Using Sequence Stratigraphy to Optimize Target Selection in Shale Plays of the Rockies (and Beyond)*

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Abstract

Sequence stratigraphy is not THE answer in optimizing the selection of horizontal targets in shale plays. But it is an extremely useful, and oftentimes necessary, tool that should be used to assess reservoir intervals and improve geosteering.

Sequence stratigraphy can aid subsurface geologic interpretation and evaluation in numerous ways. It

1) provides an increased understanding of depositional controls on reservoir vs. non-reservoir facies,
2) promotes better well-log correlations,
3) aids in reservoir prediction,
4) offers a framework for data integration,
5) guides sample collection from core,
6) delivers better reservoir flow models and volumetric calculations,
7) helps in choosing and staying within the target zone, and
8) furnishes input for completion design.

This talk focuses on optimizing horizontal targeting in shale reservoirs based on sequence stratigraphic concepts. Examples from the Marcellus, Eagle Ford, Niobrara, Mowry, and Avalon shales reveal the significance of assessing reservoir quality and mechanical properties within a systems tract and parasequence framework.

The best targets typically comprise load-bearing grains and a brittle framework, plus contain large, interconnected pores. When sediment influx is dominantly extrabasinal (detrital), load-bearing grains are delivered during highstands and lowstands. Connected interparticle pores in these systems tracts often yield the best hydrocarbon storage and deliverability. In contrast, the basal condensed section in extrabasinal systems may be the most organic-rich interval, but unconnected organic-matter pores frequently dominate, typically yielding lower flow rates and even creating drilling problems. In contrast, when input is largely intrabasinal (biogenic), late transgressions and condensed sections commonly yield microfossil-rich, brittle deposits. Interconnected interparticle pores and natural as well as induced fracturing usually make these systems tracts the optimum targets.

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- Rob Diedrich & John McLeod, SM Energy
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- Amy Noack, Chemostrat*

** previously with EOG Resources*

Sequence Stratigraphy

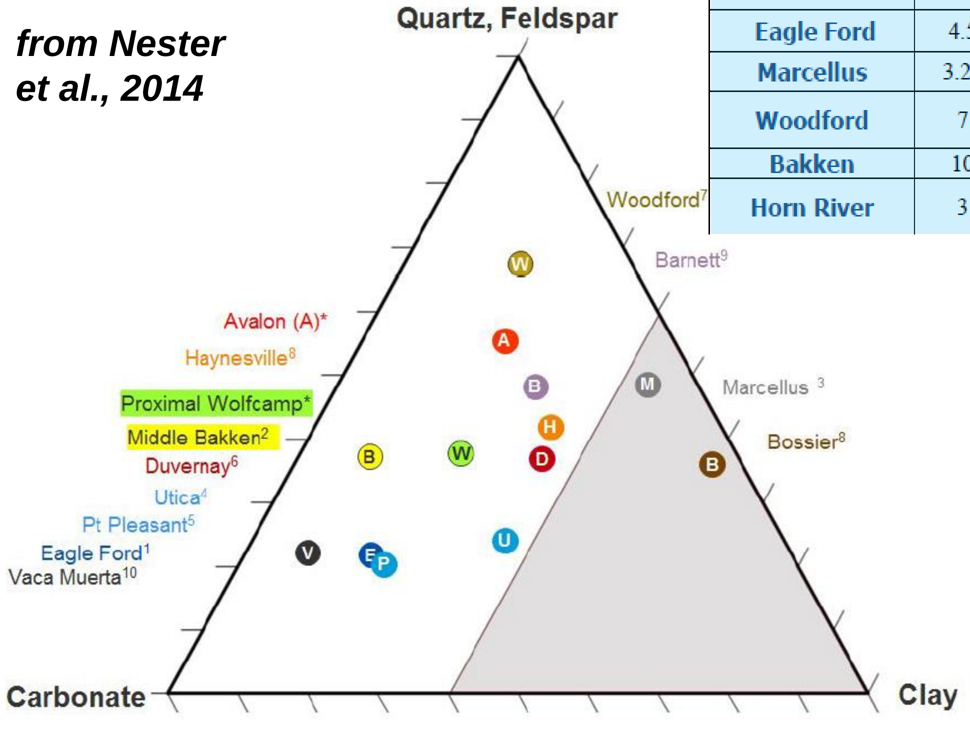
- provides another tool in your “tool box”
- promotes better well-log correlations
- offers context for depositional controls on reservoir vs. non-reservoir
- guides data collection from core
- provides framework for data integration
- delivers better reservoir models & volumetrics
- helps select & stay in horizontal target
- furnishes input for completions

Mudrocks are Heterogeneous – Beware of Averages!

from Alzahabi et al., 2014

parameters / Shales	TOC	RO	Total Porosity	Net Thickness	Adsorbed Gas	Gas Content	Depth	Permeability, nd
Barnett	4.50	2.00	4.50	350.00	25	325	6500	25-450
Ohio	2.35	0.85	4.70	65.00	50	80	3000	n/a
Antrim	5.50	0.50	9.00	95.00	70	70	1400	n/a
New Albany	12.50	0.60	12.00	75.00	50	60	1250	n/a
Lewis	0.45-1.59	1.74	4.25	250.00	72.5	29.5	4500	n/a
Fayettevillle	6.75	3.00	5.00	110.00	60	140	4000	n/a
Haynesville	3	2.2	7.3	225	18	215	12000	10-650
Eagle Ford	4.5	1.5	9.7	250	35	150	11500	1100-2500
Marcellus	3.25	1.25	4.5	350	50	80	6250	n/a
Woodford	7	1.4	6	150	n/a	250	8500	145-206
Bakken	10	0.9	5	100	n/a	n/a	10000	n/a
Horn River	3	2.5	3	450	34	n/a	8800	150-450

from Nester et al., 2014



Shale play	E	v
Barnett	3.5 E+06	0.2
Ohio	n/a	n/a
Antrim	n/a	n/a
New Albany	n/a	n/a
Lewis	n/a	n/a
Fayetteville	2.75 E+06	0.22
Haynesville	2.00 E+06	0.27
Eagle Ford	1.00:4.00 E+06	019:0.27
Marcellus	2.00 E+06	0.26
Woodford	5.00 E+06	0.18
Bakken	6.00 E+06	0.22
Horn River	3.64 E+06	0.23

Variable Grain Sizes

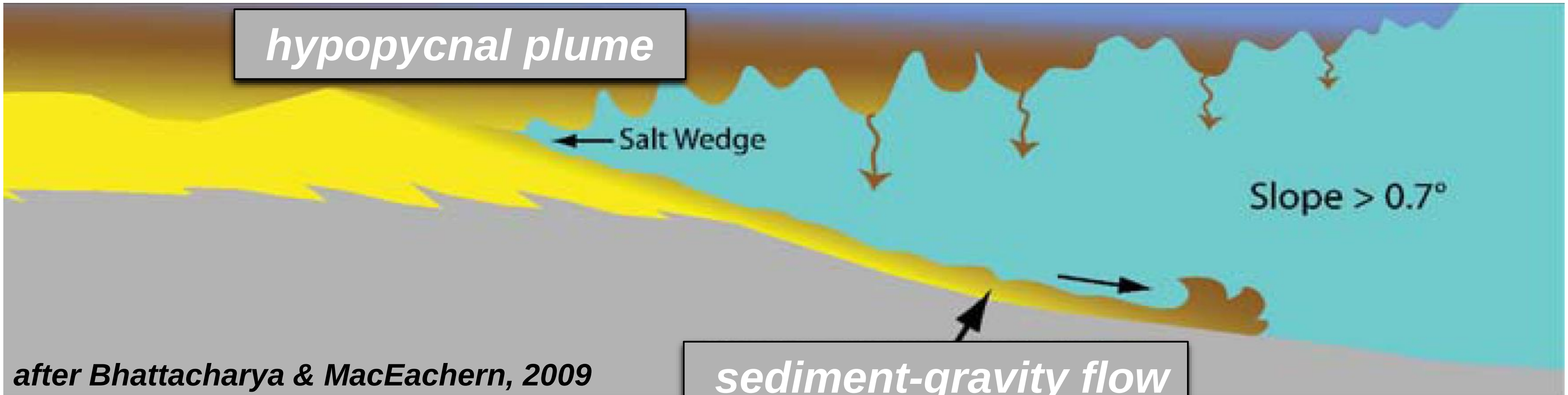
mudrock = > 50% of grains less than 62.5 microns

		silt:clay ratio	
	2/3		1/3
nonlaminated	siltstone	mudstone	claystone
laminated	siltstone	mudshale	clayshale

from Blatt, Middleton, & Murray 1980

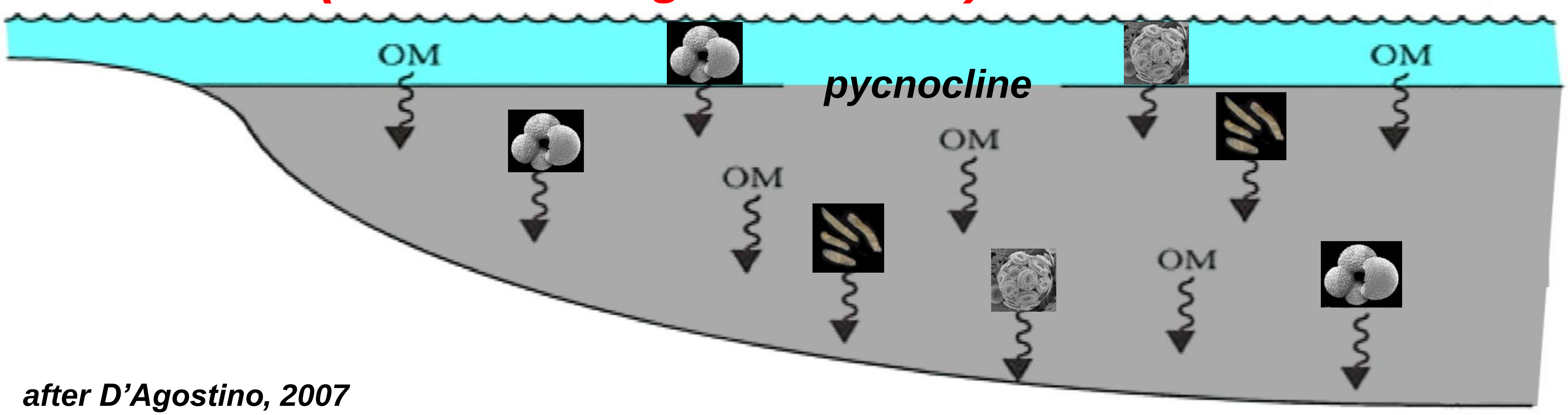
Variable Lithologies

extrabasinal (deltaic outflow or carbonate-margin shedding)



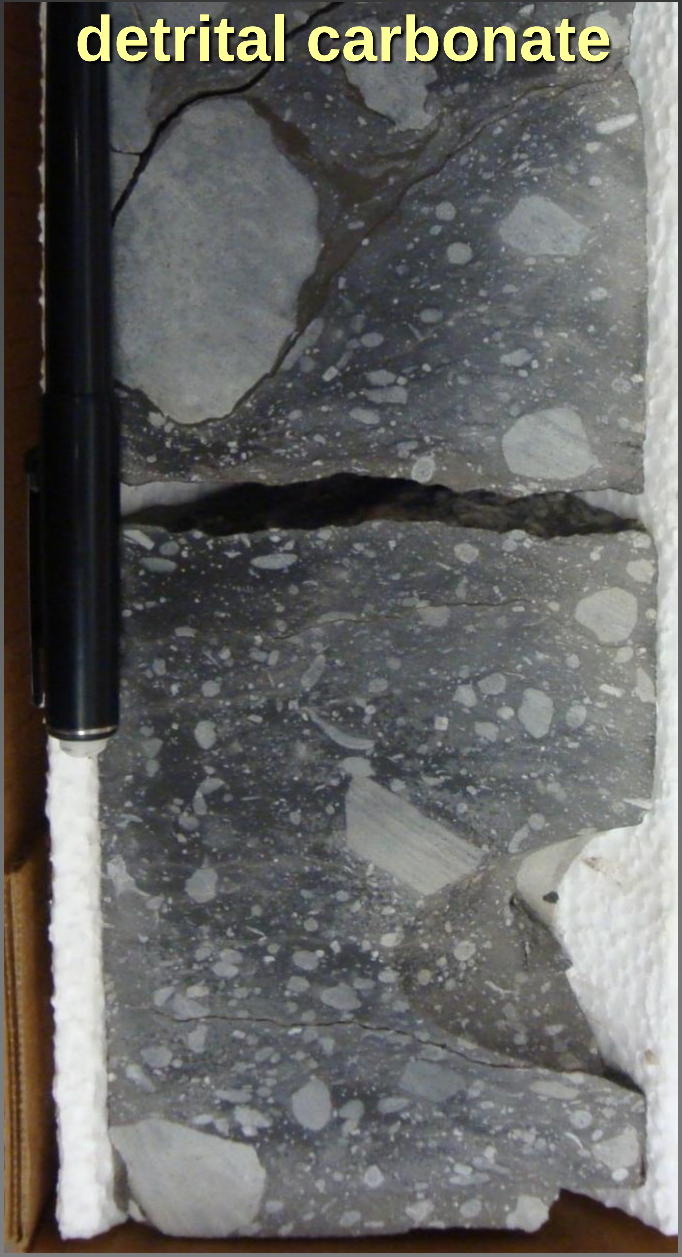
after Bhattacharya & MacEachern, 2009

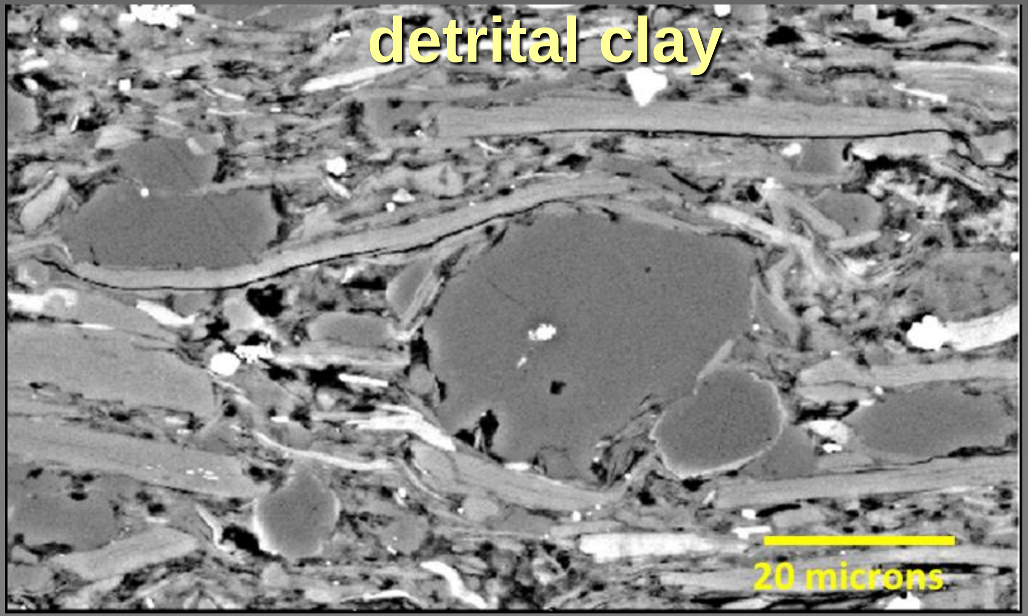
intrabasinal (skeletal & organic matter)



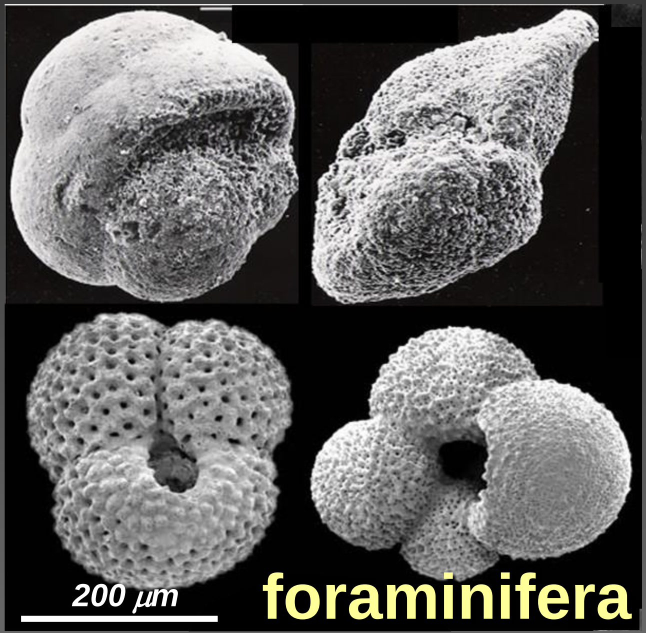
after D'Agostino, 2007

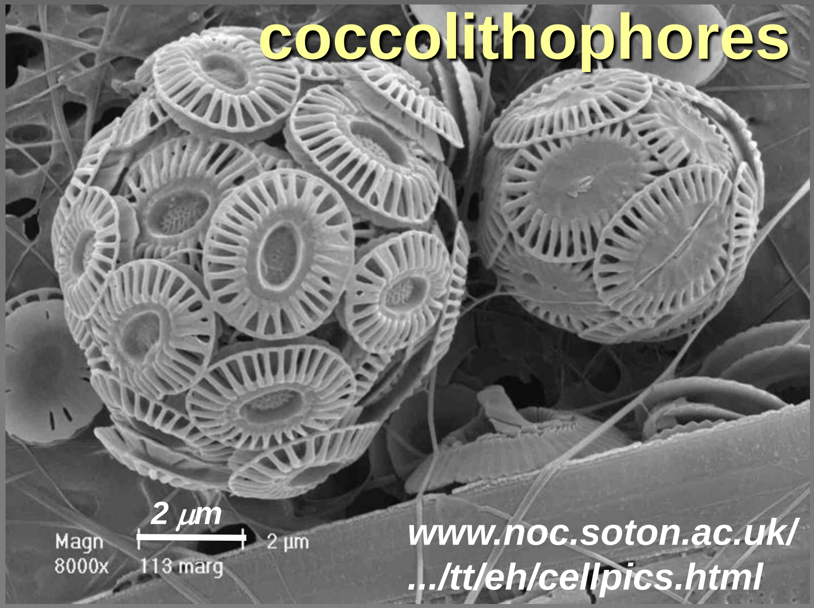
Extrabasinal Material

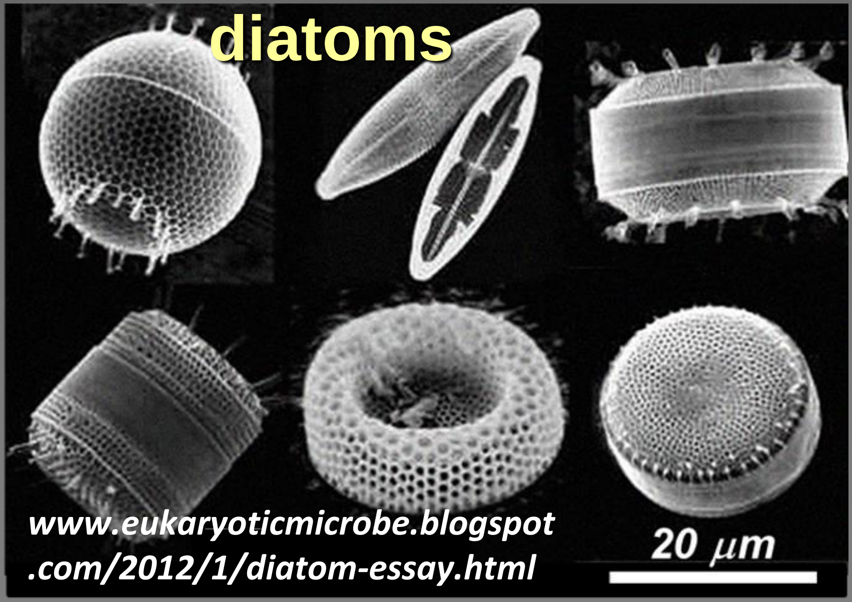




Intrabasinal Material - Skeletal

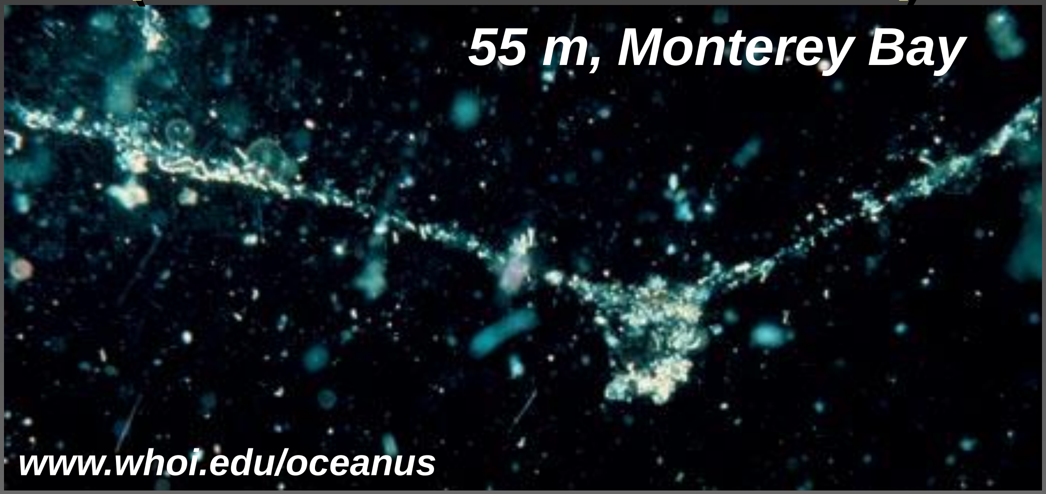


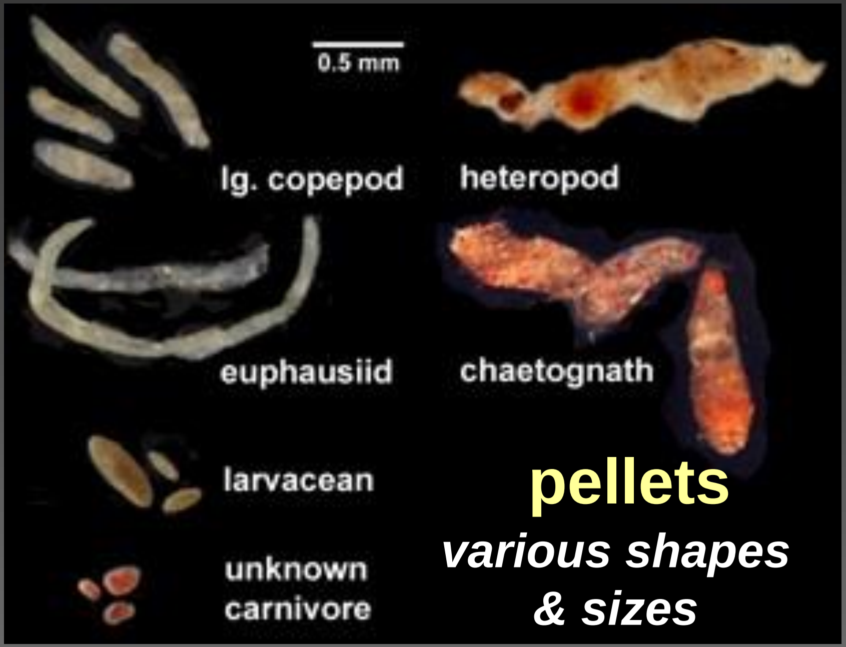


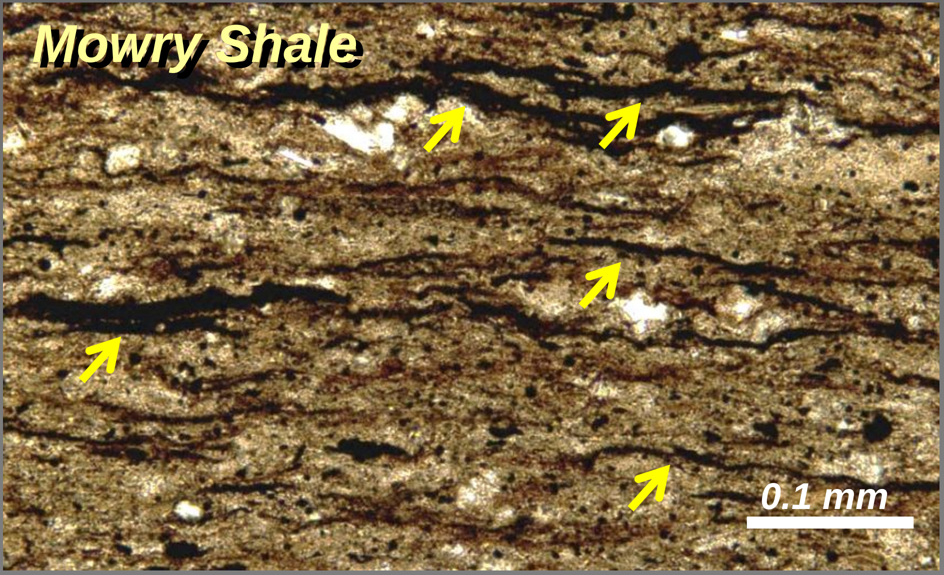


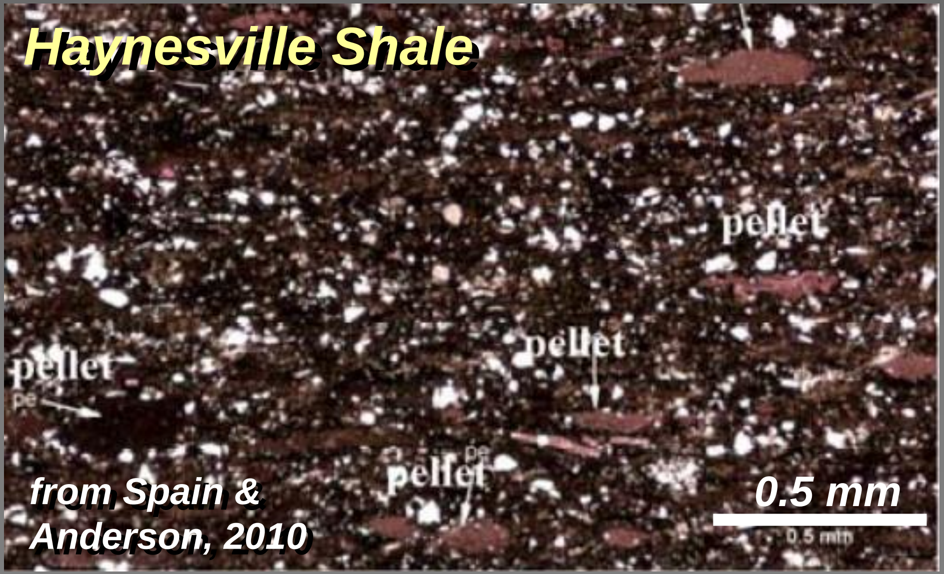
Intrabasinal Material - Organic

organo-minerallic aggregates (marine snow/carbon rain)



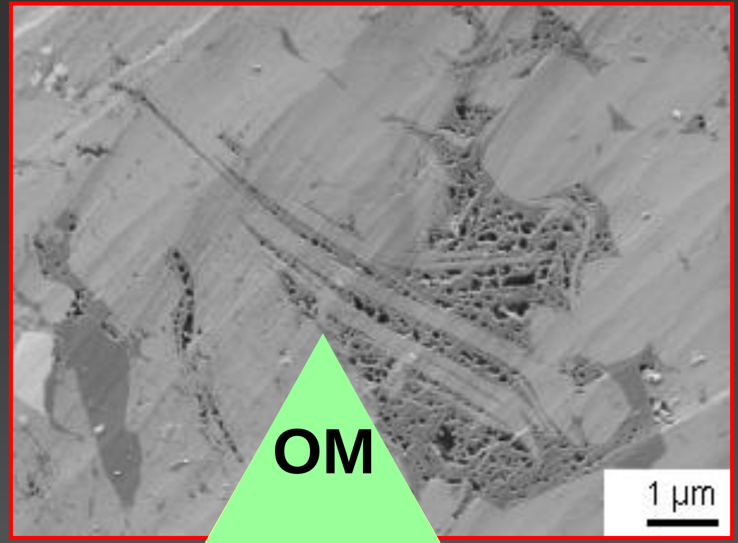


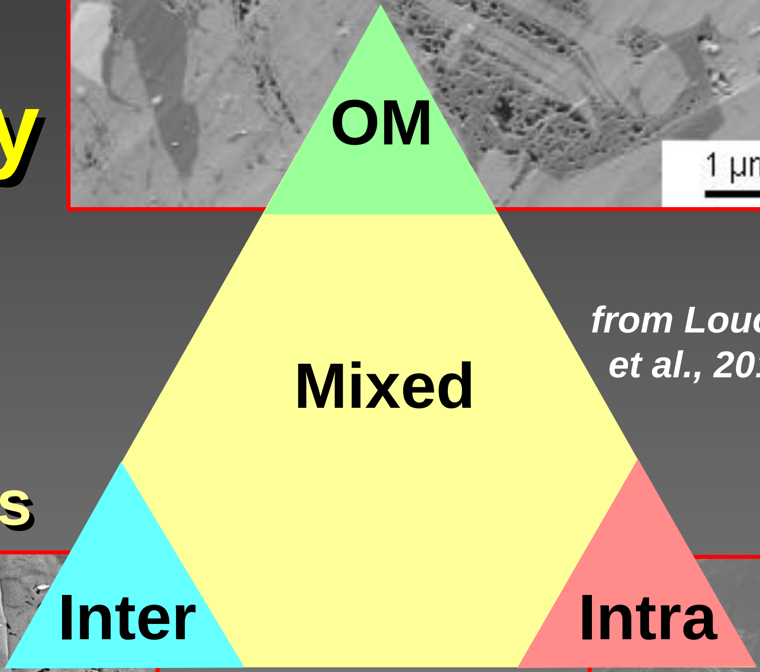




Variable Pore Types, Sizes, & Connectivity

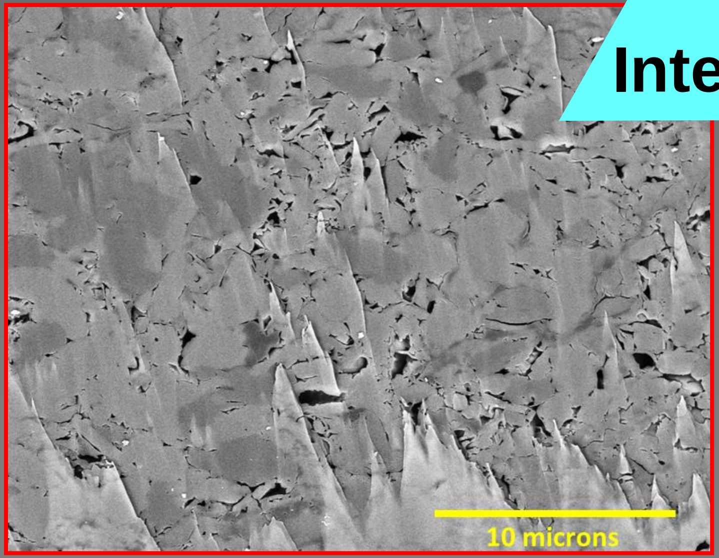
Organic Matter Pores



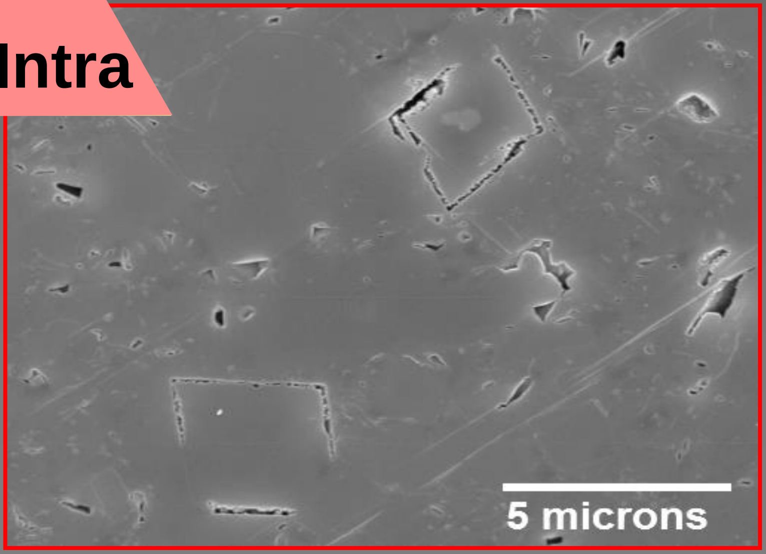


from Loucks et al., 2012

Interparticle Pores

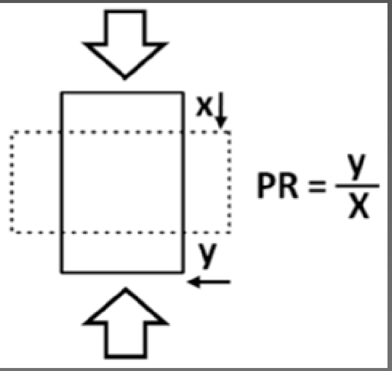


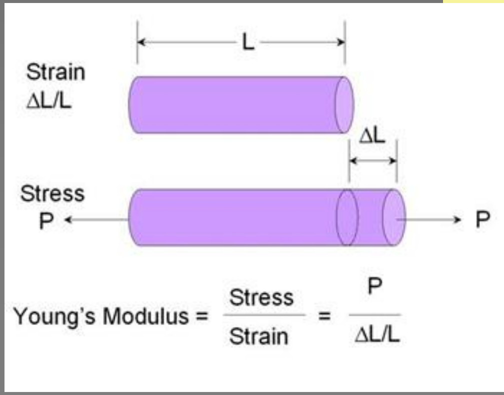
Intraparticle Pores

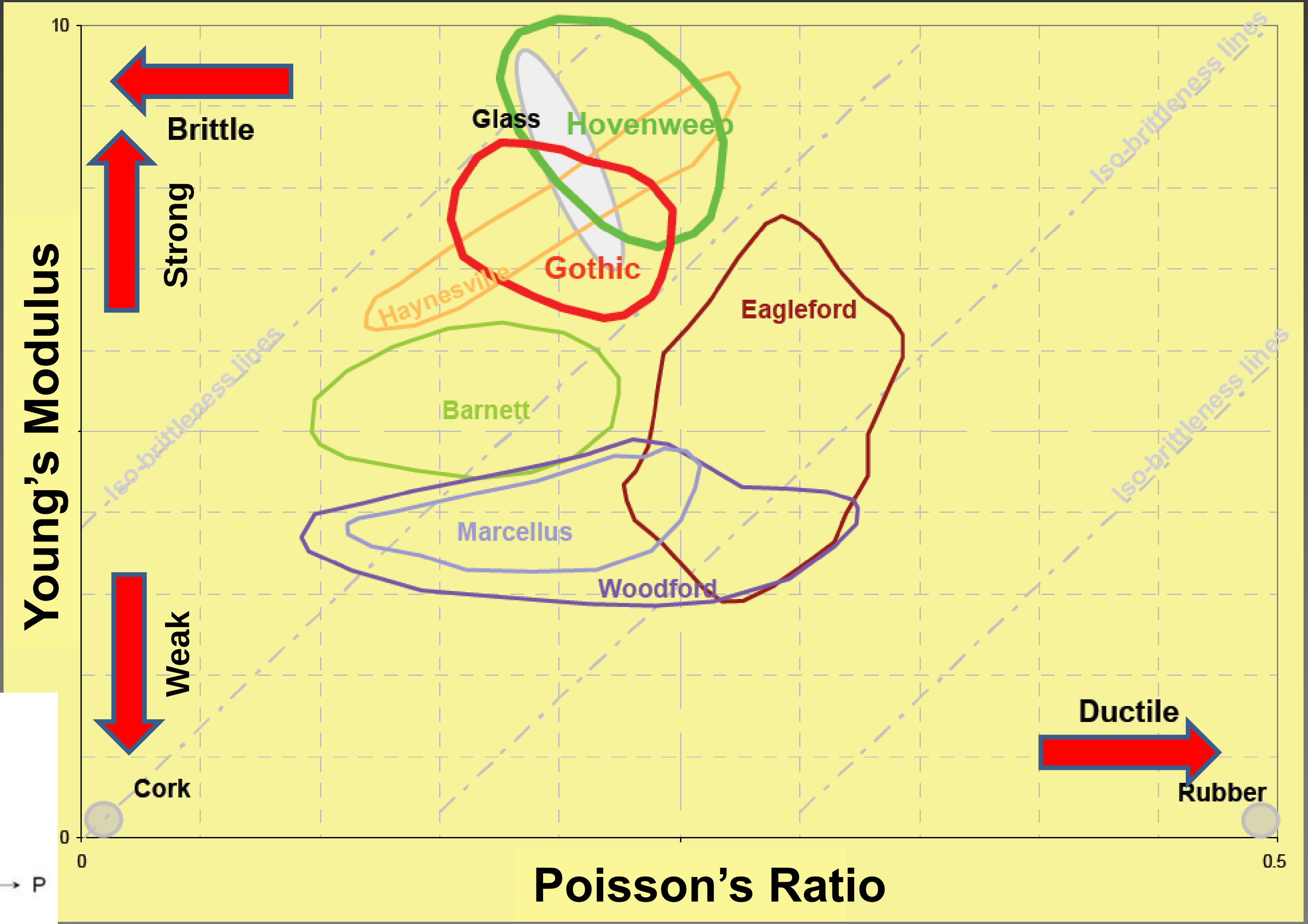


Variable Mechanical Properties

Poisson's Ratio & Young's Modulus







from Moreland & Broacha, 2010

Mudrocks are Heterogeneous – BUT Not Random

- grain size
- mineralogy
- lithologic components
- lithofacies
- organic-matter types & content
- porosity (types & sizes) and permeability
- hydrocarbon saturation
- rock mechanics (strength & brittleness)
- seals & fracture barriers

Sequence Stratigraphy & Targeting

provides the framework for deciphering heterogeneity in unconventional reservoirs

- **What controls variations in lithology, fabric, porosity, permeability, strength (YM), & brittleness (PR)?**
- **What part of the section should you target?**
- **How might reservoir & mechanical properties change vertically & laterally?**
- **What could be the areal extent of the target zone?**
- **What part of the section could form pressure seals &/or fracture barriers?**

Shale Target Selection

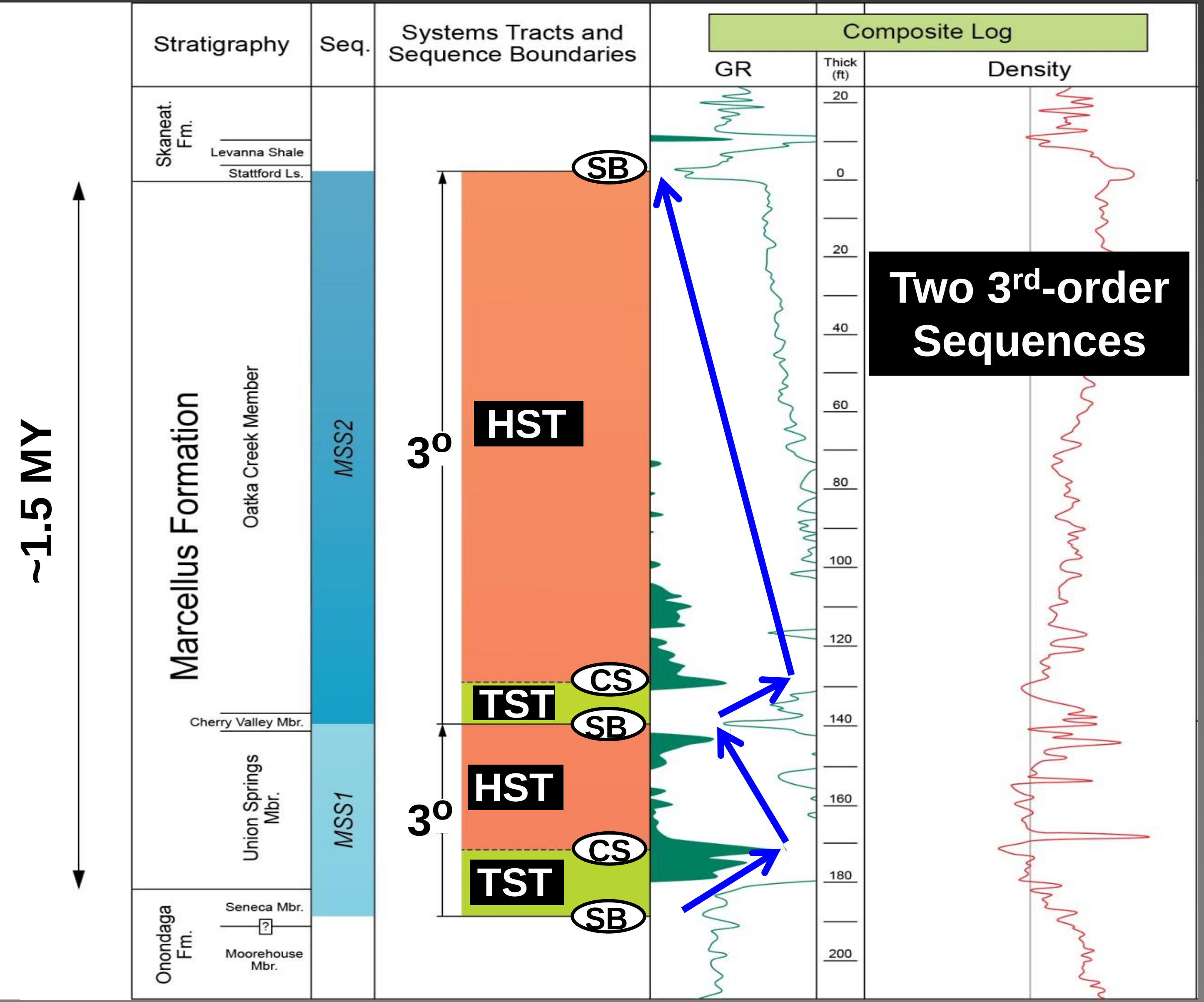
- **best reservoirs = intervals with load-bearing (strong), brittle framework AND large interconnected pores (and HC saturation)**
- **when input dominantly detrital (extrabasinal)**
  - **load-bearing grains delivered during highstands &/or lowstands**
  - **both siliciclastic & carbonate systems**
- **when input dominantly biogenic (intrabasinal)**
  - **load-bearing skeletal grains dominate (low dilution) during late transgression to condensed section**
  - **brittle framework + organic material**

Targeting Optimization

sequence stratigraphic framework of reservoir & mechanical properties

- **Marcellus (extrabasinal dominated)**
- **Eagle Ford (extrabasinal influenced)**
- **Mowry (extrabasinal influenced)**
- **Niobrara (intrabasinal dominated)**
- **Avalon (Leonard) (mixed extrabasinal & intrabasinal)**

Marcellus Sequence Stratigraphy (Extrabasinal Dominated)

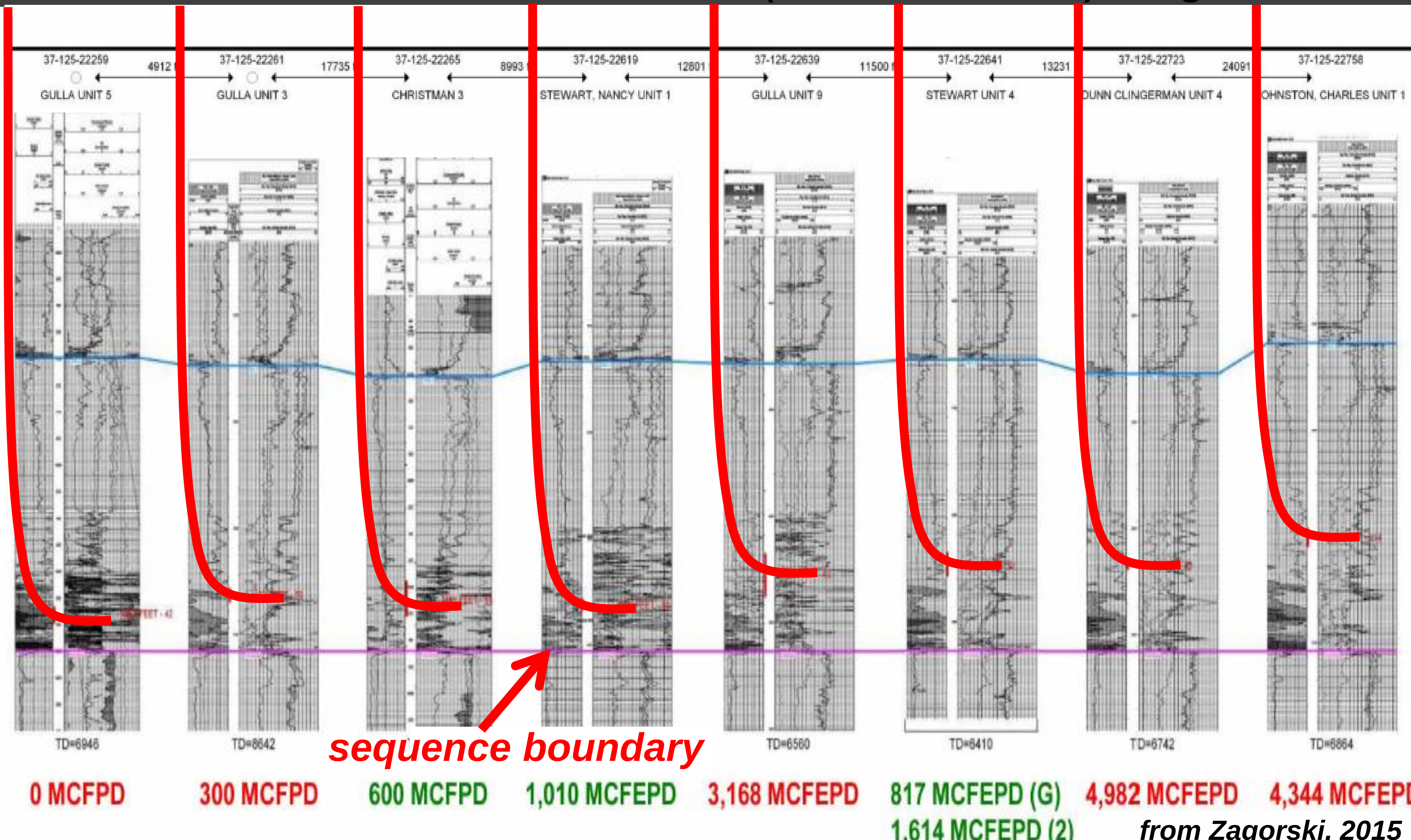


modified from Lash, 2010

Marcellus Targeting 2006-2008

initial wells in high TOC section = low IP's

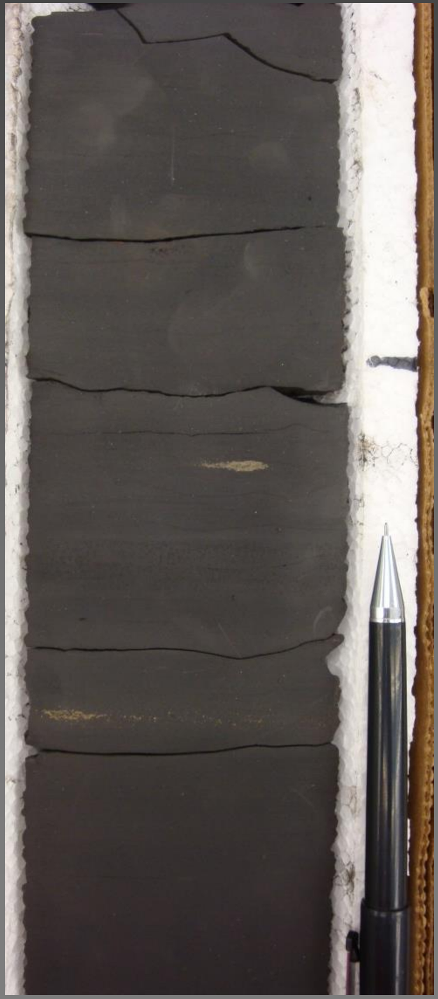
later wells slightly shallower (low TOC section) = higher IP's

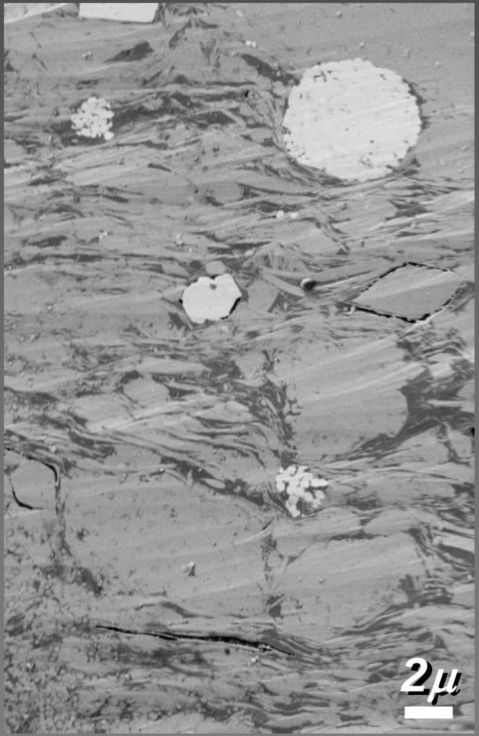


from Zagorski, 2015

Marcellus Targeting

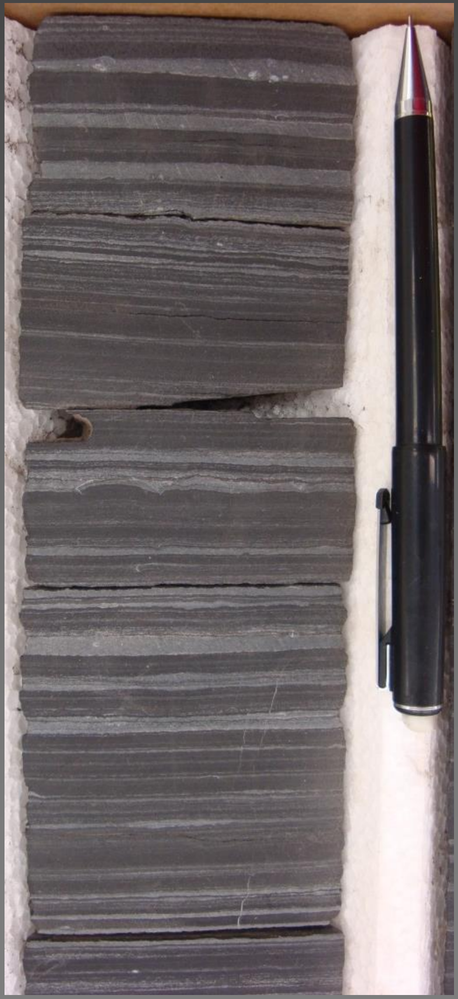
initial wells in high TOC condensed section

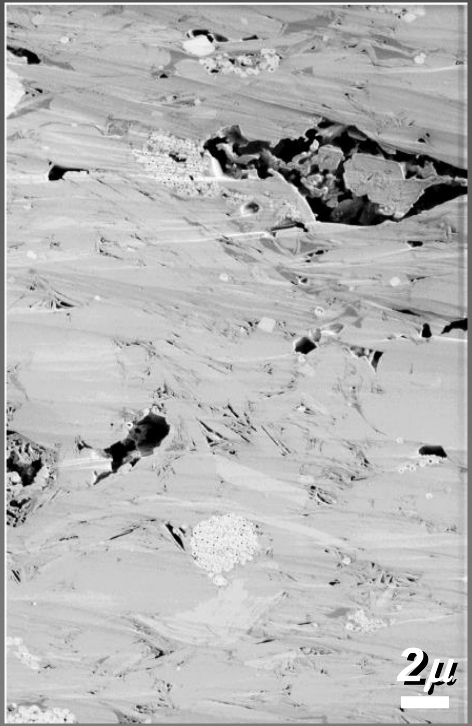




organic matter & intraparticle pores

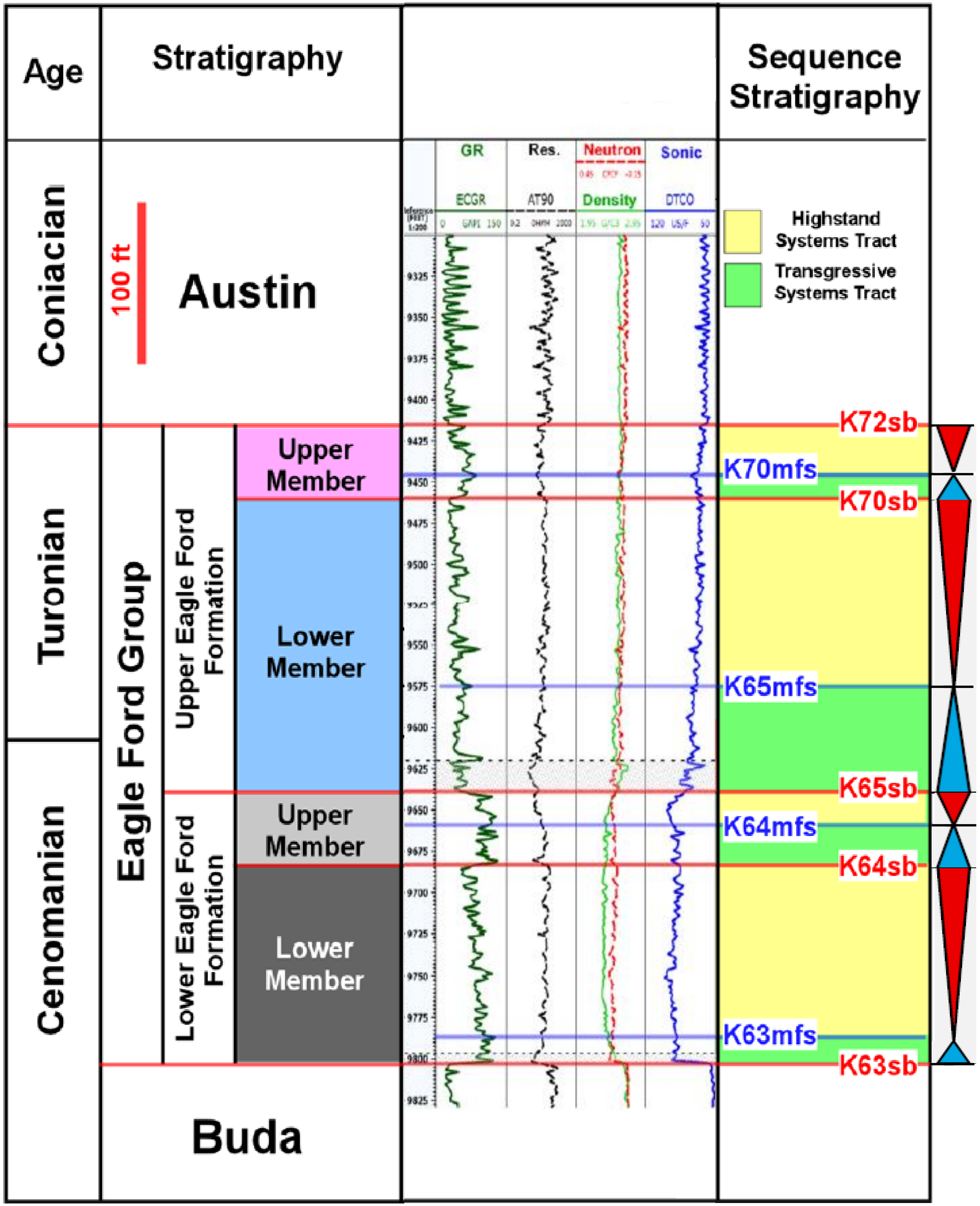
better wells in early highstand detrital section





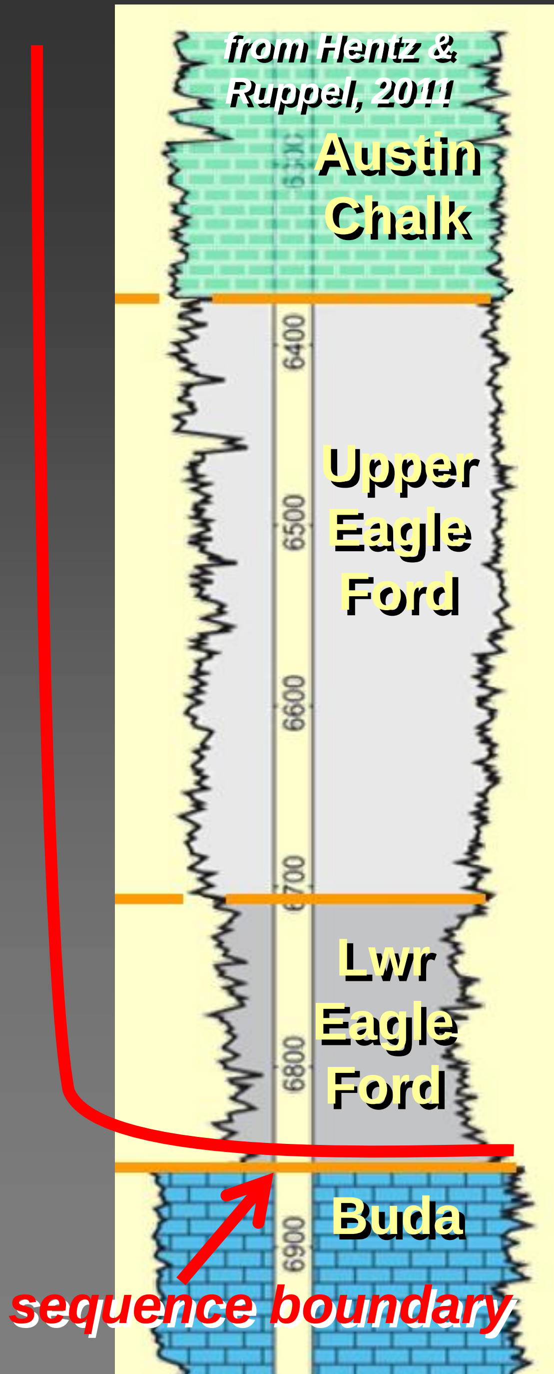
organic matter & interparticle pores

Eagle Ford Sequence Stratigraphy (Extrabasinal Influenced)



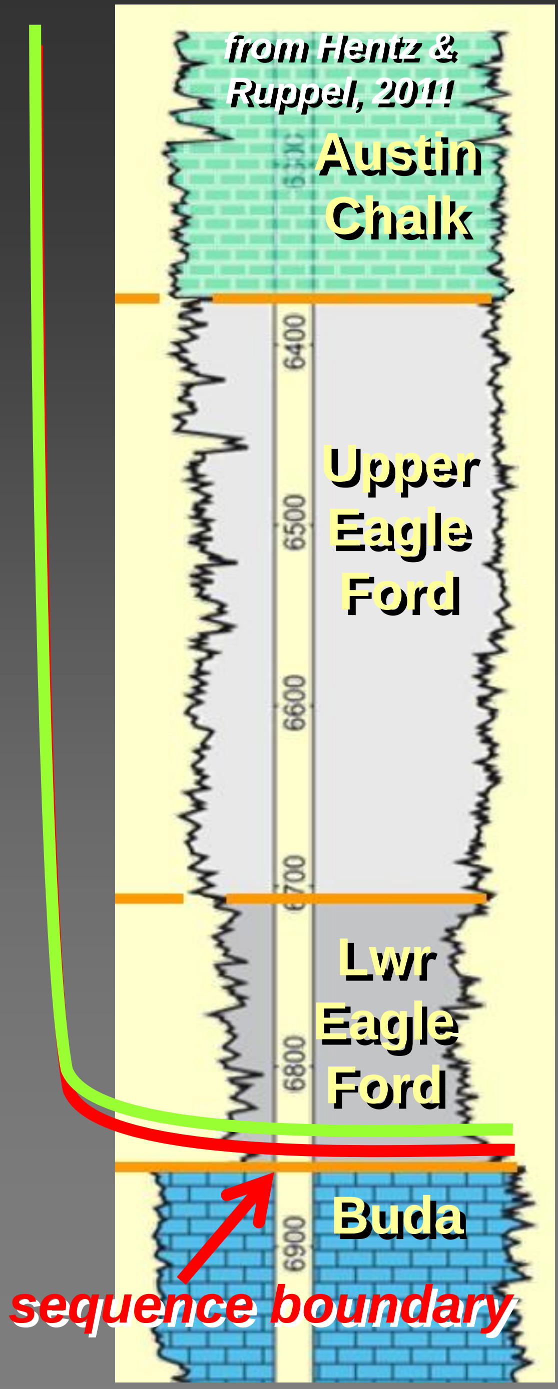
after Donovan et al., 2015

Eagle Ford Targeting



Condensed Section:
68% calcite, 12% quartz, 3% feldspar, 1% pyrite, 14% clay

Eagle Ford Targeting



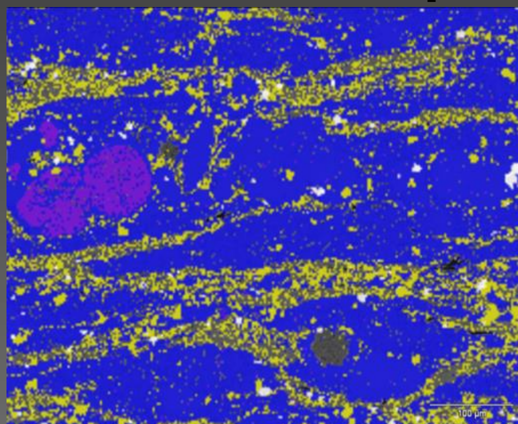
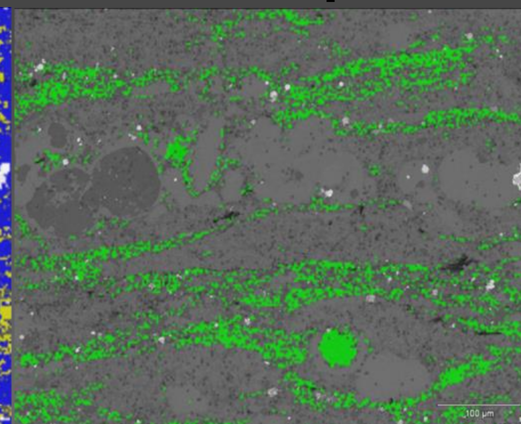
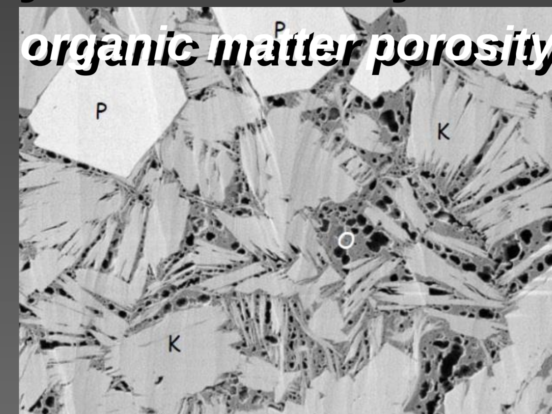
Condensed Section: 68% calcite, 12% quartz, 3% feldspar, 1% pyrite, 14% clay

Highstand: 50% calcite, 19% quartz, 8% feldspar, 3% dolomite, 2% pyrite, 16% clay

Components & Fabric Affect Eagle Ford Targeting & Reservoir Properties

Condensed Section (sticking problems)

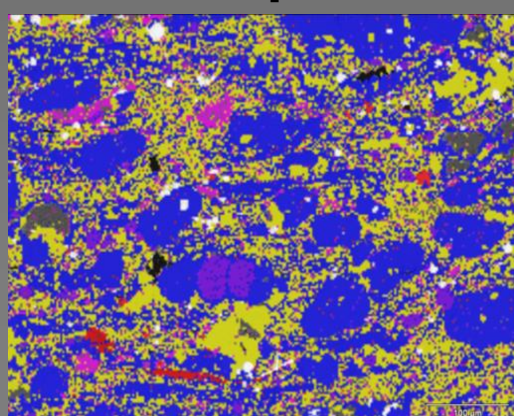
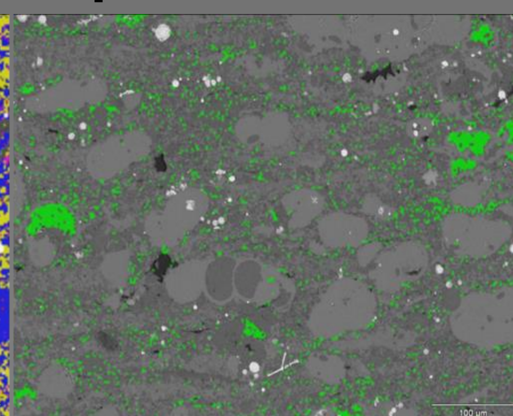
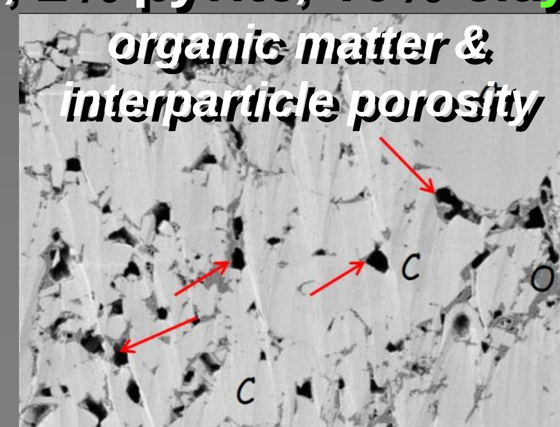
68% calcite, 12% quartz,3% feldspar, 1% pyrite, 14% clay

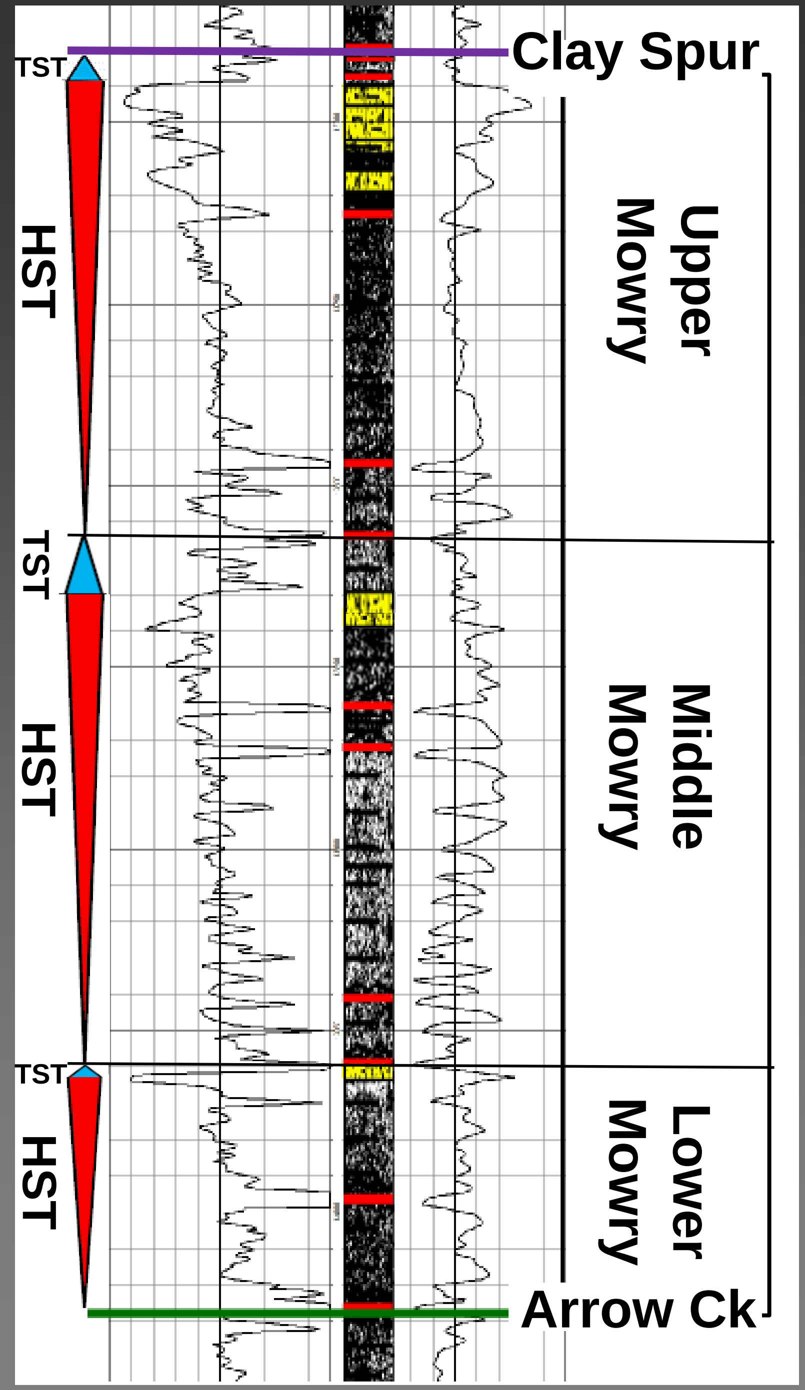
Highstand Systems Tract (detrital influence)

50% calcite, 19% qtz, 8% feldspar, 3% dolomite, 2% pyrite, 16% clay

Quartz
Pyrite
Calcite
Dolomite
Plagioclase
Apatite
Clay

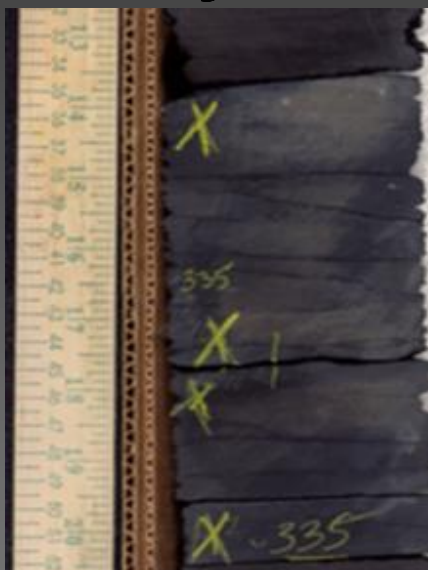




Mowry Sequence Stratigraphy (Extrabasinal Influenced)



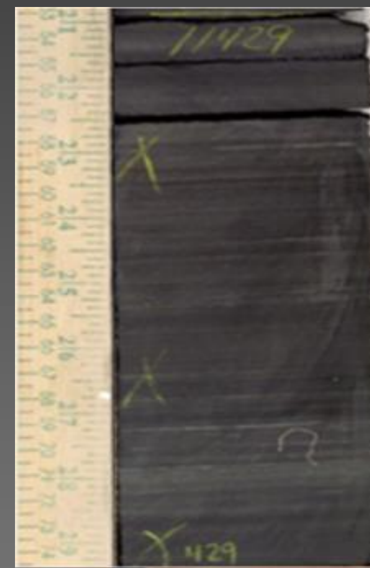
Mowry Sequence Stratigraphy & Reservoir Quality

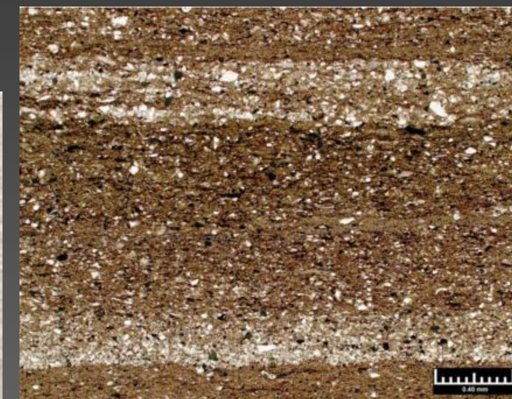
Early HST

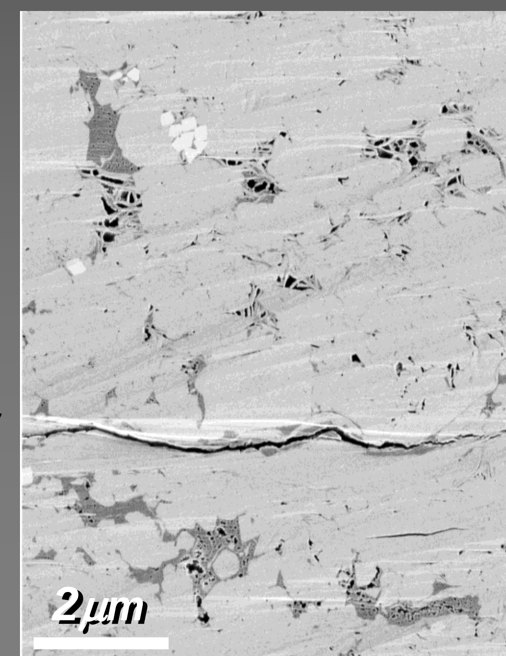


clay rich w/ few organic matter & interparticle pores

Late HST



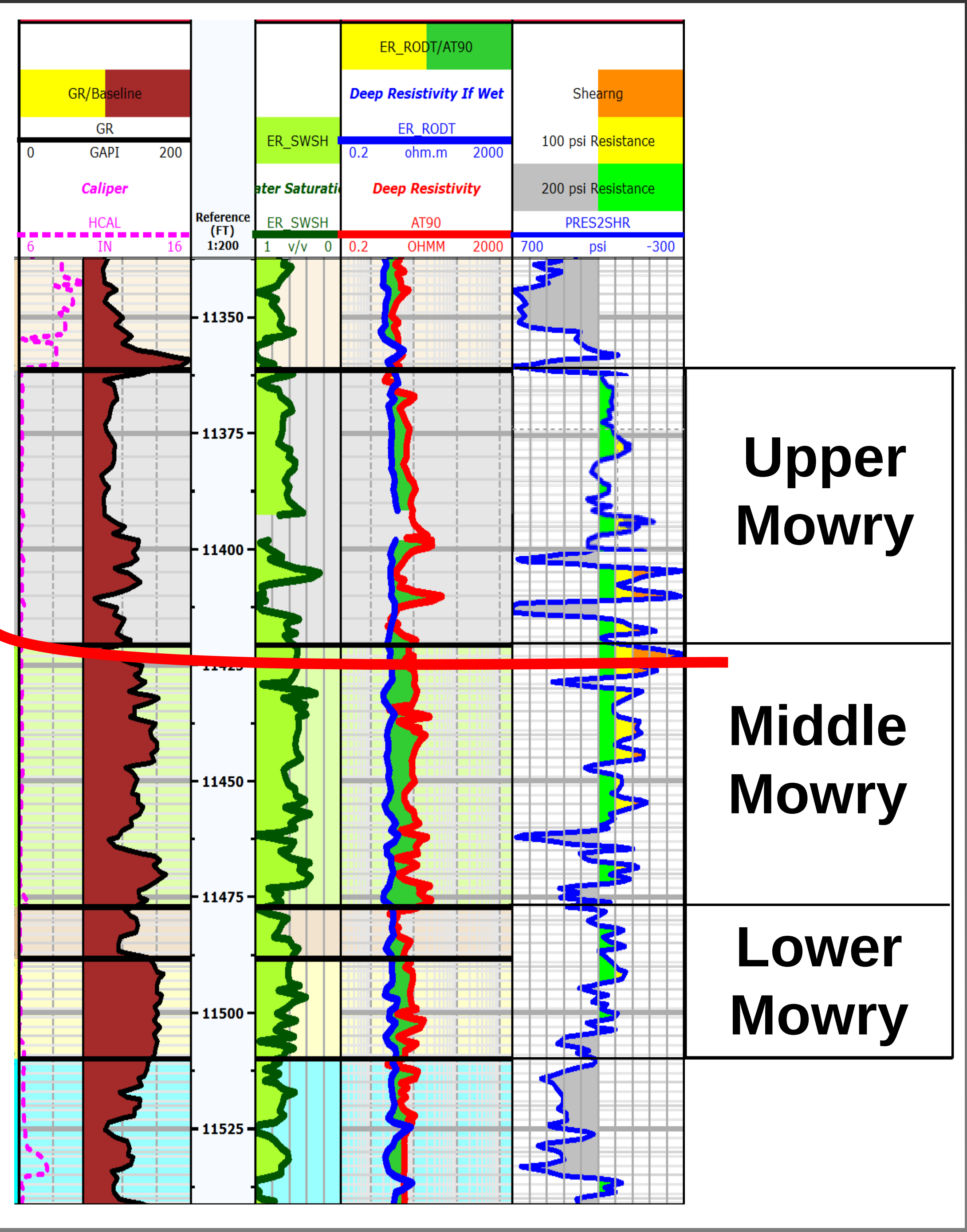




silt rich w/ abundant organic matter & interparticle pores (sheltered by silt)

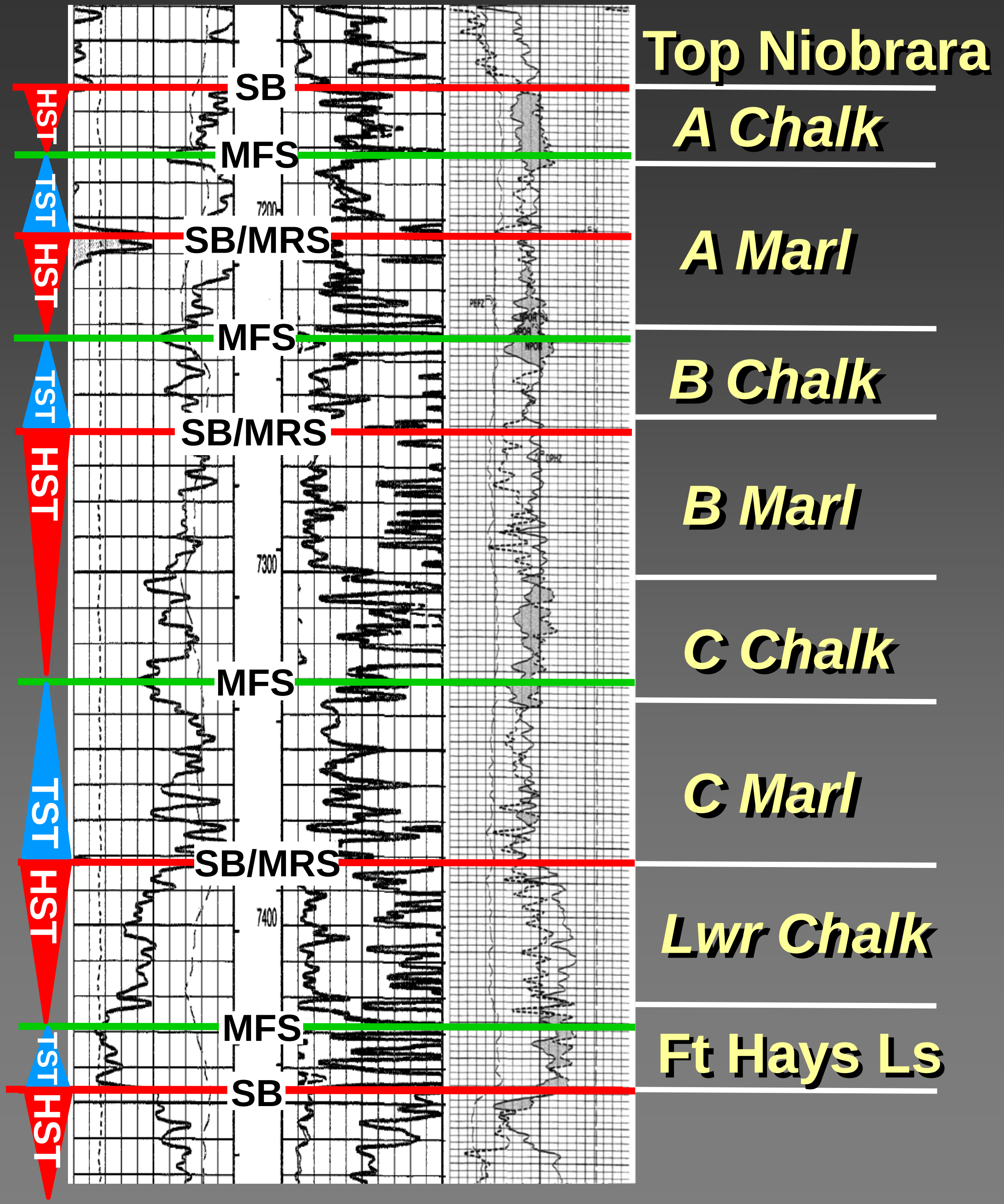
Mowry Sequence Stratigraphy & Geomechanics

closure pressure (minimum horizontal strength)



after T. Olson

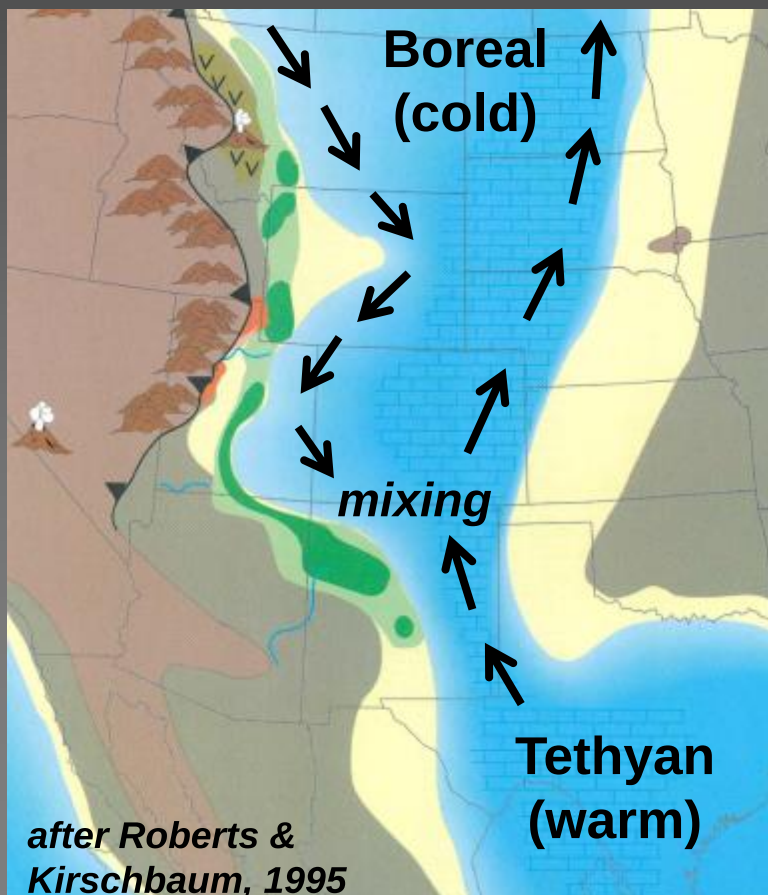
Niobrara Sequence Stratigraphy (Intrabasinal Dominated)

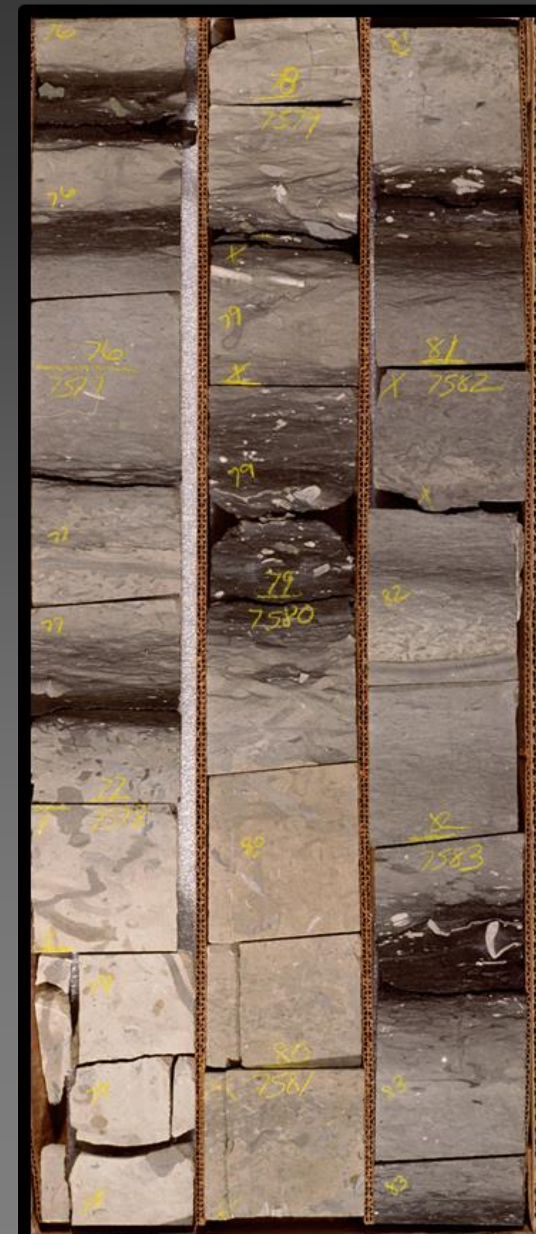


Niobrara Lithologies & Targeting

Transgressive to Condensed Section

reduced detritus + oxygenation created bioclastic-dominated rock (brittle chalk) w/ low organic matter

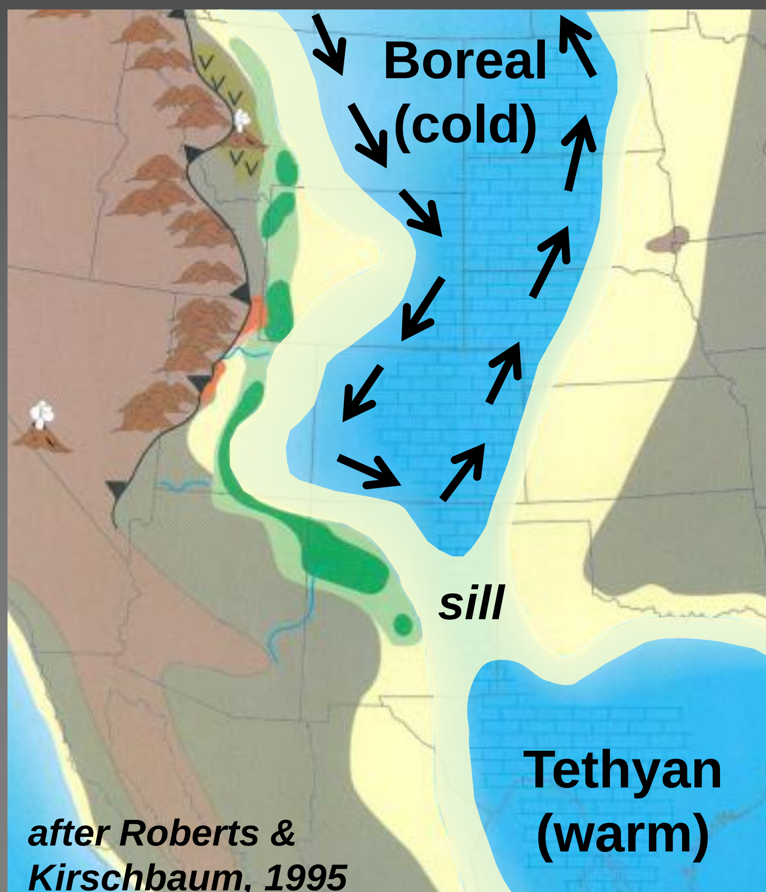




Niobrara Lithologies & Targeting

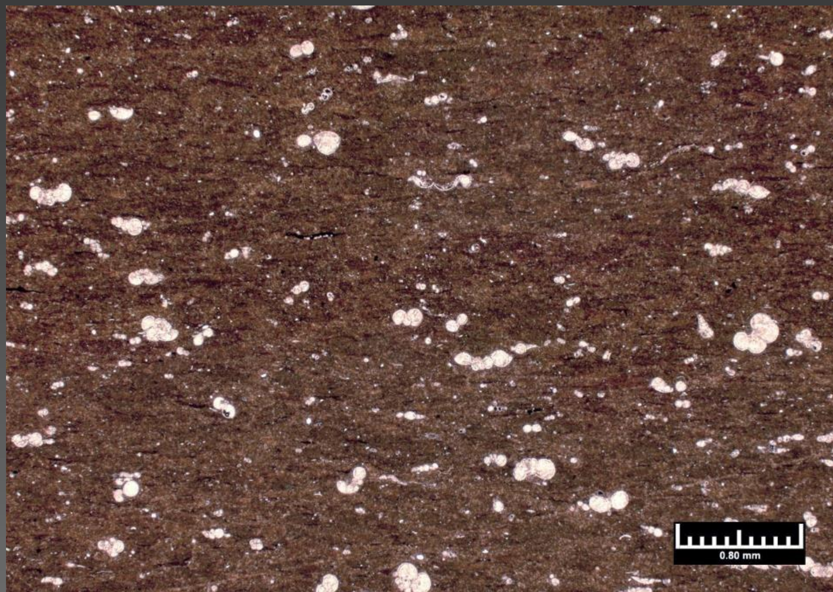
Sea-Level Highstand

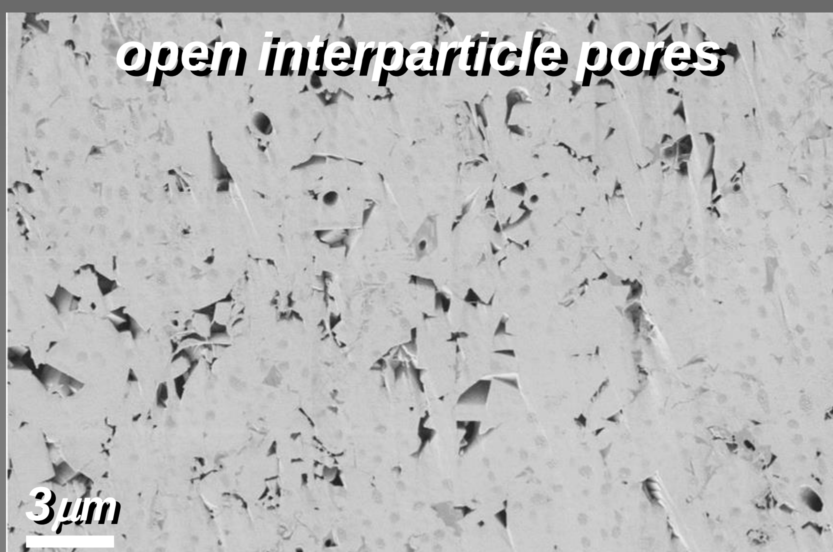
deltaic regression & detrital influx + low oxygenation created marl w/ high organic matter



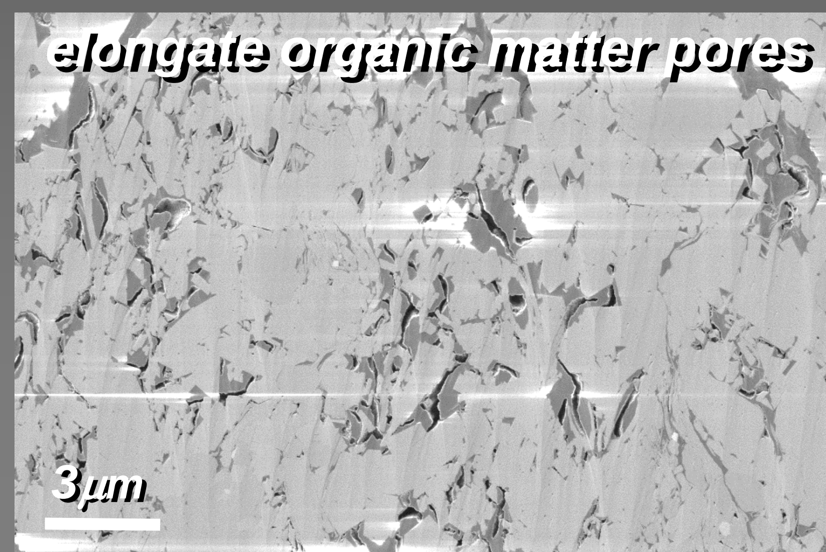
Niobrara Pore Types & Target Selection

TST to CS Chalk





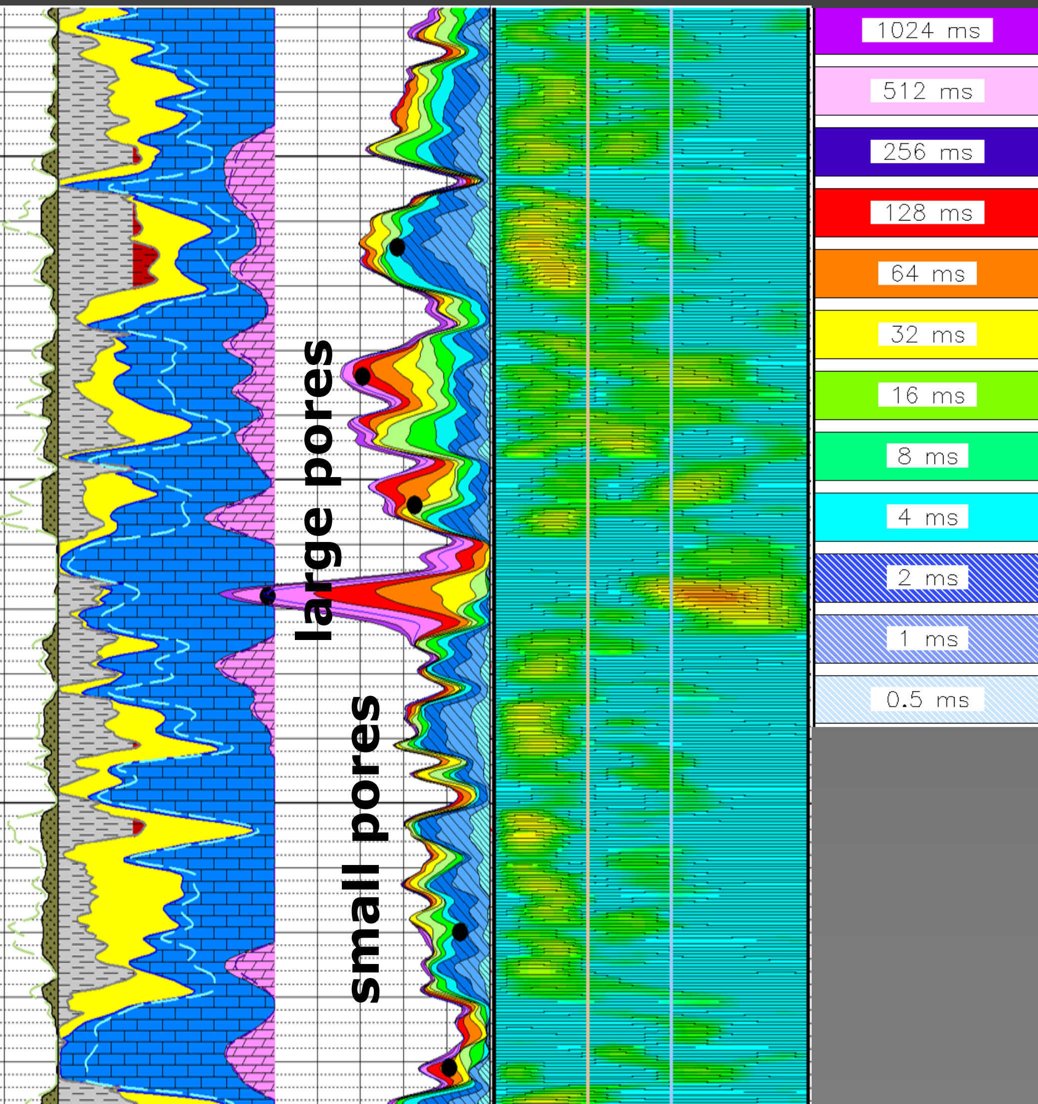
HST Marl

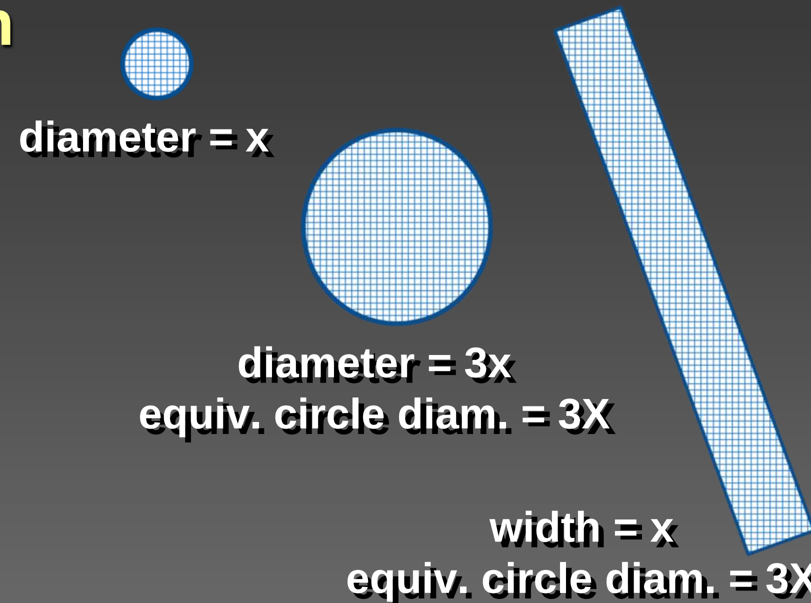


Petrophysics & Target Selection

NMR Log

Relaxation Time

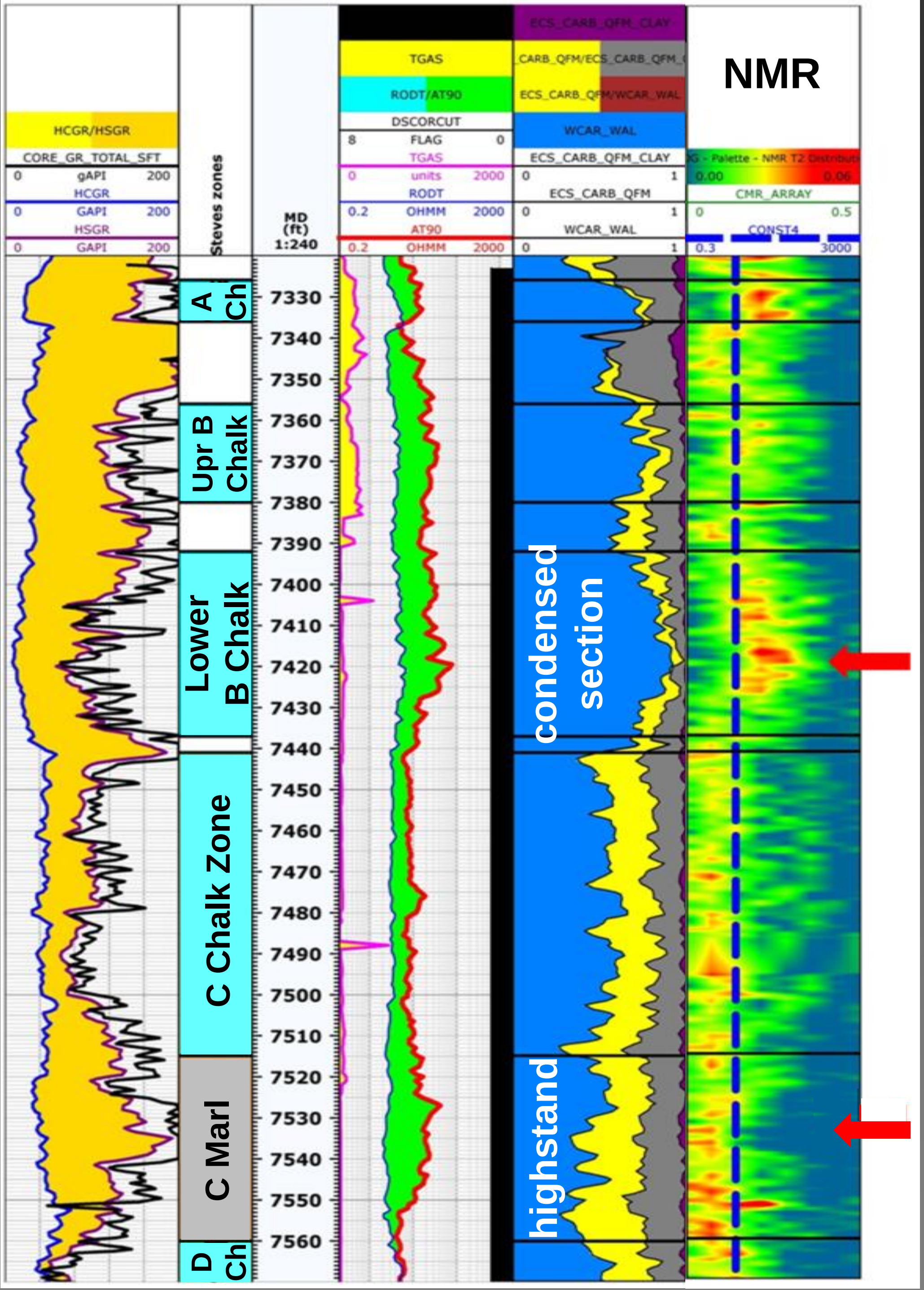




- ***pore size & shape vary with lithology & maturity***
- ***pore size seen by NMR is function of pore shape (large-pore porosity may be underestimated)***
- ***relaxivity of organic matter interferes with capturing organic pore data***

after T. Olson

C Marl = Potential Target?

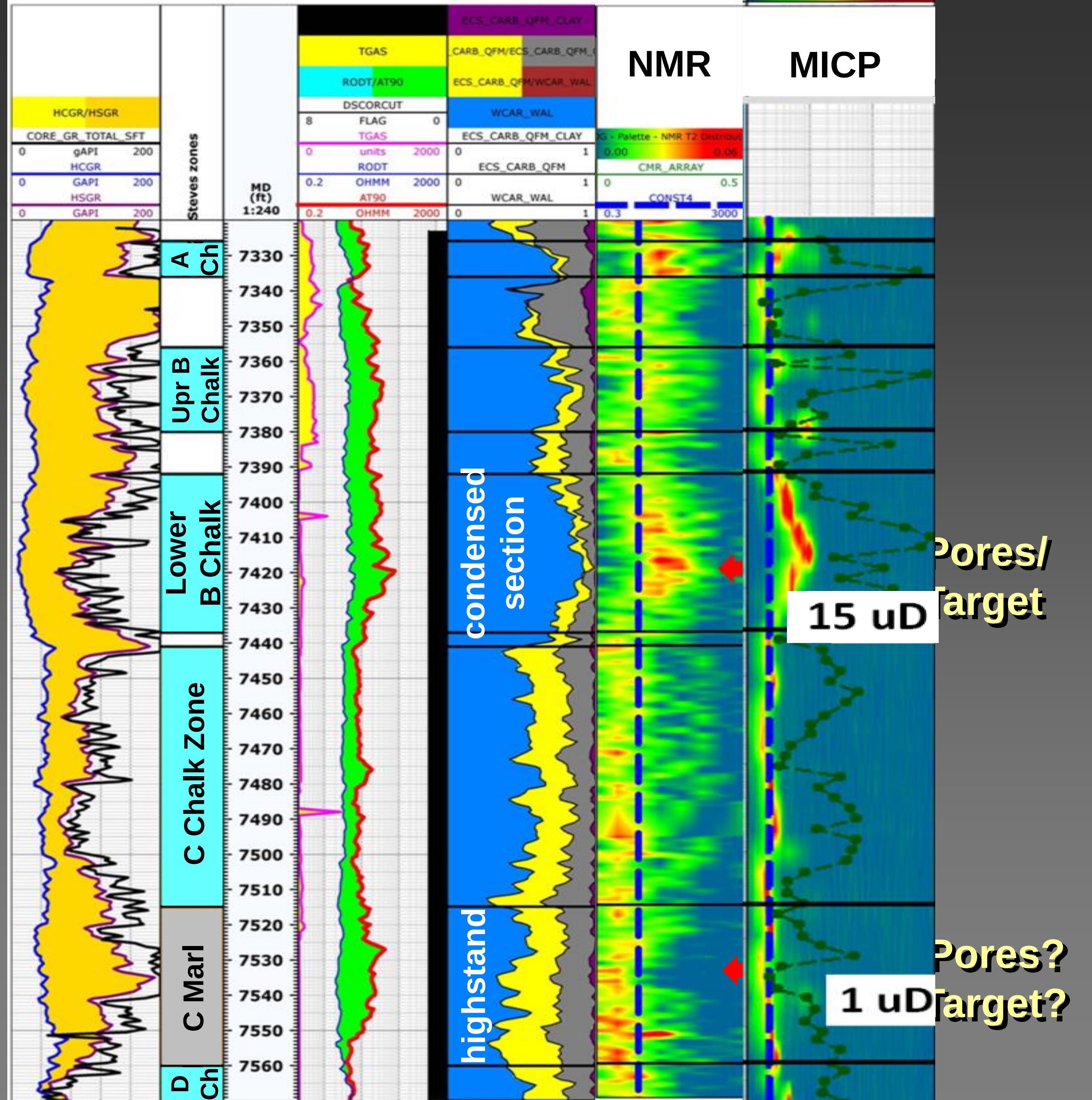


Large Pores/ Main Target

Small Pores? Poor Target?

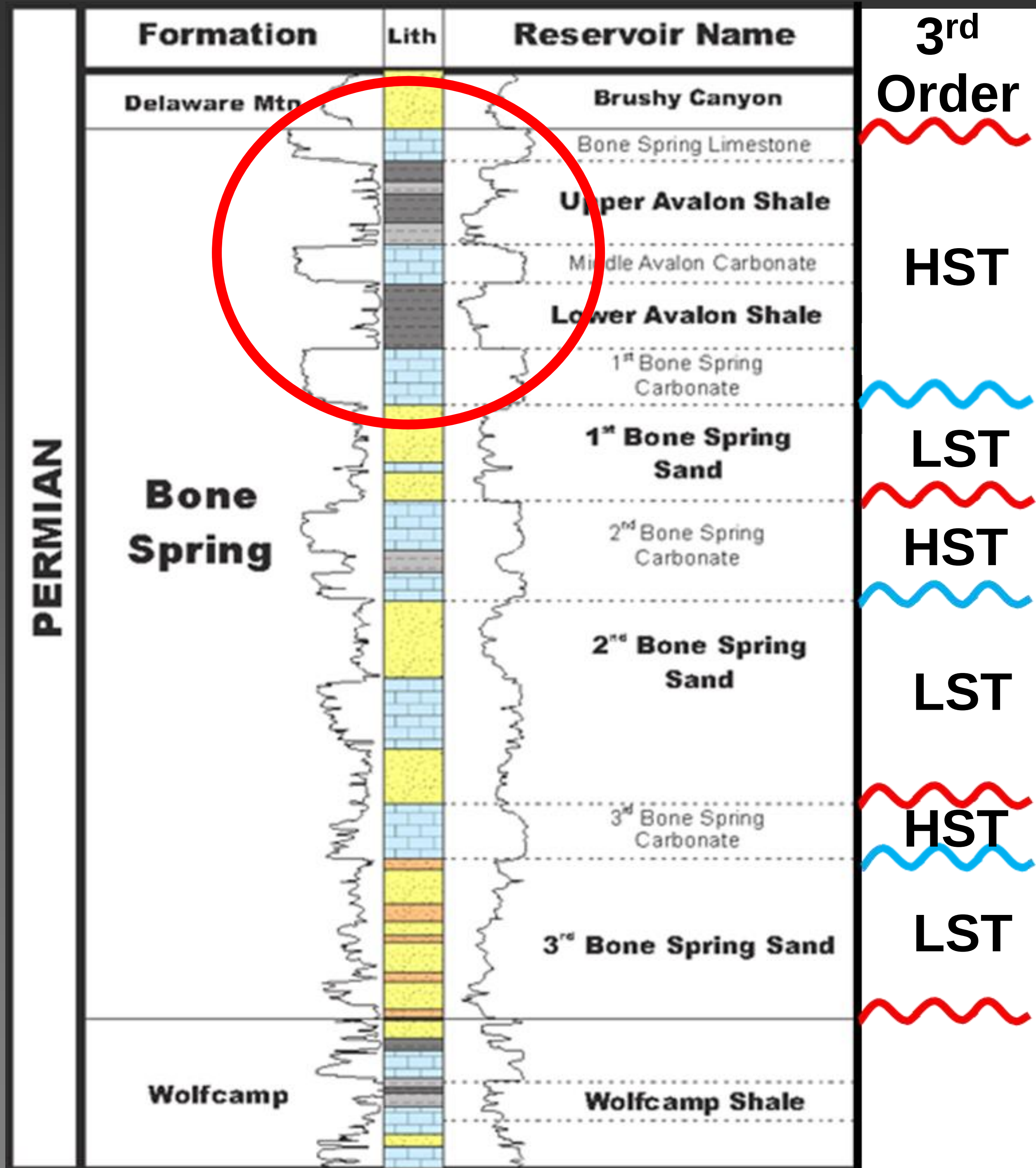
after T. Olson

C Marl = Potential Target?



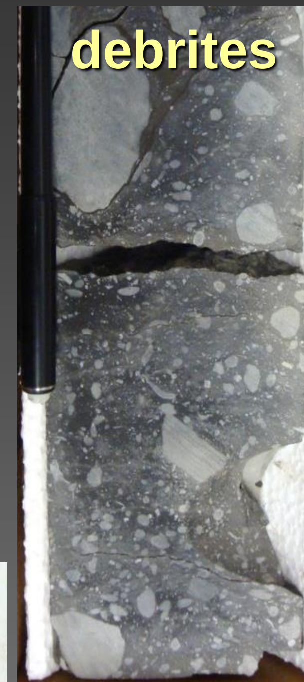
after T. Olson

Leonard (Avalon) Sequence Stratigraphy (Mixed Extrabasinal & Intrabasinal)

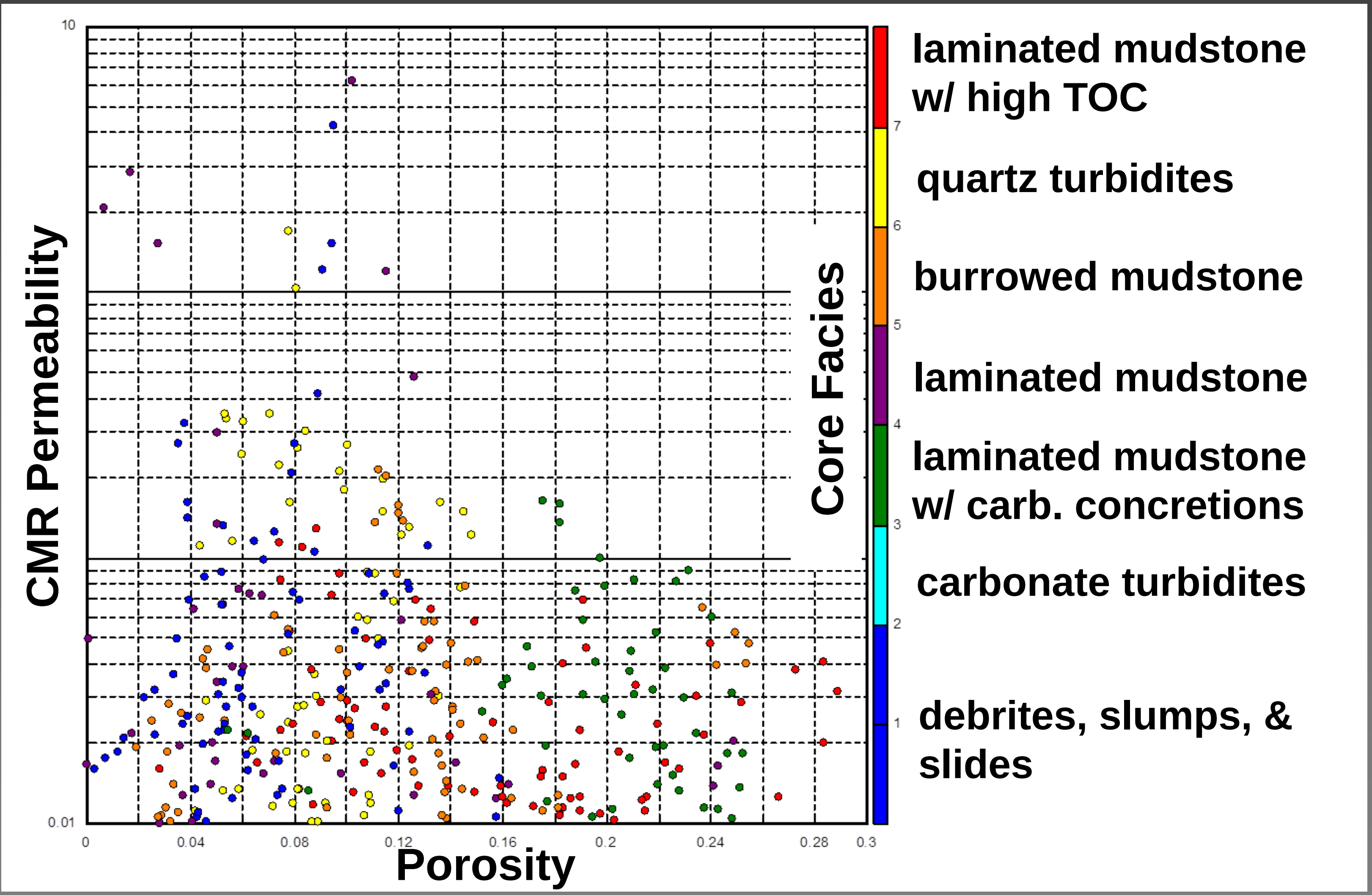


modified from www.corelab.com/ irs/studies/avalon-wolfcamp-shale

Avalon (Leonard) Facies

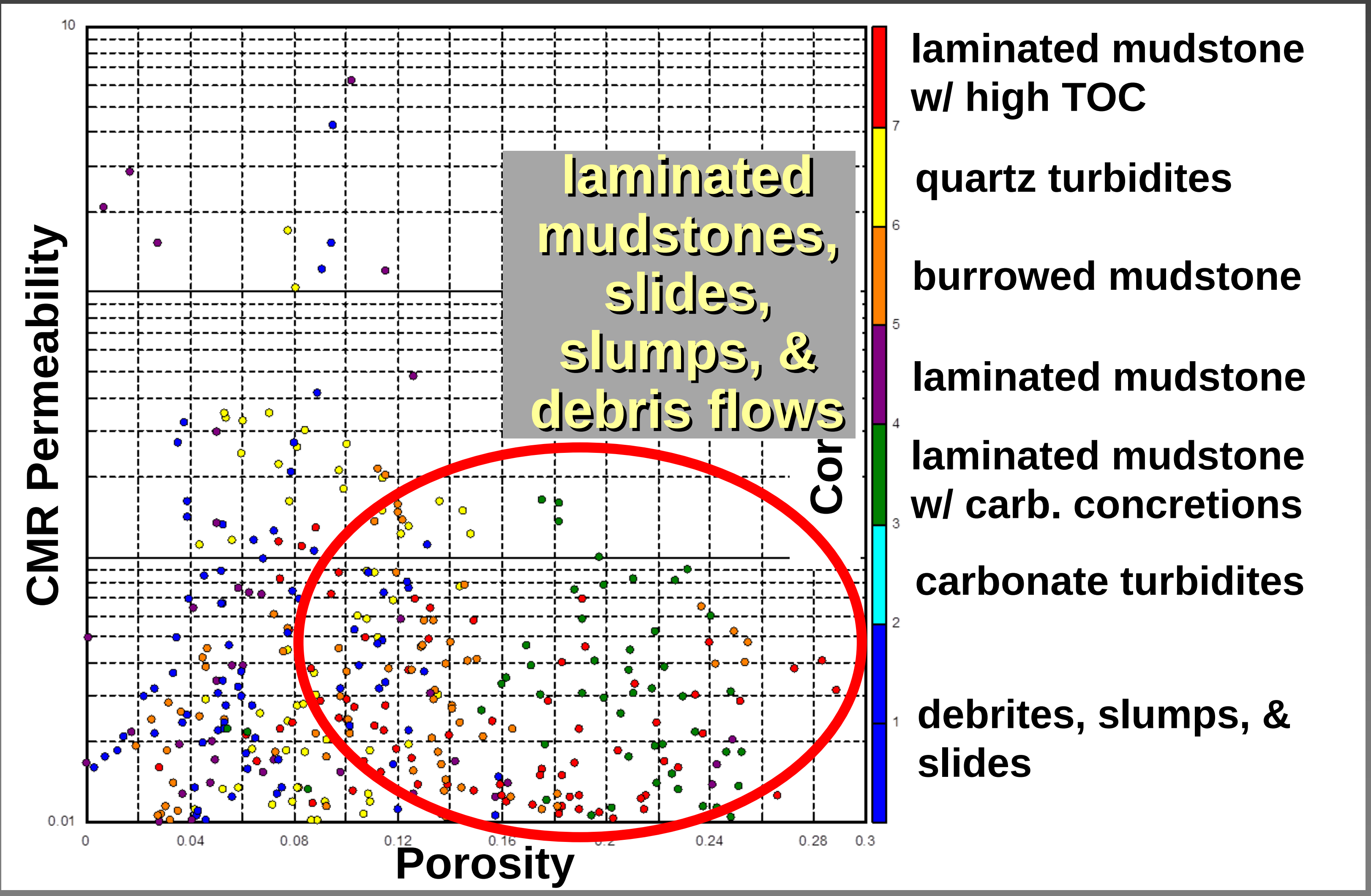


Facies Control on Reservoir Properties



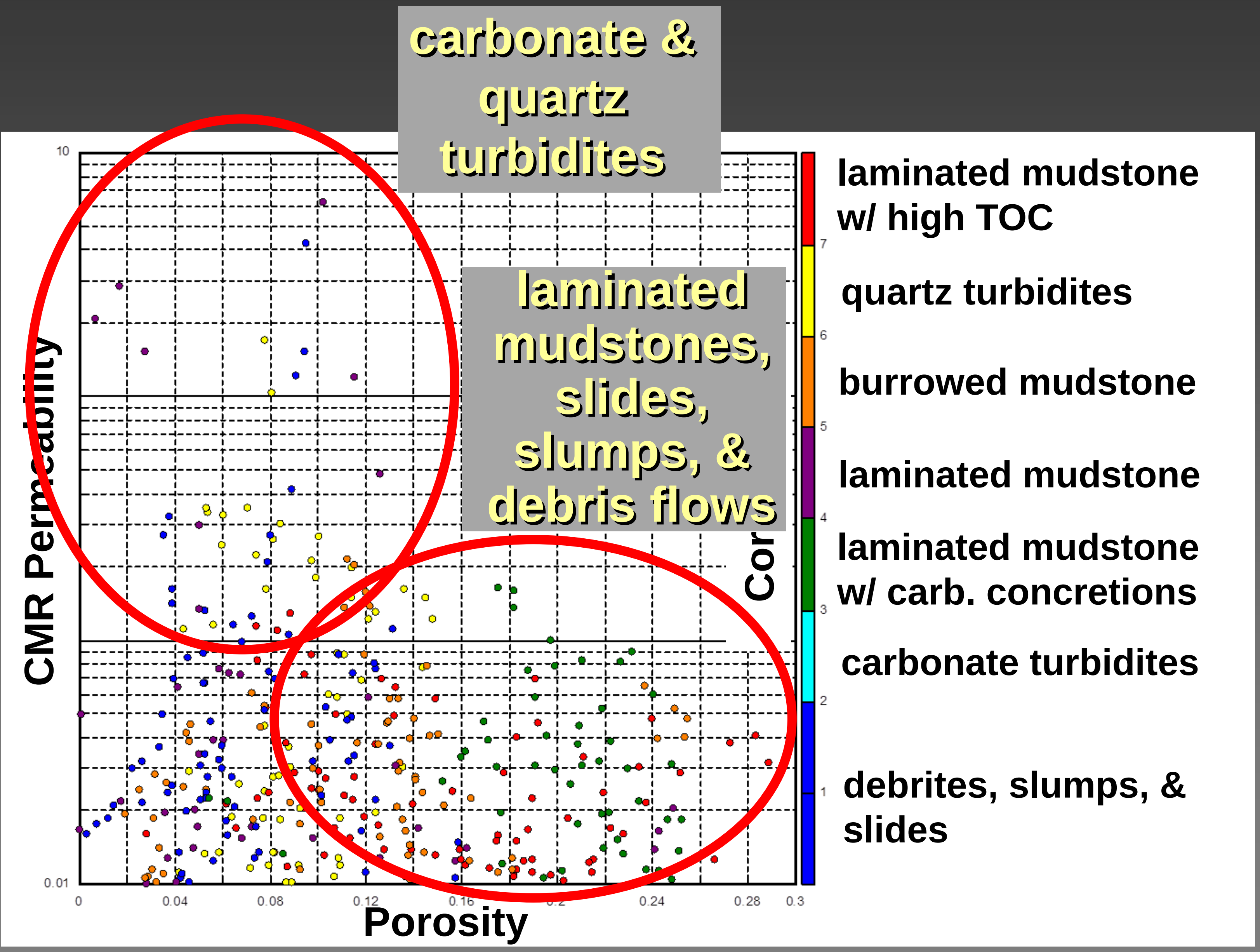
after A. Noack

Facies Control on Reservoir Properties



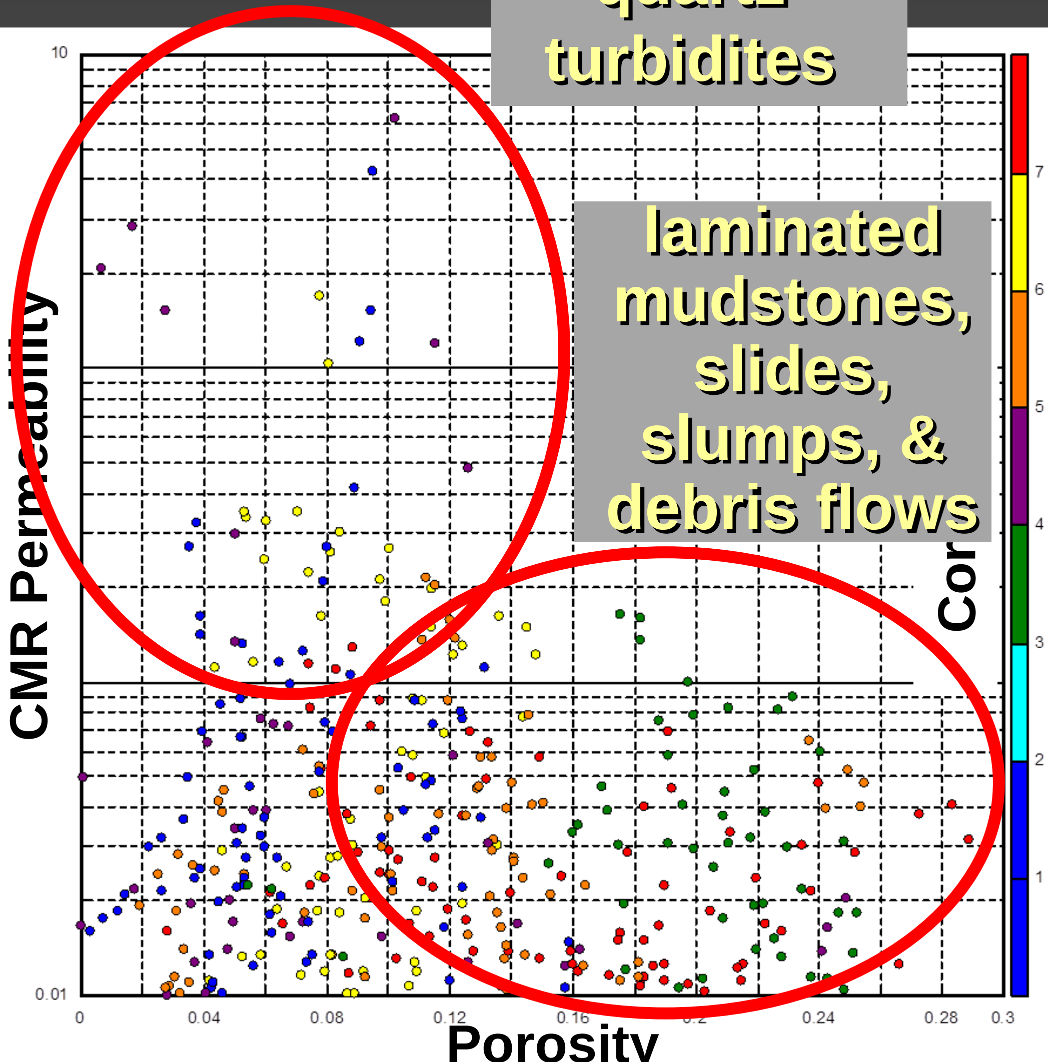
after A. Noack

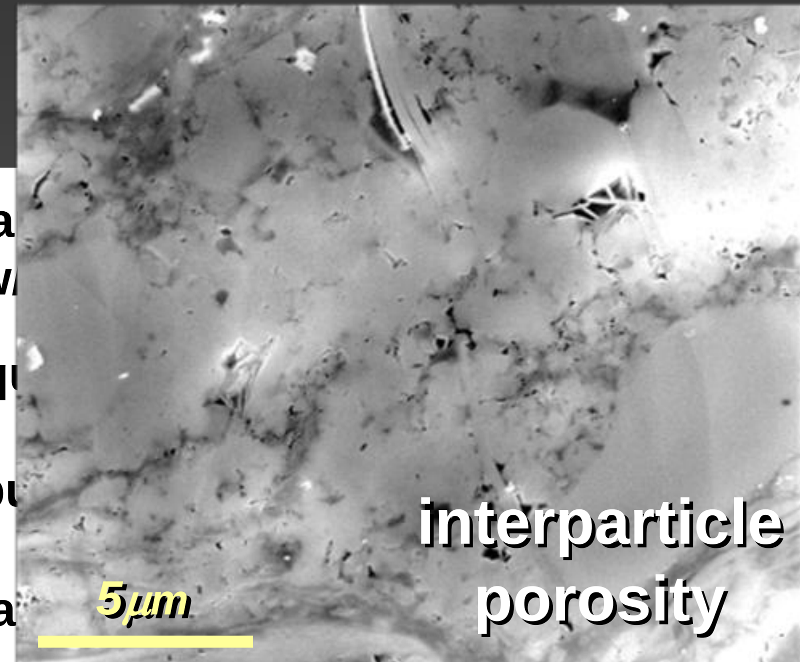
Facies Control on Reservoir Properties



after A. Noack

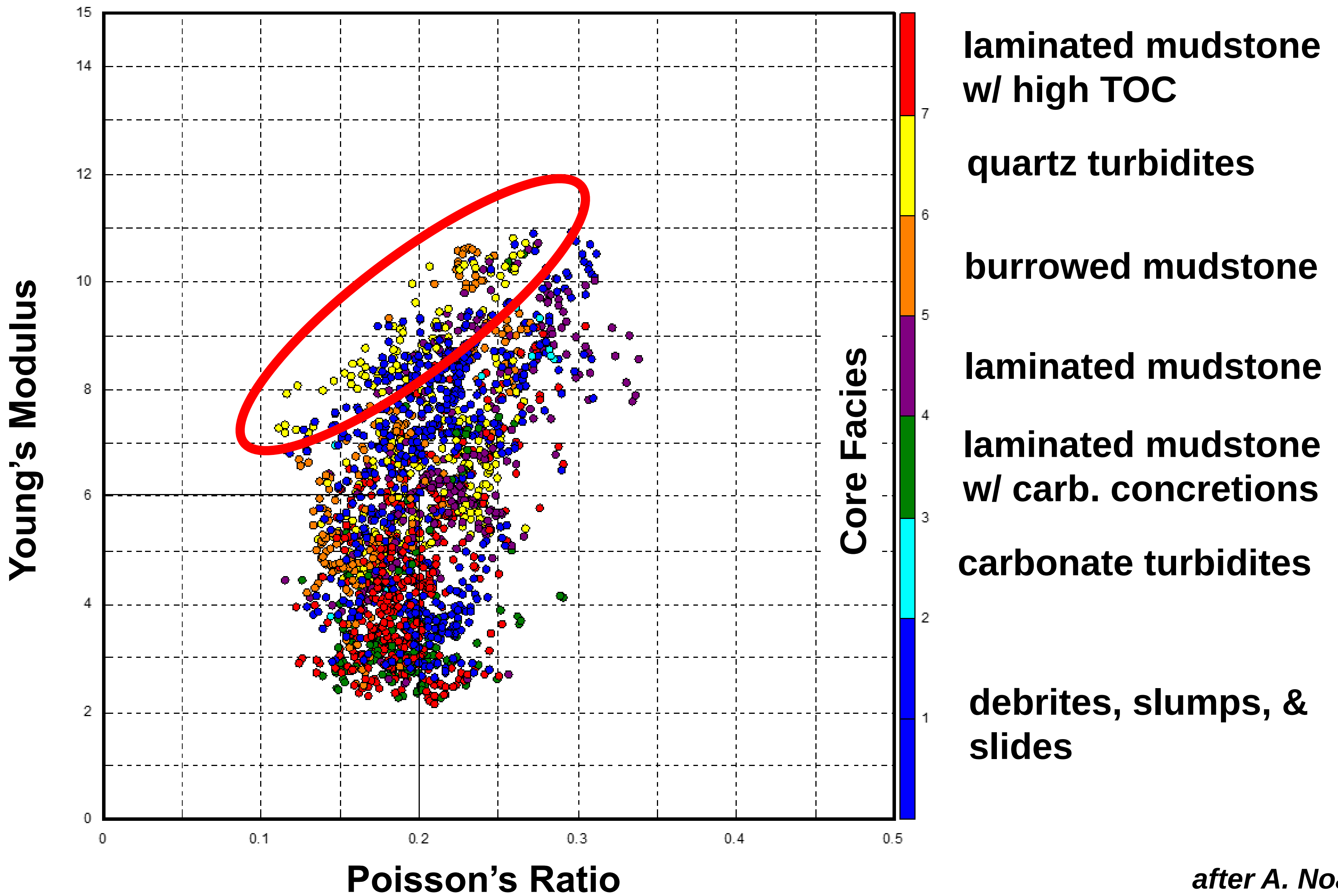
Facies Control on Reservoir Properties





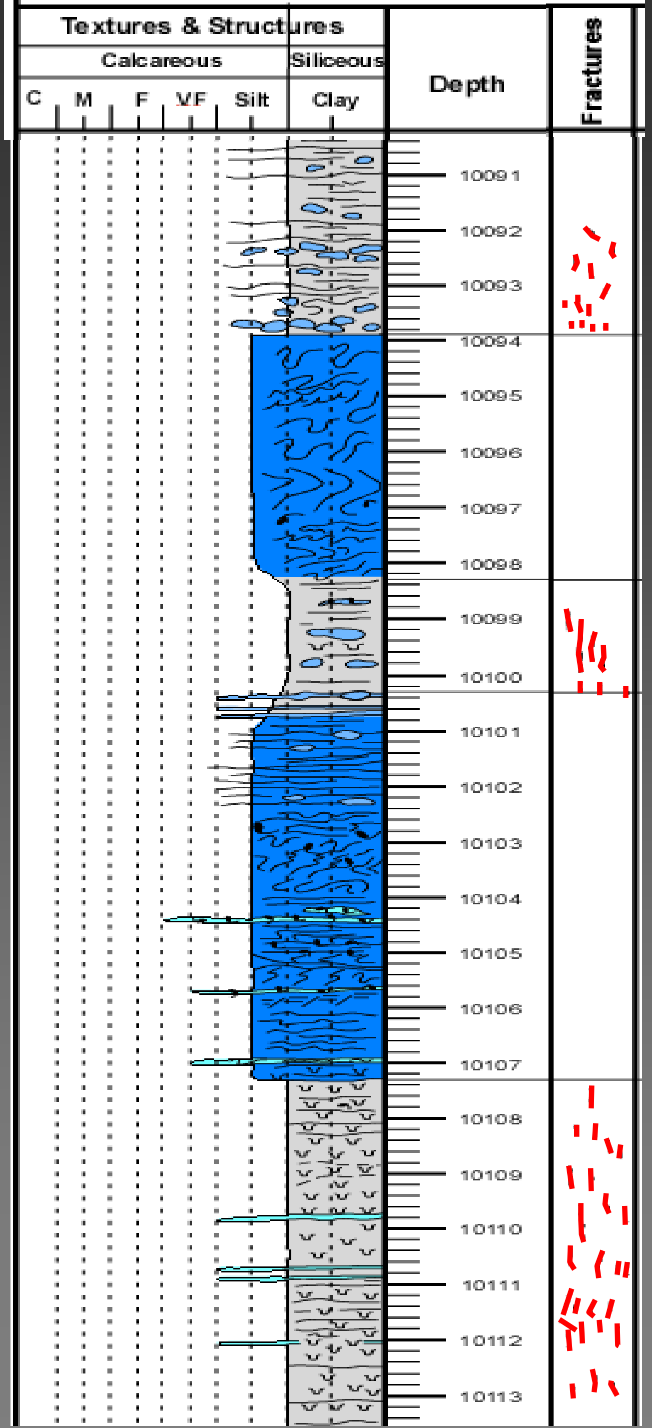
after A. Noack

Facies Control on Mechanical Properties

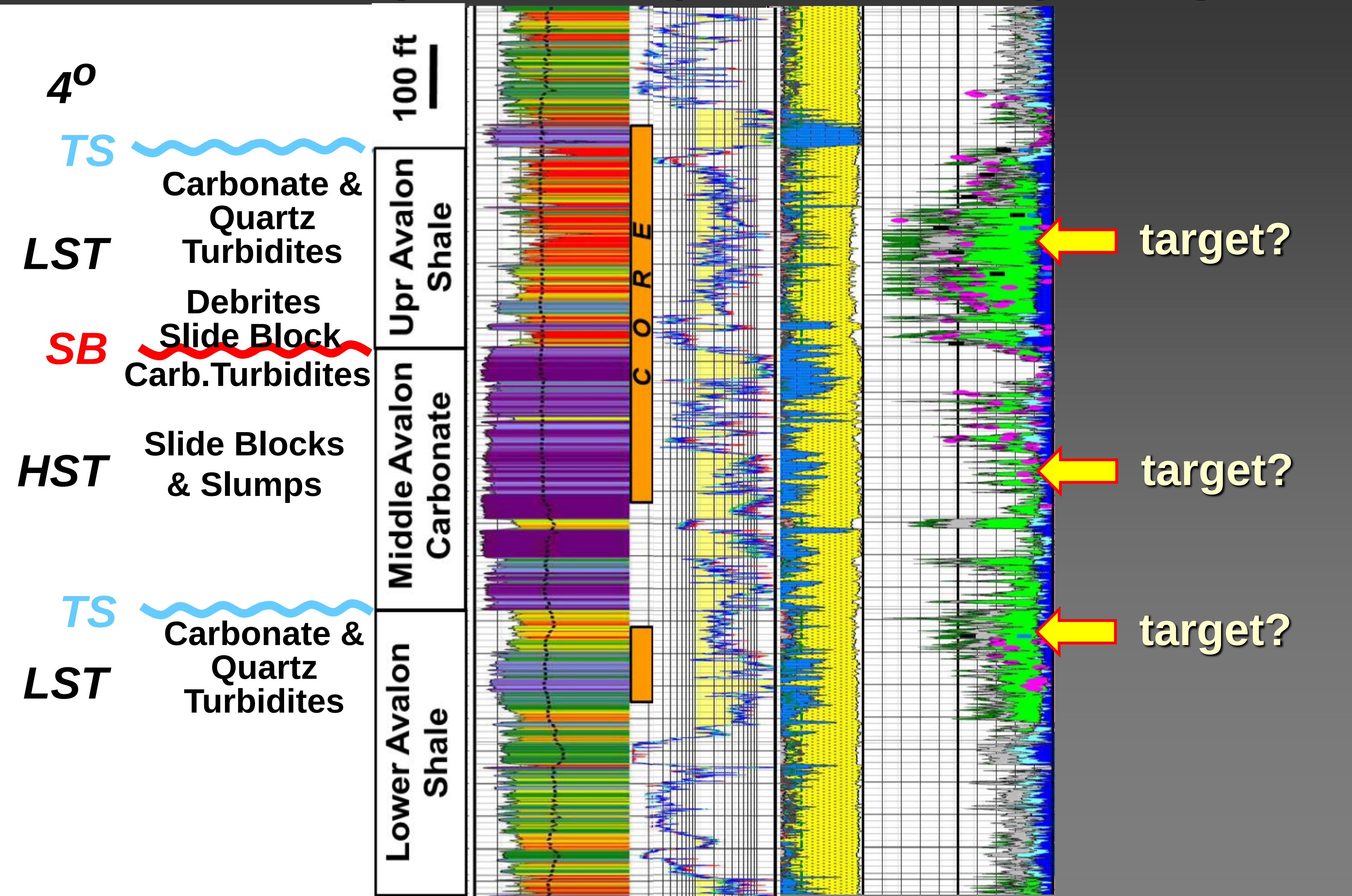


after A. Noack

Facies Control on Mechanical Properties



Avalon (Leonard) Shale Targeting



Conclusions: Sequence Stratigraphy & Horizontal Targeting

- not “THE” answer, but a useful (necessary?) tool
- increased understanding of depositional controls on reservoir vs. non-reservoir
- framework for data selection and integration
- better correlation and mapping of targets
- aids reservoir modeling & economic evaluation
- helps with selection of & staying in best zone
- additional input for completions