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

Jeffrey A. May

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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.

References Cited


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By Jeffrey A. May, PhD
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• Terri Olson, Digital Rock Petrophysics*
• 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

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from Nester et al., 2014

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Variable Grain Sizes

mudrock = > 50% of grains less than 62.5 microns

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From Blatt, Middleton, & Murray 1980
Variable Lithologies

extrabasinal (deltaic outflow or carbonate-margin shedding)

intrabasinal (skeletal & organic matter)
Extrabasinal Material

detrital carbonate
detrital quartz
detrital clay
Intrabasinal Material - Skeletal

- Radiolarians
  - [Image Link](www.bio.miami.edu/dana/pix/radiolaria.jpg)
  - Scale: 100 μm

- Foraminifera
  - [Image Link](www.noc.soton.ac.uk/...tt/eh/cellpics.html)
  - Scale: 200 μm

- Coccolithophores
  - [Image Link](www.noc.soton.ac.uk/...tt/eh/cellpics.html)
  - Scale: 2 μm

- Diatoms
  - [Image Link](www.eukaryoticmicrobe.blogspot.com/2012/1/diatom-essay.html)
  - Scale: 20 μm
Intrabasinal Material - Organic

organo-minerallic aggregates
(marine snow/carbon rain)

55 m, Monterey Bay

www.whoi.edu/oceanus

Mowry Shale

Haynesville Shale

from Spain & Anderson, 2010
Variable Pore Types, Sizes, & Connectivity

Organic Matter Pores

Mixed

OM

Intraparticle Pores

Interparticle Pores

from Loucks et al., 2012
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)

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<th>Stratigraphy</th>
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<td>SB</td>
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~1.5 MY

Two 3rd-order Sequences

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**

sequence boundary

from Zagorski, 2015
Marcellus Targeting

initial wells in high TOC condensed section

better wells in early highstand detrital section

organic matter & intraparticle pores

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

from Hentz & Ruppel, 2011

sequence boundary
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

sequence boundary

from Hentz & Ruppel, 2011
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)

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<td>B Chalk</td>
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<td>B Marl</td>
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<td>Ft Hays Ls</td>
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- **A Chalk**
- **A Marl**
- **B Chalk**
- **B Marl**
- **C Chalk**
- **C Marl**
- **Lwr Chalk**
- **Ft Hays Ls**

**Key:***
- HST: High Stand Time
- TST: Transgressive Stand Time
- MFS: Maximum Flooding Surface
- SB: Sea Base
- SB/MRS: Sea Base/Marine Regression Surface
- Top Niobrara
- Bottom Niobrara
Niobrara Lithologies & Targeting

Transgressive to Condensed Section

*reduced detritus* + *oxygenation*

created *bioclastic-dominated rock* 

(*brittle chalk*) *w/ low organic matter*

---

after Roberts & Kirschbaum, 1995
Niobrara Lithologies & Targeting

Sea-Level Highstand

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

after Roberts & Kirschbaum, 1995
Niobrara Pore Types & Target Selection

TST to CS Chalk

HST Marl

open interparticle pores

3μm

elongate organic matter pores

3μm
**Petrophysics & Target Selection**

- Pore size & shape vary with lithology & maturity.
- Pore size seen by NMR is a function of pore shape; large-pore porosity may be underestimated.
- Relaxivity of organic matter interferes with capturing organic pore data.

**Diagram:**
- NMR Log
- Relaxation Time
- Diameter = x
- Equivalent circle diam. = 3X
- Width = x
- Equivalent circle diam. = 3X

**Notes:**
- Small pores
- Large pores

*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

- Quartz turbidites
- Calcareous turbidites
- Debrisites
- Slumps
- Slide blocks
- Laminated mudstone
Facies Control on Reservoir Properties

CMR Permeability vs. Porosity

Core Facies:
1. laminated mudstone w/ high TOC
2. quartz turbidites
3. burrowed mudstone
4. laminated mudstone w/ carb. concretions
5. carbonate turbidites
6. debrites, slumps, & slides

(after A. Noack)
Facies Control on Reservoir Properties

CMR Permeability vs. Porosity

- Laminated mudstone with high TOC
- Quartz turbidites
- Burrowed mudstone
- Laminated mudstone
- Laminated mudstone with carbonate concretions
- Carbonate turbidites
- Debrites, slumps, & slides

After A. Noack
Facies Control on Reservoir Properties

- carbonate & quartz turbidites
- laminated mudstone w/ high TOC
- quartz turbidites
- burrowed mudstone
- laminated mudstone
- laminated mudstone w/ carb. concretions
- carbonate turbidites
- debrites, slumps, & slides

after A. Noack
Facies Control on Reservoir Properties

- carbonate & quartz turbidites
- laminated mudstones, slides, slumps, & debris flows
- debrites, slumps, & slides

After A. Noack
Facies Control on Mechanical Properties

- laminated mudstone
- w/ high TOC
- quartz turbidites
- burrowed mudstone
- laminated mudstone
- w/ carb. concretions
- carbonate turbidites
- debrites, slumps, & slides

after A. Noack
Facies Control on Mechanical Properties

fractured siliceous mudstone

9673'
Avalon (Leonard) Shale Targeting

- Lower Avalon Shale
  - LST
  - Carbonate & Quartz Turbidites
  - Slide Blocks & Slumps

- Middle Avalon Shale
  - LST
  - Carb. Turbidites
  - Slide Blocks

- Upr Avalon Shale
  - LST
  - Carbonate & Quartz Turbidites

- Ts
  - LST
  - Carbonate & Quartz Turbidites

Target?
Target?
Target?
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