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

By

William C. Dawson[1], William R. Almon[1], Kelly Dempster[1] and Sally J. Sutton[2]

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

[1]Chevron, Houston, TX (wdawson@chevron.com)

[2]Colorado 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

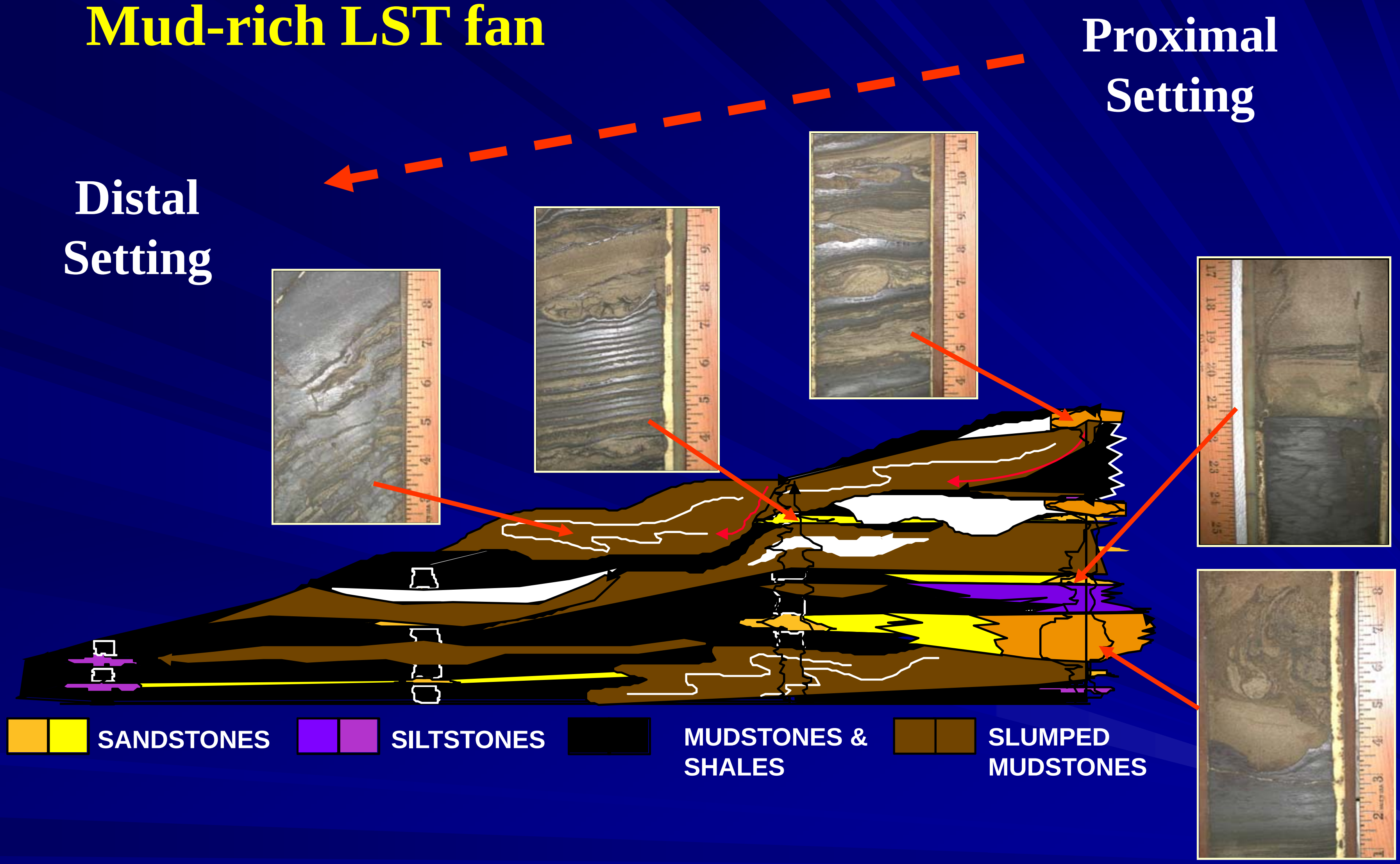
Introduction

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.

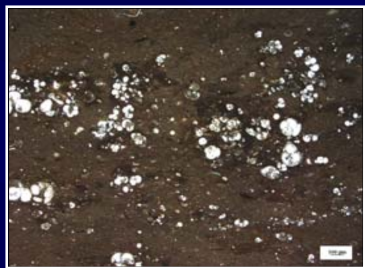
Mud-rich LST fan



(after: Reading & Richards, 1994)

Seal capacity enhanced by carbonate cementation

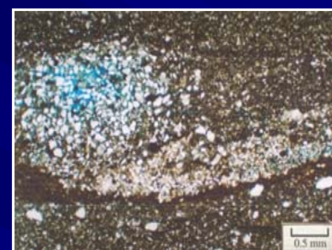
(Proximal)



Shale type 6

Shale type 5

Shale type 4



Shale type 3

(Distal)

Shale type 2

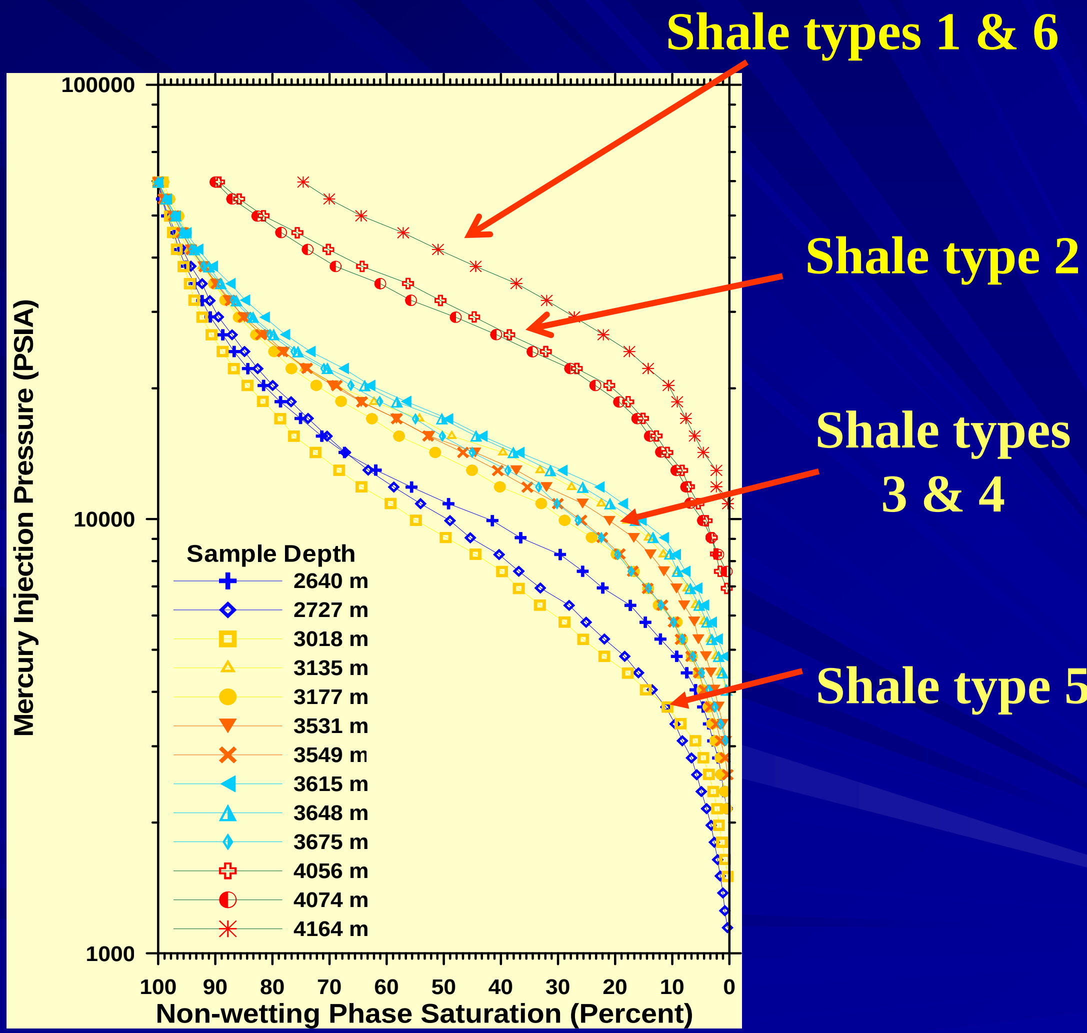
Shale type 1

Increasing Seal Capacity

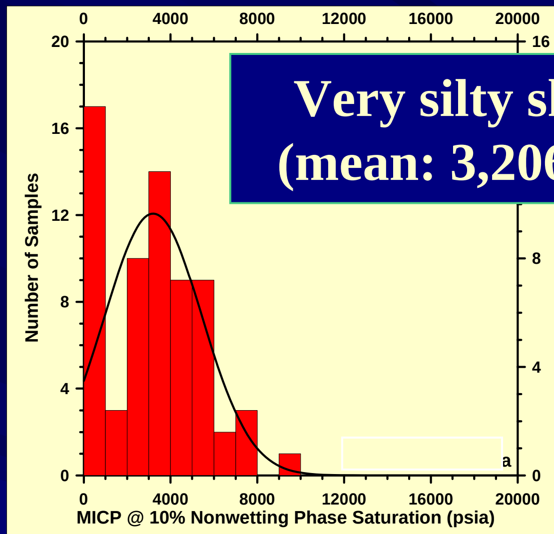
Sealing character of deepwater shales influenced by fabric & texture.

Influences on Seal Character

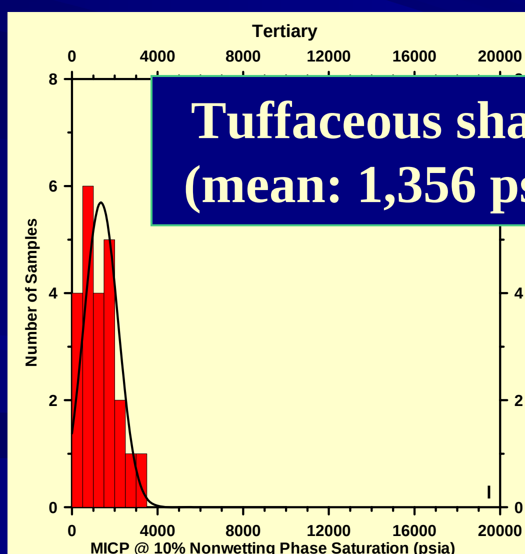
- Fabric & texture
- Sequence stratigraphic & depositional setting
- Diagenesis
- Burial history



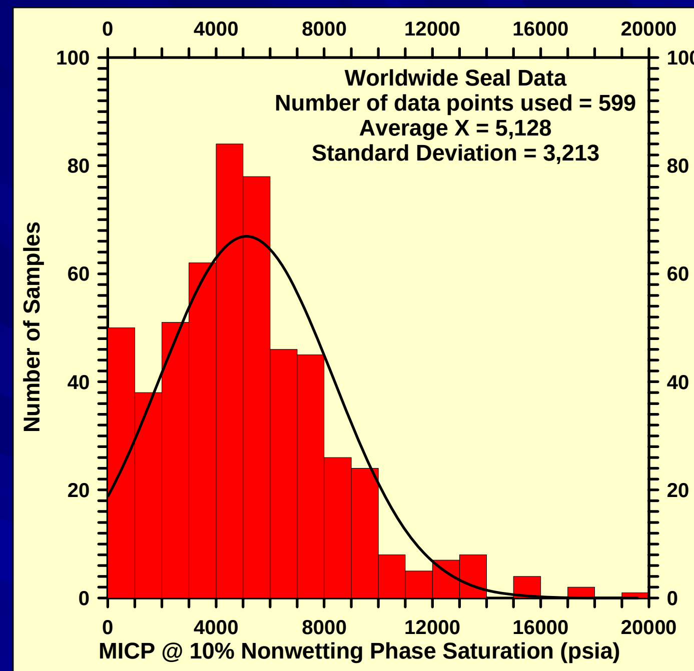
Basin Comparisons – Seal Capacity



Very silty shales (mean: 3,206 psia)

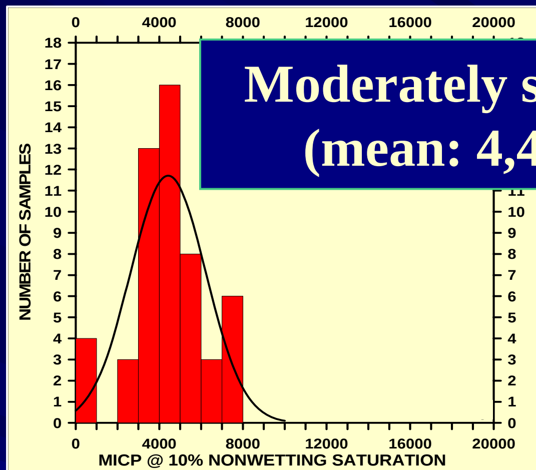


Tuffaceous shales (mean: 1,356 psia)

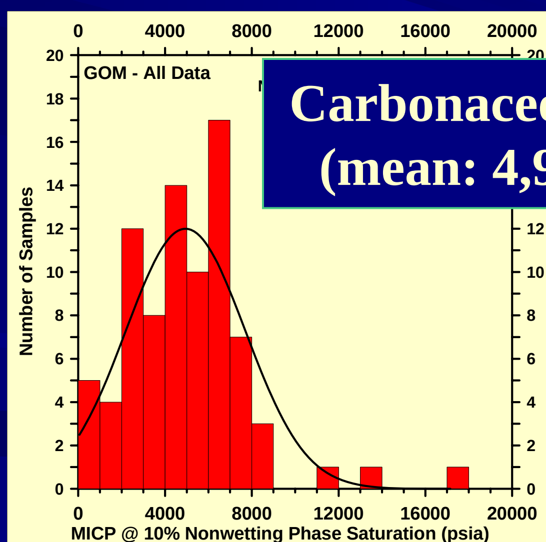


“Global” Mean

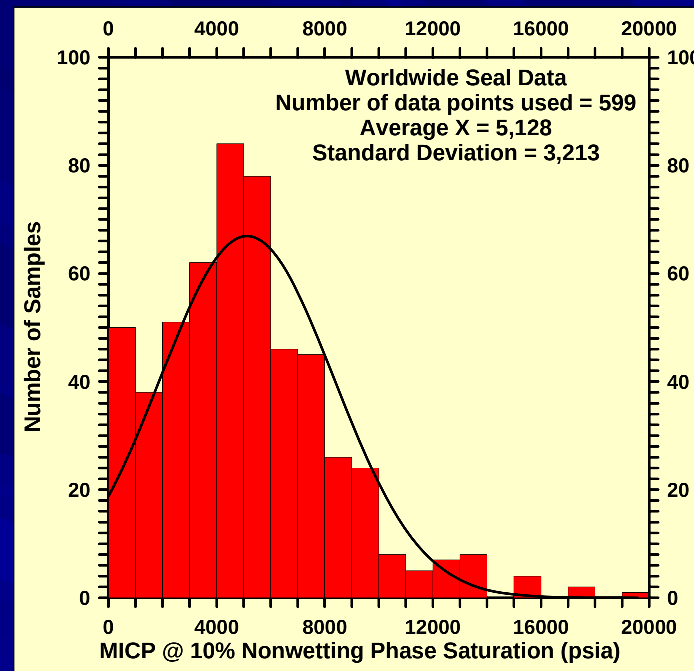
Basin Comparisons – Seal Capacity



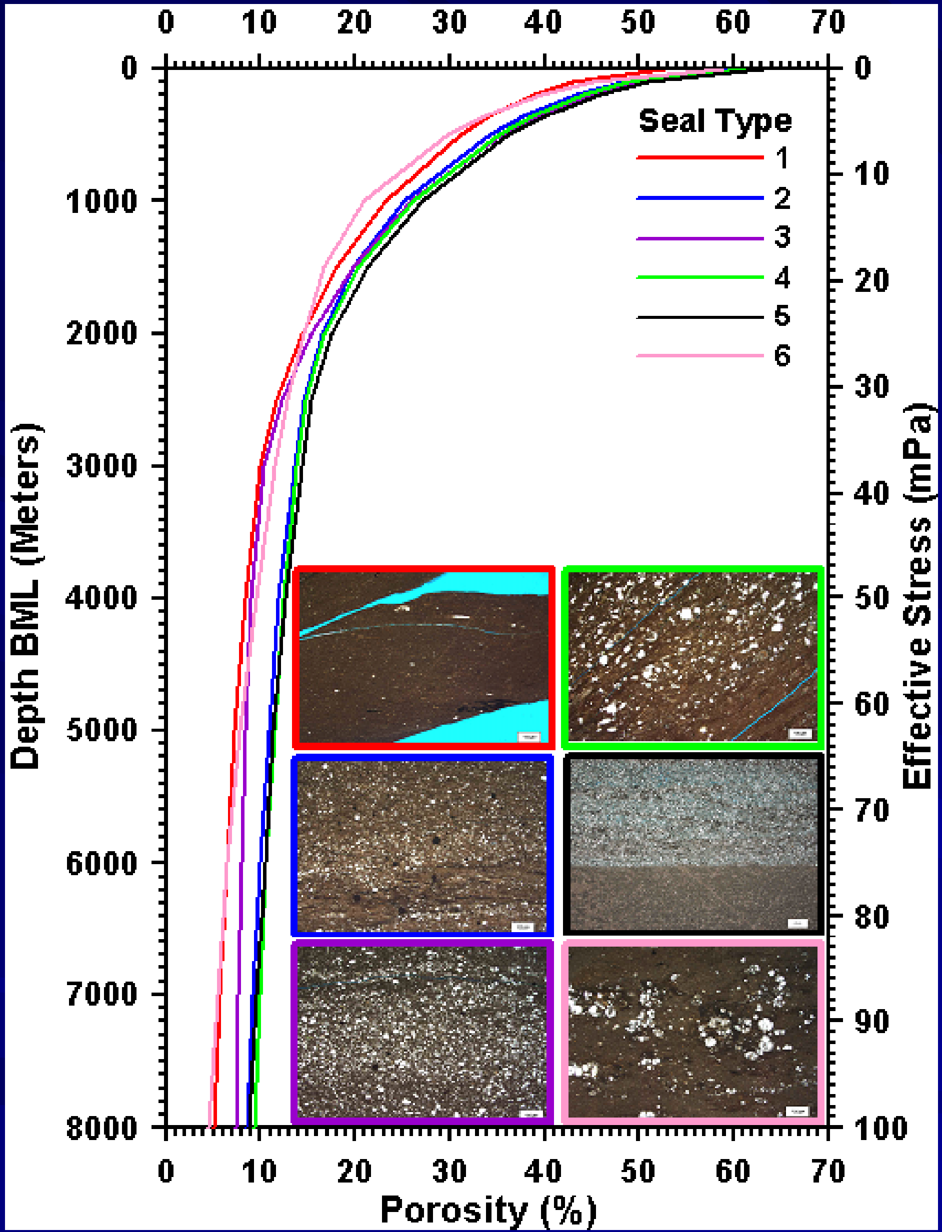
Moderately silty shales (mean: 4,425 psia)



Carbonaceous shales (mean: 4,947 psia)

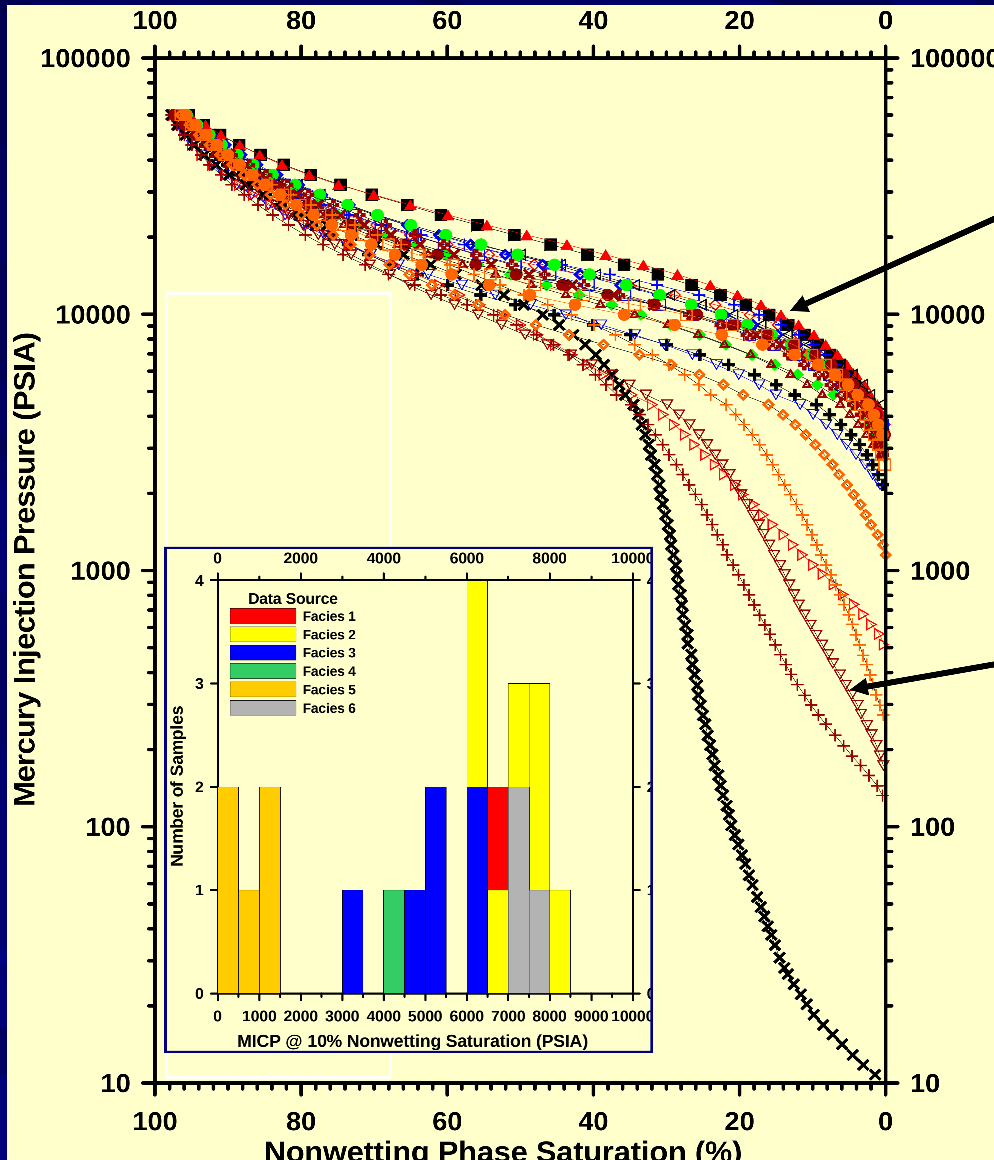


"Global" Mean



Deepwater Seal Lithotypes

(Dempster, et al, 2006)

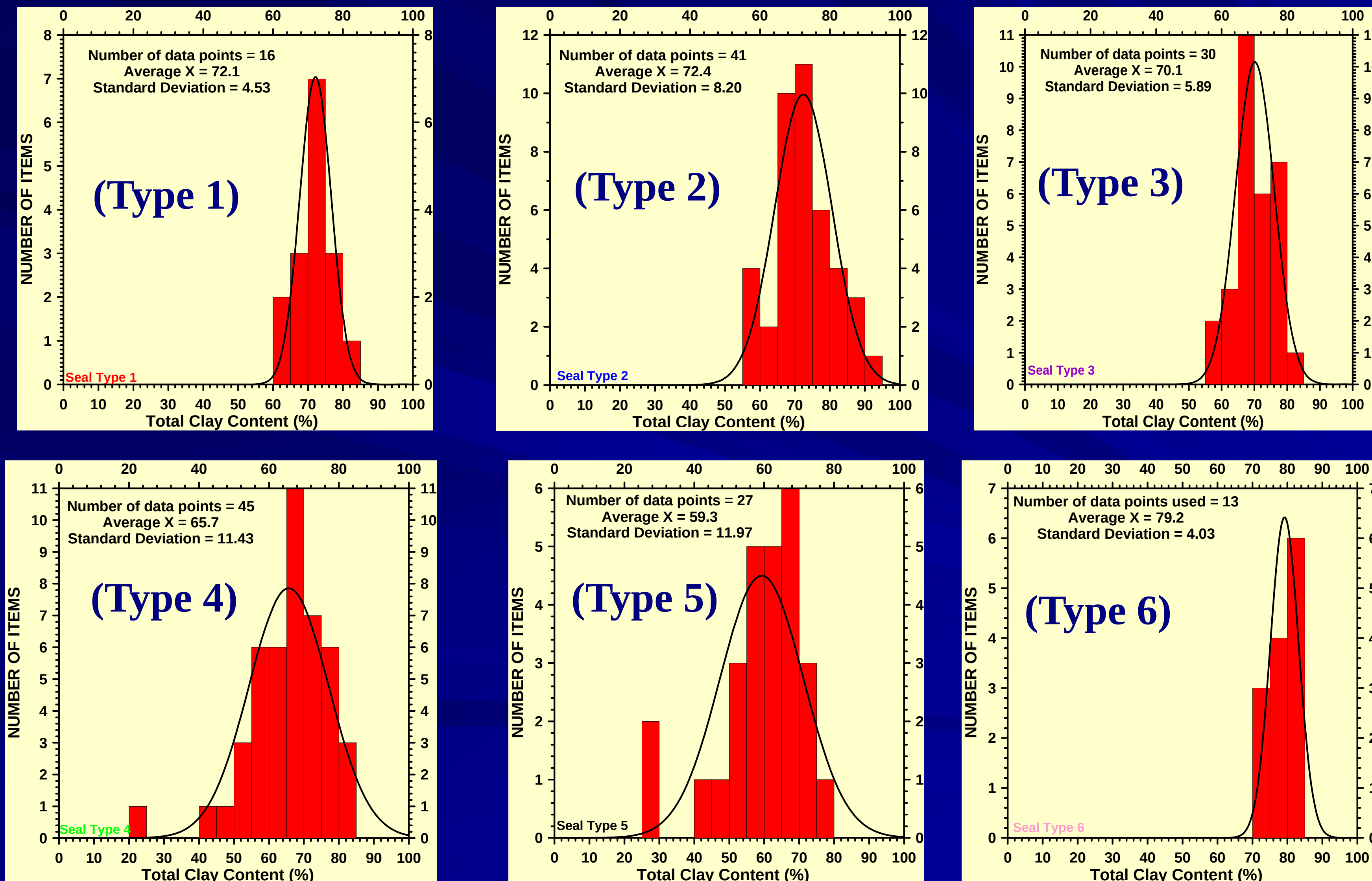


“High” quality seals (clay-rich samples)

“Low” quality seals (silt-rich samples)

Deepwater GOM Seals

Total Clay Content by Seal Type



Deepwater Shale Summary

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

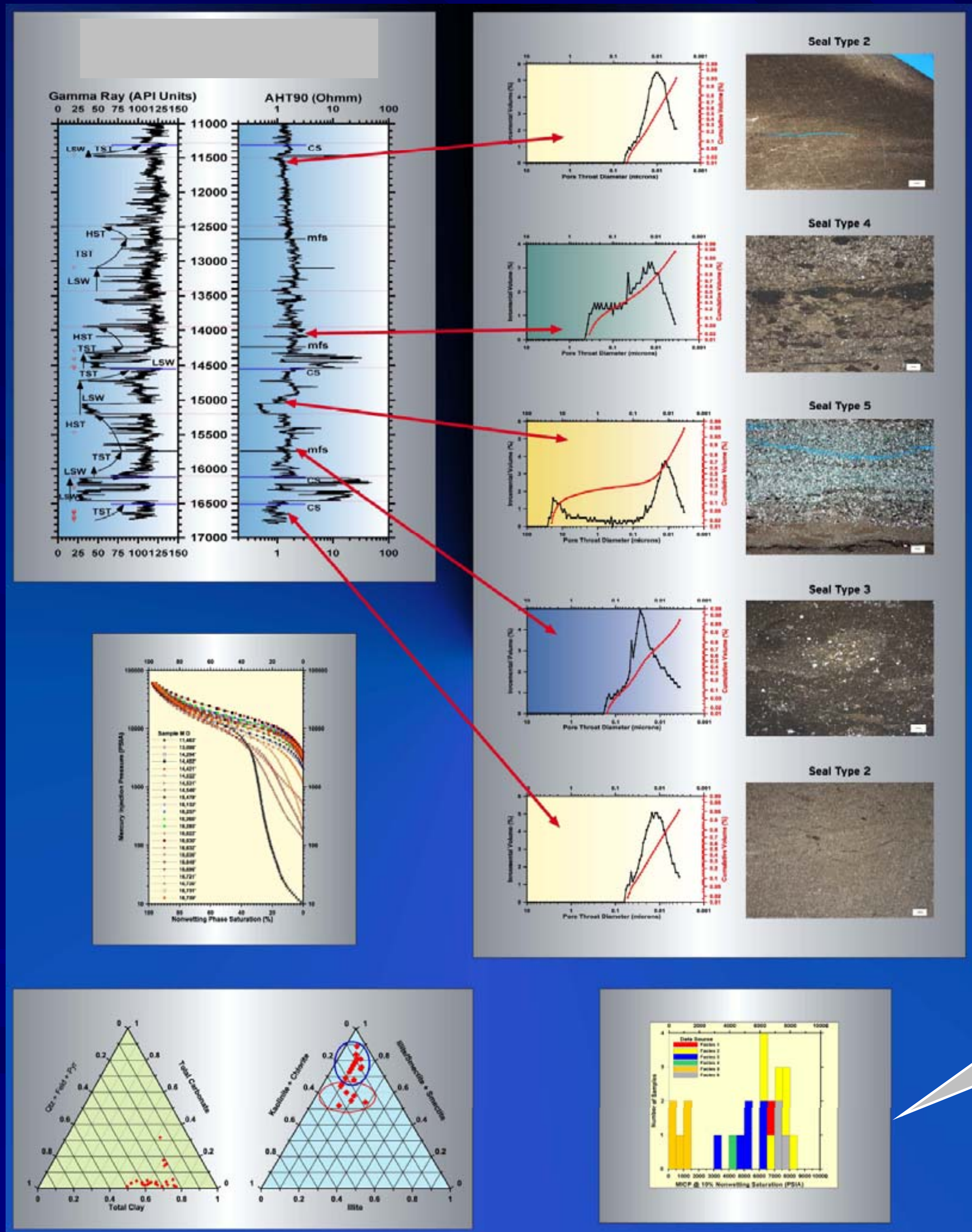
(Dawson & Almon, 2006)

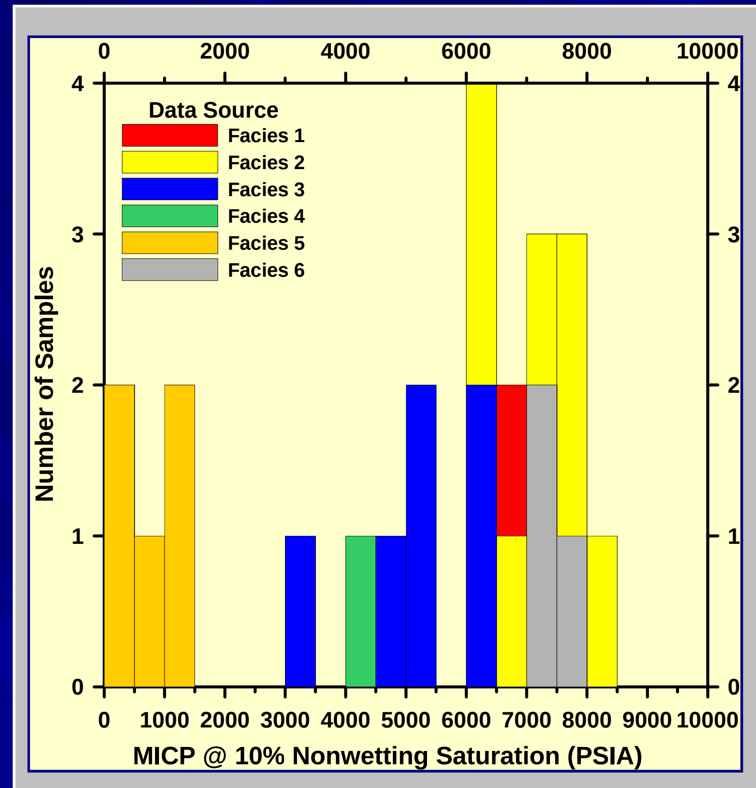
Deepwater Seal Summary

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

(Dawson & Almon, 2006)

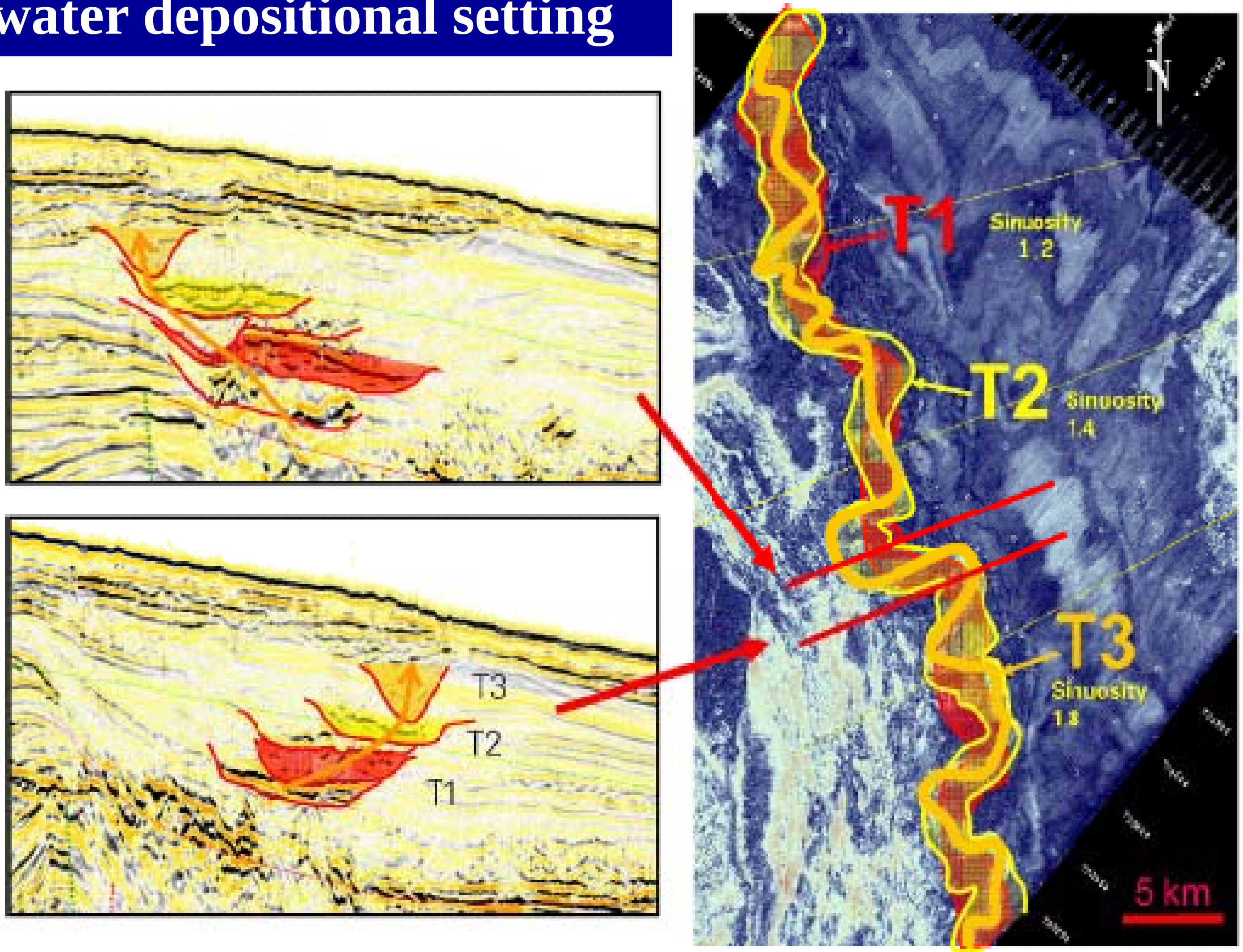
GOM Deepwater Shale/Seal Types





(Dawson & Almon, 2006)

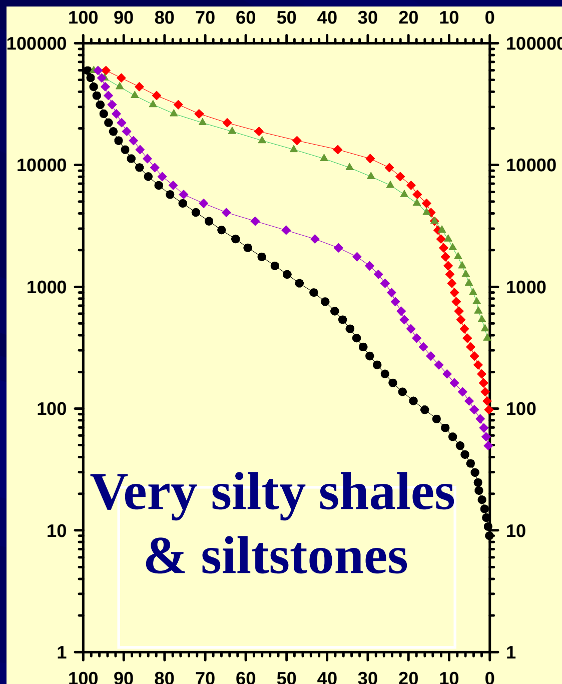
Stacked channels in deep-water depositional setting



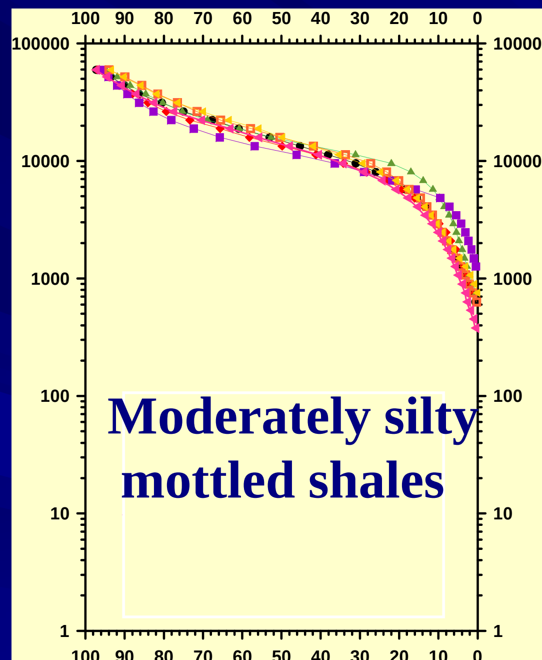
(from: Mayall et al., 2006)

Offshore West Africa (MICP data)

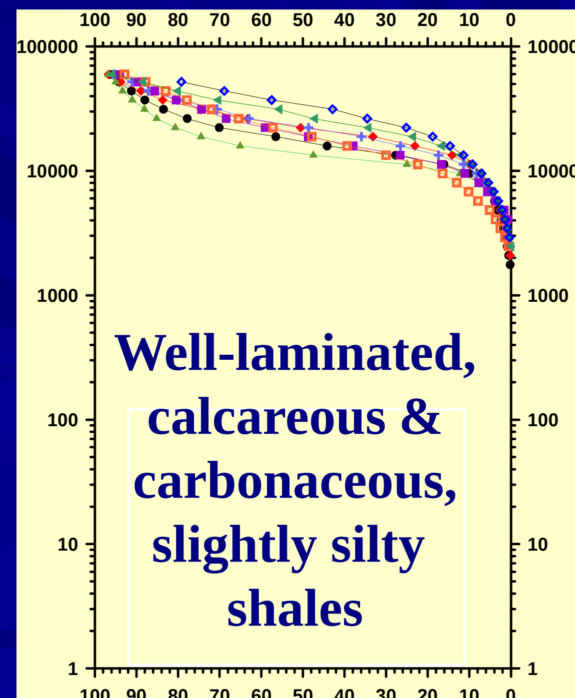
Seal types 4 & 5



Seal type 3



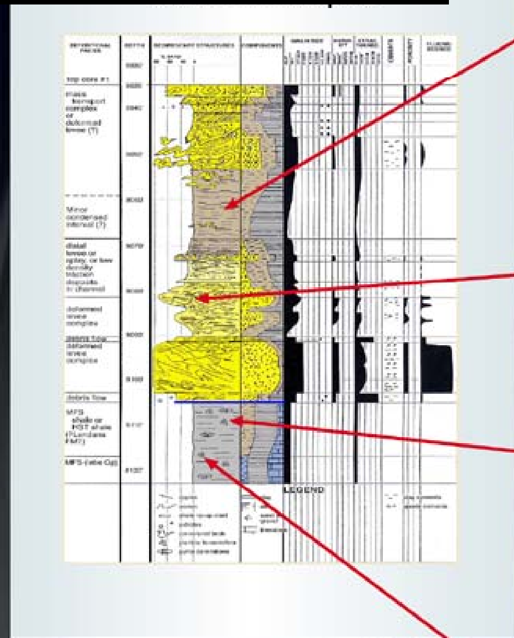
Seal type 2

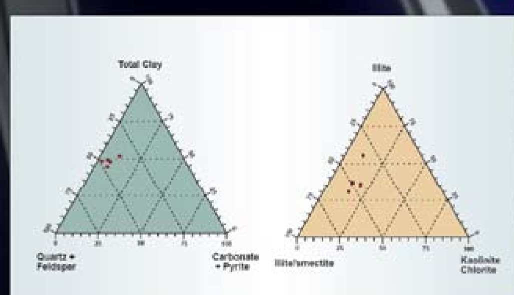


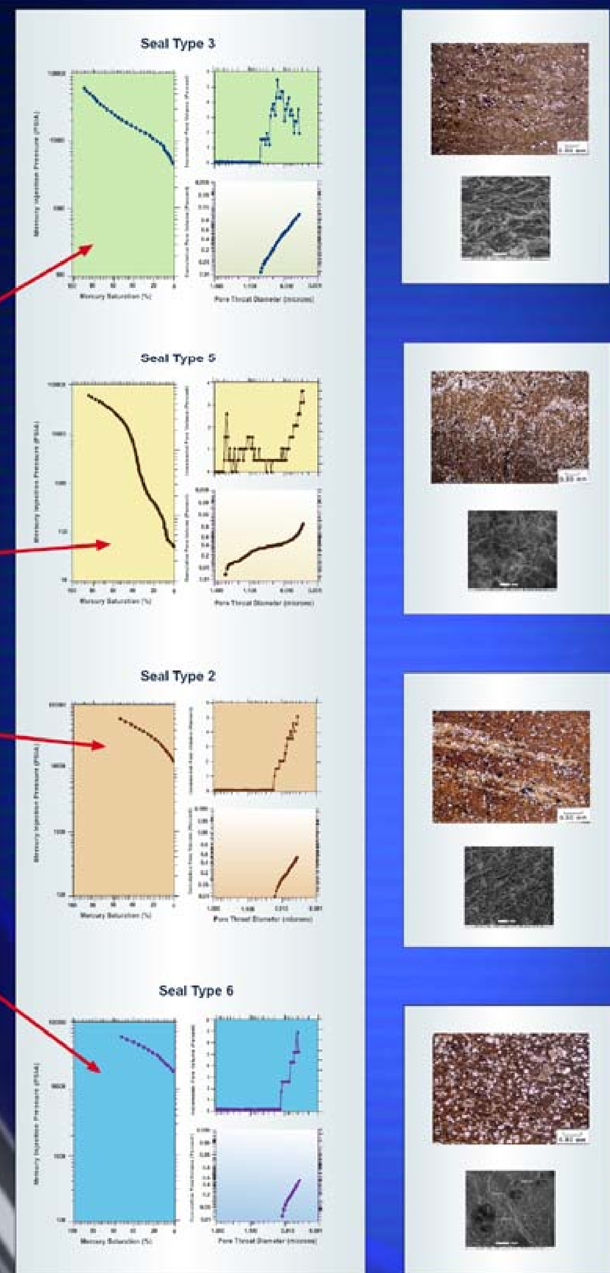
Improving Seal Capacity

(Almon & Dawson, 2003)

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

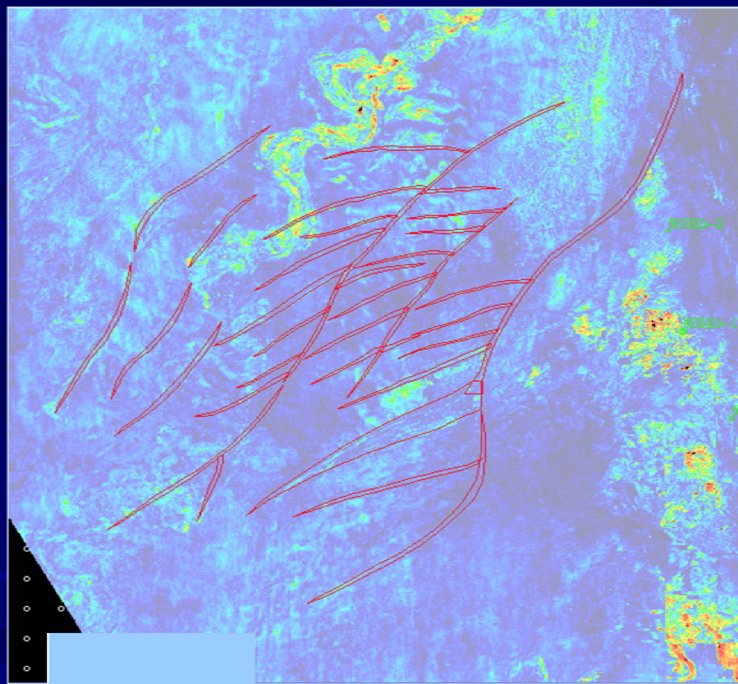


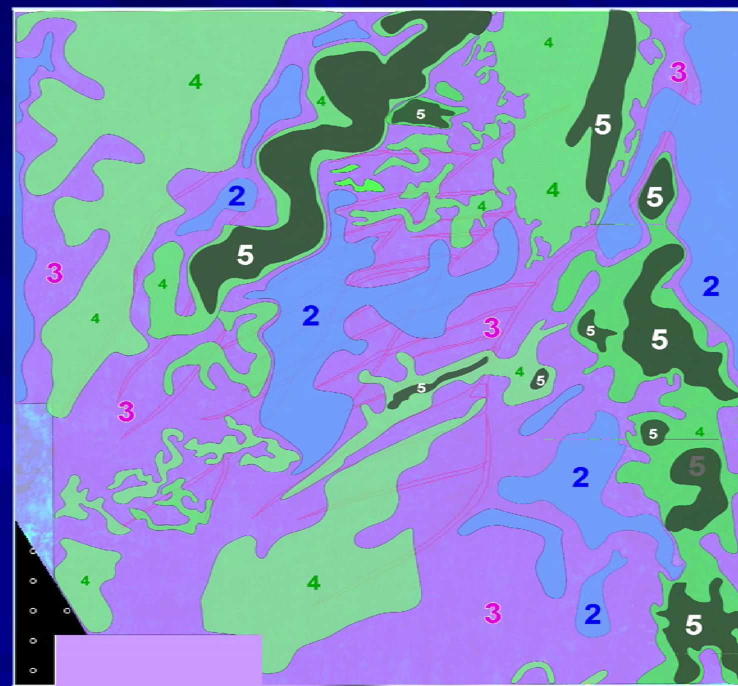




(Almon & Dawson, 2004)

Seismic-Based Shale Facies





Sand rich areas stand out in bright, warm tones. Areas away from those, with more homogeneous cool tones indicate better seals.

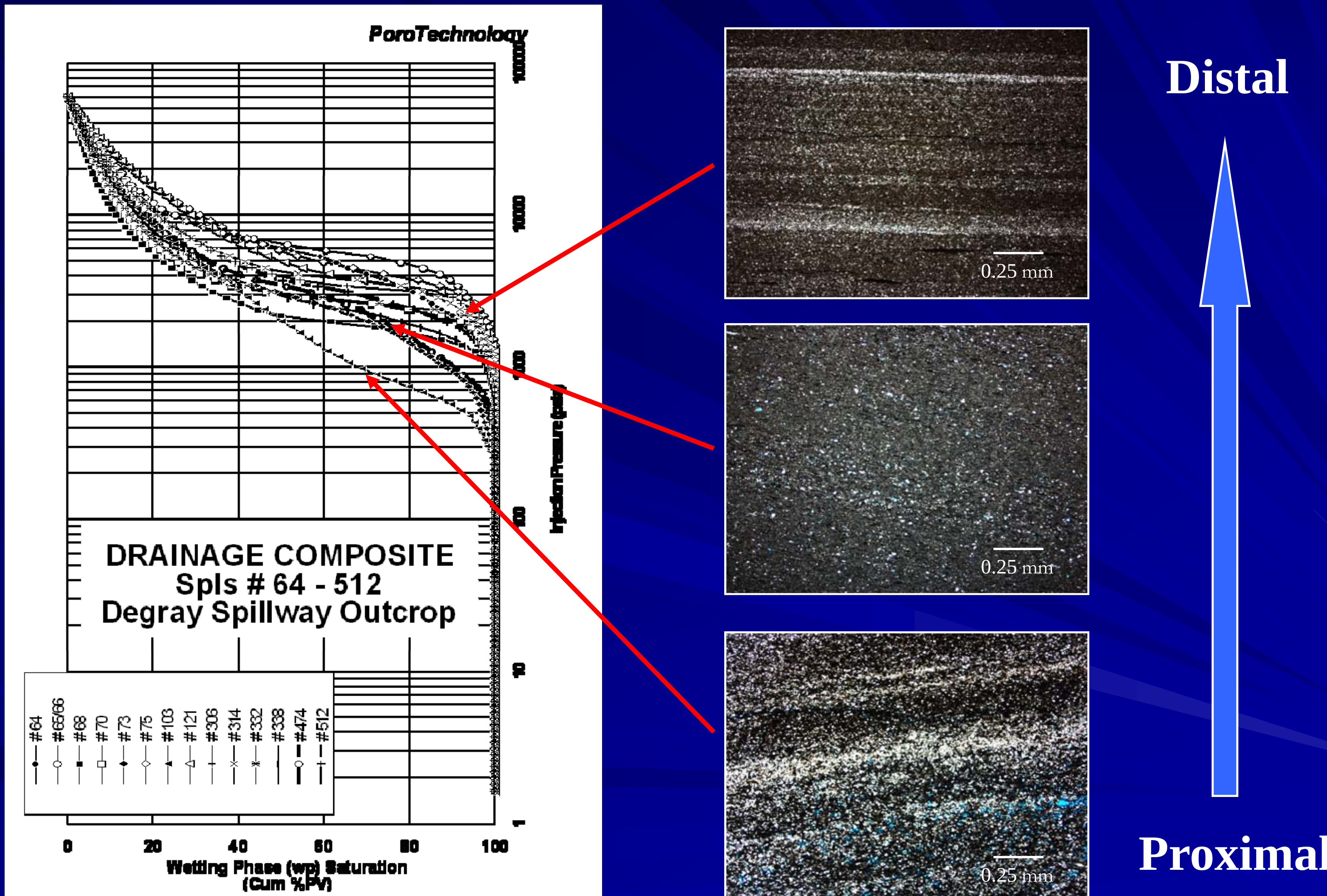
Jackfork Fm (Arkansas) - Outcrop Analogs

Proximal deepwater shales

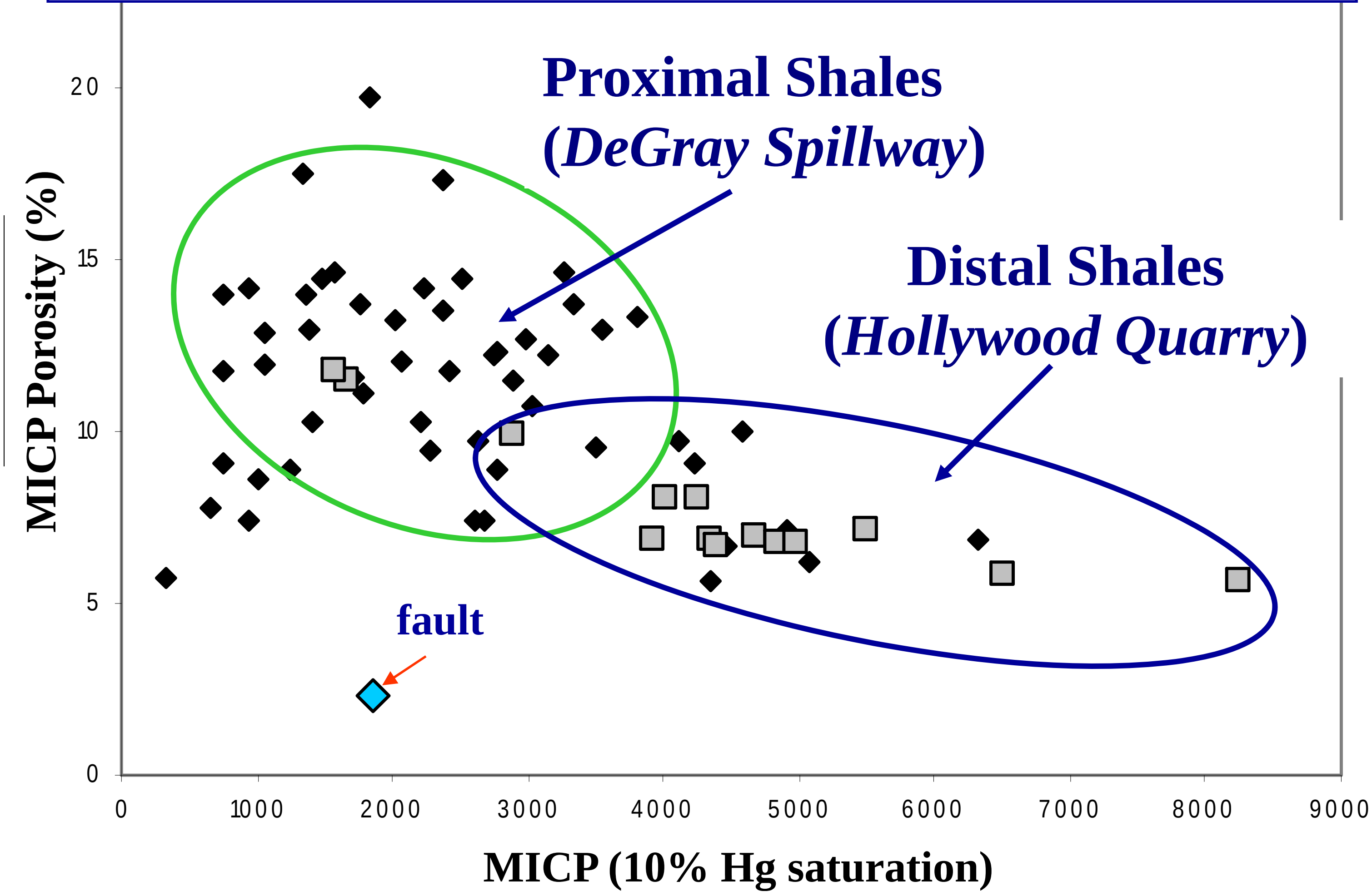
Distal deepwater shales

(after: Slatt et al., 1995)

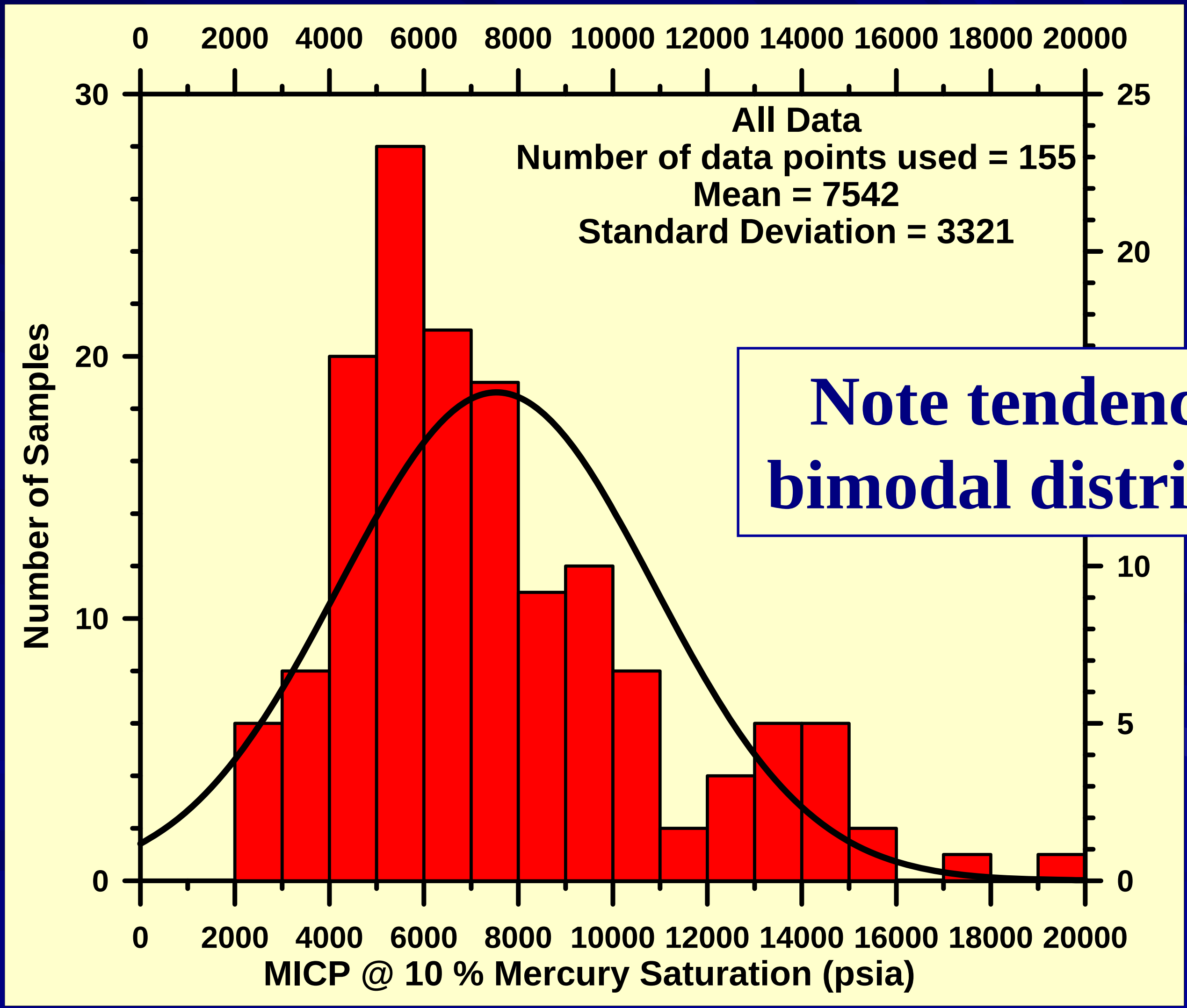
Arkansas Outcrops: MICP Data & Shale Facies



Arkansas Outcrops (Jackfork Formation)

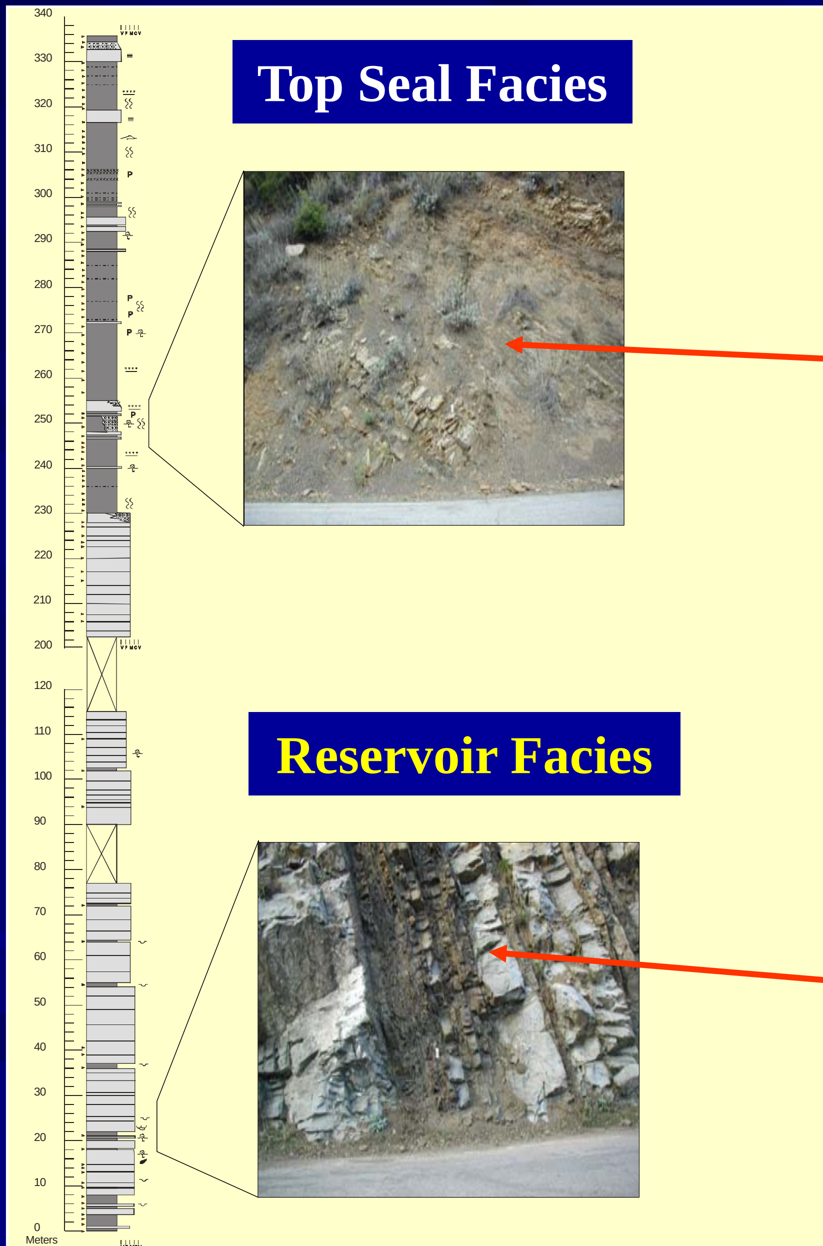


Deepwater Seal Variability



Note tendency for bimodal distribution

Outcrop Analog: Submarine Fan Sequence

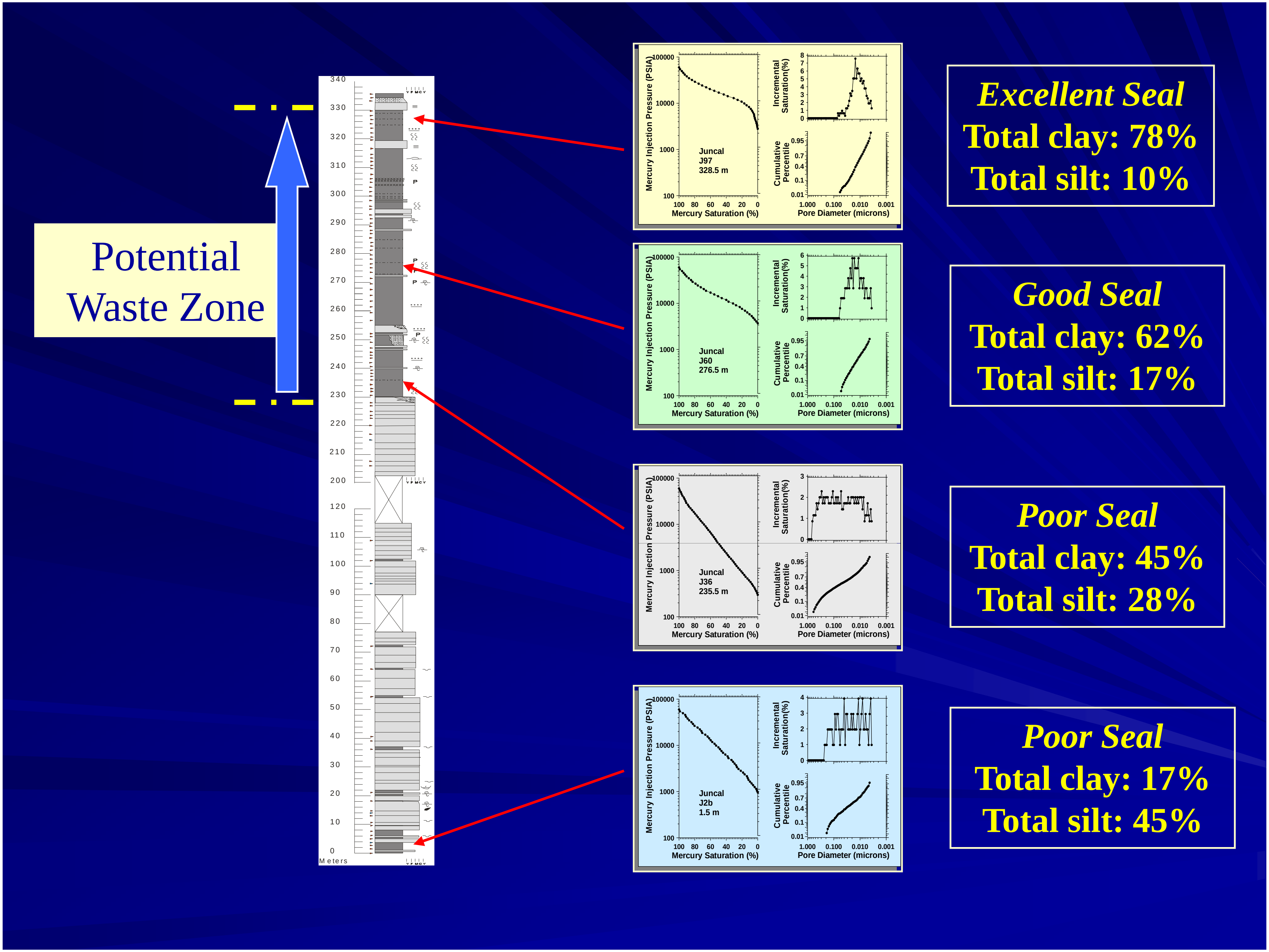


Tertiary: California

Thick shale sequence with thin, interstratified sandstones

Stratigraphic separation of reservoir & top seal intervals

Thick sandstone turbidites with interstratified thin shales


Potential Waste Zone
Meters
Mercury Injection Pressure (PSIA)
Mercury Saturation (%)
Incremental Saturation(%)
Cumulative Percentile
Pore Diameter (microns)
Juncal J97 328.5 m
Juncal J60 276.5 m
Juncal J36 235.5 m
Juncal J2b 1.5 m
Excellent Seal
Total clay: 78%
Total silt: 10%
Good Seal
Total clay: 62%
Total silt: 17%
Poor Seal
Total clay: 45%
Total silt: 28%
Poor Seal
Total clay: 17%
Total silt: 45%

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.

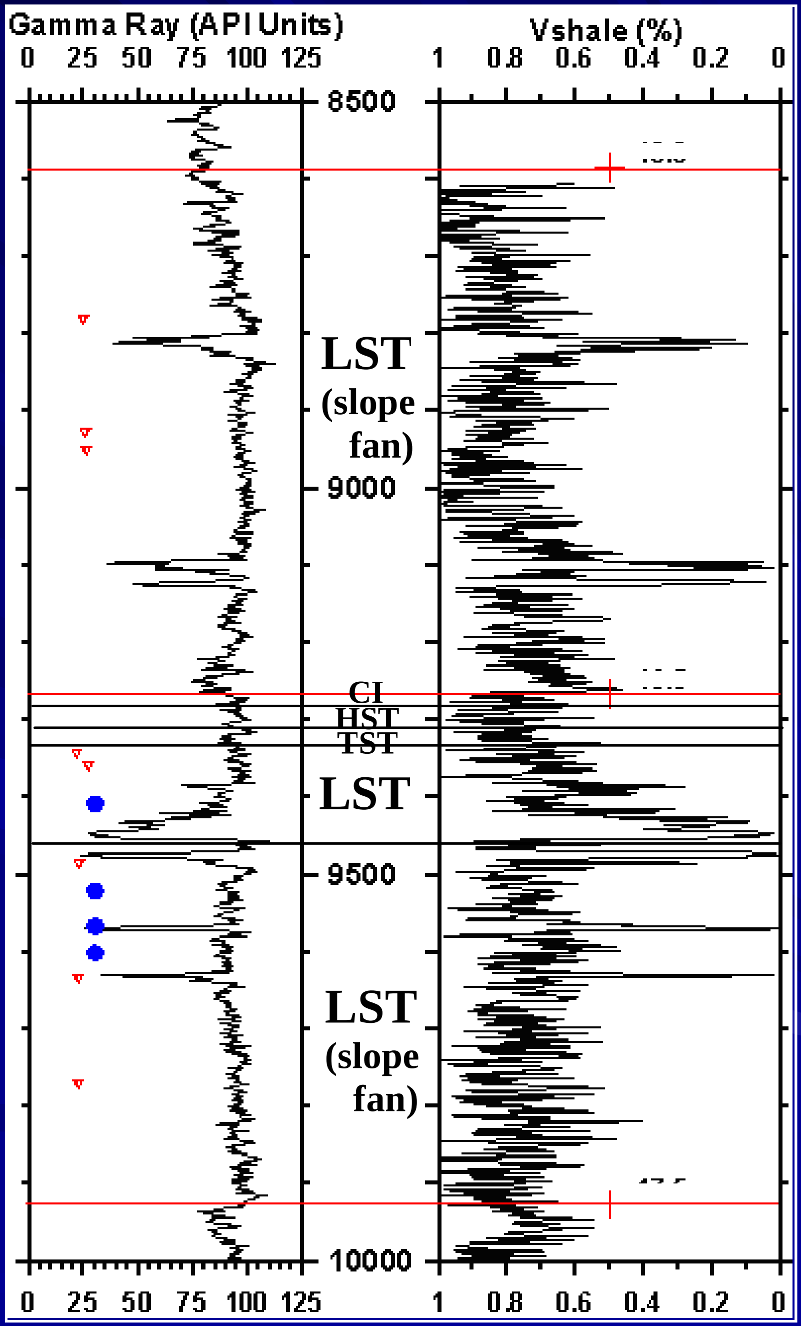
Maximum seal variability exists within proximal (i.e., highly channelized) lithofacies (associated with high potential for reservoir compartmentalization).

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

Almon, W.R., and W.C. Dawson, 2004, Seal character and variability within deep-marine depositional systems; seal quantification and prediction: Poster session AAPG Annual Meeting, Web, Search and Discovery article #40125, .searchanddiscovery.com.

Armentrout, J.M., 1999, Sedimentary basin analysis; *in* Exploring for Oil and Gas Traps: AAPG Treatise of Petroleum Geology, Handbook of Petroleum Geology, p. 4.3-4.123.

Dawson, W.C., and W.R. Almon, 2006, Shale facies and seal variability in deepwater depositional systems: Poster session AAPG Annual Meeting, Web, Search and Discovery article #40199, .searchanddiscovery.com.

Dawson, W.C., W.R. Almon, F.G. Ethridge, S.J. Sutton, and B. Costeblanco, 2003, Sedimentology and petrophysical character of Cretaceous marine shale sequences in foreland basins; seismic response of seal horizons: AAPG Annual Meeting Abstracts, p. 38.

Dempster, K., W.R. Almon, W.C. Dawson, and M. Hertle, 2006, Impact of realistic shale properties on exploration-scale vertical migration modeling: AAPG International Conference and Exhibition Program Abstracts, one (1) CD-Rom.

Mayall, M., E. Jones, and M. Casey, 2006, Turbidite channel reservoirs; key elements in facies prediction and effective development: Marine and Petroleum Geology, v. 23/8, p. 821-841.

Reading, H.C., and M. Richards, 1994, Turbidite systems in deep-water basin margins classified by grain size and feeder system: AAPG Bulletin, v. 78/5, p. 792-822.

Slatt, R.M., J.M. Borer, B.W. Horn, H.A. Al-Siyabi, and S.R. Pietraszek, 1995, Outcrop gamma-ray logging applied to subsurface petroleum geology: The Mountain Geologist, v. 32/4, p. 81-94.