The Use of Chemostratigraphy to Refine Ambiguous Sequence Stratigraphic Correlations in Marine Shales: An Example From the Woodford Shale, Oklahoma*

Bryan W. Turner[1], Jessica A. Tréanton[2], and Roger M. Slatt[3]

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[1]ConocoPhillips School of Geology and Geophysics, University of Oklahoma, Norman, OK (bryturner@gmail.com)
[2]Noble Energy, Houston, TX
[3]ConocoPhillips School of Geology and Geophysics, University of Oklahoma, Norman, OK

Abstract

The Woodford Shale provides an opportunity to test recent advances in handheld XRF (HHXRF) technology to develop and refine sequence stratigraphic frameworks by comparing chemostratigraphic profiles directly to gamma ray logs obtained from the same locations. Three cores from Lincoln, Pottawatomie, and Pontotoc Counties in Oklahoma and two outcrops at the Hunton Anticline Quarry (HAQ) in Murray County, OK represent both proximal and distal environments of the Woodford Shale. Clean surfaces at each area are scanned at no greater than one foot intervals using HHXRF to determine the elemental profiles. At the same resolution, a gamma ray profile is scanned using a GR scintillator or core spectral gamma ray. The lithologic description, gamma ray profile, and elemental profiles are then used to develop the sequence stratigraphic interpretation.

Stratigraphic successions that are correlatively ambiguous based on GR profiles alone are able to be properly correlated by utilizing surfaces that are recognized within chemostratigraphic profiles. Certain elements act as proxies for local depositional and environmental conditions during sedimentation. The principal elements used in this study are titanium (Ti), zirconium (Zr), silicon (Si), calcium (Ca), strontium (Sr), phosphorous (P), aluminum (Al), potassium (K), molybdenum (Mo), and vanadium (V).

Ti and Zr are associated with continentally derived sediment. Ca and Sr are associated with carbonate accumulation. Al and K are associated with feldspars and clays. Mo and V can be used as an indication of redox conditions. Si is found in biogenic quartz, detrital quartz, feldspars, and clays. As such, it is useful to evaluate Si as a ratio between Si/Al. When evaluated in conjunction with the Ti and Zr concentrations, the Si/Al ratio provides a rough approximation for the amount of biogenic quartz present within a horizon. At several horizons in the Woodford the Si/Al value spikes, these spikes are interpreted as algal blooms at these locations. Immediately above these blooms, there is typically a sudden peak in carbonate proxies, interpreted as incipient hard-ground formation. When found together, these horizons are interpreted as surfaces of non-deposition that can be used for building a correlative stratigraphic framework. These chemostratigraphic successions are capable of resolving high frequency cyclicity that can refine a sequence stratigraphic framework.

References Cited

Algeo, T.J., and J.B. Maynard, 2004, Trace-Element Behavior and Redox Facies in Core Shales of Upper Pennsylvanian Kansas-Type Cyclothems: Chemical Geology, v. 206, p. 289-318.

Algeo, T.J., and H. Rowe, 2012, Paleoceanographic Applications of Trace-Metal Concentration Data: Chemical Geology, v. 324-325, p. 6-18.

Banner, J.L., 1995, Application of the Trace Element and Isotope Geochemistry of Strontium to Studies of Carbonate Diagenesis: Sedimentology, v. 42, p. 805-824.

Blakey, R., 2011, Paleogeography and Geologic Evolution of North America: Colorado Plateau Geosystems, Arizona USA.

Brumsack, H.J., 2006, Trace-Element Behavior and Redox Facies in Core Shales of Upper Pennsylvanian Kansas-Type Cyclothems: Palaeogeography Palaeoclimatology Palaleoecolology, v. 232, p. 344-361.

Harris, N.B., C.A. Mnich, D. Selby, and D. Korn, 2013, Minor and Trace Element and Re-Os Chemistry of the Upper Devonian Woodford Shale, Permian Basin, West Texas: Insights Into Metal Abundance and Basin Processes: Chemical Geology, v. 356, p. 76-93.

Johnson, J.G., G. Klapper, and C.A. Sandberg, 1985, Devonian Eustatic Fluctuations in Euramerica: Geological Society of America Bulletin, v. 96, p. 567–587.

Molinares-Blanco, C.E., 2013, Stratigraphy and Palynomorphs Composition of the Woodford Shale in the Wyche Farm Shale Pit, Pontotoc County, Oklahoma: M.S. Thesis, University of Oklahoma, Norman, OK.

Pearce, T.J., B.M. Besly, D.S. Wray, and D.K. Wright, 1999, Chemostratigraphy: A Method to Improve Interwell Correlation in Barren Sequences – A Case Study Using Onshore Duckmantian/Stephaniansequences (West Midlands, U.K.): Sedimentary Geology, v. 124, p. 197-220.

Pearce, T.J., and I. Jarvis, 1992, Applications of Geochemical Data to Modelling Sediment Dispersal Patterns in Distal Turbidites: Late Quaternary of the Madeira Abyssal Plain: Journal of Sedimentary Petrology, v. 62, p. 1112-1129.

Rowe, H., N. Hughes, and K. Robinson, 2012, The quantification and Application of Handheld Energy-Dispersive X-Ray Fluorescence (ED-XRF) in Mudrock Chemostratigraphy and Geochemistry: Chemical Geology, v. 324-325, p. 122-131.

Sageman, B., and T. Lyons, 2004, Geochemistry of Fine-grained Sediments and Sedimentary Rocks, *in* F. MacKenszie (ed.), Sediments, Diagenesis, and Sedimentary Rocks: Treatise on Geochemistry, v. 7, p. 115-158.

Slatt, R.M., and N.D. Rodriguez, 2012, Comparative Sequence Stratigraphy and Organic Geochemistry of Gas Shales: Commonality or Coincidence?: Journal of Natural Gas Science and Engineering, v. 8, p. 68-84

Tréanton, J.A., 2014, Outcrop-derived Chemostratigraphy of the Woodford Shale, Murray County, Oklahoma: M.S. Thesis, University of Oklahoma, Norman, OK.

Tréanton, J.A., B.W. Turner, and R.M. Slatt, 2014, Outcrop Derived Inorganic Geochemistry of the Woodford Shale, Murray County, Oklahoma: Houston Geological Society Applied Geoscience Conference (Mudrocks), Houston, TX.

Tribovillard, N., T.J. Algeo, T. Lyons, and A. Riboulleau, 2006, Trace Metals as Paleoredox and Paleoproductivity Proxies: An Update: Chemical Geology, v. 232, p. 12-32.

Turner, B.W., C.E. Molinares-Blanco, and R.M. Slatt, 2014, Chemostratigraphic, Palynostratigraphic, and Sequence Stratigraphic Analysis of the Woodford Shale, Wyche Farm Quarry, Pontotoc County, Oklahoma: Interpretation, v. 3, p. SH1-SH9.

The Use of Chemostratigraphy to Refine Ambiguous Sequence Stratigraphic Correlations in Marine Shales:

An Example of the Woodford Shale, Oklahoma

Bryan W. Turner*, Jessica A. Tréanton, Roger M. Slatt

*PhD Candidate
ConocoPhillips School of Geology and Geophysics
University of Oklahoma - Norman, OK

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ConocoPhillips
SCHOOL OF
GEOLOGY &
GEOPHYSICS
The University of Oklahoma

Purpose

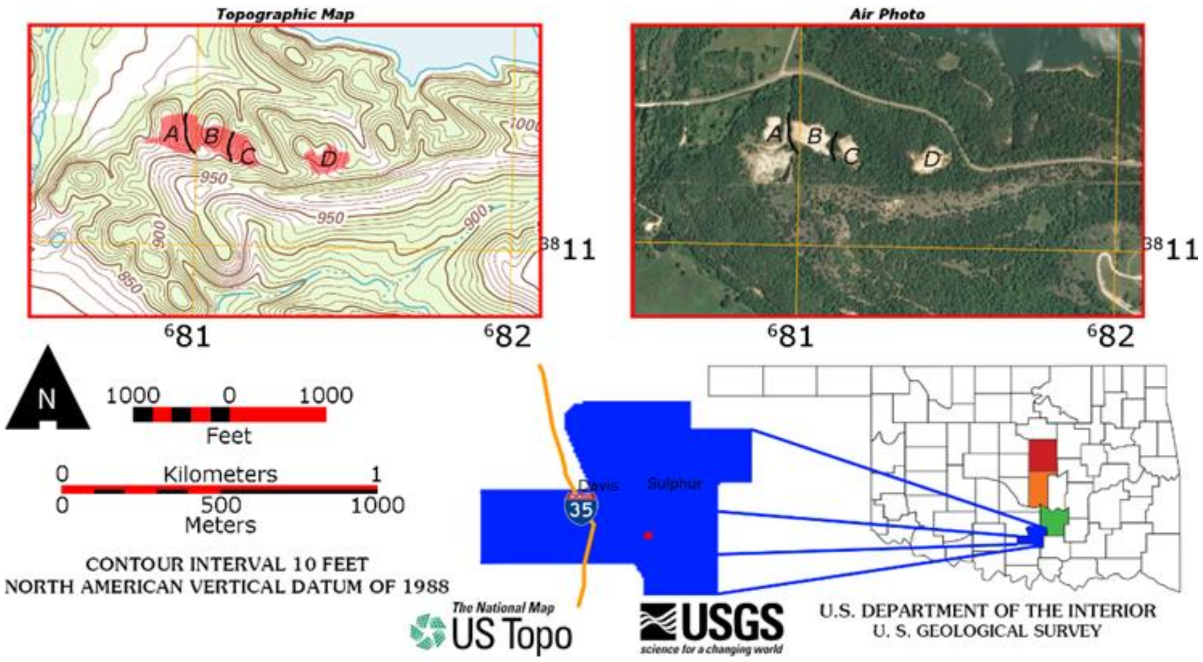
- To utilize a series of elemental proxies to develop a sequence stratigraphic framework that can be used to correlate fine-grain lithologies.
  - Lateral facies shifts within mudrocks are subtle, but can be significant and pervasive.
  - Highlight these shifts with greater precision than is possible in coarser lithologies.

Methods

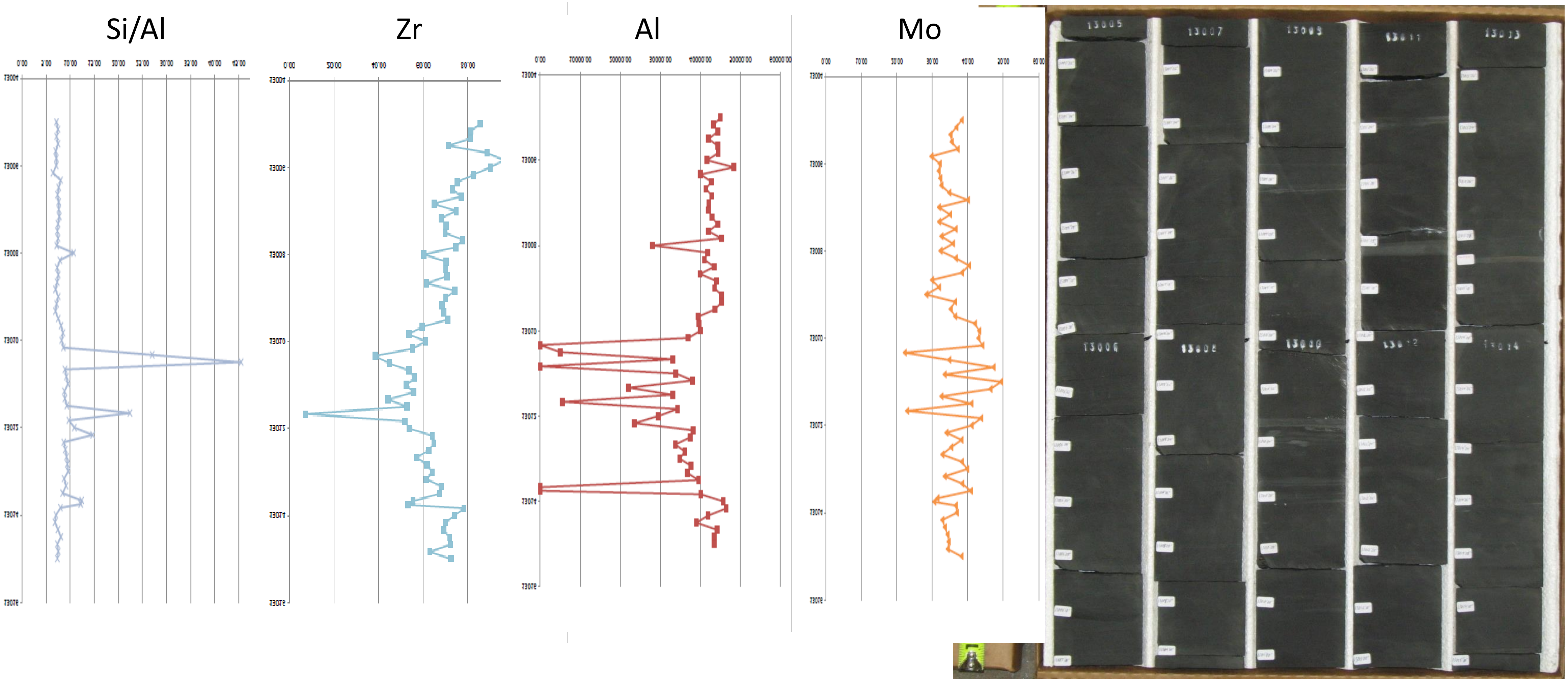
Regional Framework

- Four sites selected spanning 70 miles
  - Two outcrops within a quarter mile
    - To confirm the signal is locally reproducible
  - Three additional subsurface cores
- Samples scanned using HHXRF
- Outcrops sampled every stratigraphic foot
- Core sample spacing varied
  - 6” to 2” depending on time with the core
- Gamma ray data used when present (core gamma, down-hole gamma, outcrop gamma)

- Local, cumulative shoreline trajectories used to build the regional chemosequence stratigraphic framework based on individual chemostratigraphic profiles



Homogenous Black Shale?



Elemental Proxies

- Certain elements have been found to be commonly found in association with different types of sediment:

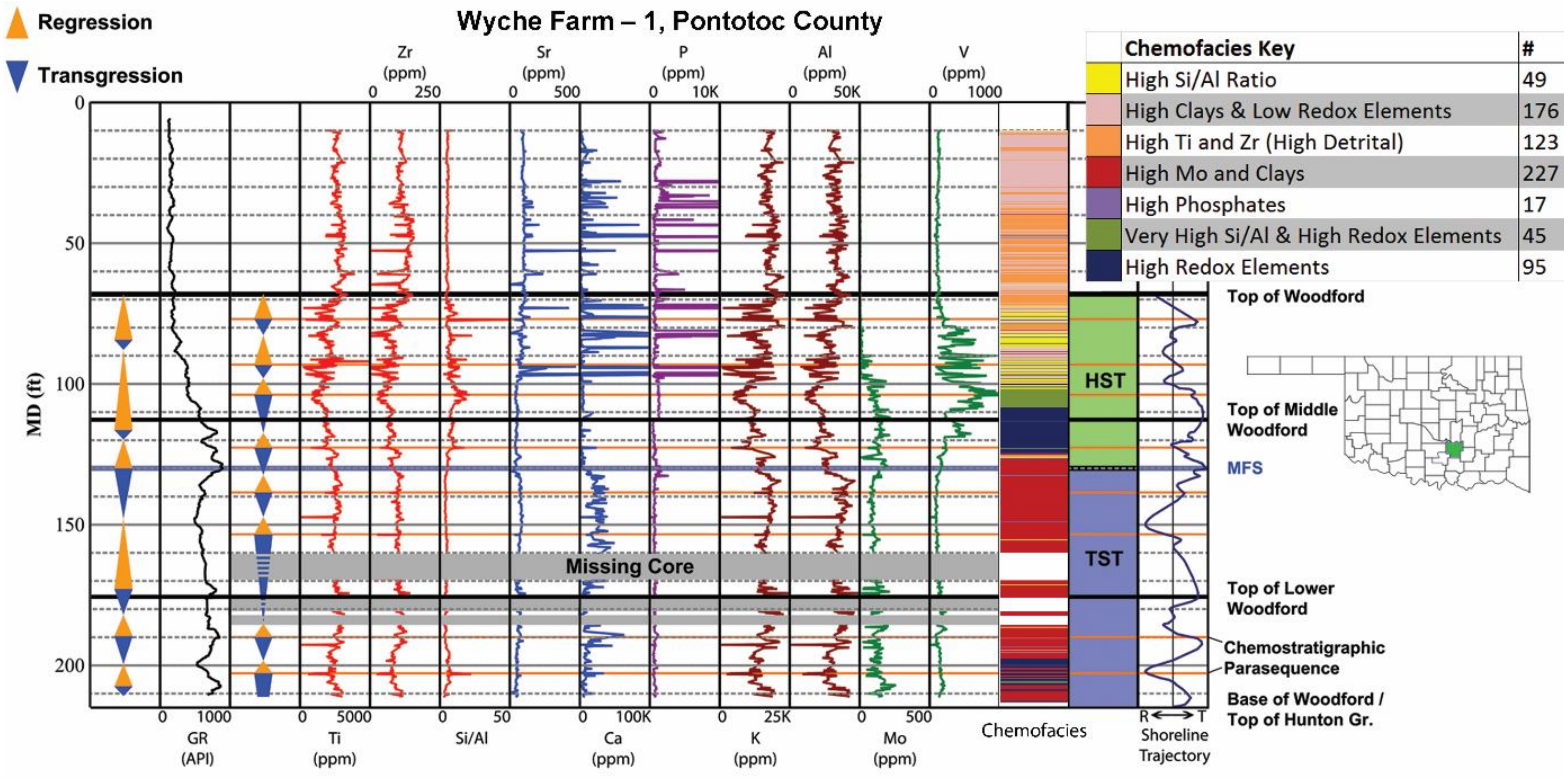
Element(s):	Indicates:	Source(s):
Ti and Zr	Continental Sediment	(c.f. Sageman and Lyons, 2004; Tribovillard et al., 2006)
Ca and Sr	Typically carbonate material, but can be associated with clay minerals, feldspars, phosphates, or sulfates	(c.f. Banner, 1995)
K and Al	In mudrocks, usually clay minerals, but can also be found in feldspars	(c.f. Sageman and Lyons, 2004; Tribovillard et al., 2006)
Mo and V	The degree of anoxia present within a basin	(c.f. Tribovillard et al., 2006; Algeo and Rowe, 2012)
Si/Al or Si/Ti	How much quartz is present within the sediment	(c.f. Pearce and Jarvis, 1992; Pearce et al., 1999; Tribovillard et al., 2006)

- These elements are generally considered “immobile”, but it is best to utilize multiple proxies to make interpretations.

Chemosequence Stratigraphic Predictions

- LST: A general increasing trend in detrital signals (Ti, Al, Zr, K)
  - Al and K are more likely to be associated with feldspars
  - Isolated mini-basins may show high degrees of restriction (high Mo and V)
- TST: A general decreasing trend in continental proxies (Ti and Zr)
  - Al and K become more associated with the clay fraction, and may remain high with respect to Ti and Zr
  - General decline in levels of restriction within the basins
- HST: A general increasing trend in detrital signals
  - Capped by a surface of erosion (non-waltherian facies shift)
  - Bottom waters should be well circulated (low Mo and V)
  - In a carbonate system, HST will be dominated by increases in Ca and Sr.

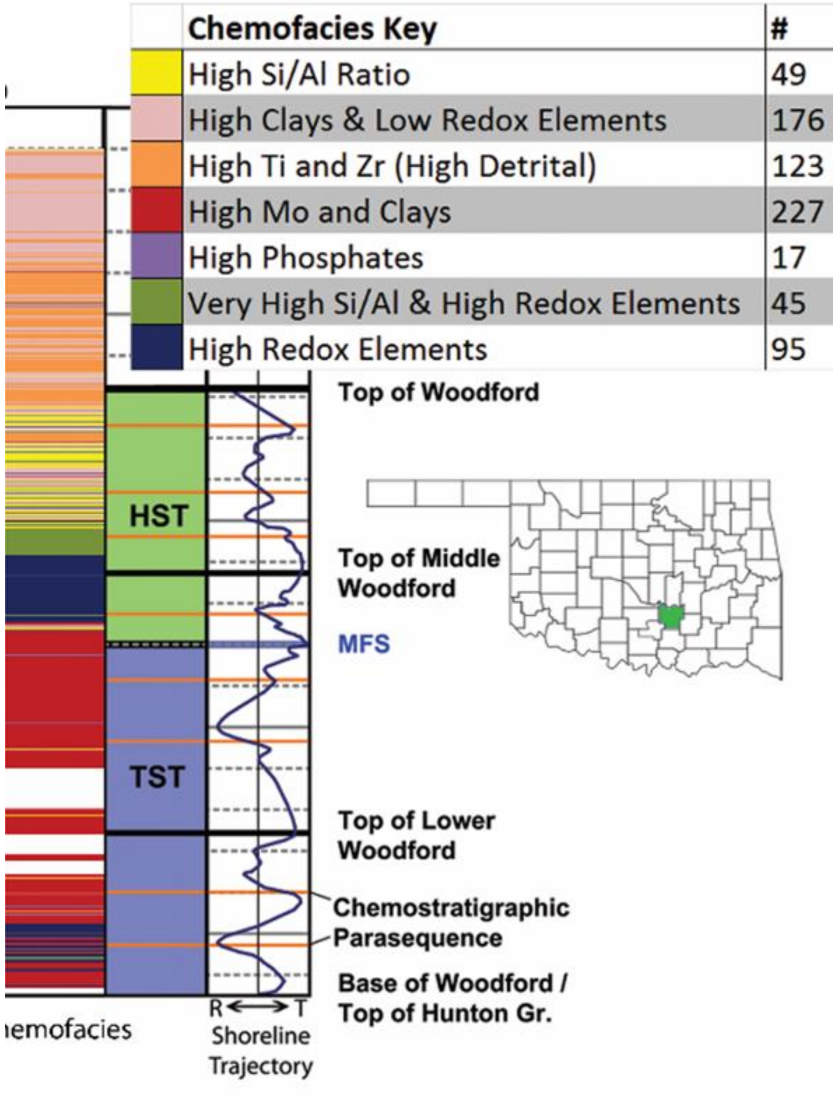
Wyche Farm Quarry – Type Well

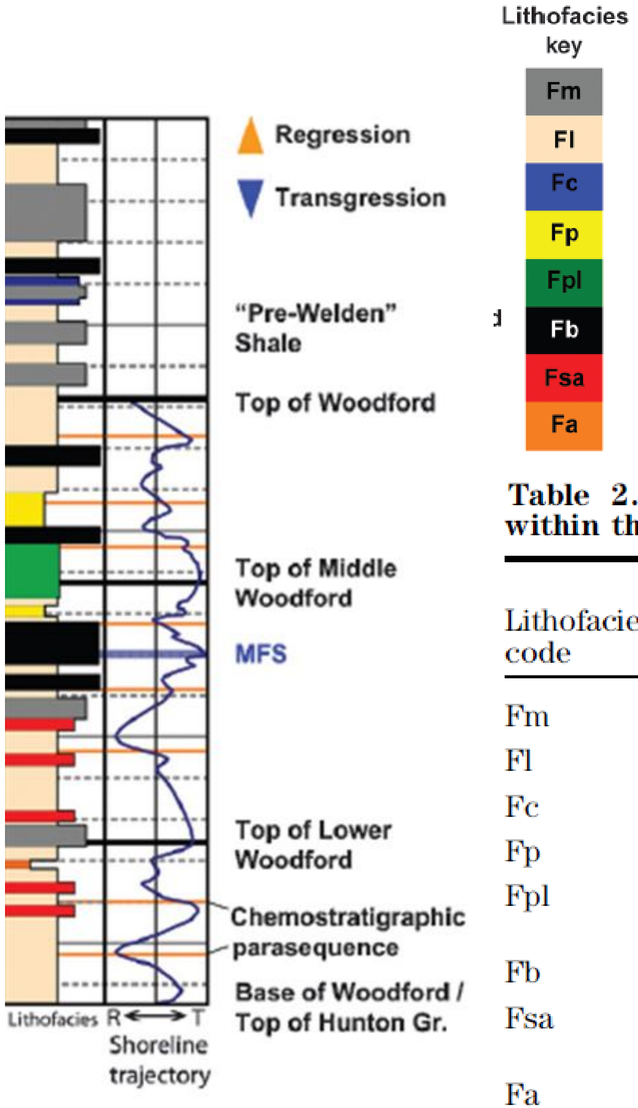


Chemofacies Key	#
High Si/Al Ratio	49
High Clays & Low Redox Elements	176
High Ti and Zr (High Detrital)	123
High Mo and Clays	227
High Phosphates	17
Very High Si/Al & High Redox Elements	45
High Redox Elements	95

Modified from Turner et al., 2015

Chemofacies vs. Lithofacies



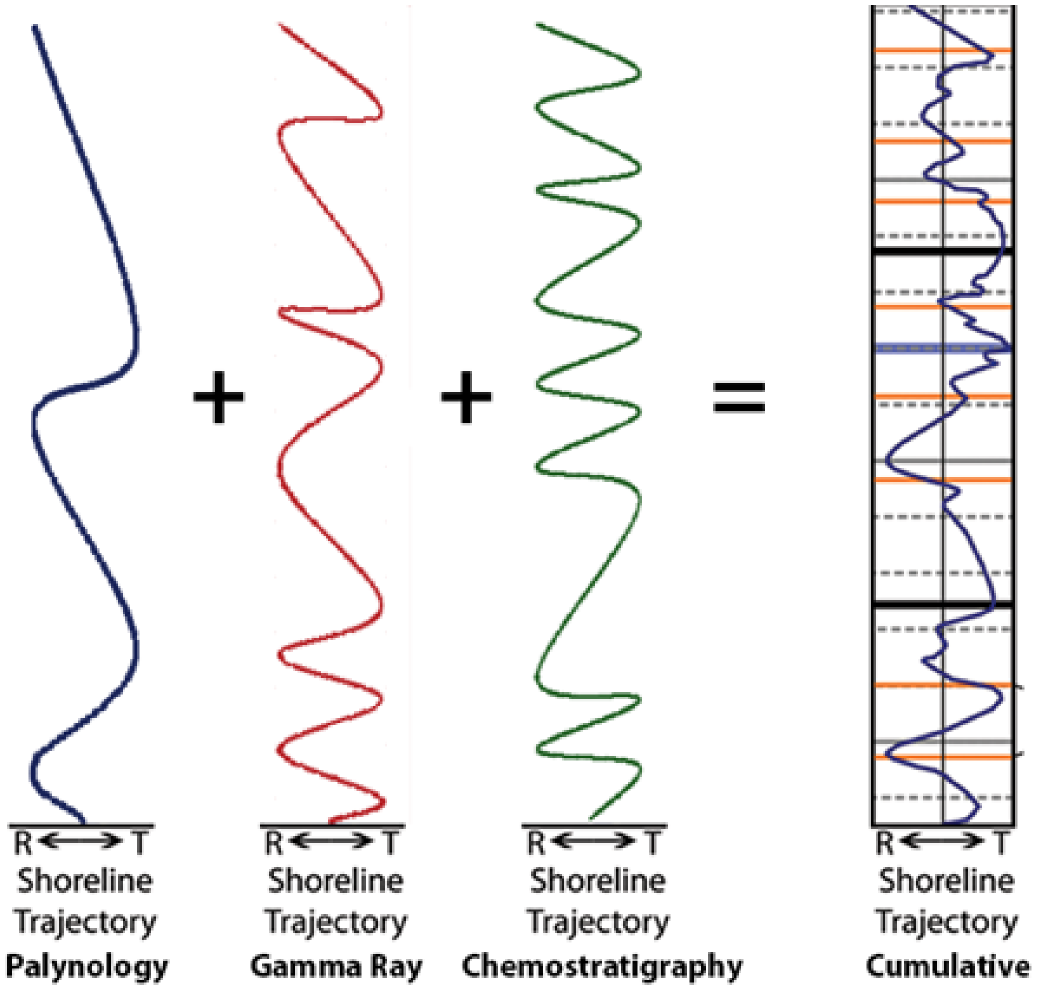


Modified from Turner et al., 2015

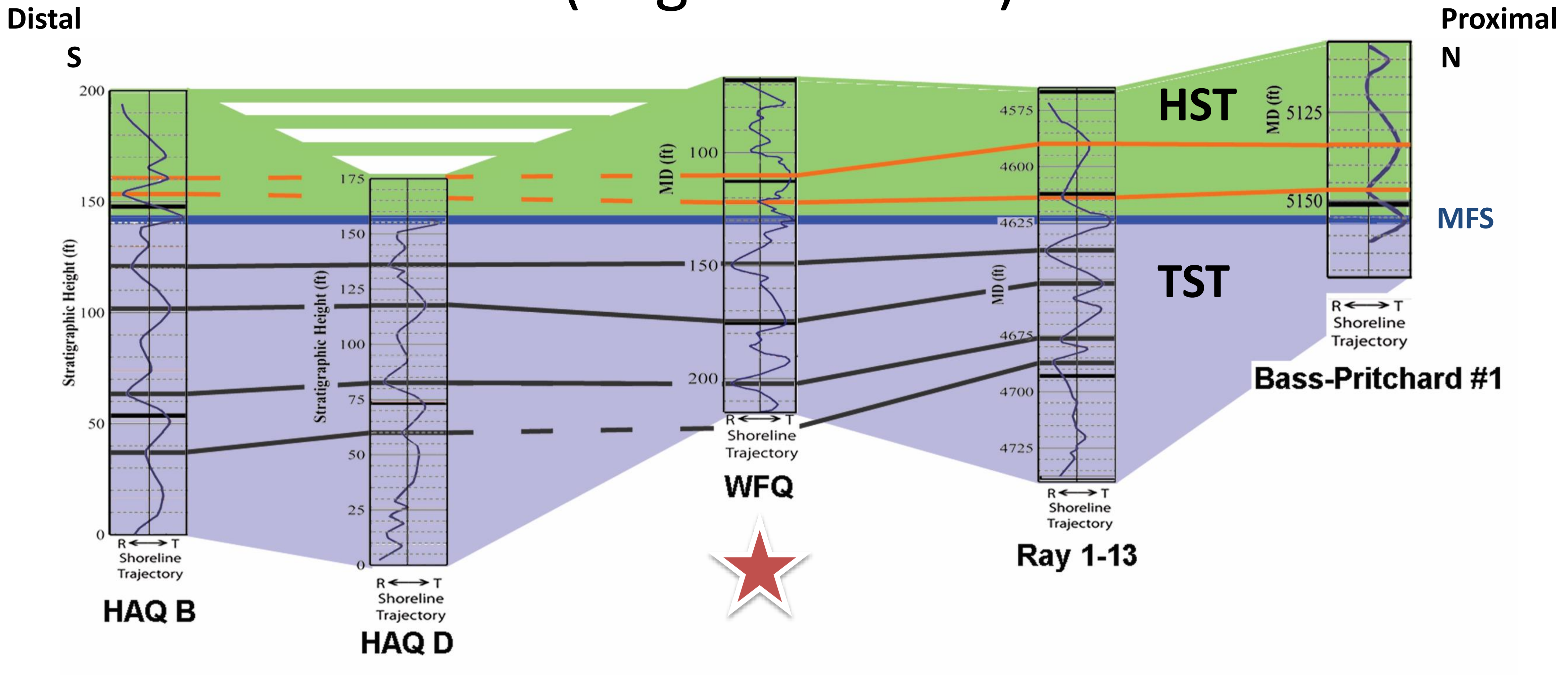
Table 2. Facies codes for the lithofacies identified within this core.

Lithofacies code	Description
Fm	Siliceous massive mudrock
Fl	Siliceous laminated mudrock light gray
Fc	Calcareous mudrock
Fp	Siliceous mudrock with phosphatic nodules
Fpl	Laminated siliceous mudrock with phosphatic nodules
Fb	Black to dark-gray laminated siliceous mudrock
Fsa	Mixed siliceous-argillaceous mudrock with thin clay lamina
Fa	Argillaceous mudrock with detrital quartz

The Individual Shoreline components



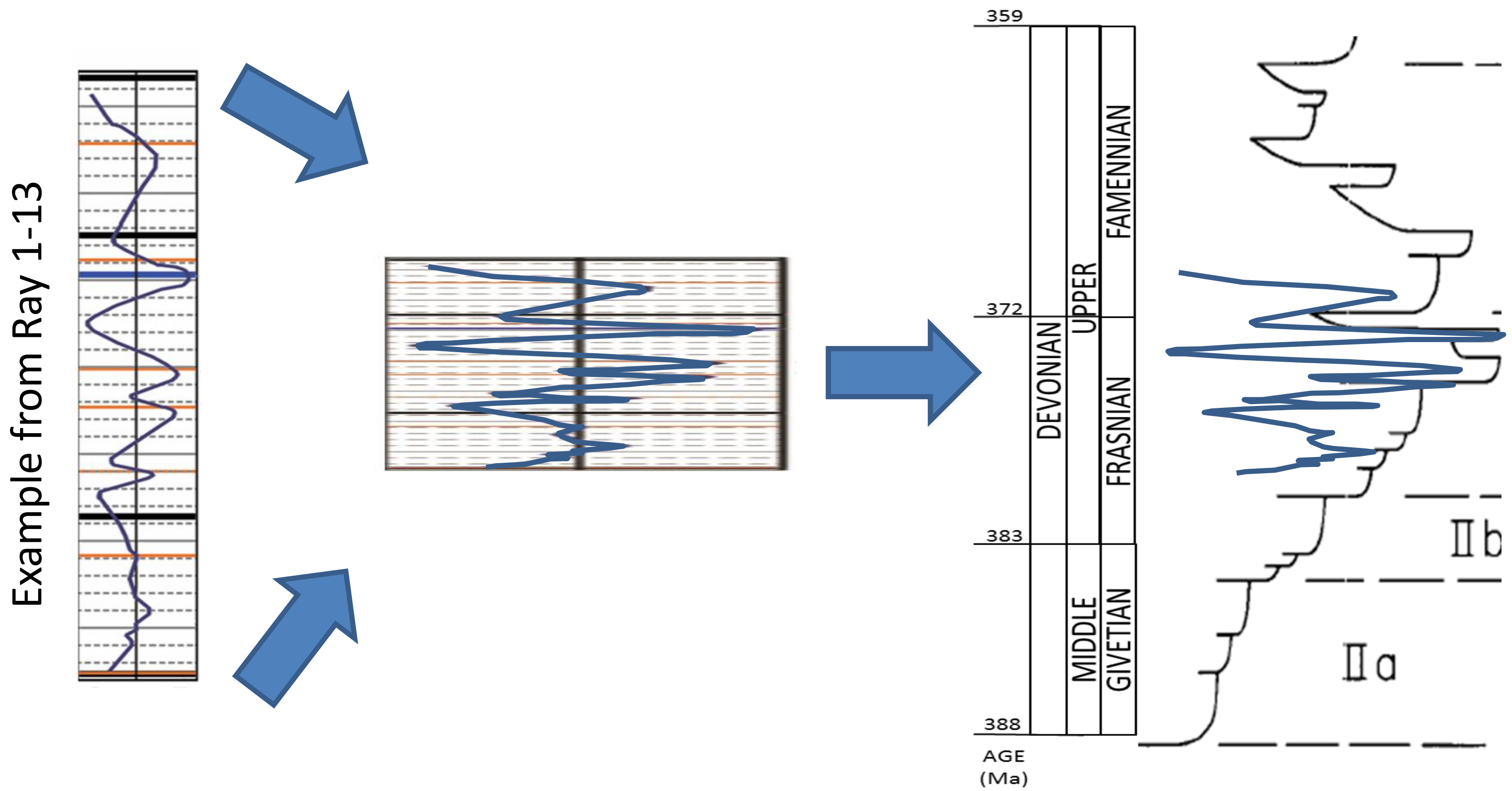
Chemosequence Stratigraphic Framework (Regional Scale)



Modified from Turner et al., 2014

Local Sea Level vs Global Sea Level

- The trends in local sea level for the Arkoma Basin are in good agreement with previous work interpreting the global sea level trends at this time.



(Johnson et al., 1985)

Conclusions

- With the recent advances in HHXRF, it is becoming increasingly cost-effective to collect data for high resolution chemostratigraphic data sets.
- The fine-grained nature of mudrocks, which contributes to the development of subtle stratigraphic surfaces, are ideal for analysis with HHXRF.
- Chemostratigraphic proxies can be used to develop sequence stratigraphic frameworks.

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References:

- Algeo, T.J. and Maynard, J.B. (2004) Trace-element behavior and redox facies in core shales of Upper Pennsylvanian Kansas-type cyclothems. *Chem. Geo.*, **206**, p.289-318.
- Algeo, T.J. and Rowe, H. (2012) Paleoceanographic applications of trace-metal concentration data: Chemical Geology, **324-325**, p. 6-18.
- Banner, J.L., 1995: Application of the trace element and isotope geochemistry of strontium to studies of carbonate diagenesis: *Sedimentology*, **42**, p.805-824.
- Blakey (2011) Paleogeography and Geologic Evolution of North America. http://www2.nau.edu/rcb7/namD360.html. Accessed 10-16-2012
- Brumsack, H.J. (2006) Trace-element behavior and redox facies in core shales of Upper Pennsylvanian Kansas-type cyclothems. *Palaeogeog. Palaeoclim. Palaleoecol.*, **232**, p.344-361.
- Harris, N.B., C.A. Mnich, D. Selby, and D. Korn, 2013, 2013, Minor and trace element and Re-Os chemistry of the Upper Devonian Woodford Shale, Permian Basin, West Texas: Insights into metal abundance and basin processes: Chemical Geology, **356**, 76-93.
- Molinares-Blanco, C.E., 2013, Stratigraphy and palynomorphs composition of the Woodford Shale in the Wyche Farm Shale Pit, Pontotoc County, Oklahoma: M.S. thesis, University of Oklahoma.
- Pearce, T.J., Besly, B.M., Wray, D.S., Wright, D.K., 1999: Chemostratigraphy: a method to improve interwell correlation in barren sequences – a case study using onshore Duckmantian/Stephanian sequences (West Midlands, U.K.): *Sedimentary Geology*,**124**, p.197-220.
- Pearce, T.J. and Jarvis, I., 1992: Applications of geochemical data to modelling sediment dispersal patterns in distal turbidites: Late Quaternary of the Madeira Abyssal Plain: *Journal of Sedimentary Petrology*, **62**, p.1112-1129.
- Rowe, H., Hughes, N., and Robinson, K. (2012) The quantification and application of handheld energy-dispersive x-ray fluorescence (ED-XRF) in mudrock chemostratigraphy and geochemistry. *Chem. Geo.*, **324-325**, p. 122-131.
- Sageman, B. and T. Lyons (2004) Geochemistry of Fine-grained Sediments and Sedimentary Rocks *in* MacKenszie, F. ed. Sediments, Diagenesis, and Sedimentary Rocks, *Treatise on Geochemistry*, **7**, p.115-158.
- Slatt, R.M. and Rodriguez, N.D. (2012) Comparative sequence stratigraphy and organic geochemistry of gas shales: Commonality or coincidence?: *Journal of Natural Gas Science and Engineering*, **8**, p.68-84
- Tréanton, J.A. (2014) Outcrop-derived chemostratigraphy of the Woodford Shale, Murray County, Oklahoma: M.S. thesis, University of Oklahoma.
- Tréanton, J.A., Turner, B.W., and Slatt, R.M. (2014) Outcrop Derived Inorganic Geochemistry of the Woodford Shale, Murray County, Oklahoma. Houston Geological Society Applied Geoscience Conference (Mudrocks), Houston, TX.
- Tribovillard, N., Algeo, T.J., Lyons, T., and Riboulleau A. (2006) Trace metals as paleoredox and paleoproductivity proxies: An update. *Chem. Geo.*, **232**, p. 12-32.
- Turner, B.W., Molinares-Blanco, C.E., and Slatt, R.M. (2015) Chemostratigraphic, palynostratigraphic, and sequence stratigraphic analysis of the Woodford Shale, Wyche Farm Quarry, Pontotoc County, Oklahoma: *Interpretation*, **3**, p.SH1-SH9