Geologic Commonalities (and Differences) Among Resource Shale Plays*

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Abstract

Most of the gas- and oil-producing resource shales have a number of fundamental properties in common: they all:

- have some porosity and permeability for storage and transport of hydrocarbons,
- are composed of common minerals that partially govern geomechanical properties,
- contain organic matter as a hydrocarbon source rock,
- have geomechanical properties that affect drilling and fracturing,
- are stratified, which also affects geomechanical properties, and
- exhibit a generally common sequence stratigraphic stacking pattern.

However, there are differences in these properties among the various shales, as follows:

- there are several different pore types, and their abundance differs among the shales;
- common minerals as quartz, calcite, clays, and dolomite vary in abundance among the shales;
- TOC varies in abundance, distribution, and maturity among the shales;
- geomechanical properties are a function of mineralogy, porosity and TOC content, and thus vary with these properties of the shales;
- thickness, amount, composition and orientation of laminae and strata differ among the shales, which also affects geomechanical properties;
- orders of cyclicity are recorded in stratigraphic stacking patterns at a number of scales, thus affecting the stacking of brittle and ductile strata, often into 'brittle-ductile couplets'.

These properties are all interrelated, and often predictable when viewed within a sequence stratigraphic framework. This can lead to improved stratigraphically-targeted drilling of horizontal wells and identification of stratigraphic sweet spots. To optimize this improvement, one should seek to document the detailed differences in addition to the commonalities of the shales. In the case of the resource shales "the devil is in the details".

Selected References

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Wang, F.P., and J.F.W. Gale, 2009, Screening criteria for shale-gas systems: GCAGS Transactions, v. 59, p. 779-793.

Geologic commonalities (and differences) among resource shale plays

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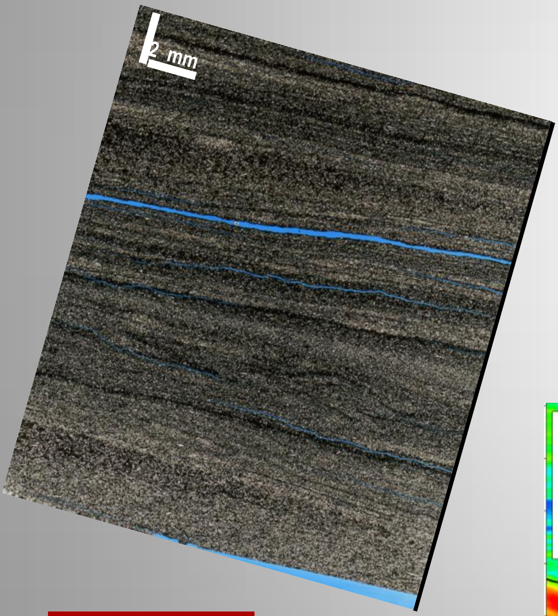
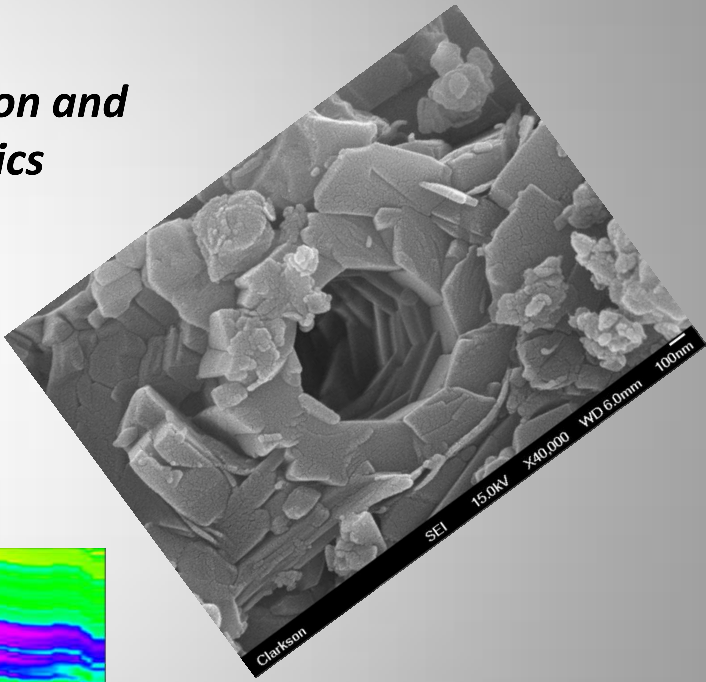
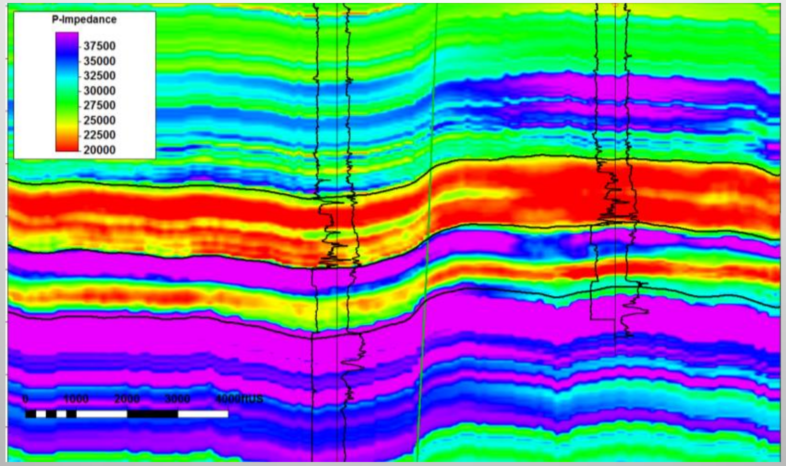






Commonality	Difference	Importance
-***Porosity (and perm.):*** Present in shales; low	Different types of pores and connectivity for different shales.	***Reservoir fluid flow; Volumetric calculations.***
-***Composition:*** Similar minerals ("silica", etc.)	Mineral proportions differ among different shales.	***Brittle or ductile; 'Fracability'; frac barriers***
-Geomechanical properties Present in shales	Vary with mineral composition, TOC, and porosity	***Brittle or ductile; 'Fracability'; frac barriers***
-Stratigraphic properties: Similar layering patterns	Variable thicknesses and composition trends	***Predicting better target zones for drilling.***

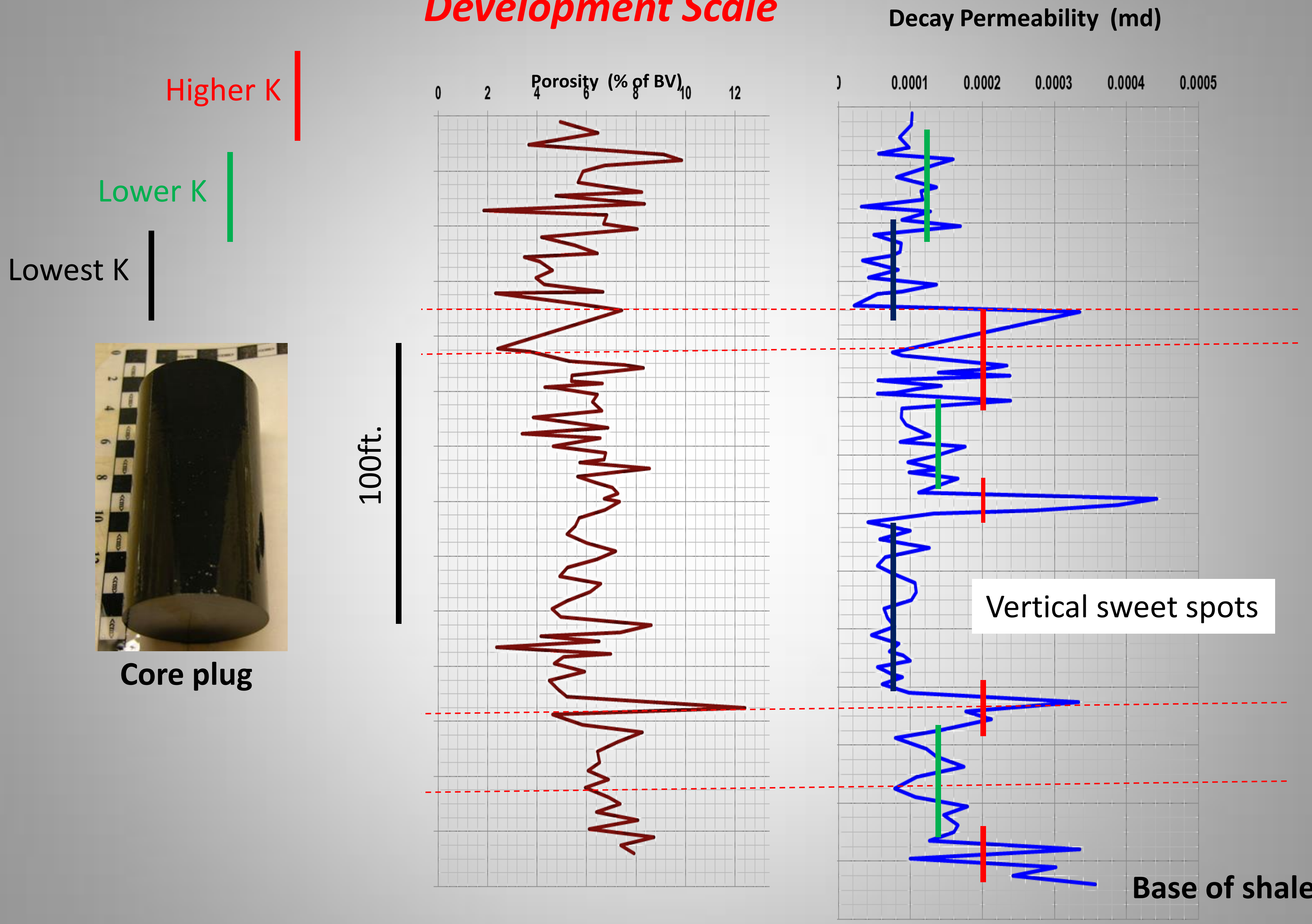
Interrelate the properties

Exploration Scale

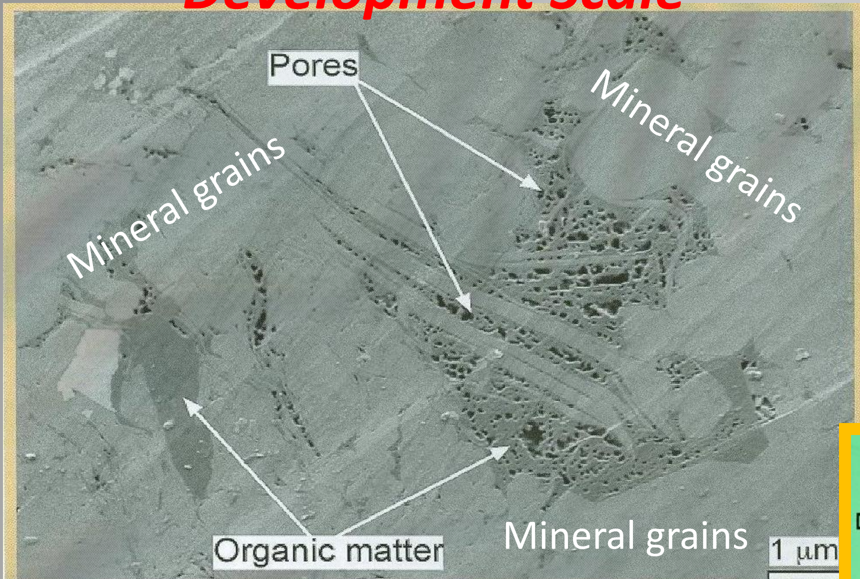
Parameter	Fort Worth-Barnett[1]	Arkoma-Woodford[1]	Eagle Ford[2]	Anadarko-Woodford[1]
Depth	6,000-9,000	6,000-14,000	5,500-14,000	10,000-16,000
Thickness, ft.	300-500	100-220	100-300	120-280
Total organic carbon, TOC%	3.5-8%	3-10%	2.0-6.5	3-9%
Porosity %	4-6%	3-6.5%	3-14%	4-10%
Recovery factor, %	20-50%	35-50%	20-25%	25-35%
Gas-in-place Bcf/section	50-200	40-120	180-210	145-200

1. Source Deutsche Bank, July 22, 2008 report "Shale to Shining Shale: and XEC Anadarko-Woodford estimates
2. CLR internal estimates and TXCO Resources investor presentation 2/09

Development Scale



Development Scale

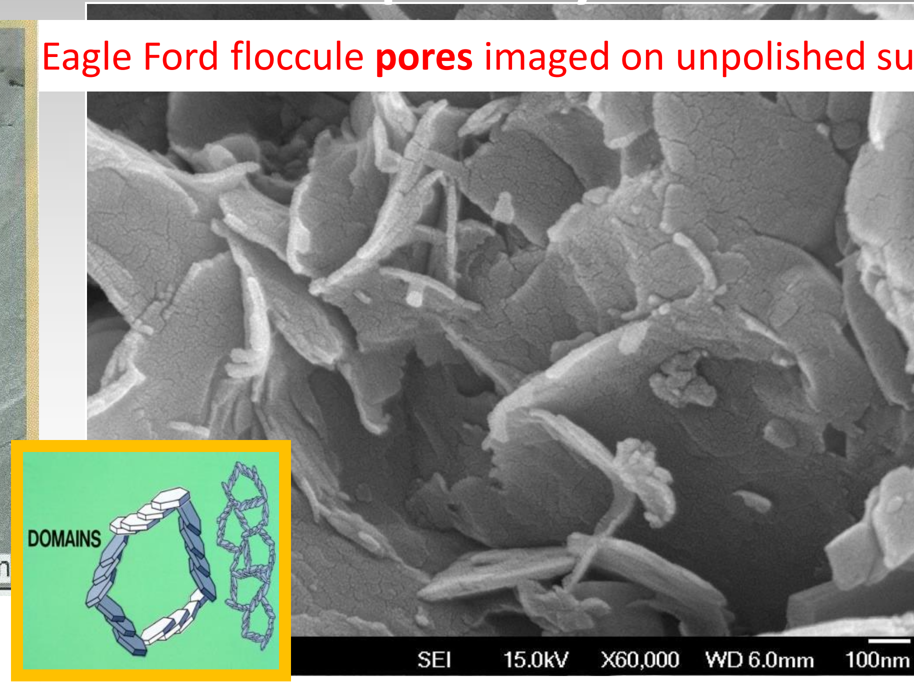


Organo-**pores** viewed on Ar-ion milled (FIB) surface of shale(image provided by R. Reed)

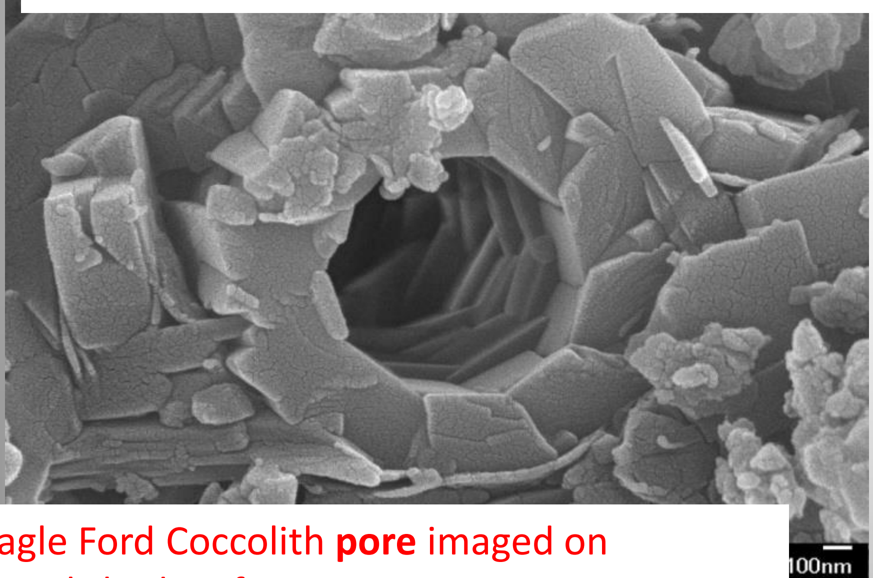
Loucks et al., 2009

Pores and porosity

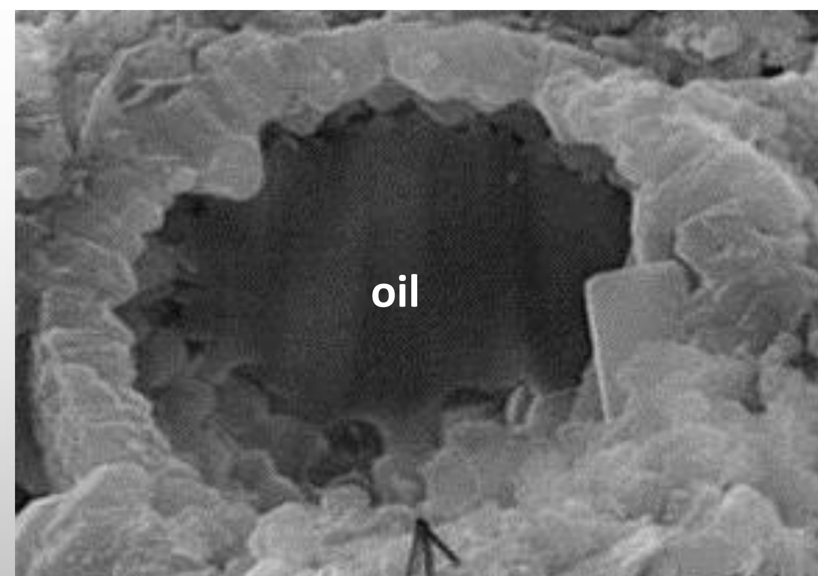
Eagle Ford floccule **pores** imaged on unpolished surface



Eagle Ford coccolith with oil in chamber on unpolished surface (after heating to 350d./4 days)



Eagle Ford Coccolith **pore** imaged on unpolished surface



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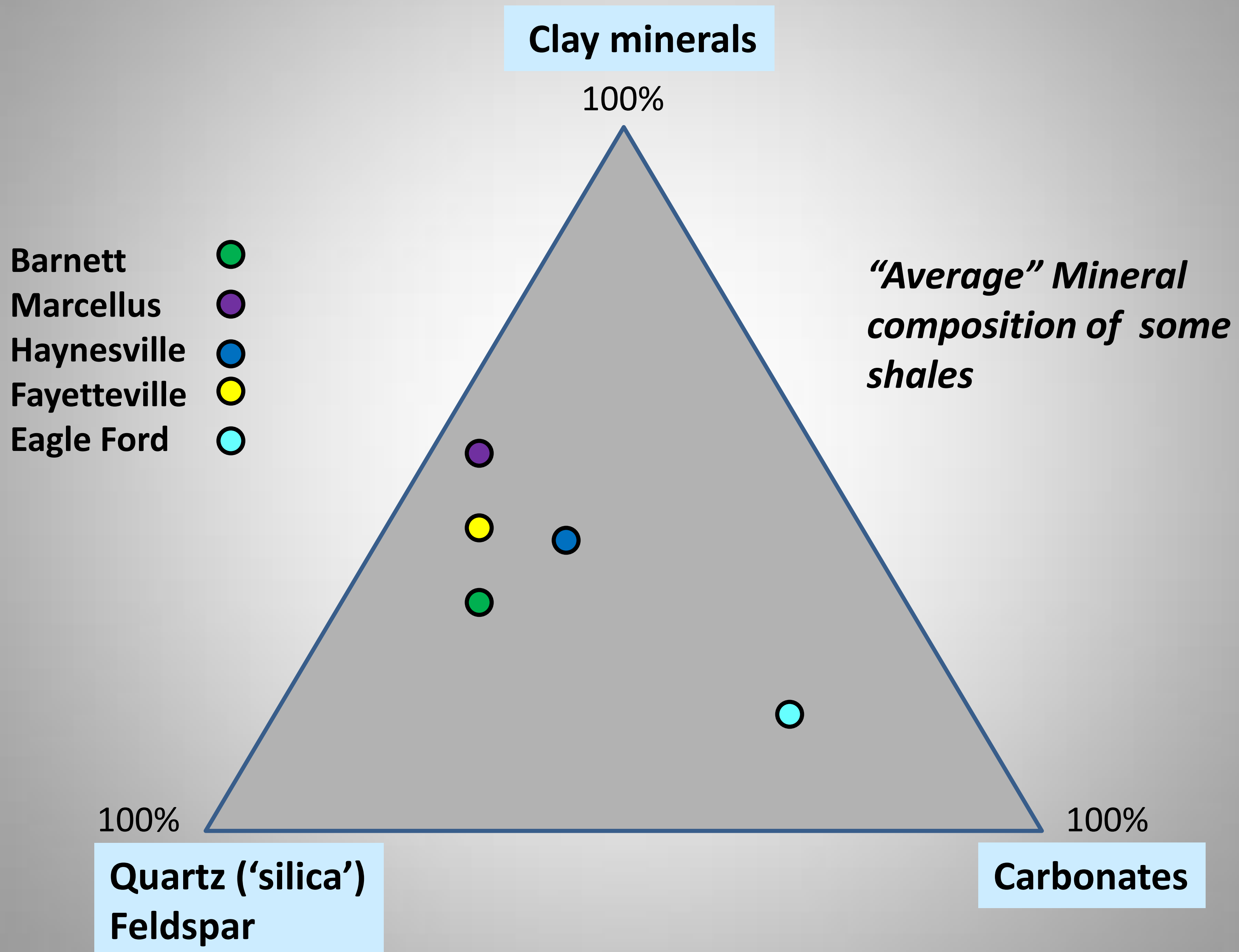
Interrelate the properties

Exploration Scale



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Interrelate the properties

Development Scale

An interval is classified (by drillers) to be:

Ductile

A lot of pumping to break

High fracture gradient

Brittle

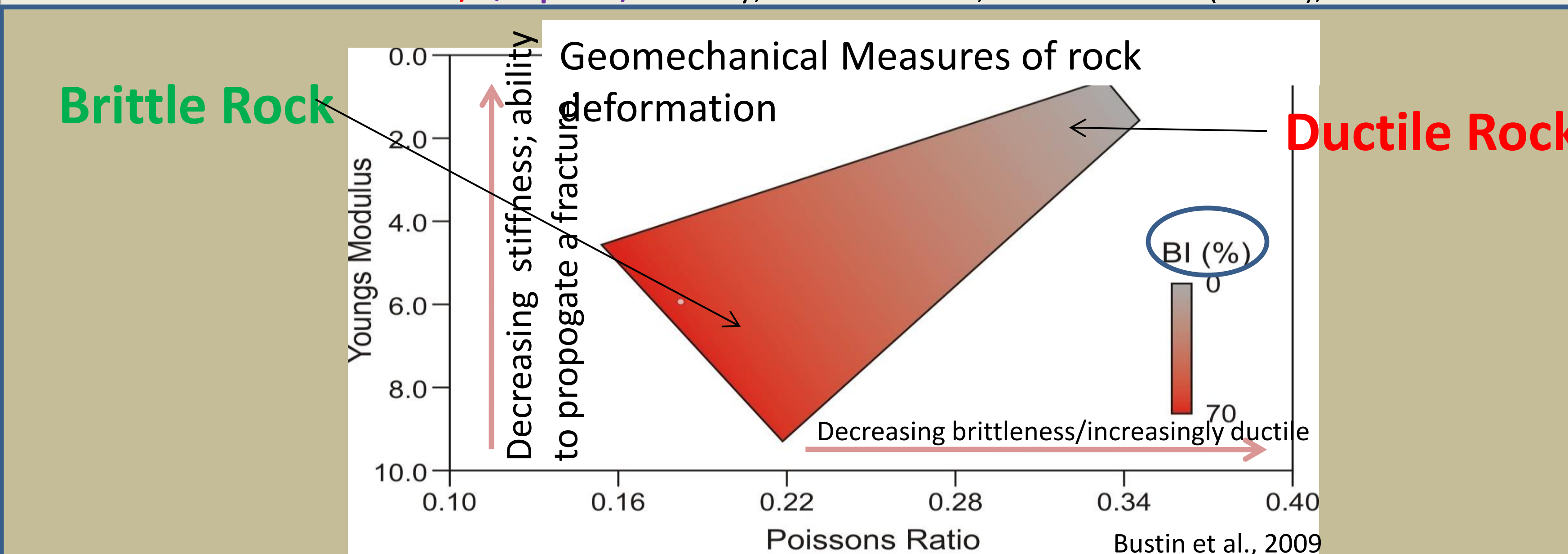
Not as much pumping as the "ductile" intervals

Lower fracture gradient

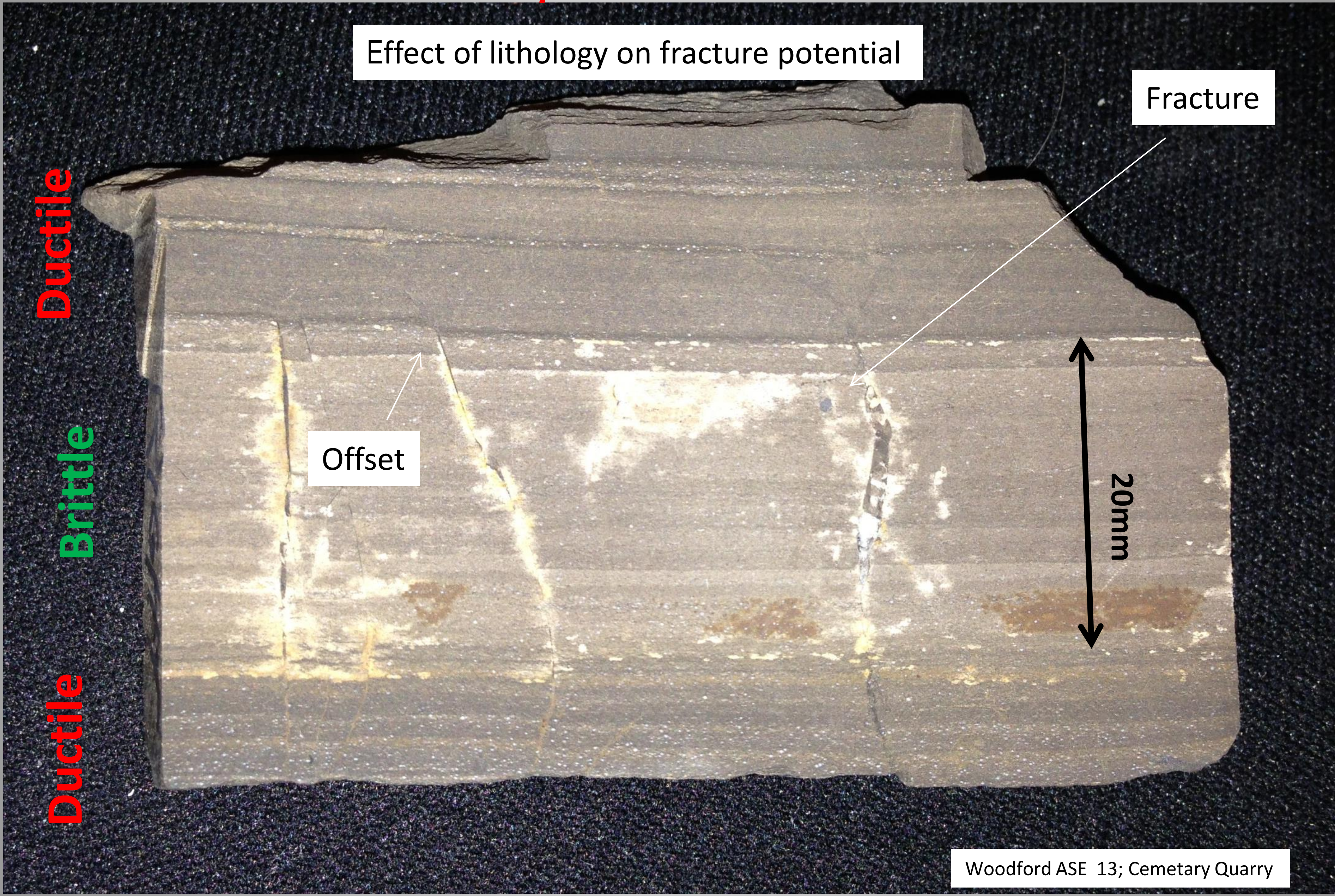
Mineralogic effect on rock fracturability(brittleness)(Wang & Gale,2009)

BI = (Q + Dol + Lm)/ (Q + Dol + Lm + Cl + TOC)

Where BI = brittleness index; Q = quartz; C l = clay; **Dol = dolomite**; Lm = limestone (calcite); TOC = Total



Development Scale



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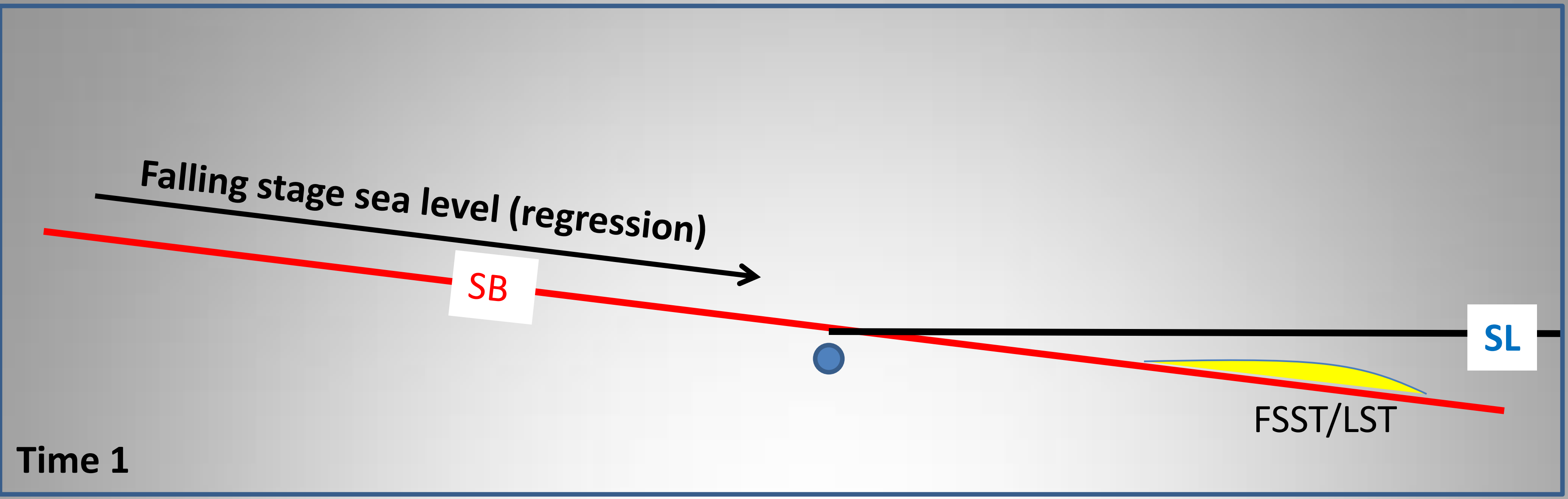
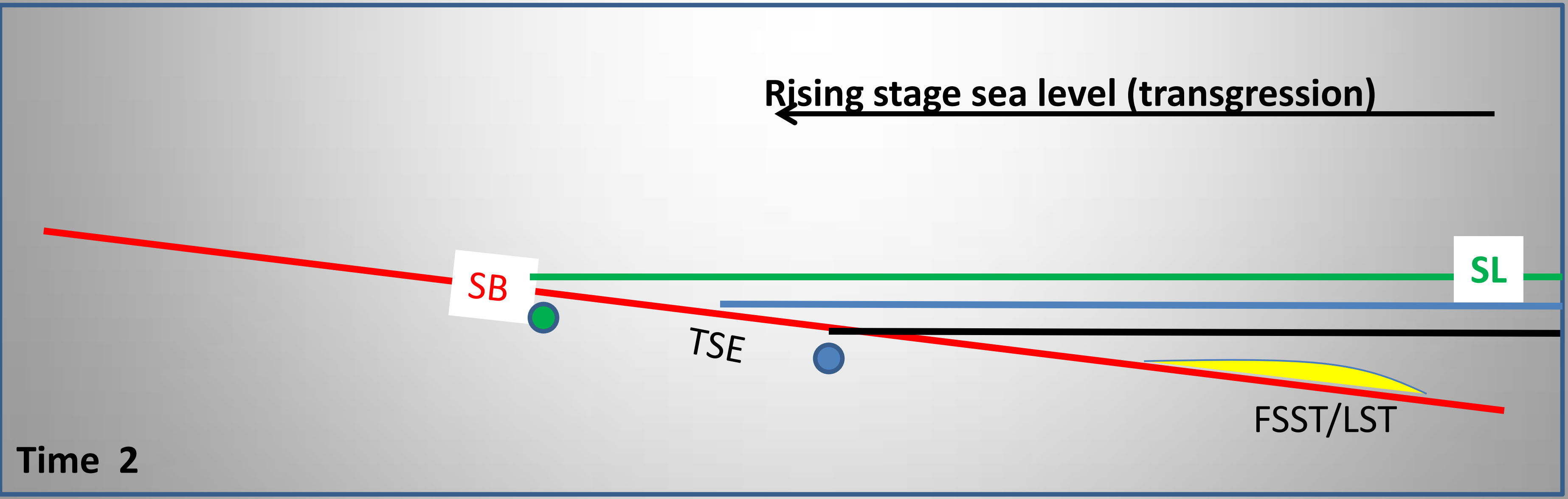
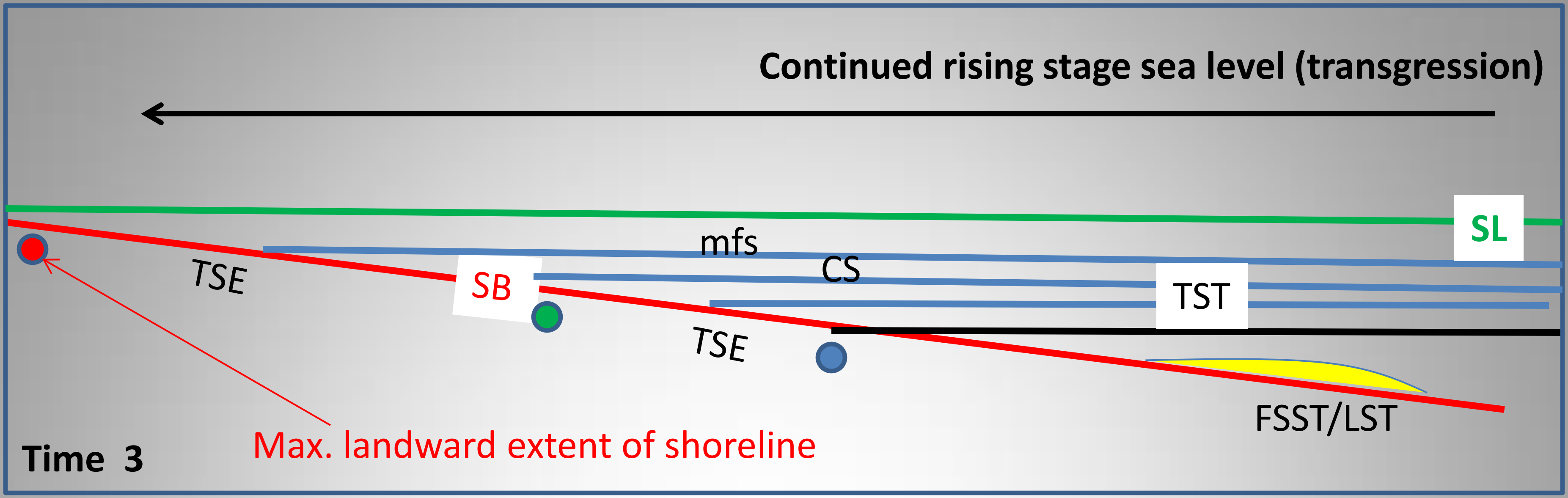
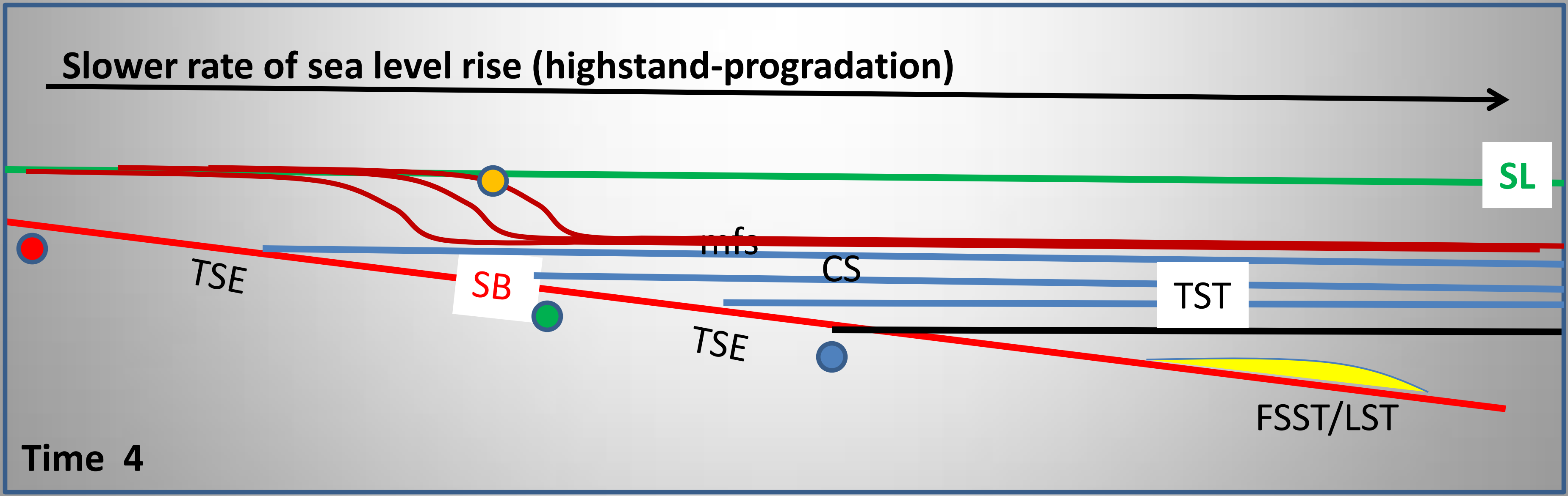
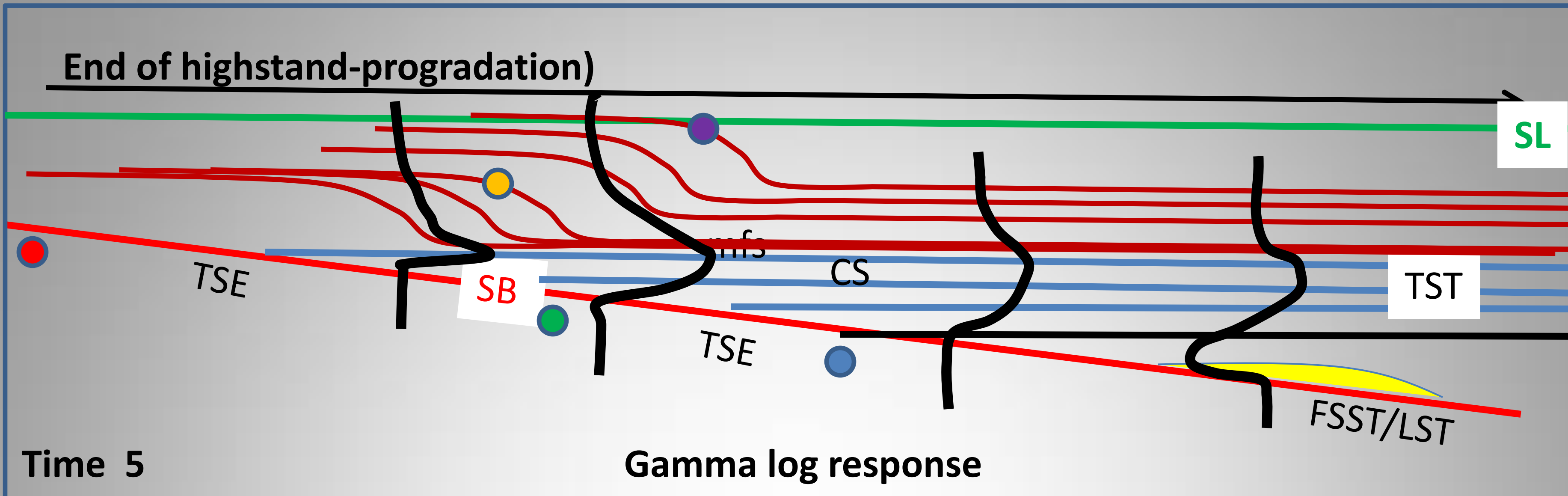
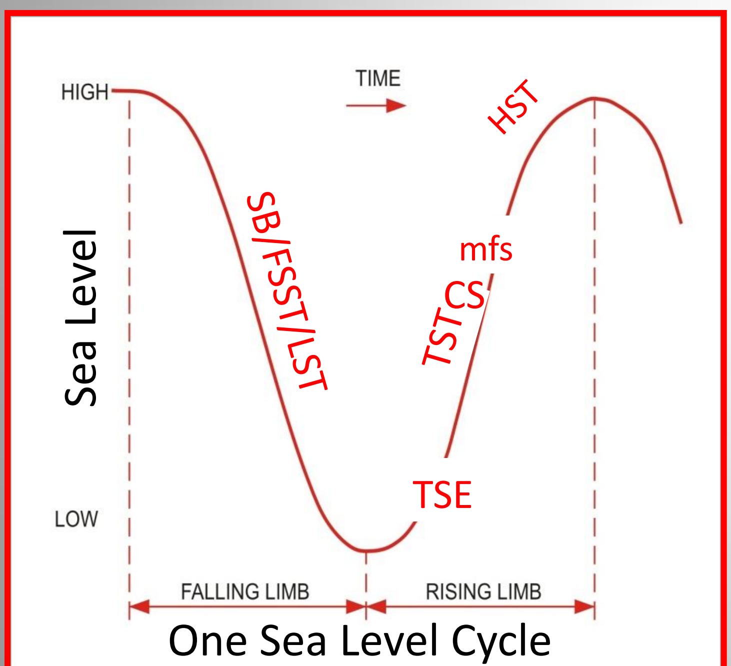

Falling stage sea level (regression)
SB
SL
FSST/LST
Time 1

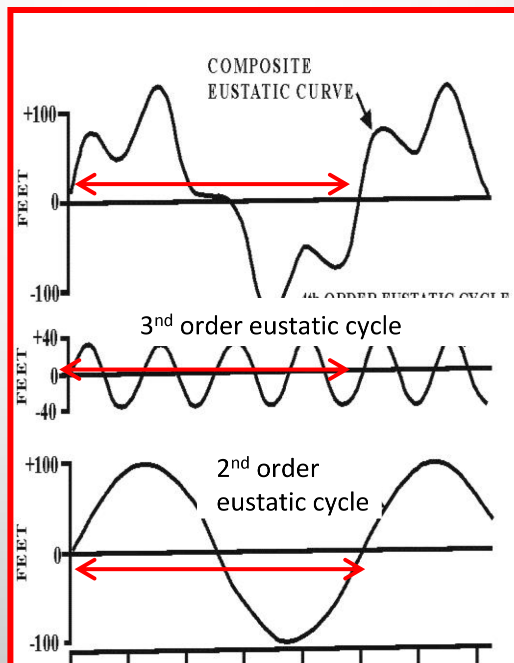

Rising stage sea level (transgression)
SB
SL
TSE
FSST/LST
Time 2


Continued rising stage sea level (transgression)
SL
mfs
CS
TSE
SB
TST
TSE
FSST/LST
Time 3
Max. landward extent of shoreline


Slower rate of sea level rise (highstand-progradation)
SL
mfs
TSE
SB
CS
TST
TSE
FSST/LST
Time 4

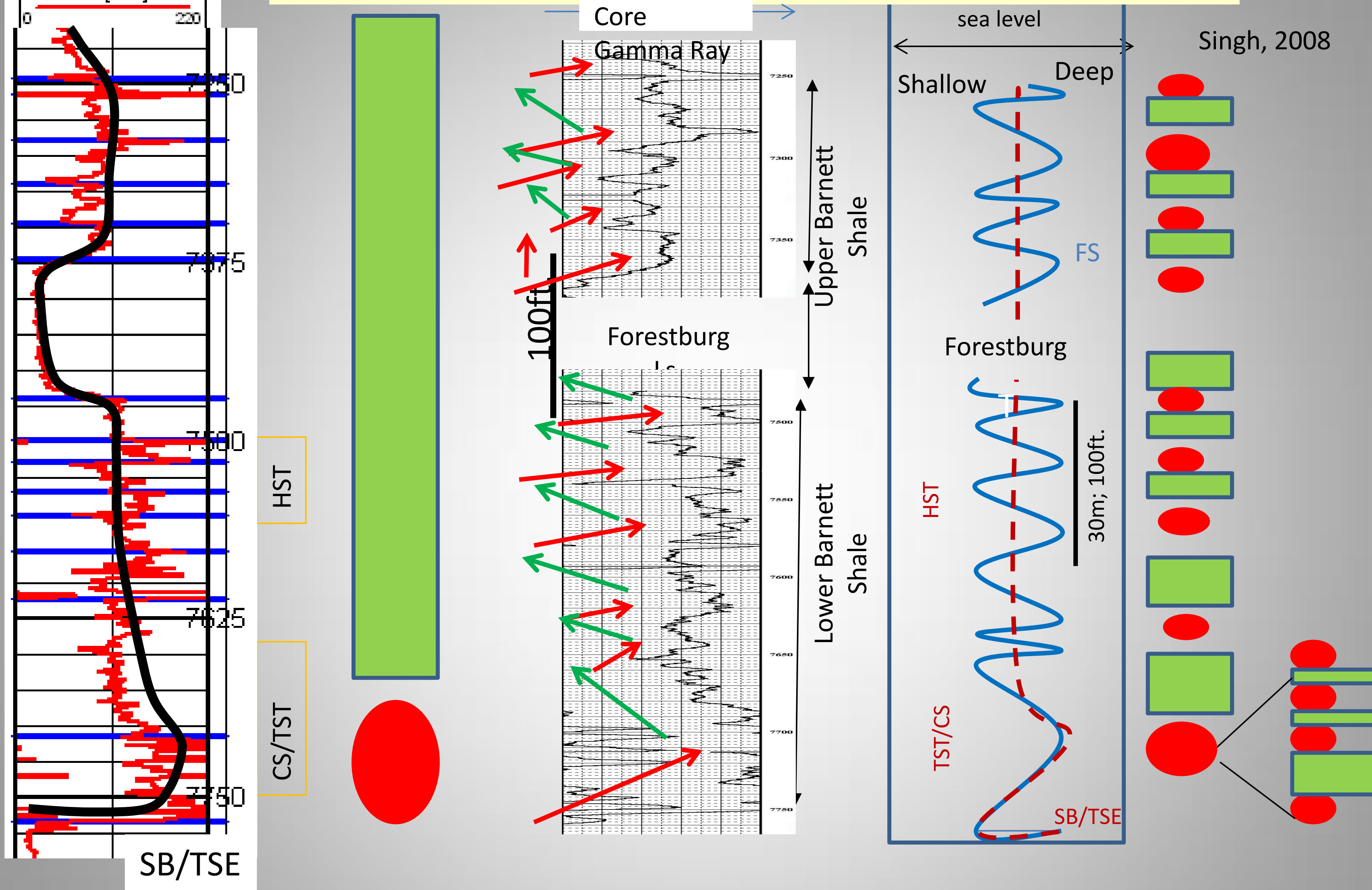






Woodford
Eagle Ford
Marcellus
New Albany
Caney
Fayetteville
Horn River
Haynesville
Longmaxi
LaLuna
Brown shale

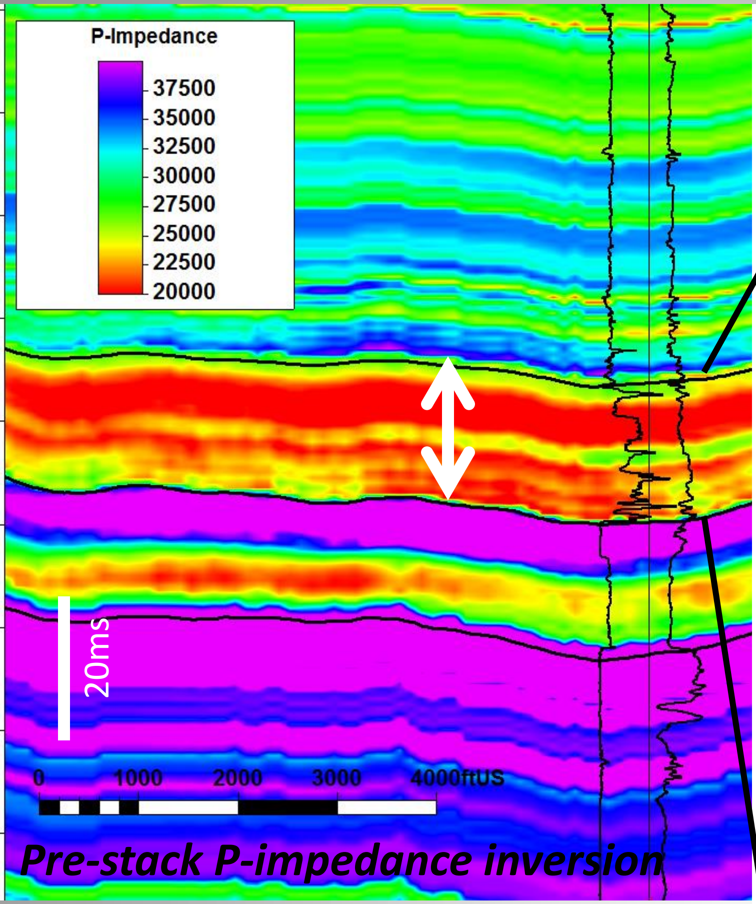
Ductile-Brittle Couplets: Barnett Shale example

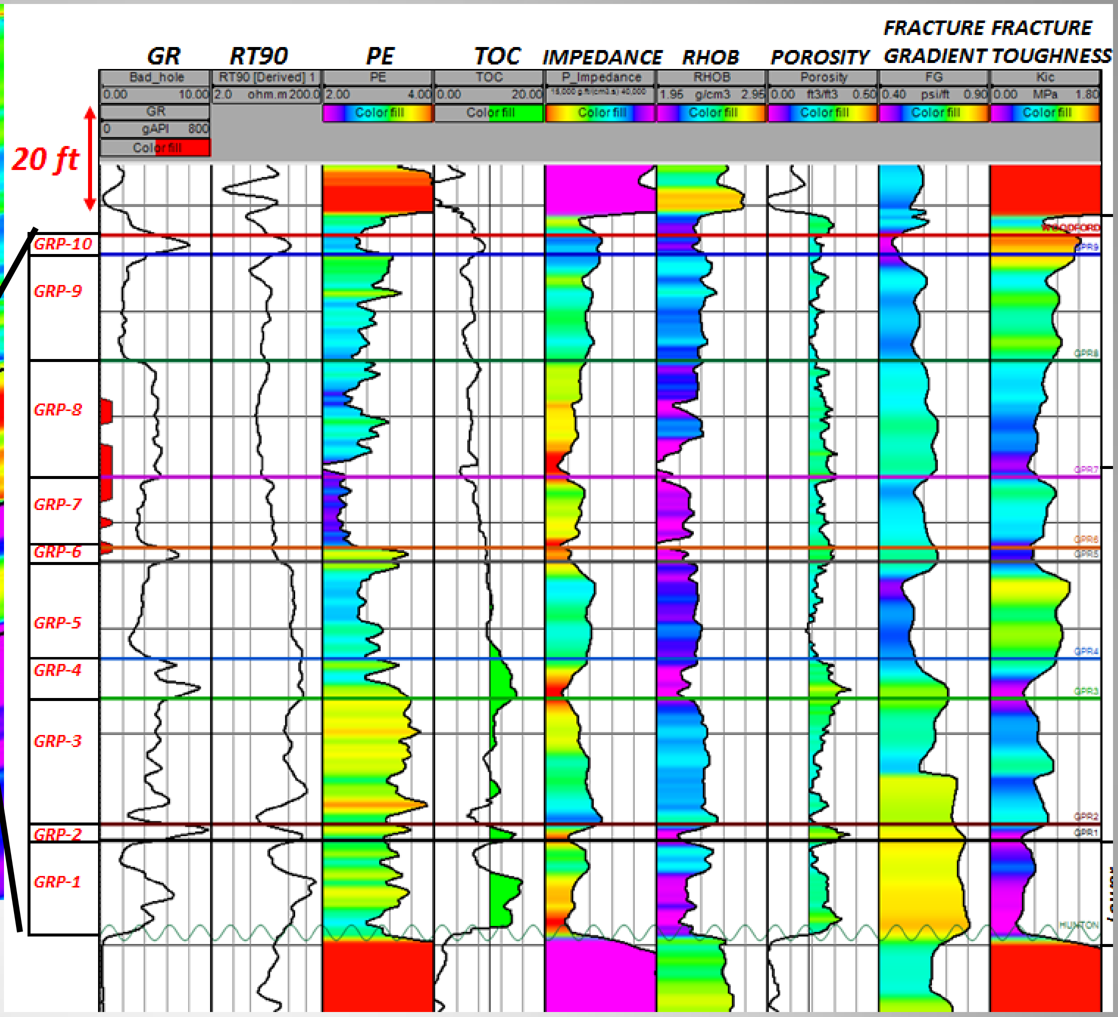


Organic-poor, more brittle rocks (quartz/carbonates)

Organic-rich, more ductile rocks (clay/TOC)

Slatt and Abousleiman, 2011



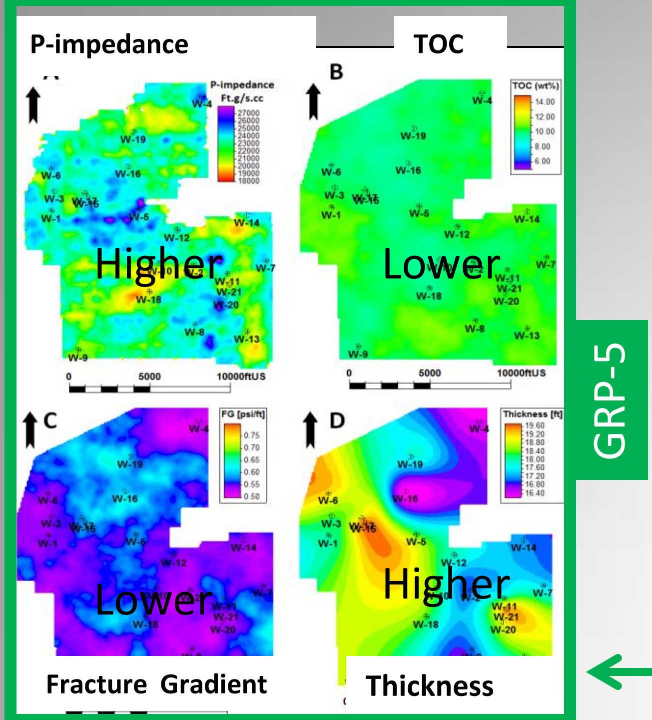


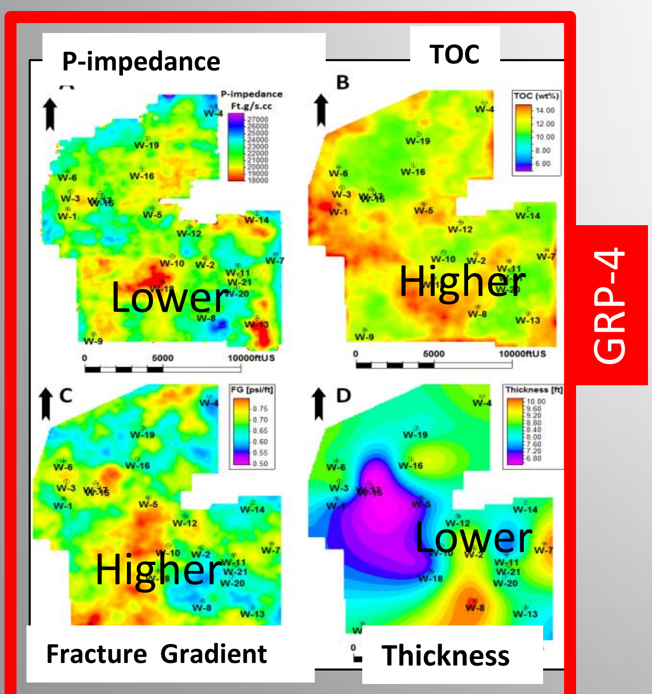
Woodford: 3D seismic survey
With well control

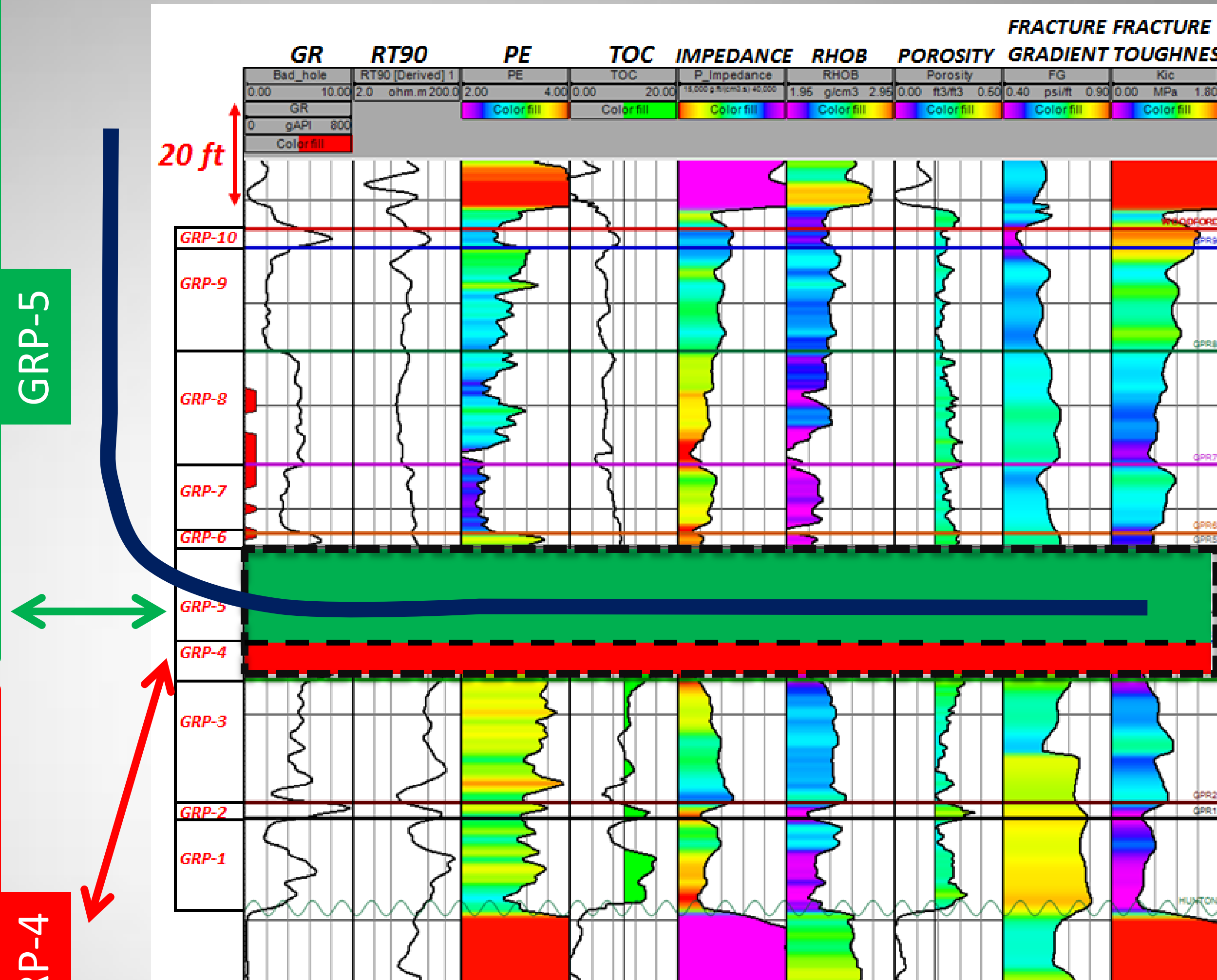
Identify areas with:

- High Thickness
- Low FG
- High TOC
- High impedance

Amorocho, 2012







Identify areas with:

- High Thickness
- Low FG (brittle)
- High TOC
- High impedance

Amorocho, 2012

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