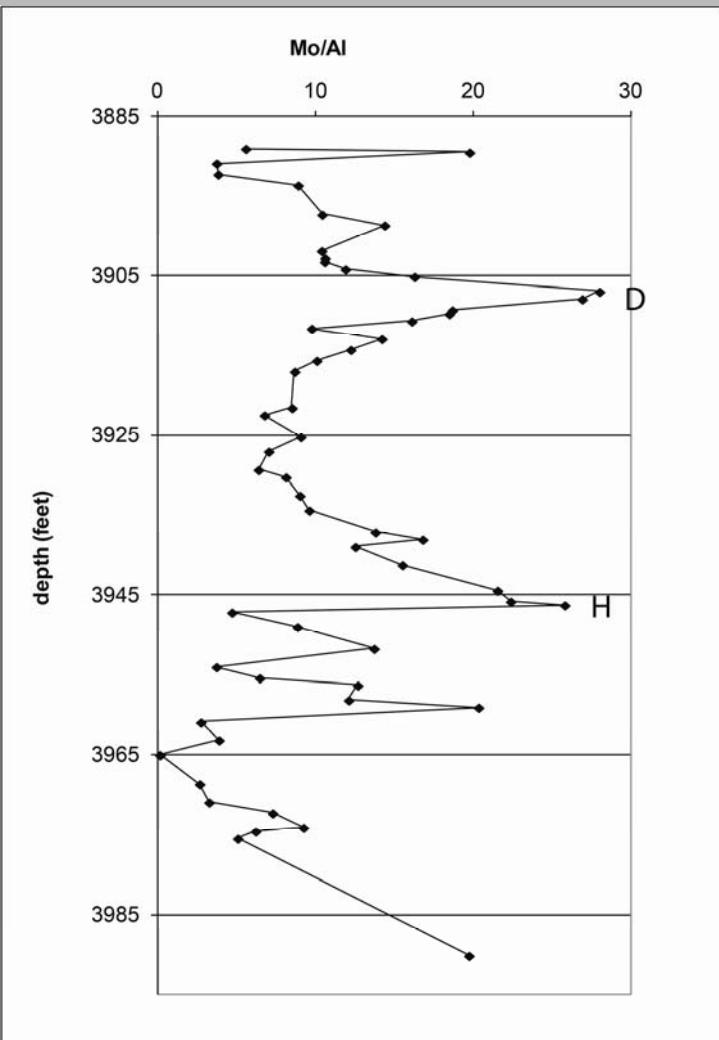
A strong association between TOC and some redox sensitive elements (U, Mo, Ni)

Mo as a redox proxy



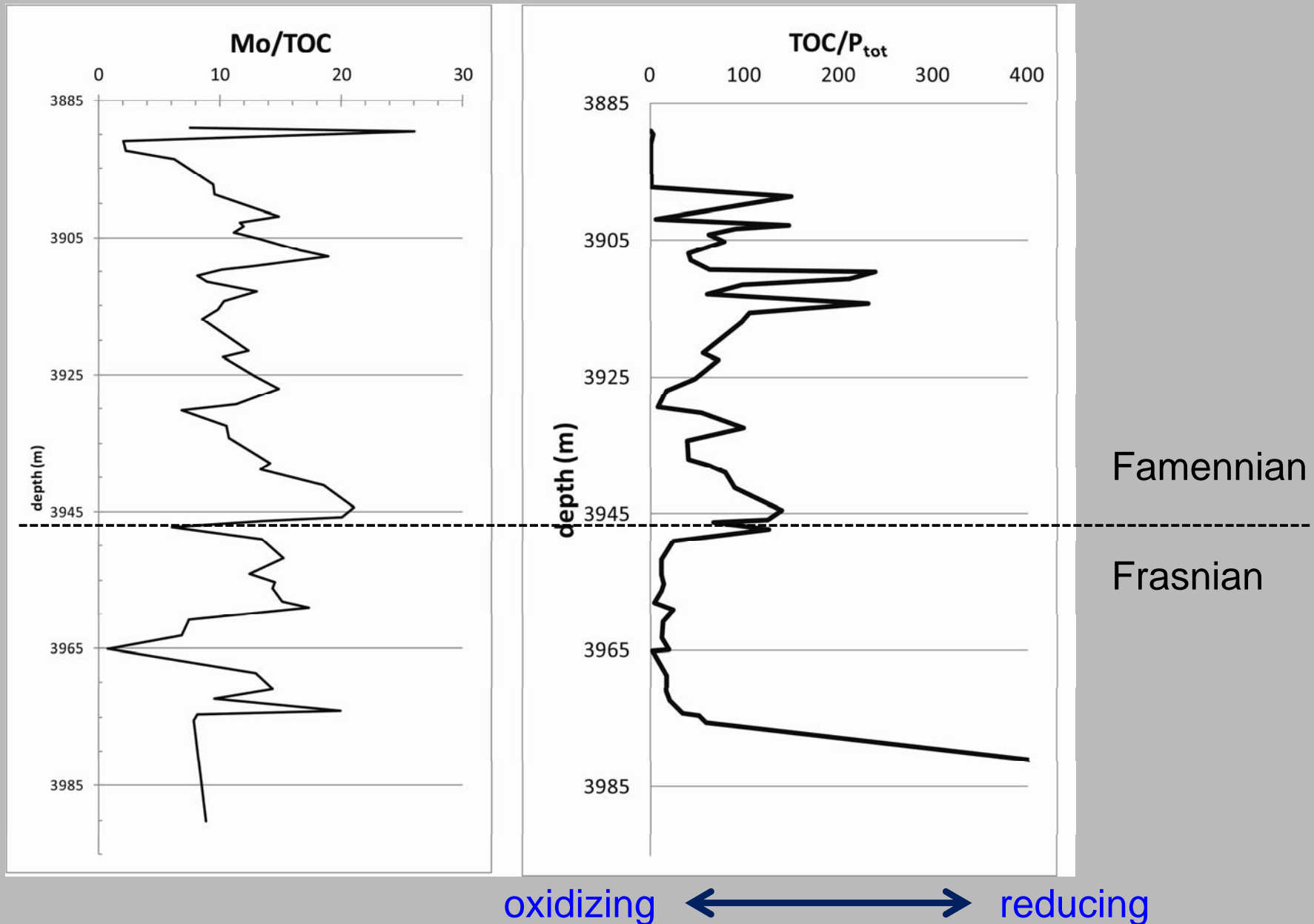
- 1) Elevated Mo indicates reducing conditions throughout.
- 2) Extremes associated with high TOC intervals

V as a redox proxy

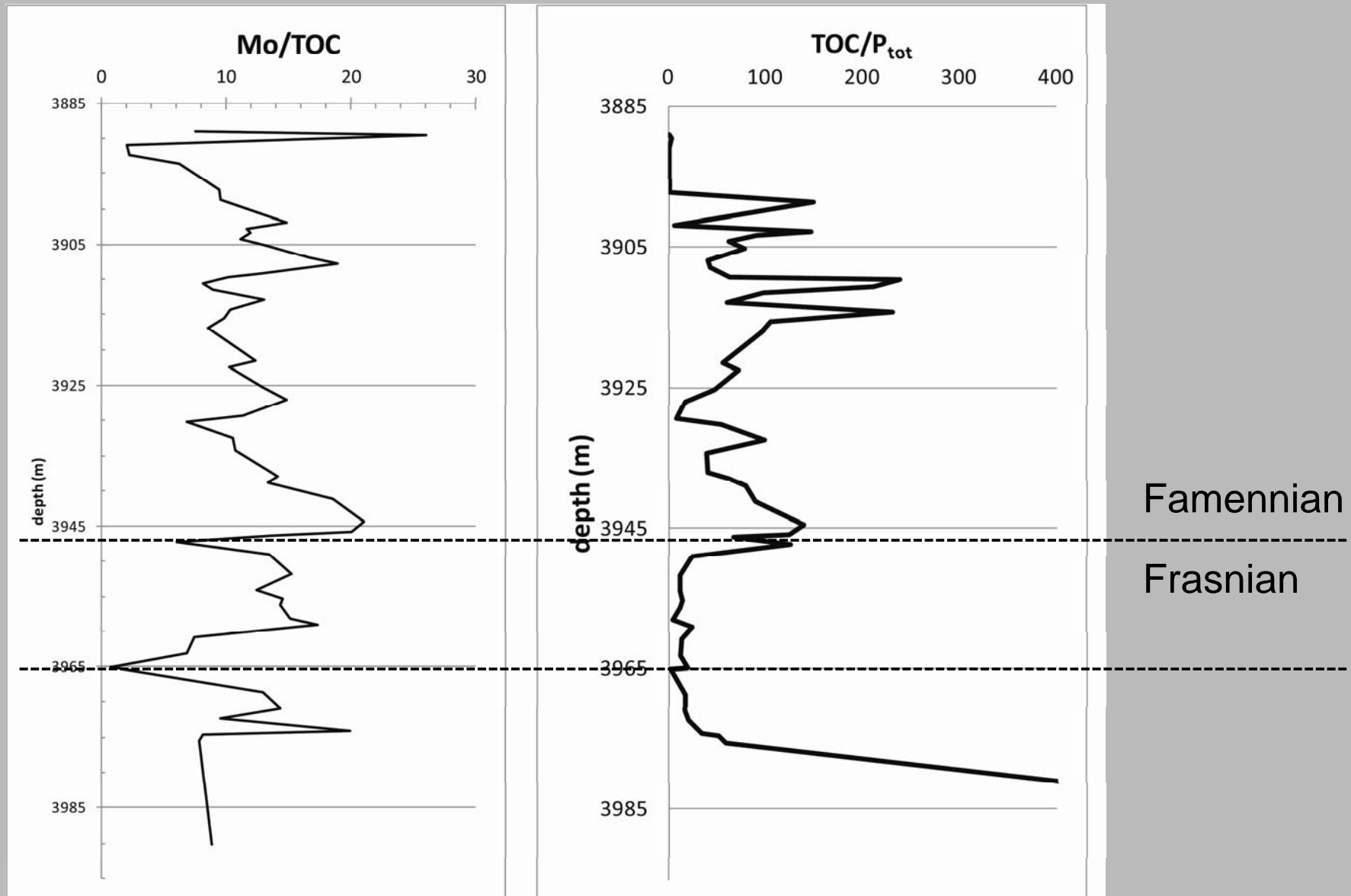


- 1) Elevated V also indicates reducing conditions throughout.
- 2) But peaks occur at different points, suggesting different precipitation mechanisms.

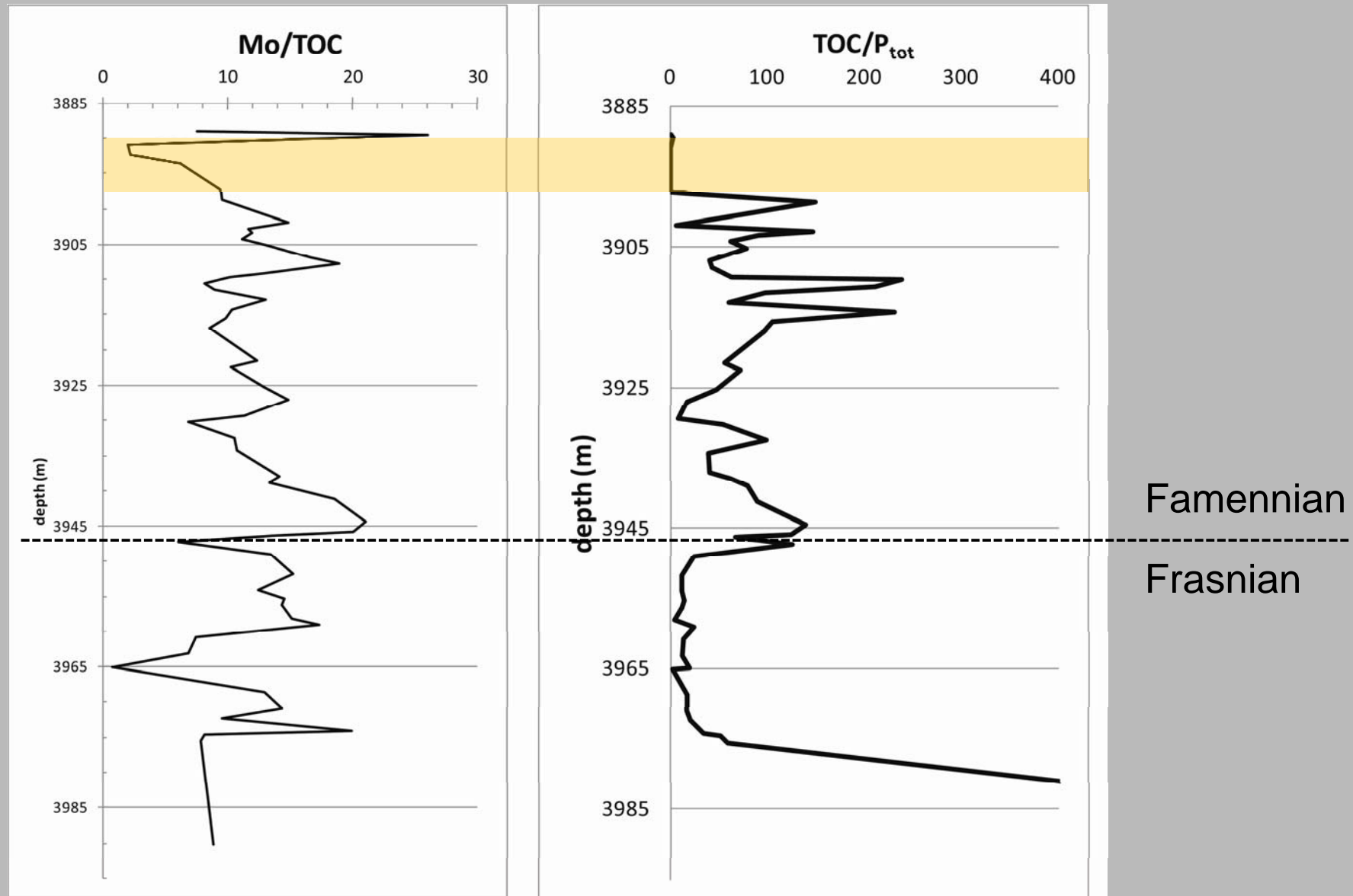
Phosphate and redox conditions

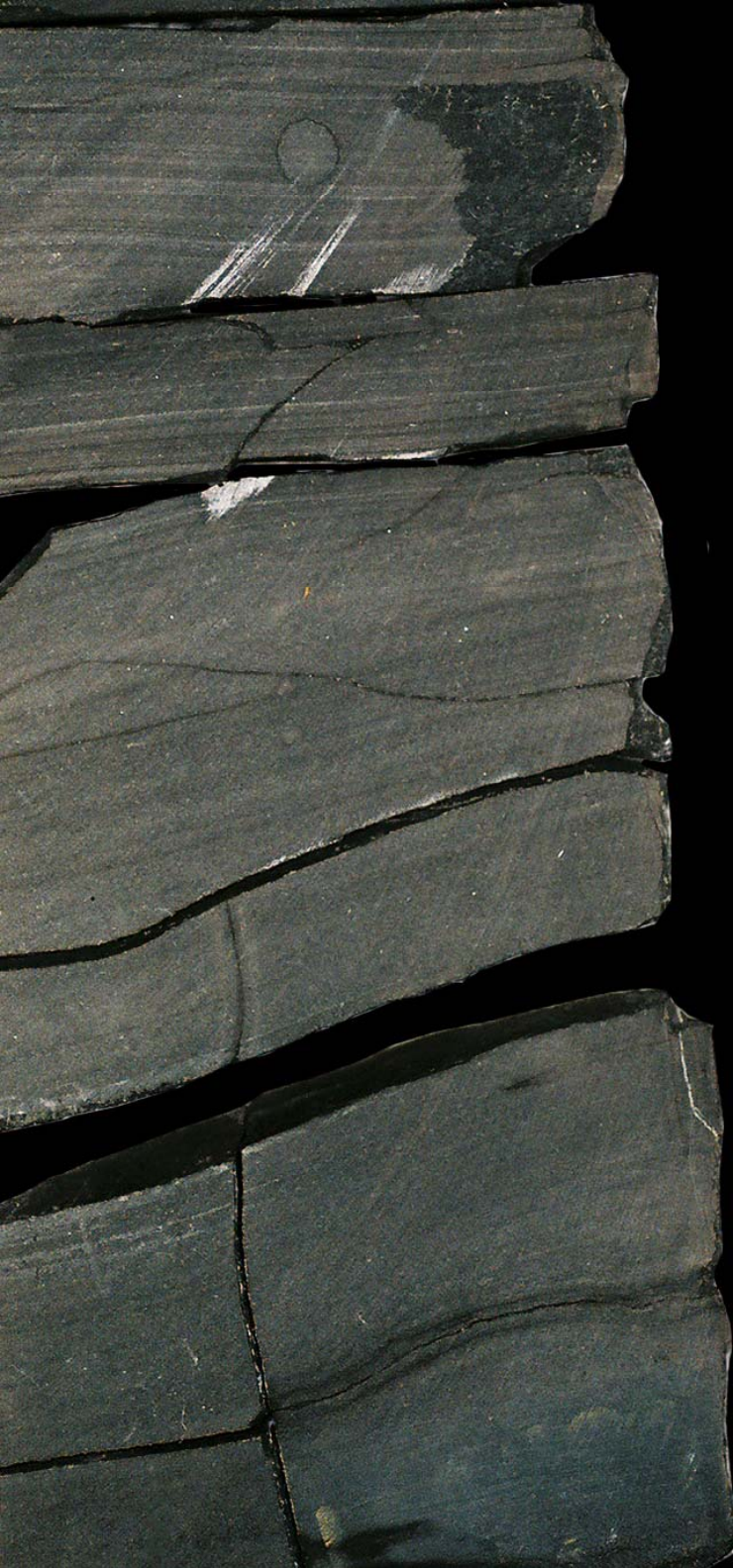


Sea level versus redox



Sea level versus redox



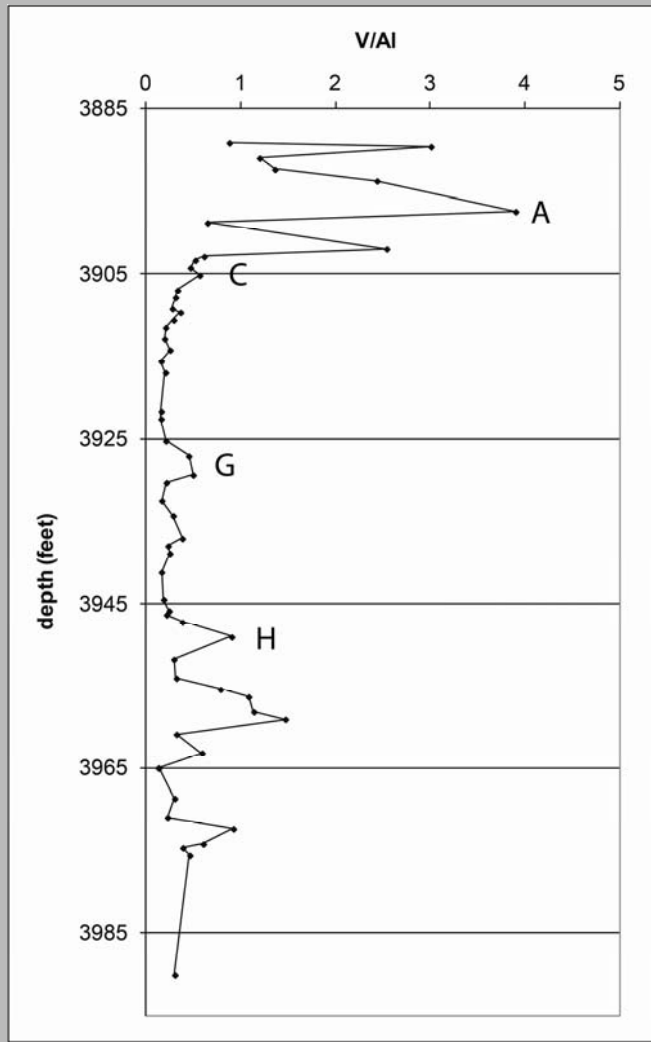


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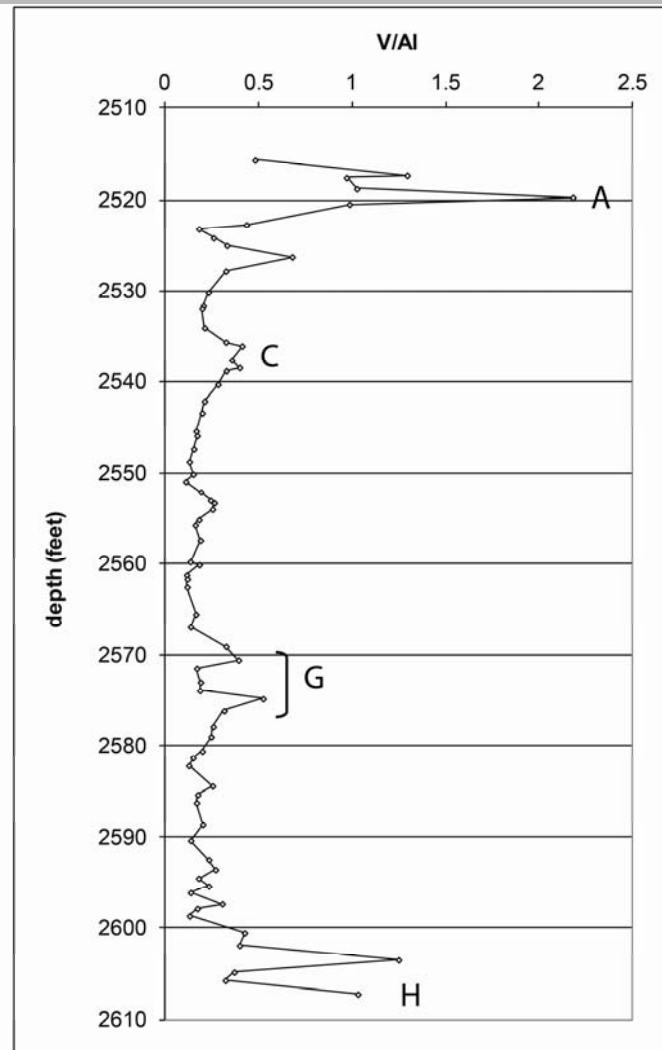
- 1) A correlation tool

Trace elements for stratigraphic correlation

RTC 1, Pecos Co.
Woodford = 100 m



KCC 503, Winkler Co.
Woodford = 200 m



CONCLUSIONS

- Trace elements provide insight into:
 - (1) restriction in sedimentary basins, the 'basin reservoir' effect and therefore sea level.
 - (2) redox conditions
 - (3) Stratigraphic correlation
 - (4) Sediment sources
- P is a significant measure of redox conditions. Mo and U also indicates redox conditions; V appears to be affected by different precipitation mechanisms. But all can be used for correlations.