Can Sequence Stratigraphic Concepts be Applied in Mudrock Systems?*

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Abstract

The concepts of sequence stratigraphy have become well-established approaches for defining and predicting facies architecture in sandstone/shale and carbonate systems since their development began in the 1970's. In recent years, there have been many attempts to apply these same concepts in mudrock systems. However, a review of recent literature reveals substantial departures from original concepts of both terms and application in all sedimentary systems, but especially in mudrocks. Confusion and inconsistencies exist in the usage of basic terms (e.g., sequence, sequence boundary, transgression, maximum flooding, etc.) as well as in the types of data necessary to define such surfaces and events. Equally significant problems exist in the interpretation of facies stacking patterns in terms of depositional environments and accommodation.

A fundamental difference between many mudrock successions and carbonate and sandstone/shale systems is the fact that the latter are defined largely by variations in sediment supply and accommodation observed along a gradient (i.e., depositional dip). These changes can typically be related to changes in sea level, climate, tectonics, or sediment supply. Some mudrock successions, in contrast, may show no such variations, instead, being a function of geographically largely in situ variations in sediment genesis and deposition. So can we apply sequence stratigraphic concepts in mudrock systems in a way that will result in improved understanding of facies architecture? Yes, No, and Maybe. The answer depends on available datasets. Critical to success are detailed data on sediment type and origin, a depositional model that predicts changes in sediment distribution (i.e., facies) along depositional gradient, and a data set that demonstrates lateral changes in facies geometries driven by dip-related variations in sediment supply. The potential for applying sequence stratigraphy is greatest in proximal areas of mudrock systems where platform shedding of shallow water clastics and carbonates is most common and poorest in distal settings where these deposits are rare or absent.

References Sited

Baumgardner, Robert W., Jr., and Harry D. Rowe, 2017, Using Hierarchical Cluster Analysis to Improve Facies Definitions in Permian Mudrocks (Wolfcamp and Lower Leonard), Midland Basin, Texas: 2016 AAPG Annual Convention and Exhibition, Calgary, Alberta, Canada, June 19-22, 2016, AAPG Search and Discovery Article #41986 (2017) . Website accessed May 10, 2017. http://www.searchanddiscovery.com/documents/2017/41986baumgardner/ndx_baumgardner.pdf

Catuneanu, O., W.E. Galloway, C.G.St.C. Kendall, A.D. Miall, H.W. Posamentier, A. Strasser, and M.E. Tucker, 2011, Sequence stratigraphy: methodology and nomenclature: Newsletters on Stratigraphy, v. 44/3, p. 173-245.

Handford, C. Robertson, and Robert G. Loucks, 1993, Carbonate depositional sequences and systems tracts - Responses of carbonate platforms to relative sea-level changes, Chapter 1: AAPG Memoir 57, p. 3-41.

Hamlin, H. Scott, and Robert W. Baumgardner, 2012, Wolfberry Play, Midland Basin, West Texas: 2012 AAPG Southwest Section Meeting, Ft. Worth, Texas, 19-22 May 2012, AAPG Search and Discovery Article #10419 (2012). Website accessed May 10, 2017. http://www.searchanddiscovery.com/pdfz/documents/2012/10419hamlin/ndx_hamlin.pdf.html

Kirschbaum, M.A., and R.D. Hettinger, 2004, Facies analysis and sequence stratigraphic framework of upper Campanian strata (Neslen and Mount Garfield Formations, Bluecastle Tongue of the Castlegate Sandstone, and Mancos Shale), eastern Book Cliffs, Colorado and Utah: U.S. Geological, Survey Digital Data Series DDS-69-G, 40 p., 7 plates.

Mitchum, R.M., 1977, Seismic stratigraphy and global changes of sea level, part 1: Glossary of terms used in seismic stratigraphy, *in* C.E. Payton, ed., Seismic stratigraphy - applications to hydrocarbon exploration: AAPG Memoir 26, p. 205-212.

Nail, Robert S., 2014, SE Delaware Basin Slope: Debrites, Turbidites, Organics, Oh My!: 2014 AAPG Southwest Section Annual Convention, Midland, Texas, May 11-14, 2014, AAPG Search and Discovery Article #10419 (2014). Website accessed May 10, 2017. http://www.searchanddiscovery.com/documents/2014/10611nail/ndx_nail.pdf

Ruppel, Stephen C., and W. Bruce Ward, 2013, Outcrop-based characterization of the Leonardian carbonate platform in west Texas: Implications for sequence-stratigraphic styles in the Lower Permian: AAPB Bulletin, v. 97/2, p. 223-250.

Vail, P.R., 1987, Seismic stratigraphy interpretation using sequence stratigraphy, Part I: Seismic stratigraphy interpretation procedure, *in* A.W. Bally, ed., Atlas of Seismic Stratigraphy, p. 1-10: AAPG, Stud. Geol. No. 27, v. 1, 125 p.

Can We Apply Sequence Stratigraphic Concepts in Mudrock Successions?

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AAPG Annual Convention 2017
Houston, TX

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My Key Points in this Talk

•Sequence stratigraphic methods *cannot* be applied to all data sets.

• Sequence stratigraphy is especially difficult to apply in many mudrock successions

• *Depositional Sequences* can be defined in many proximal mudrock successions but are difficult to define in distal successions

• In distal settings, lithostratigraphy, guided by biostratigraphy and event beds, may be the best method for defining stratal architecture

• Application of sequence stratigraphic terminology and surfaces to weak data sets can result in confusing and in some cases meaningless correlations of facies and their interrelationships

What is a Depositional Sequence Anyway?

Original Definition

- Succession of genetically-related facies bounded by unconformities or correlative conformities (Mitchum, 1977)

Modern Definition

- Succession of strata deposited during a full cycle of change in accommodation or sediment supply (Catuneanu et al., 2011)

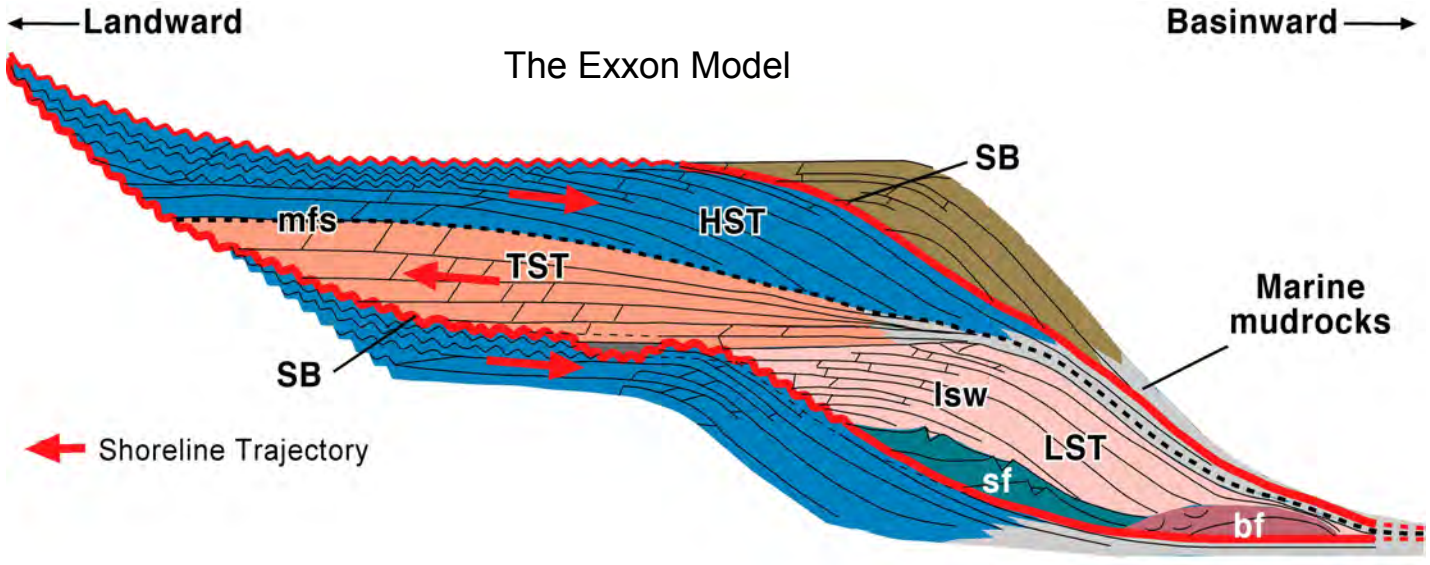
A More Specific Definition

- Succession of temporally-related facies deposited during a full cycle of change in accommodation or sediment supply that display dip-related offsets.

The Original Depositional Sequence Model

Note:

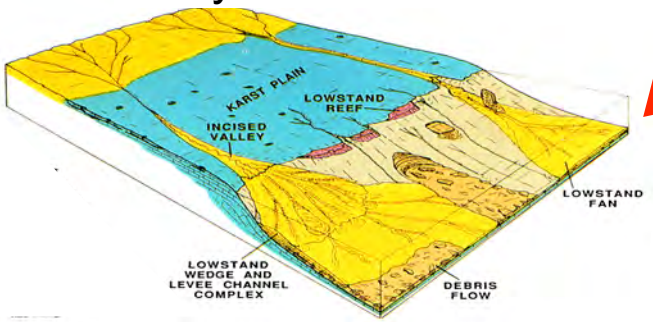
- Landward and Basinward Shifts in Systems Tracts (and Facies)
- Distal Position of Mudrock Successions



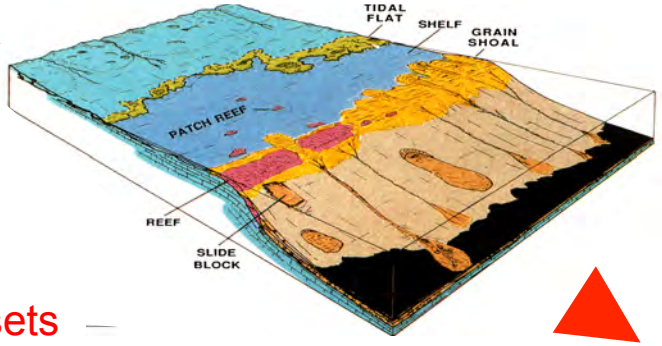
Modified after Vail (1987)

Facies & Systems Tract Offsets

Lowstand Systems Tract

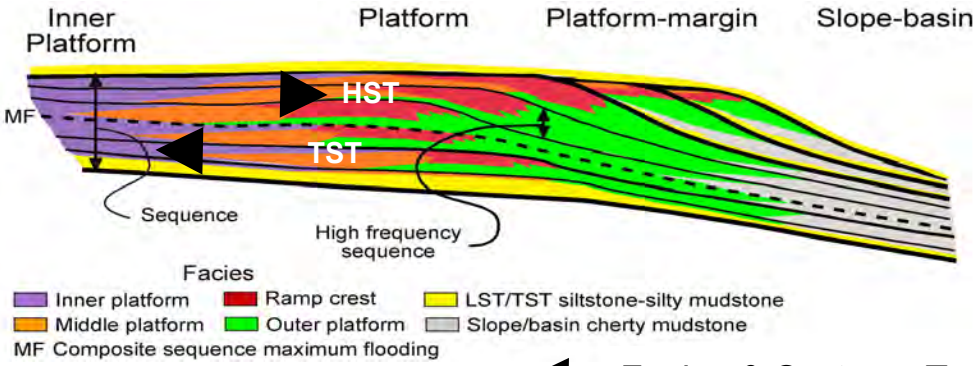


Transgressive Systems Tract



Mudrocks

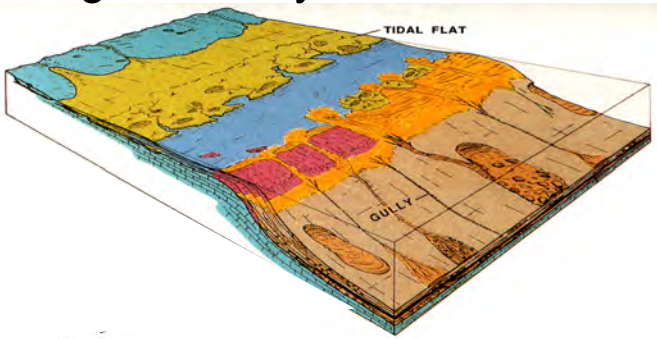
Note Facies & Systems Tract Offsets



From Ruppel and Ward (2013)

Facies & Systems Tract Offset

Highstand Systems Tract



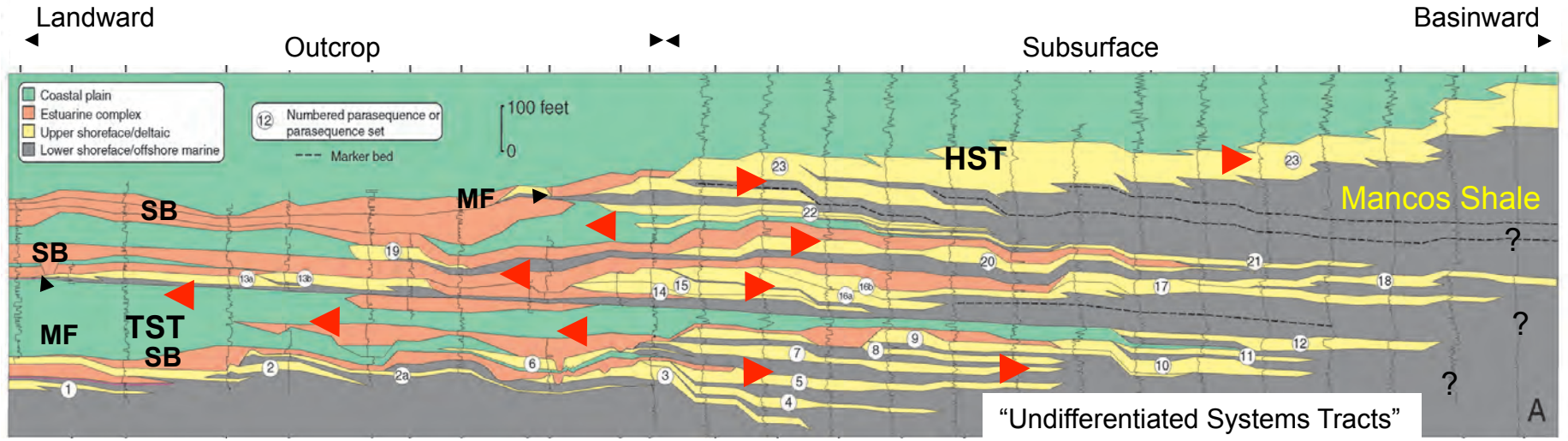
From Handford and Loucks (1993)

Facies Offsets and Sequences in a Proximal Basin Setting

Upper Cretaceous: Uinta-Piceance Basin

Note:

- Landward & basinward shifts in facies & systems tracts (i.e., offsets) caused by variations in sediment supply & accommodation
- Sequences definable in proximal areas; not in distal areas



Shoreline Trajectory

From Kirschbaum and Hettinger (2004)

How Can Facies Offset Be Defined In Mudrock Successions?

- Need to recognize superposed proximal & distal facies
- Need depositional facies models
- Need integrated chemostratigraphic and microscopy data
- Need cores and/or *calibrated* logs
- Need data oriented along depositional dip

Dominant Proximal Mudrock Sediment and Sources

Quartz: Terrestrial/Detrital

- Flux increased during lowstands (or by climate or tectonics)
- Must be defined by microscopy
- Sand, silt and clay
- Fluvial, aeolian, and gravity transport
- Barnett, Woodford, Marcellus, Wolfcamp, Leonard, Eagle Ford, etc

Carbonate: Detrital

- Flux variable (function of sea-level and/or tectonics)
- Must be defined by microscopy
- Shallow water carbonate grains and lithoclasts
- Gravity transport
- Barnett, Haynesville, Wolfcamp, Leonard

Clay Minerals: Terrestrial/Detrital

- Flux can be relatively constant
- Defined by logs or XRF
- Suspension transport
- Ubiquitous

Dominant Distal Mudrock Sediment and Sources

Quartz/Silica: Pelagic Biogenic

- Flux driven by nutrient supply and productivity
- No apparent control by sea level change
- Must be defined by microscopy
- Spicules, radiolaria
- Barnett, Woodford, Marcellus

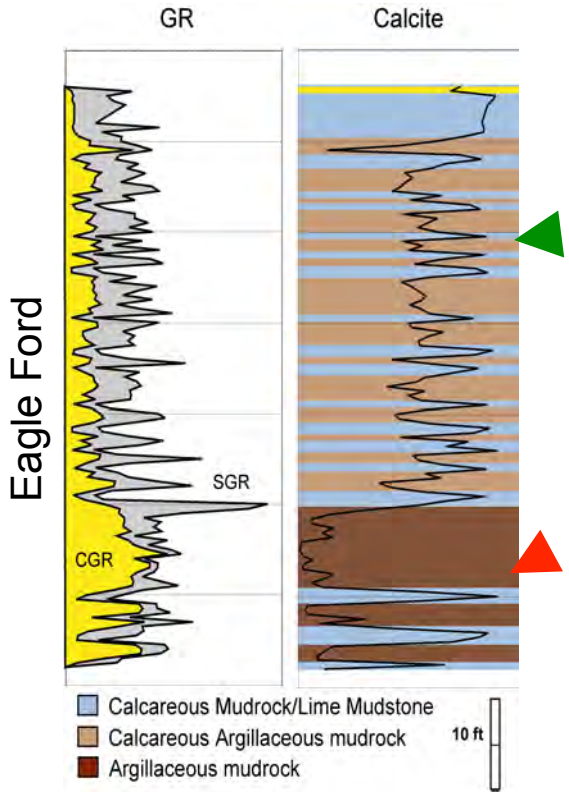
Calcite: Pelagic Biogenic

- Flux driven by nutrient supply and productivity
- No apparent control by sea level change
- Must be defined by microscopy
- Nanofossils, forams
- Eagle Ford

Clay Minerals: Terrestrial/Detrital

- Flux can be relatively constant
- Defined by logs or XRF
- Suspension transport
- Ubiquitous

Proximal vs Distal Sediment Supply Varies Laterally & Temporally

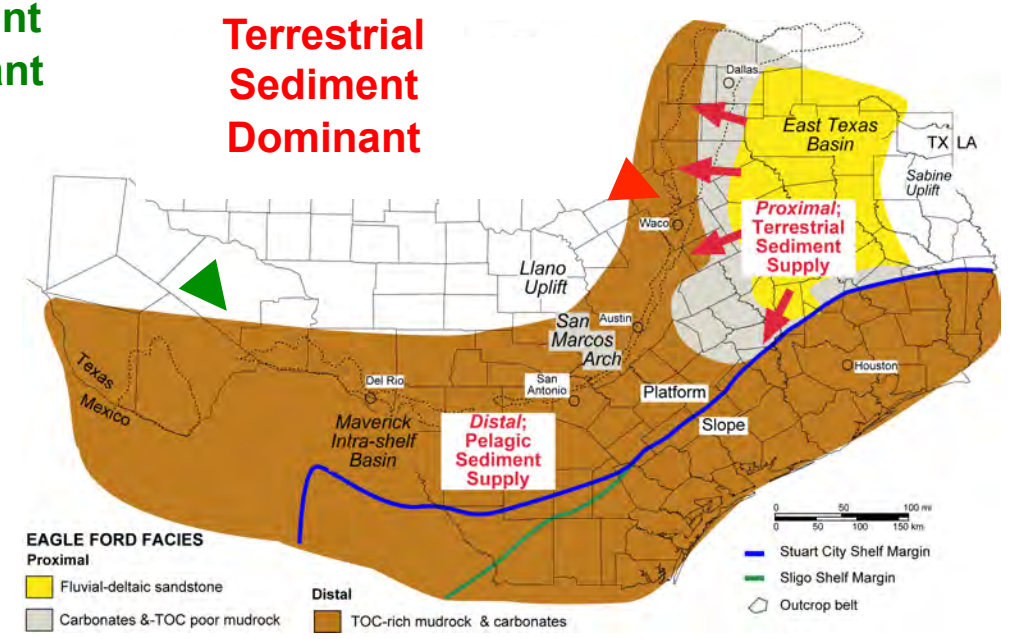


DISTAL: Pelagic Sediment Dominant

PROXIMAL: Terrestrial Sediment Dominant

Also: Woodford, Barnett, Marcellus, Haynesville

Eagle Ford, South Texas

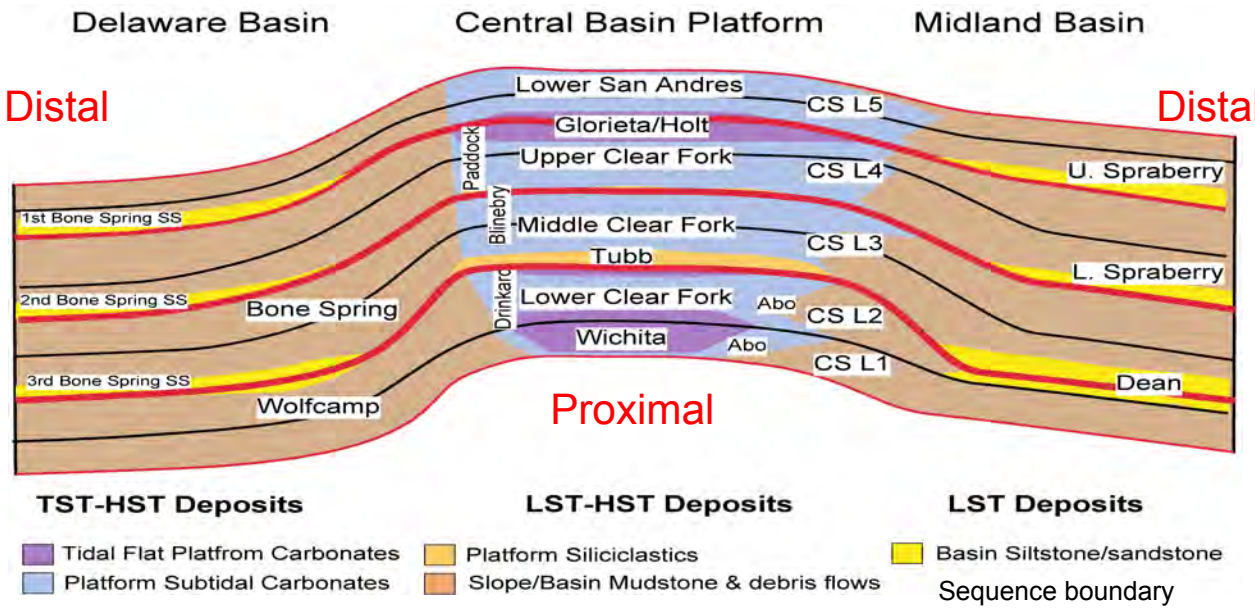


Challenges in Applying Sequence Stratigraphy in Distal Organic Matter-rich Mudrock Systems

- Proximal sediment is limited; pelagic biogenic sediment is dominant
- Logs must be calibrated with core data for facies characterization
- None of the following necessarily imply changes in water depth
  - OM abundance
  - Redox
  - Cyclicity
  - Current structures
  - Faunal assemblages
- Hiatuses common but not necessarily related to sequence surfaces
- Many facies have limited lateral extent due to bottom current erosion and re-deposition

An Exception: The Leonardian of the Permian Basin

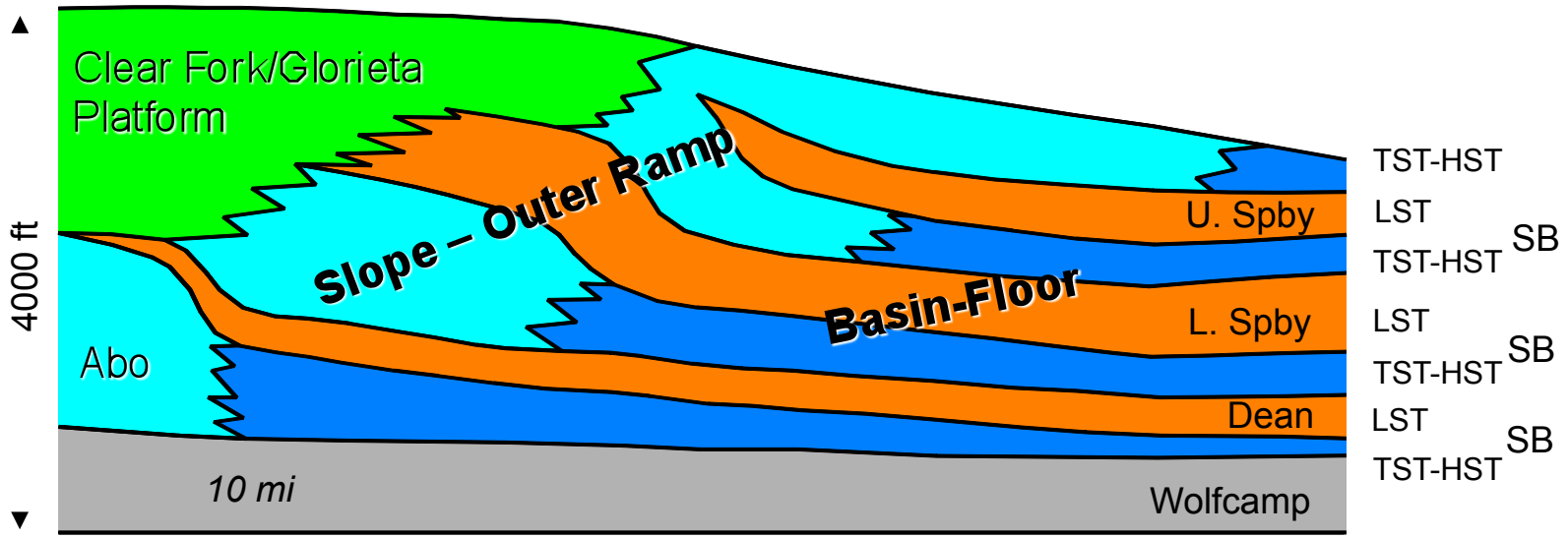
- High platform-shedding sediment flux recognizable in proximal *and* distal settings
- Sequences defined by dip-related facies offsets caused by relative sea level change



From Ruppel, in review

Leonardian Sequence Stratigraphy

Midland Basin



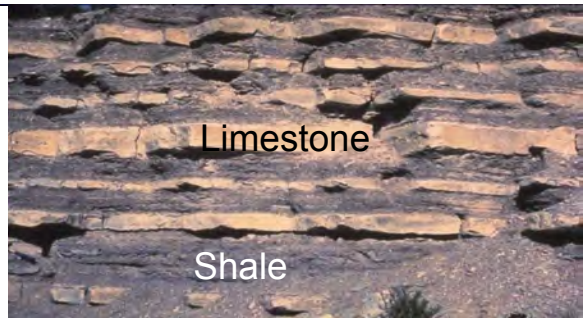
Leonardian Depositional Facies

- Platform carbonates
- Slope and basin clastics
- Slope carbonates
- Basin calcareous & siliceous mudrocks

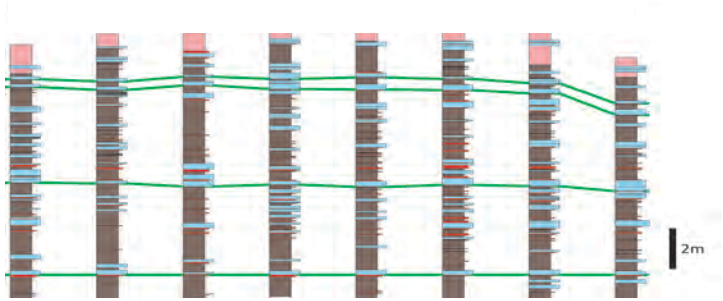
From Hamlin and Baumgardner, 2012

What About Cyclicity for Correlations and Sequences?

- Not all cycles define platform shedding events or facies offset
- Logs cannot define grain types & paleoenvironments
- Facies commonly discontinuous

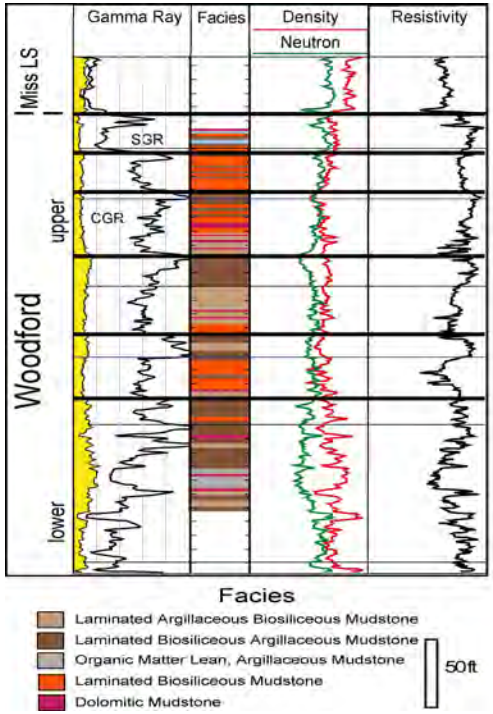


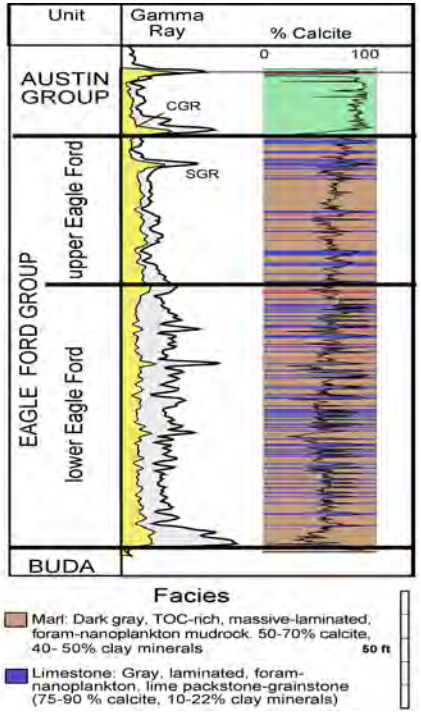
From Bohacs and Lazar, 2010



From Frebourg, et al (2016)

Distal Cyclicity





So How Can We Define Distal Mudrock Architecture?

Basic Tools

Biostratigraphy & Geochronology: for temporal relationships

Lithostratigraphy

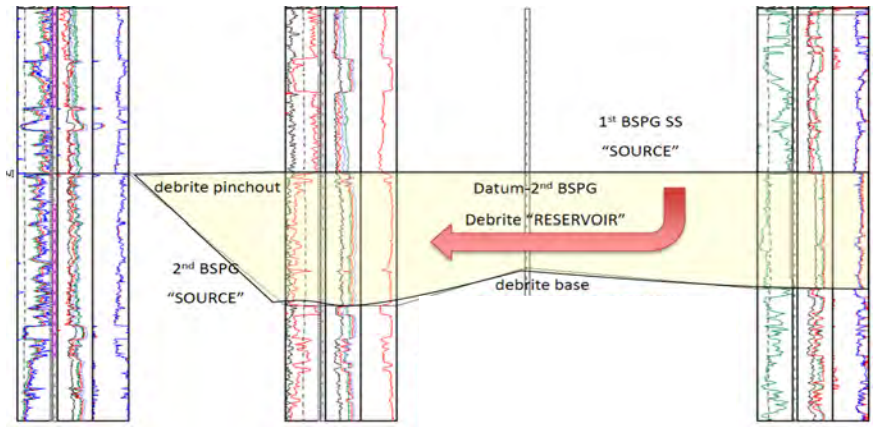
- XRF & integrated microscopy from cores
  - For facies identification and log calibration
- Logs
  - All logs must be calibrated to cores
  - Spectral Gamma Ray log can define clay mineral abundance and TOC/redox variations

If combined, these data *may* form the basis for defining sequences and surfaces.

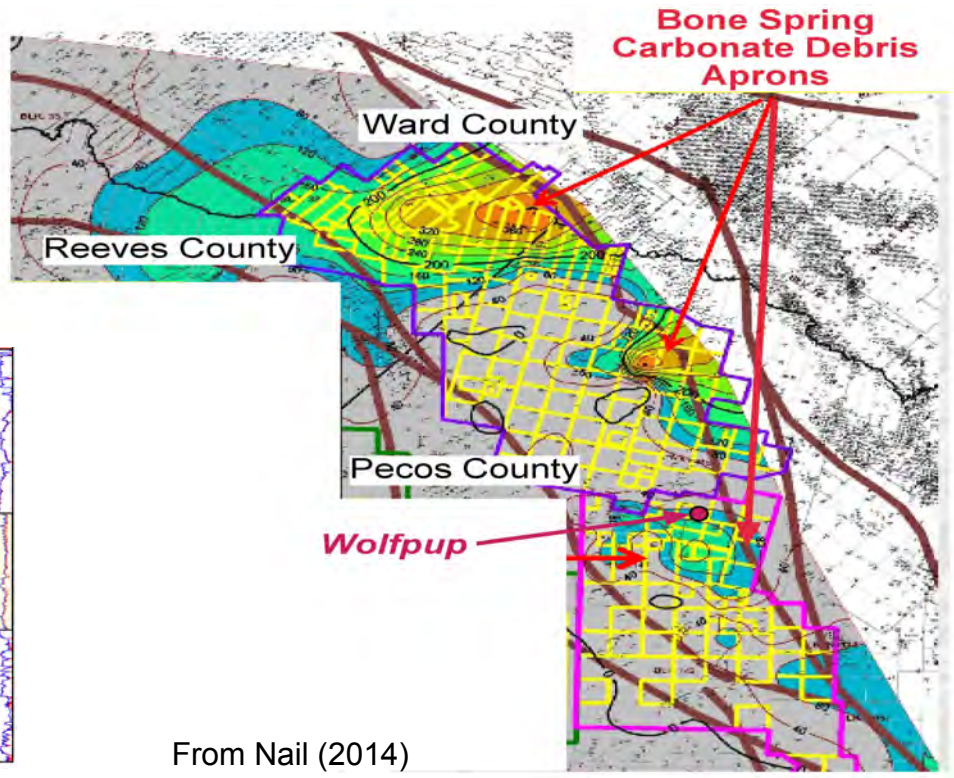
Event Beds, Correlations, & Sequences

- Can be good correlation markers
- BUT: Point-sourced; geometry variable
- AND: Less common distally
- AND: Uncertain connection to sequence surfaces & systems tracts

Debris Bed Correlations



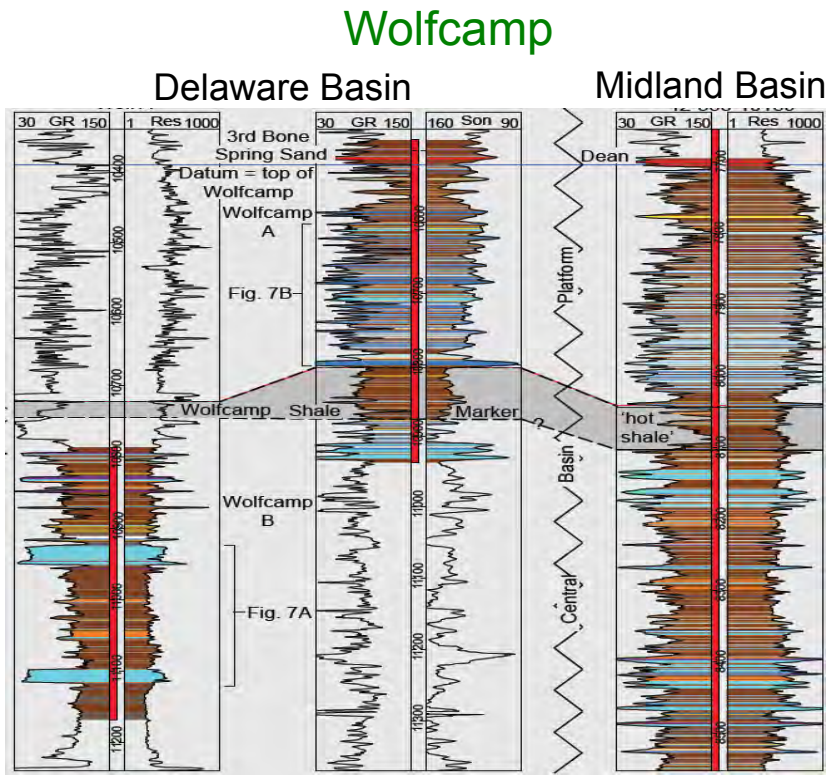
Point Sourced Debris Complexes



From Nail (2014)

Event Beds for Correlations (and Sequences?) in a Distal Mudrock Succession

- Define platform shedding events
- *May* be relatable to changes in sea level
- But, are commonly point-sourced!



From Baumgardner et al (2017)

So: Can We Apply Sequence Stratigraphic Concepts in Mudrock Successions?

Yes

Commonly in proximal settings where cores and calibrated logs define facies offsets related to changes in sediment flux or sea level along dip sections

No

In many distal settings where deposition is dominated by pelagic marine sediment, or where cores & calibrated logs are unavailable, or where facies offsets cannot be defined

Maybe

Where event beds and other lithostratigraphic units can be tied to changes in sediment flux or relative sea level

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