Shale Variability in Deep-Marine Depositional Systems: Implications for Seal Character - Subsurface and Outcrop Examples*

By
William C. Dawson¹, William R. Almon¹, Kelly Dempster¹ and Sally J. Sutton²

Search and Discovery Article #50128 (2008)
Posted October 7, 2008

*Adapted from oral presentation at AAPG Annual Convention, San Antonio, TX, April 20-23, 2008

¹Chevron, Houston, TX (wdawson@chevron.com)
²Colorado State University, Fort Collins, CO

Abstract

Shales are arguably the least understood lithotype causing significant uncertainty in the interpretation of basin modeling results and seal risk. Burial-driven compaction (i.e., systematic reduction of pore throat size during progressive burial) is not the primary control on seal behavior. Rather, variations in depositional conditions, related to high-frequency stratigraphic fluctuations, appear responsible for broad variations in shale properties and seal character. Analyses of samples from deep-water (submarine fan) depositional settings reveal strong relationships between mudstone facies and sealing character. Silt-poor well-laminated shales generally have excellent to exceptional sealing behavior. Increased percentages of silt-sized detrital grains (> 20%) enhance preservation of relatively large-diameter pore throats, thereby lowering sealing capacities. Sub-parallel-alignment clay minerals and organic matter and early marine carbonate cementation can significantly enhance sealing capacity. Bioturbation generally degrades sealing capacity. Sandy injectites can compromise seal effectiveness. Silt-poor well-laminated shales typify more distal parts of submarine fan deposits. In contrast, mudstones associated with proximal channel-levee complexes commonly exhibit highly deformed fabrics and are moderately to very silty (clay-poor) and consequently have relatively low sealing potential. Compartmentalization by shale laminae is common in channel margins. Comparable shale facies patterns are observed in samples from deepwater Gulf of Mexico wells, offshore West Africa wells, and outcrop analogs (Arkansas and Wyoming). Because of variations in fabric and texture, deepwater shale types exhibit different compaction rates, which can result in erroneous interpretations of burial history.
Shale Variability in Deep-Marine Depositional Systems: Implications for Seal Character – Subsurface and Outcrop Examples

William C. Dawson, William R. Almon & Kelly Dempster
Chevron ETC, Houston, TX

Sally J. Sutton
Colorado State University, Fort Collins, CO
Introduction

Observed ranges/variations in seal data are attributed to differences in shale facies (i.e., differences in shale fabric).

Deep-marine depositional systems contain 6 to 8 shale/seal lithotypes (based on analyses of Tertiary & Cretaceous subsurface & outcrop sample sets).

Seal character exhibits systematic variability from proximal to distal parts of deepwater depositional settings.
Mud-rich LST fan

Proximal Setting

Distal Setting

SANDSTONES  SILTSTONES  MUDSTONES & SHALES  SLUMPED MUDSTONES

(after: Reading & Richards, 1994)
Seal capacity enhanced by carbonate cementation

Sealing character of deepwater shales influenced by fabric & texture.
Influences on Seal Character

- Fabric & texture
- Sequence stratigraphic & depositional setting
- Diagenesis
- Burial history

![Graph showing non-wetting phase saturation](image)

Shale types 1 & 6
Shale type 2
Shale types 3 & 4
Shale type 5
Basin Comparisons – Seal Capacity

**Very silty shales (mean: 3,206 psia)**

**Tuffaceous shales (mean: 1,356 psia)**

**“Global” Mean**

Worldwide Seal Data
Number of data points used = 599
Average X = 5,128
Standard Deviation = 3,213

Angola - All Data
Very silty shales
(mean: 3,206 psia)

Brazil
Tertiary
Tuffaceous shales
(mean: 1,356 psia)
Basin Comparisons – Seal Capacity

GOM - All Data
Number of data points used = 83
Average X = 4,947 psia
Standard Deviation = 2,760
Carbonaceous shales
(mean: 4,947 psia)

Worldwide Seal Data
Number of data points used = 599
Average X = 5,128
Standard Deviation = 3,213
“Global” Mean

Moderately silty shales
(mean: 4,425 psia)

Basin Comparisons – Seal Capacity

Columbia - Tertiary
Moderately silty shales
(mean: 4,425 psia)
Deepwater Seal Lithotypes

(Dempster, et al, 2006)
“High” quality seals (clay-rich samples)

“Low” quality seals (silt-rich samples)

Deepwater GOM Seals
Total Clay Content by Seal Type

(Type 1)
Number of data points = 16
Average X = 72.1
Standard Deviation = 4.53

(Type 2)
Number of data points = 41
Average X = 72.4
Standard Deviation = 8.20

(Type 3)
Number of data points = 30
Average X = 70.1
Standard Deviation = 5.89

(Type 4)
Number of data points = 45
Average X = 65.7
Standard Deviation = 11.43

(Type 5)
Number of data points = 27
Average X = 59.3
Standard Deviation = 11.97

(Type 6)
Number of data points used = 13
Average X = 79.2
Standard Deviation = 4.03
## Deepwater Shale Summary

<table>
<thead>
<tr>
<th>Seal type</th>
<th>Clay</th>
<th>Silt</th>
<th>Carbonate</th>
<th>TOC</th>
<th>Shale Fabric</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>72%</td>
<td>17%</td>
<td>2.3%</td>
<td>1.70</td>
<td>well-laminated</td>
</tr>
<tr>
<td>2</td>
<td>63%</td>
<td>22%</td>
<td>5.6%</td>
<td>1.58</td>
<td>faint laminations</td>
</tr>
<tr>
<td>3</td>
<td>61%</td>
<td>35%</td>
<td>3.7%</td>
<td>0.61</td>
<td>clay mottles</td>
</tr>
<tr>
<td>4</td>
<td>59%</td>
<td>37%</td>
<td>5.1%</td>
<td>0.41</td>
<td>silt mottles</td>
</tr>
<tr>
<td>5</td>
<td>56%</td>
<td>41%</td>
<td>2.3%</td>
<td>0.33</td>
<td>silt laminae</td>
</tr>
<tr>
<td>6</td>
<td>64%</td>
<td>18%</td>
<td>16.2%</td>
<td>1.32</td>
<td>massive</td>
</tr>
</tbody>
</table>

(Dawson & Almon, 2006)
## Deepwater Seal Summary

<table>
<thead>
<tr>
<th>Seal type</th>
<th>Clay</th>
<th>Silt</th>
<th>Carbonate</th>
<th>10% MICP</th>
<th>Shale Fabric</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>72%</td>
<td>17%</td>
<td>2.3%</td>
<td>8,395 psia</td>
<td>well-laminated</td>
</tr>
<tr>
<td>2</td>
<td>63%</td>
<td>22%</td>
<td>5.6%</td>
<td>7,445 psia</td>
<td>faint laminations</td>
</tr>
<tr>
<td>3</td>
<td>61%</td>
<td>35%</td>
<td>3.7%</td>
<td>4,950 psia</td>
<td>clay mottles</td>
</tr>
<tr>
<td>4</td>
<td>59%</td>
<td>37%</td>
<td>5.1%</td>
<td>3,175 psia</td>
<td>silt mottles</td>
</tr>
<tr>
<td>5</td>
<td>56%</td>
<td>41%</td>
<td>2.3%</td>
<td>1,360 psia</td>
<td>silt laminae</td>
</tr>
<tr>
<td>6</td>
<td>64%</td>
<td>18%</td>
<td>16.2%</td>
<td>7,655 psia</td>
<td>massive</td>
</tr>
</tbody>
</table>

(Dawson & Almon, 2006)
GOM Deepwater Shale/Seal Types

(Dawson & Almon, 2006)
Stacked channels in deep-water depositional setting

(from: Mayall et al., 2006)
Seal types 4 & 5

Offshore West Africa (MICP data)

Seal type 3

Seal type 2

Very silty shales & siltstones

Moderately silty mottled shales

Well-laminated, calcareous & carbonaceous, slightly silty shales

Improving Seal Capacity

(Almon & Dawson, 2003)
Data integration reveals stratigraphic patterns (e.g., stacking of seal & reservoir lithofacies).

(Almon & Dawson, 2004)
Sand rich areas stand out in bright, warm tones. Areas away from those, with more homogeneous cool tones indicate better seals.
Jackfork Fm (Arkansas) - Outcrop Analogs

DeGray Spillway

Proximal deepwater shales

(after: Slatt et al., 1995)

Hollywood Quarry

Distal deepwater shales
Arkansas Outcrops: MICP Data & Shale Facies
Arkansas Outcrops (Jackfork Formation)

Proximal Shales  
(DeGray Spillway)

Distal Shales  
(Hollywood Quarry)

MICP Porosity (%)  

MICP (10% Hg saturation)

fault
Deepwater Seal Variability

All Data
Number of data points used = 155
Mean = 7542
Standard Deviation = 3321

Note tendency for bimodal distribution
Outcrop Analog: Submarine Fan Sequence

Tertiary: California

Top Seal Facies

Thick shale sequence with thin, interstratified sandstones

Reservoir Facies

Stratigraphic separation of reservoir & top seal intervals

Thick sandstone turbidites with interstratified thin shales
Conclusions – 1

Deepwater depositional systems contain a variety of shale facies, each exhibiting a range of seal characteristics.

Variations in deepwater seal character are related strongly to variations in shale textures & fabrics.

Seal character is enhanced in well-laminated, silt-poor, organic-rich shales (enhanced by diagenesis: e.g., carbonate cementation).
Conclusions – 2

Seal prediction models based on single parameters (e.g., total clay content) lack tenability.

Maximum seal variability exists within proximal (i.e., highly channelized) lithofacies (associated with high potential for reservoir compartmentalization).

Analyses of shale outcrops are valuable as seal analogs.

Waste zone is a common aspect of deepwater HC accumulations.
Quiz

Can you identify the “best” seal?
References


