Facies Variability Within a Single, Deep-Water Basin-Floor, Mixed Carbonate-Siliciclastic Fan (Upper Wolfcamp Fm., Permian, Delaware Basin, New Mexico)*

Erik Kvale[1], Christopher Bowie[1], Christopher Mace[1], Buddy Price[2], and Jarret Borell[1]

Search and Discovery Article #51608 (2019)**
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Abstract

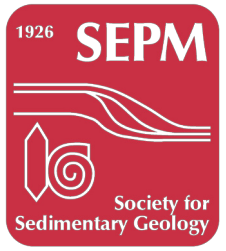
Rarely are sea-floor fans containing a significant volume of carbonate detritus documented or discussed. Such fans are common within the lower Permian Wolfcamp Fm. in the Delaware Basin in SE New Mexico and west Texas, U.S.A. Three cores retrieved as part of an unconventional oil/gas exploration and development program in SE New Mexico Wolfcamp preserve interlayered wackestone, packstone, and mixed siliciclastic-carbonate mudstones. Core combined with regional subsurface studies show that the sediments are organized into an approximately 350 ft. thick mixed carbonate-siliciclastic deep-water fan. Carbonate debrites are concentrated in more axial positions and siliciclastic mudstones in more distal areas. Cores collected represent the frontal to distal fringe, off-axis, and lateral fringe portions of the fan. The fan prograded SW. The carbonate dominated portion of the fan trends at least 35 mi. in a NE-SW direction and 11 mi. NW-SE across. It is partially bounded to the east by a fault. Lobe complexes can be recognized which are bounded by regionally correlative horizons (A, B, C, and D, from older to younger). An overall upward fining across B and C horizons records a progressive back-stepping of the fan through time. Unlike siliciclastic fans where axial facies are dominated more by turbulent flow deposits (turbidites), the axis, off-axis, and lateral fringe facies in the Wolfcamp are dominated by laminar flow deposits such as coarse carbonate debrites and mass transport deposits (MTDs). Mixed carbonate siliciclastic hybrid event beds (HEBs) and finer grained background sediments form a minor component in these areas. Coarse carbonate deposition decreases towards the frontal fringe areas where facies are dominated by mixed carbonate-siliciclastic mud-rich HEBs and background sedimentation. The core through the lateral fringe differs from the off-axis core in that the debrites in the lateral fringe are thinner and often rheologically stratified with finer grained debrites sitting directly on top of coarse-grained debrites suggesting a genetic link in their formation. The axial facies appear to be dominated by thick (amalgamated?) ungraded debrites and MTDs. Facies changes from axis to frontal fringe are gradual but facies changes from axis to lateral fringe are rapid and may change significantly over a 2 mi. horizontal well.

Selected References

Haughton, P., C. Davis, W. McCaffrey, and S. Barker, 2009, Hybrid sediment gravity flow deposits – classification, origin and significance: Marine and Petroleum Geology, v. 26, p. 1900-1918.

Pierce, Colm S., Peter D. W. Haughton, Patrick M. Shannon, Andy J. Pulham, Simon P. Barker, and Ole J. Martinsen, 2018, Variable character and diverse origin of hybrid event beds in a sandy submarine fan system, Pennsylvanian Ross Sandstone Formation, western Ireland: Sedimentology, v. 65/3, p. 952-992.

Stow, D.A.V. and Mayall, M., editors, 2000. Deep-water Sedimentary Systems: Thematic Set, Marine and Petroleum Geology, Volume 17, No. 2.



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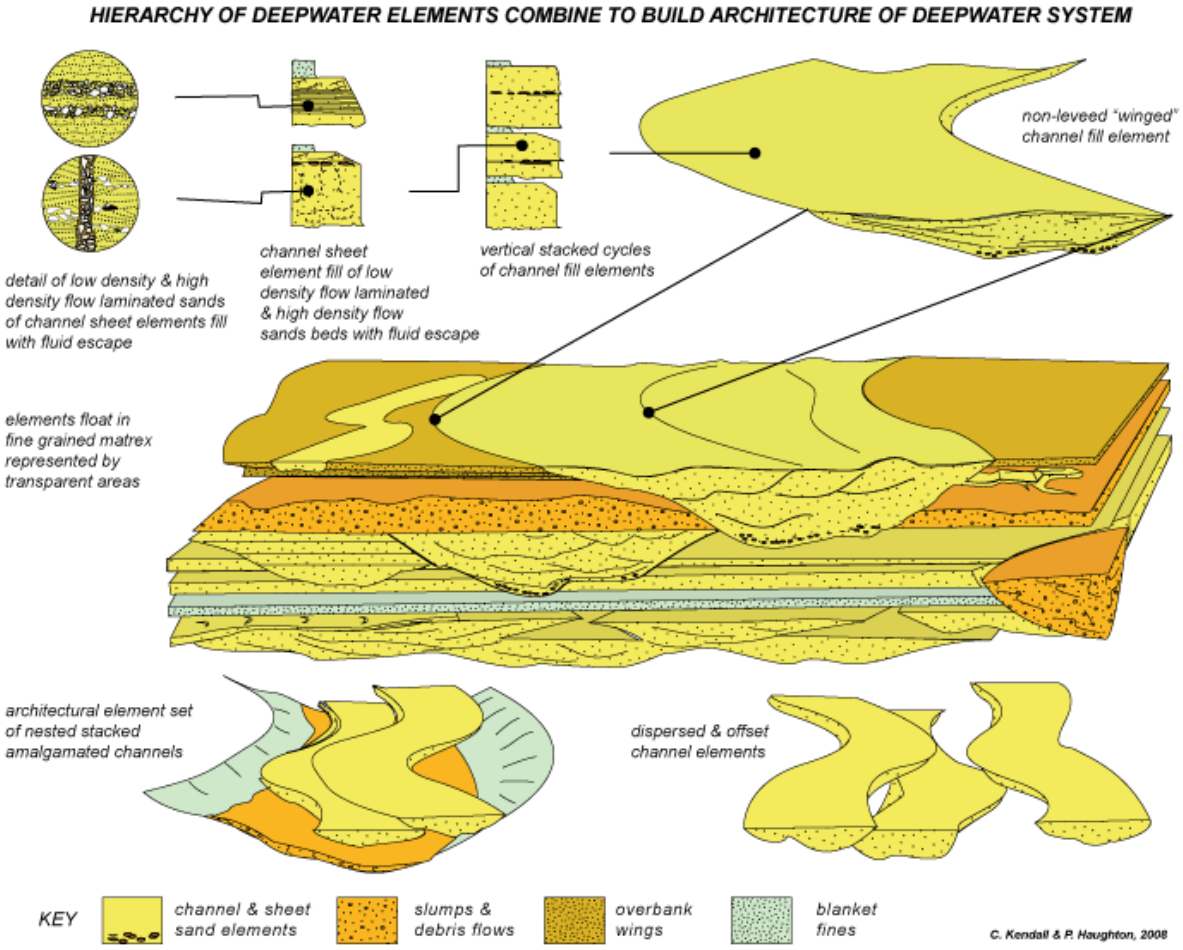
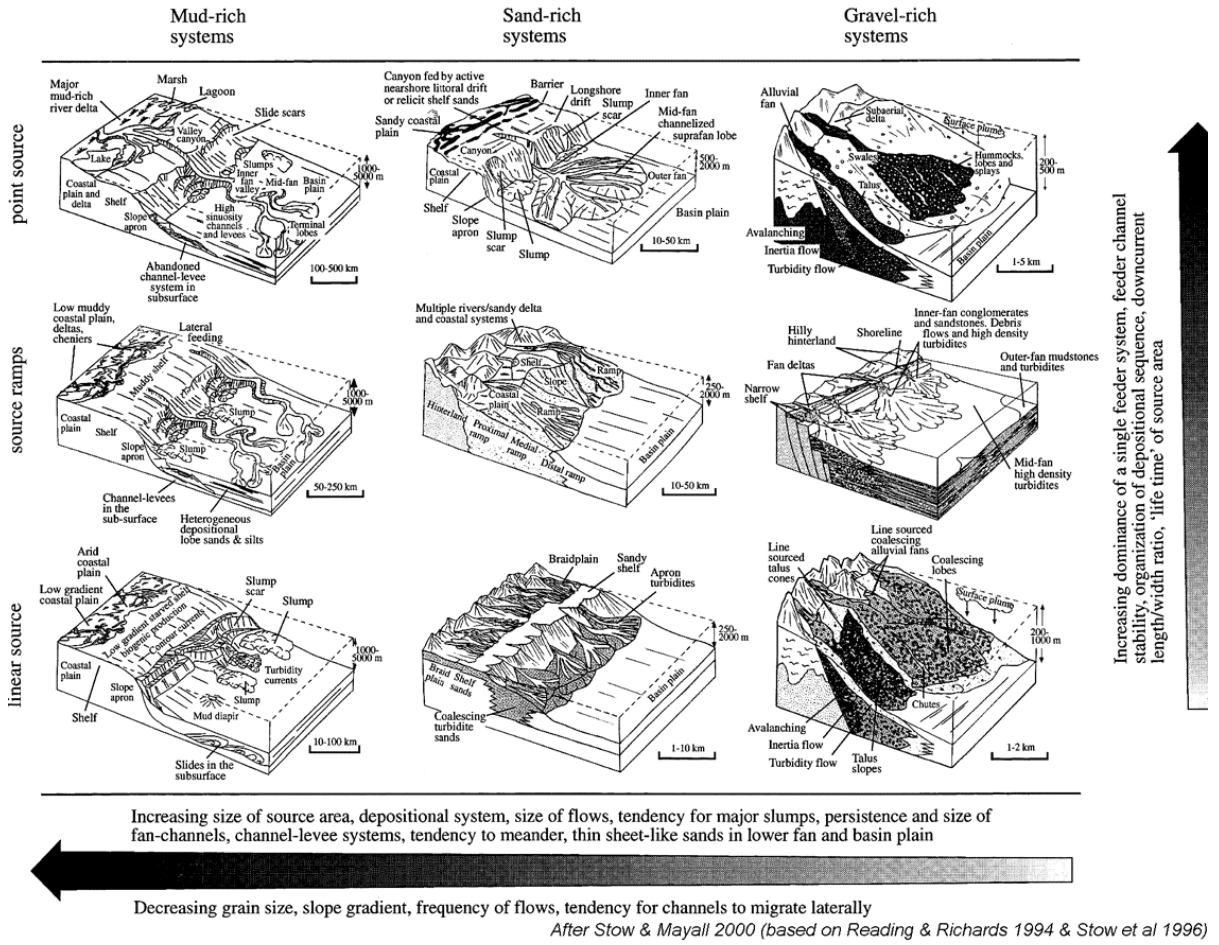
Observation: Most of what is known about deep-water fans comes from siliciclastic-dominated systems



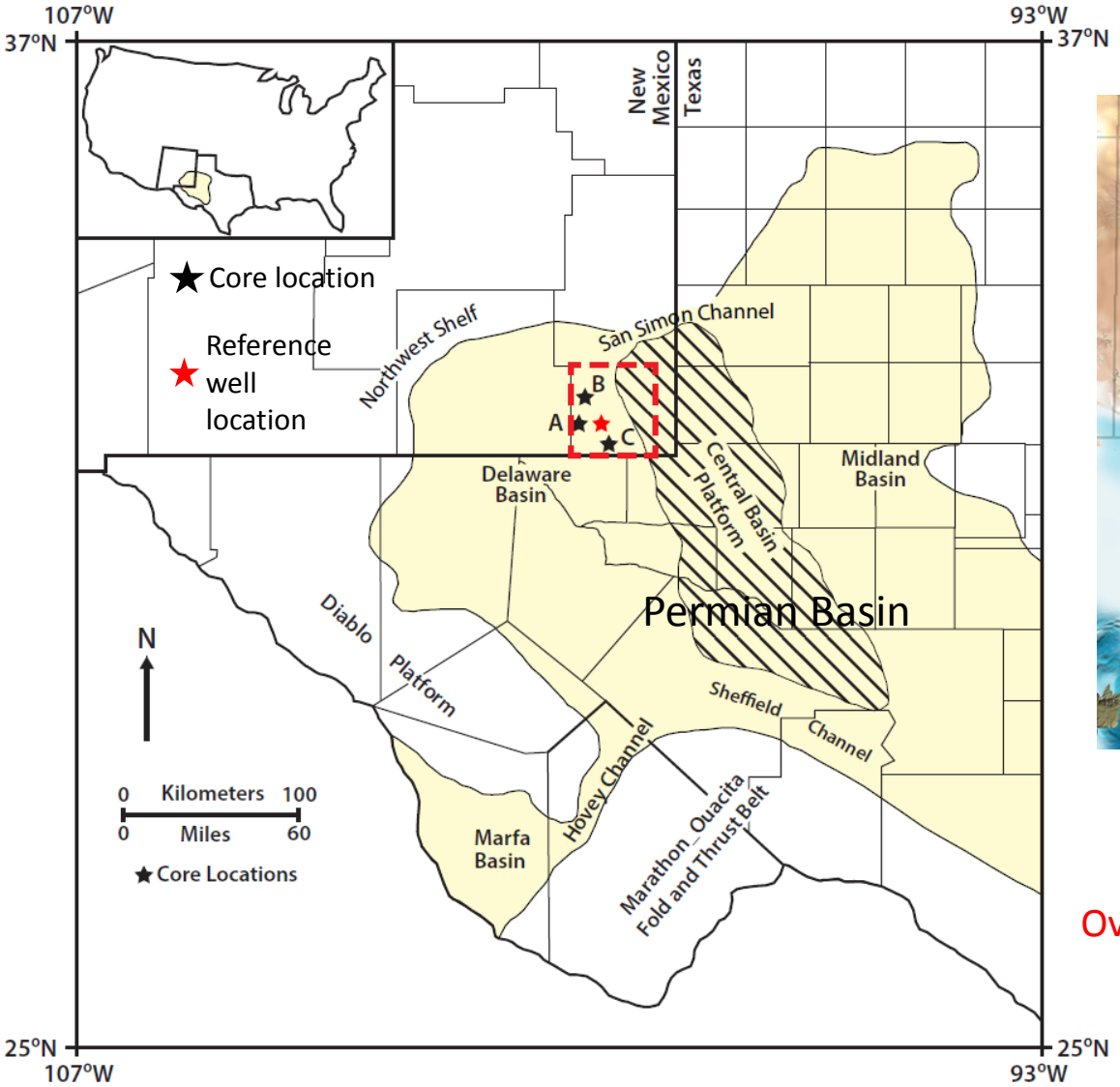


Figures from: http://www.sepmstrata.org/page.aspx?&pageid=40&3

Presentation Outline

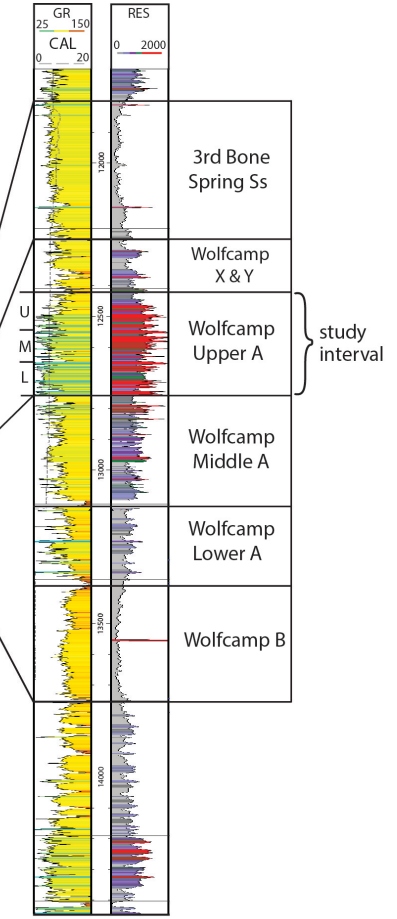
- Location of study area, stratigraphy and paleogeography
- Show map and cross-sections through a Permian mixed carbonate-siliciclastic fan in the Delaware Basin, New Mexico and discuss how it was mapped
- Show a technique that allows a decent integration of detailed core facies to petrophysical logs
- Discuss facies and depositional processes
- Show how facies vary across the fan
- Summary

The Delaware Basin is the perfect place to look for mixed carbonate-siliciclastic fans and to begin to put together depositional models



Blakey, Paleogeography of W. North America
290 Ma Early Permian

SYSTEM	SERIES	GROUP	OPERATIONAL UNIT
Permian	Guadalupian	Delaware	Bell Canyon
			Cherry Canyon
			Brushy Canyon
	Leonardian		Leonard
			1st Bone Spring Ss
			2nd Bone Spring Ss
			3rd Bone Spring Ss
	Wolfcampian		Wolfcamp
Pennsylvanian	Virgilian		Cisco
	Missourian		Canyon
	Des Moinian		Strawn
	Atokan		Atoka



Reference Well

Over 400,000 wells drilled in the PB in the last 100 years

-*http://fortune.com/longform/permian-basin-oil-fortune-500/*

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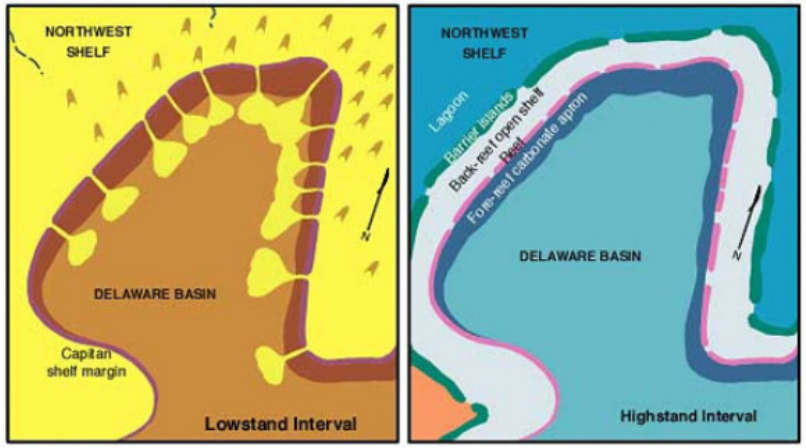
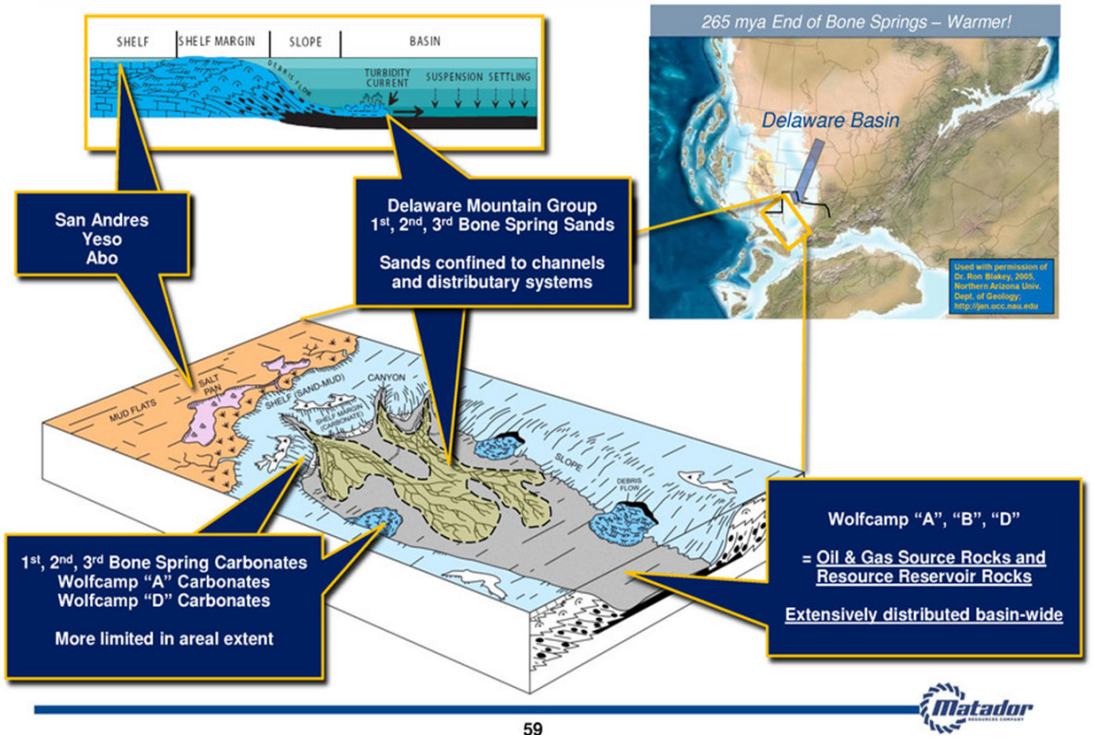
Reciprocal model of sedimentation in Delaware Basin – Traditionally, carbonate fans are not generally recognized

Scholle, 2002

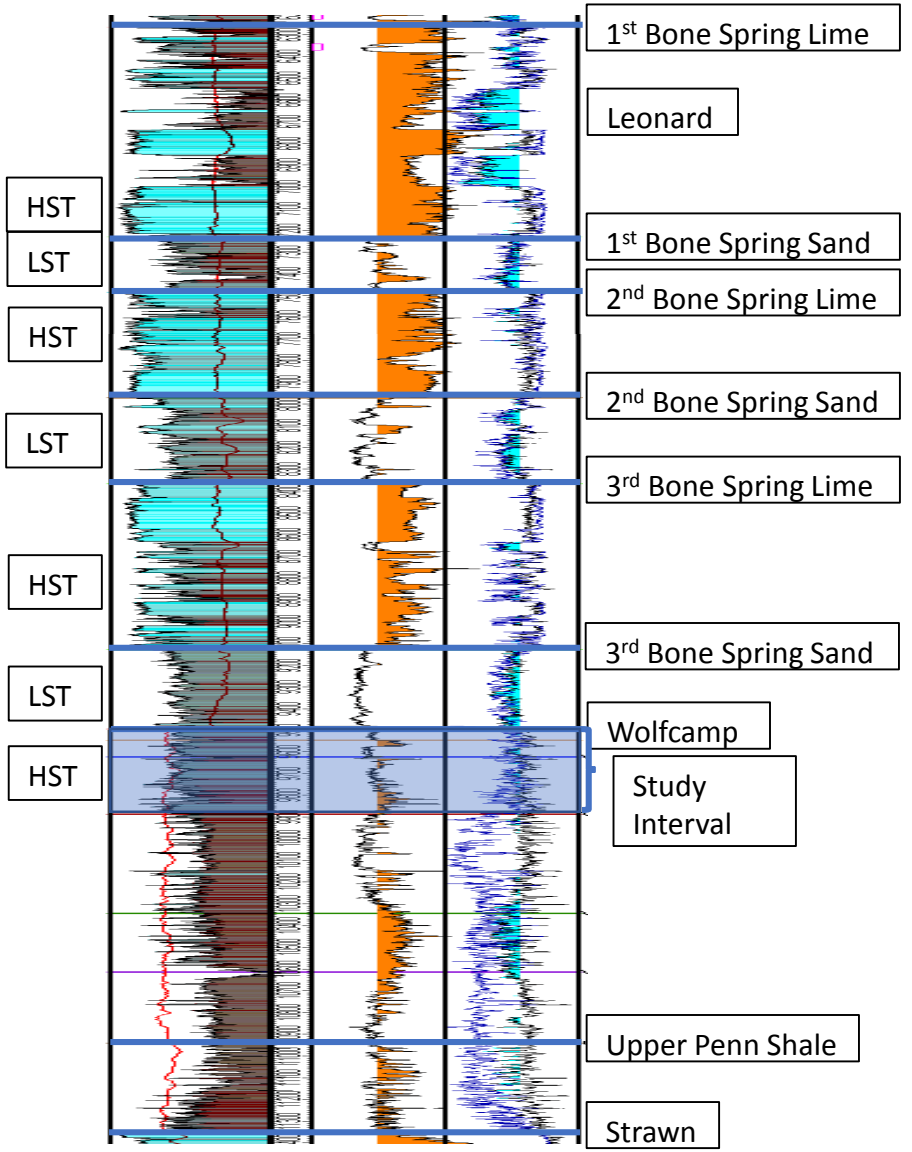


Matador August 2015 Investor Presentation. *https://www.sec.gov/Archives/edgar/data/1520006/000152000615000140/matadoraugust2015investo.htm*

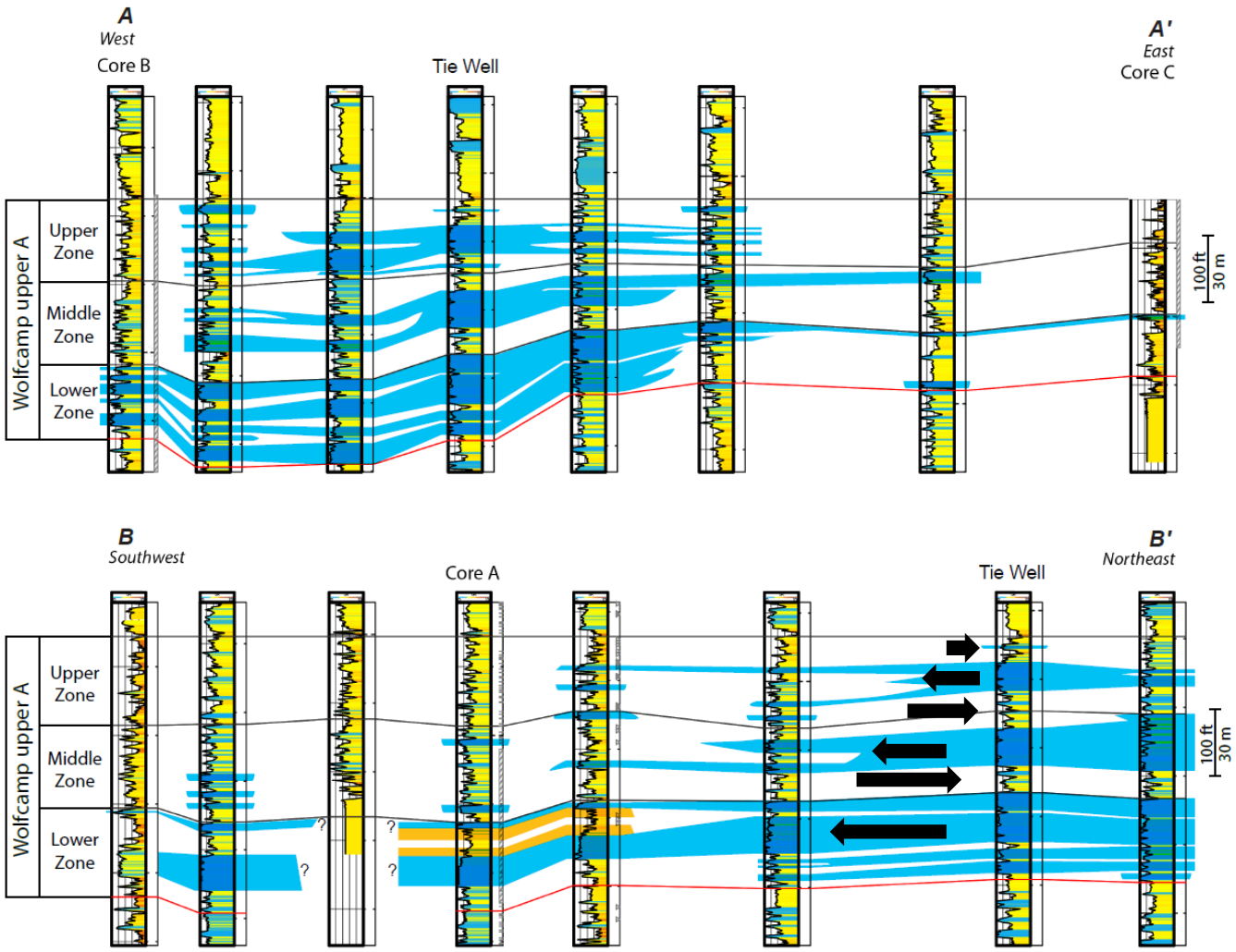


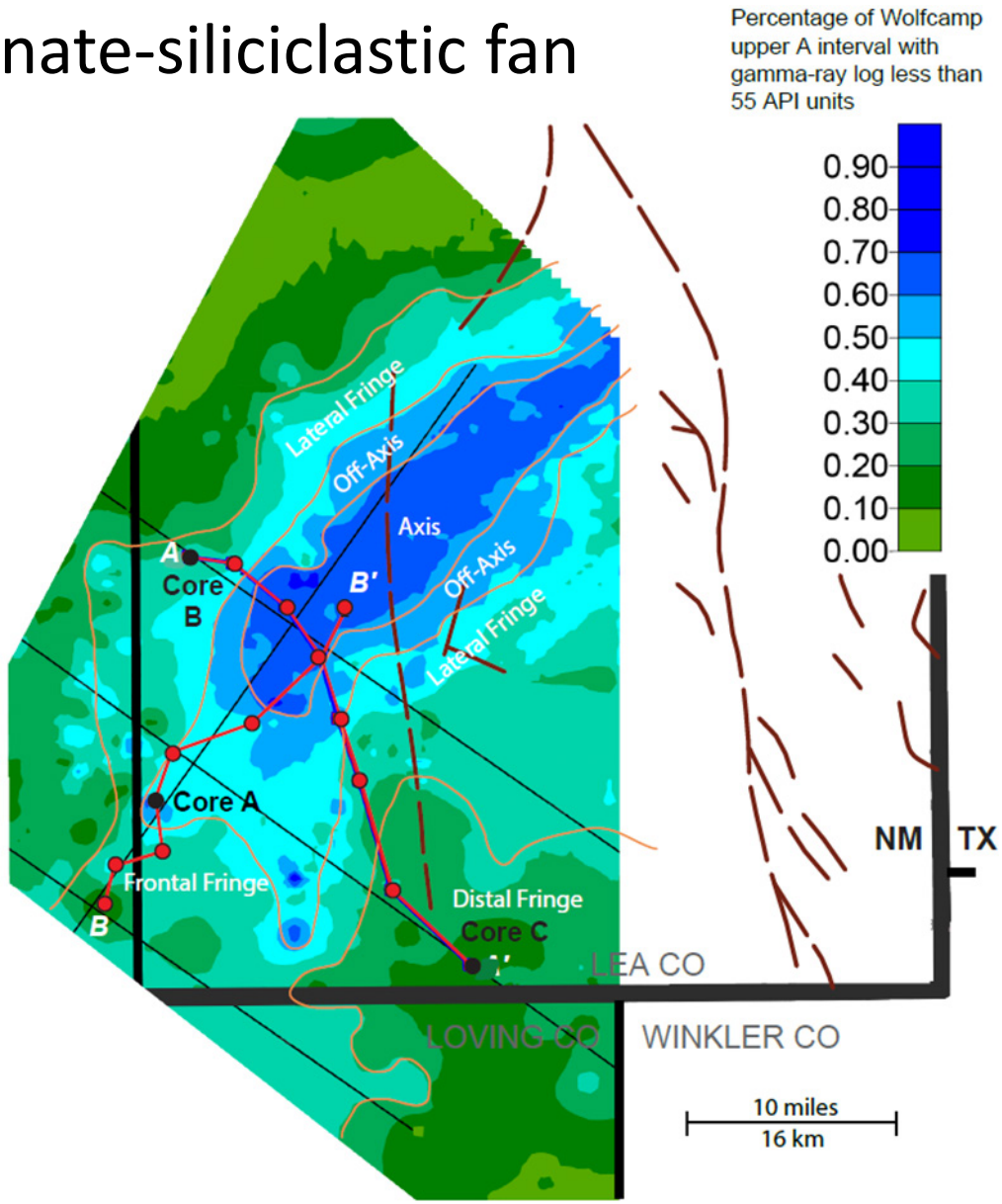
Paradigm:

1. Most interpretations are a variant of Handford (1981, American Association Petroleum Geologists Bulletin, v. 65, p. 1602-1616.)
2. Mudstones deposited from suspension settling
3. Carbonate-dominated turbidites and debris flows largely restricted to basin margins



Example of upper Wolfcamp mixed carbonate-siliciclastic fan





From Kvale et al., in press, Facies variability within a mixed carbonate-siliciclastic sea-floor fan (upper Wolfcamp Fm., Permian, Delaware Basin, New Mexico). AAPG Bull.

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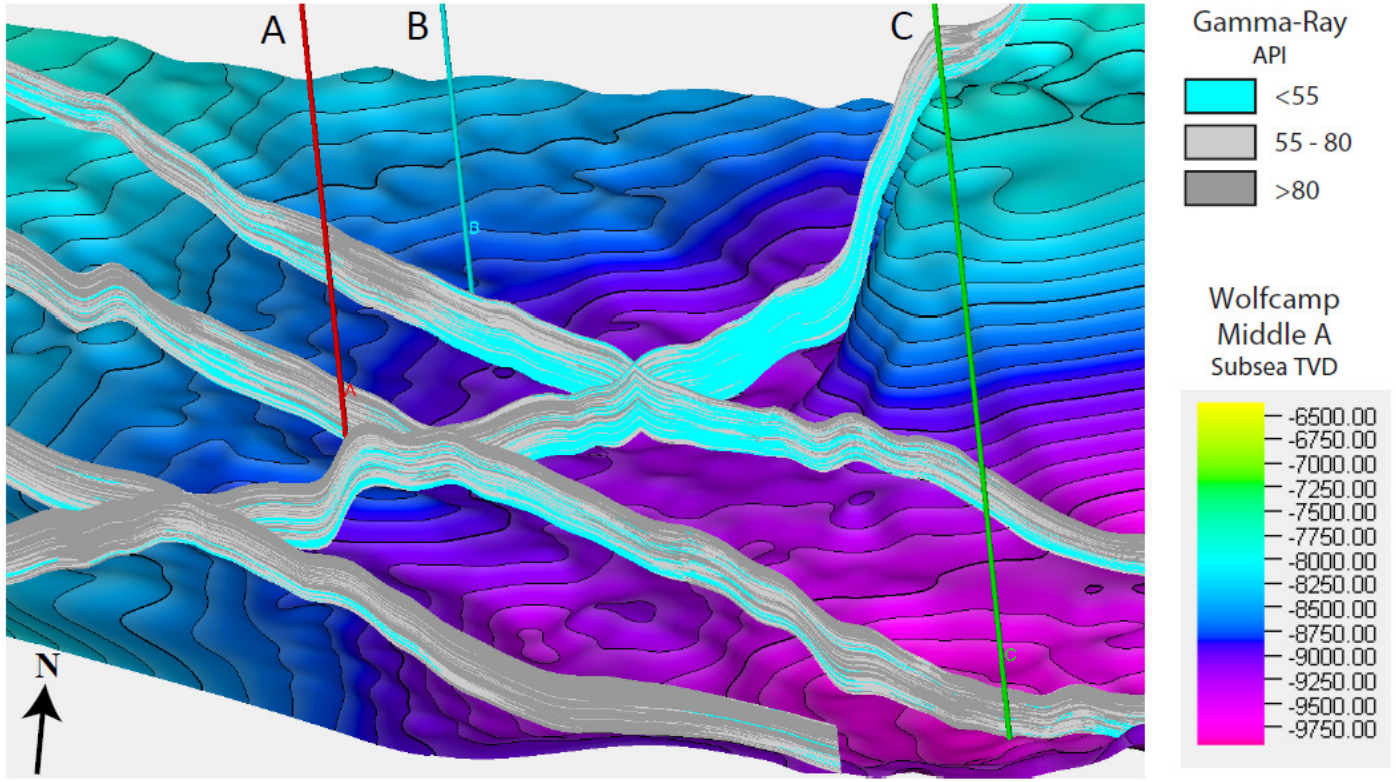
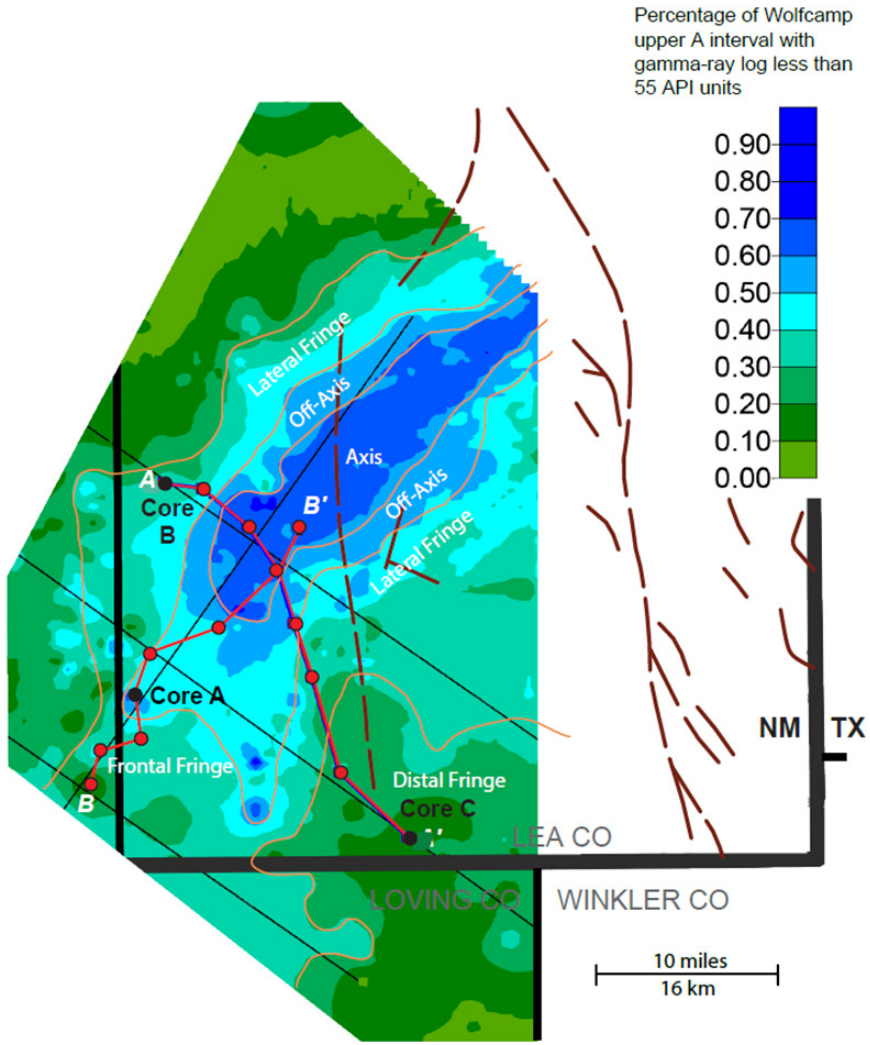
Zonation of Wolfcamp fan and paleotopography



3-D Petrel model derived from gamma-ray logs
Over 100 well logs used to generate map



Net-to-gross map showing percentage of gamma-ray log interval of less than 55 API

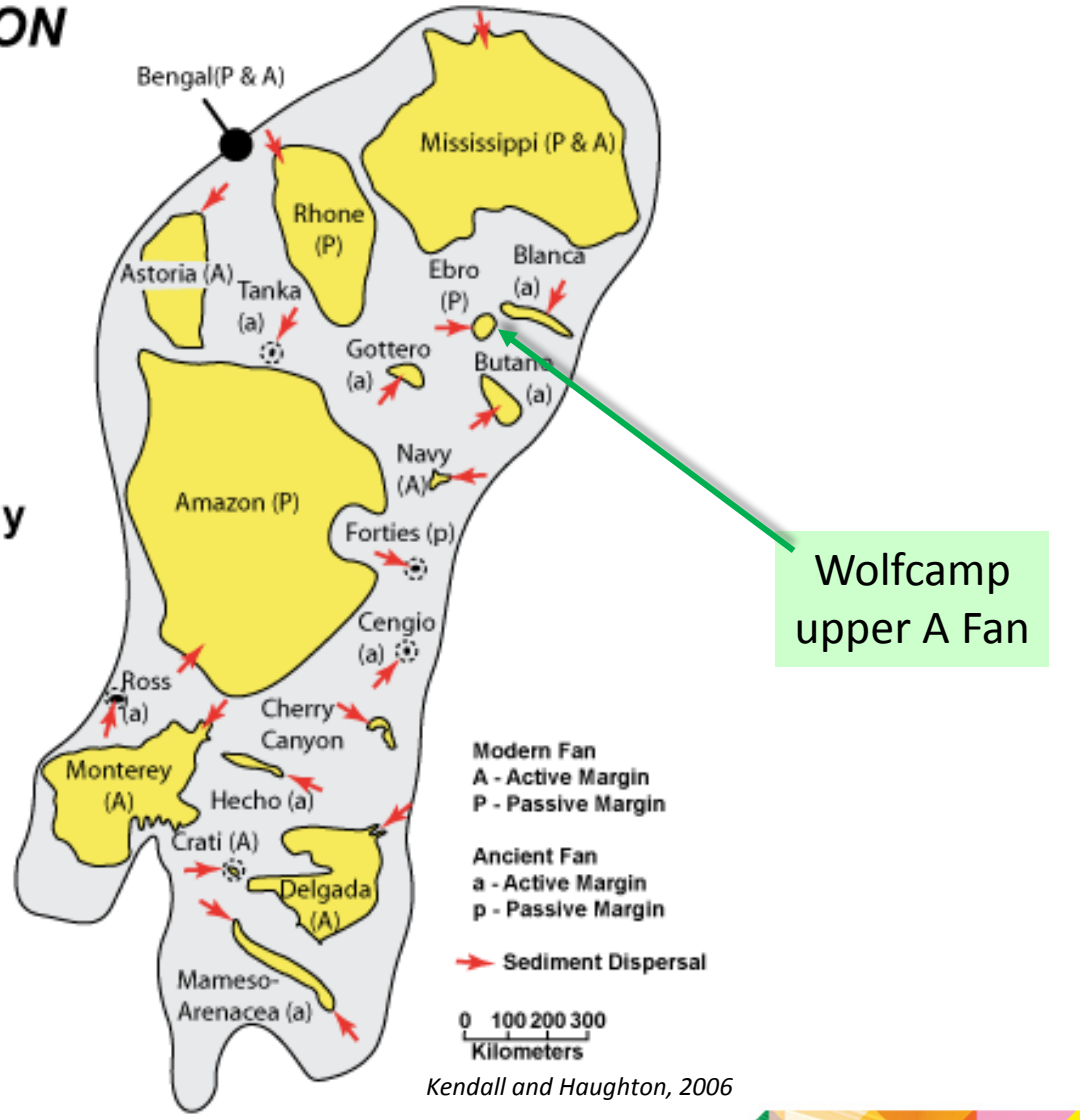
From Kvale et al., in press, AAPG Bull.

Just How Big is the Wolfcamp upper A fan?

SUBMARINE FAN SIZE VARIATION

Wide range of size & shape

Each deepwater fan is unique, with an internal structure, elements, & lithology that vary across a range of scales in response to local processes of the depositional setting, including those tied to physiography, tectonics & source terrain.

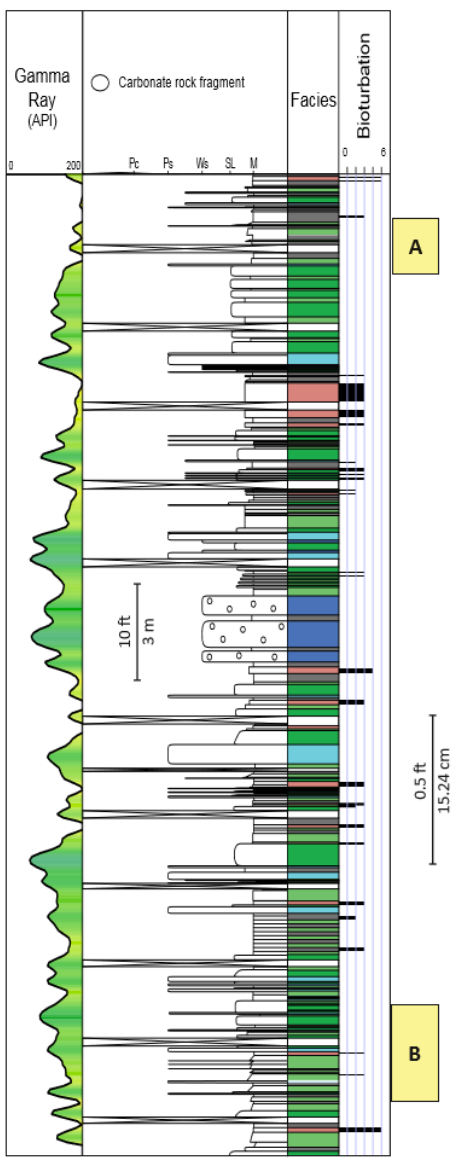


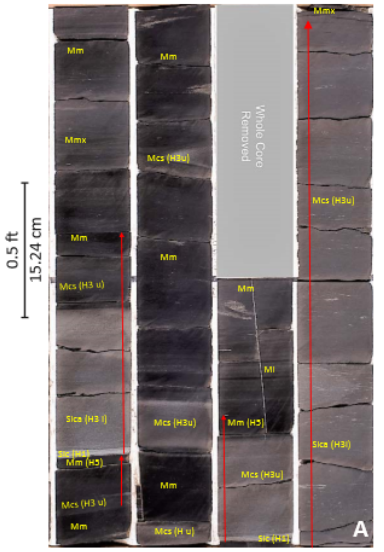
Kendall and Haughton, 2006

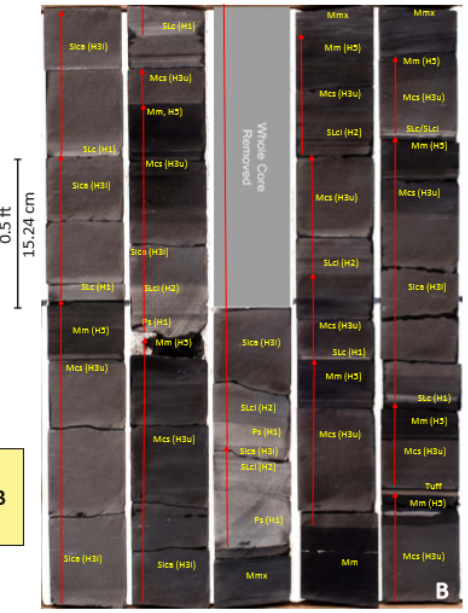
http://www.sepmstrata.org/page.aspx?&pageid=40&3

AAPG ACE 2019
ANNUAL CONVENTION & EXHIBITION
19-22 May • San Antonio, Texas

Scaling core facies to petrophysical logs using facies inventory plots

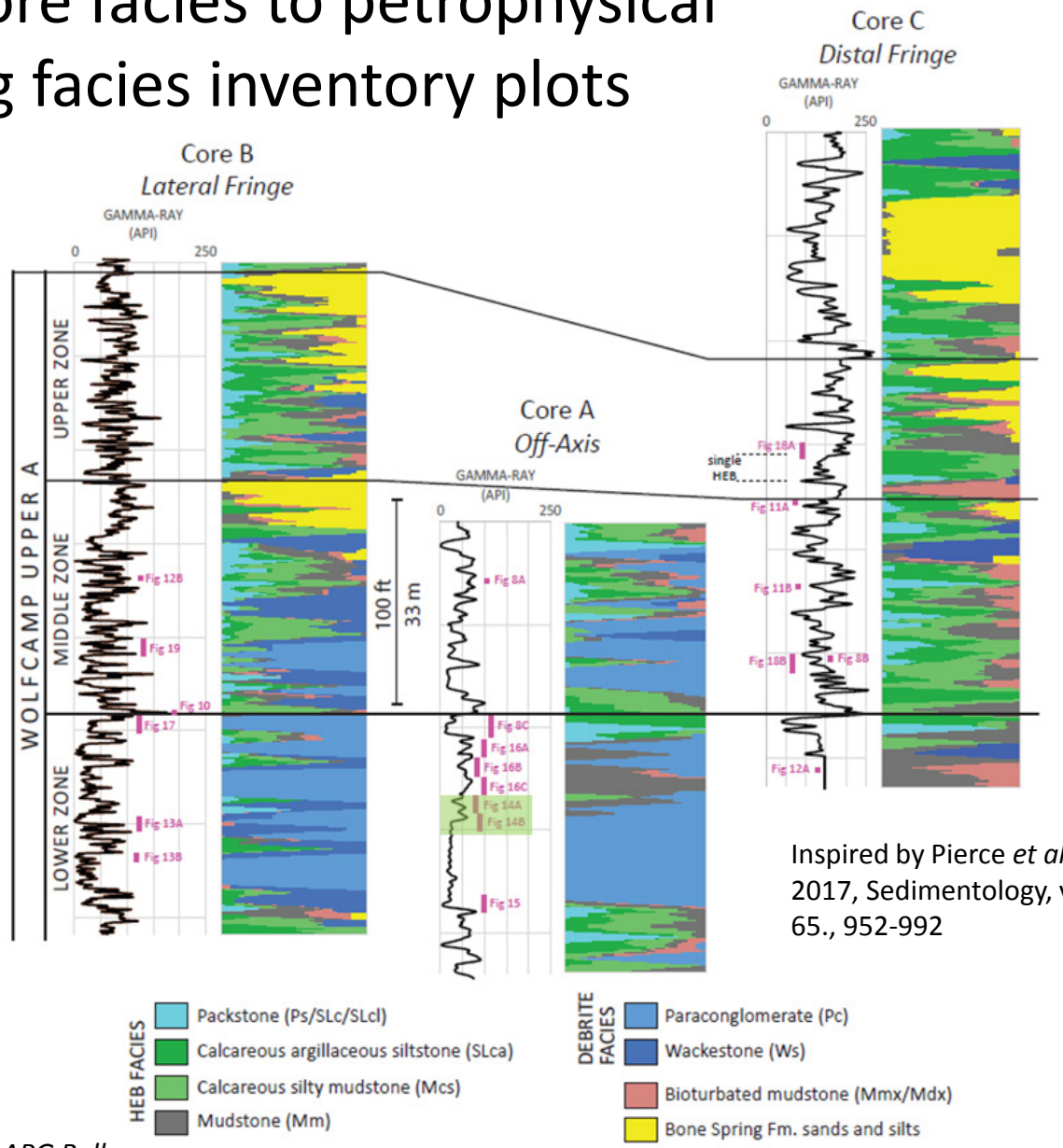






Facies inventory plots:

- Documents proportions of facies over a 1 m (3ft) moving window
- Minimizes short term facies variability
- Highlights longer-term stratigraphic trend
- Mimics changes in gamma-log response



Inspired by Pierce *et al.*, 2017, Sedimentology, v 65., 952-992

From Kvale et al., in press, AAPG Bull.

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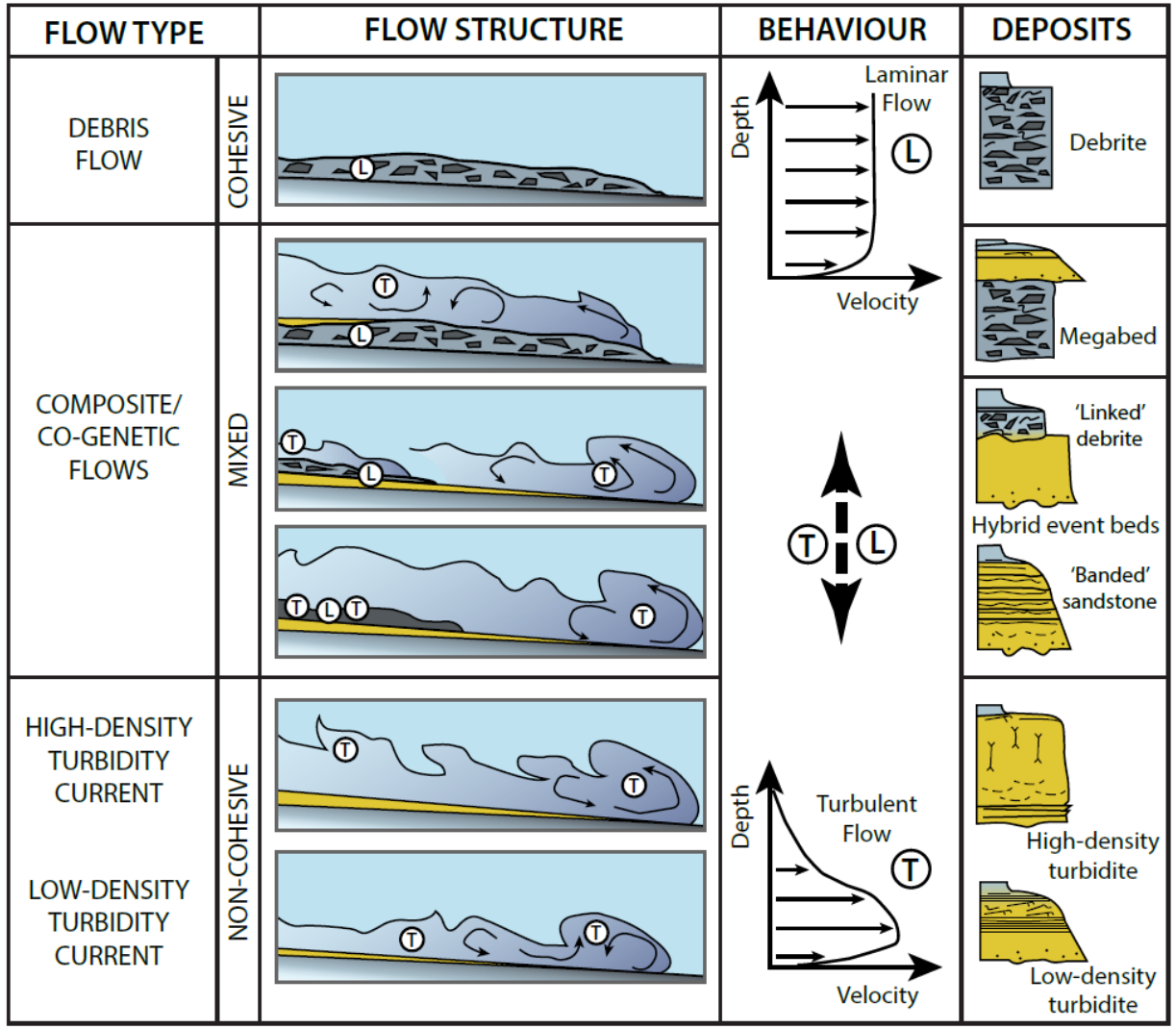
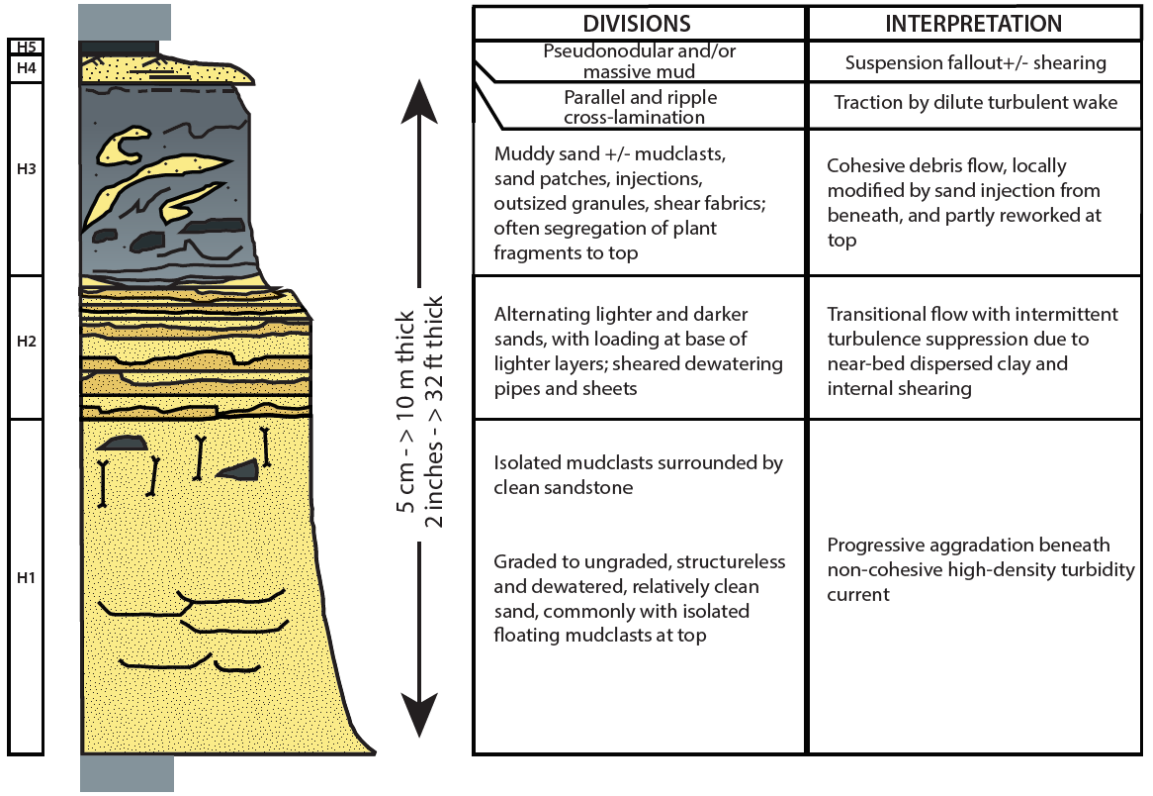
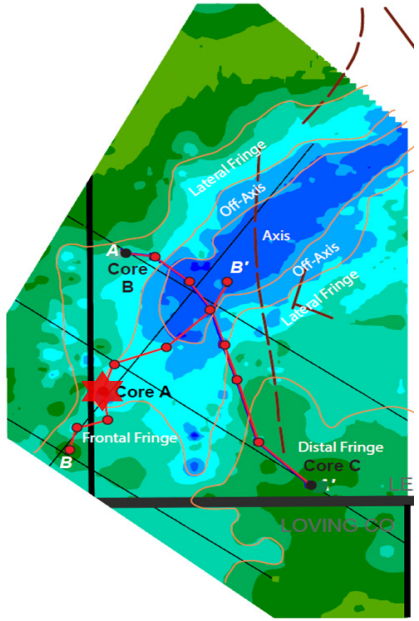
Depositional processes – Facies in Wolfcamp mixed carbonate-siliciclastic fan are dominated by sediment gravity flow deposits

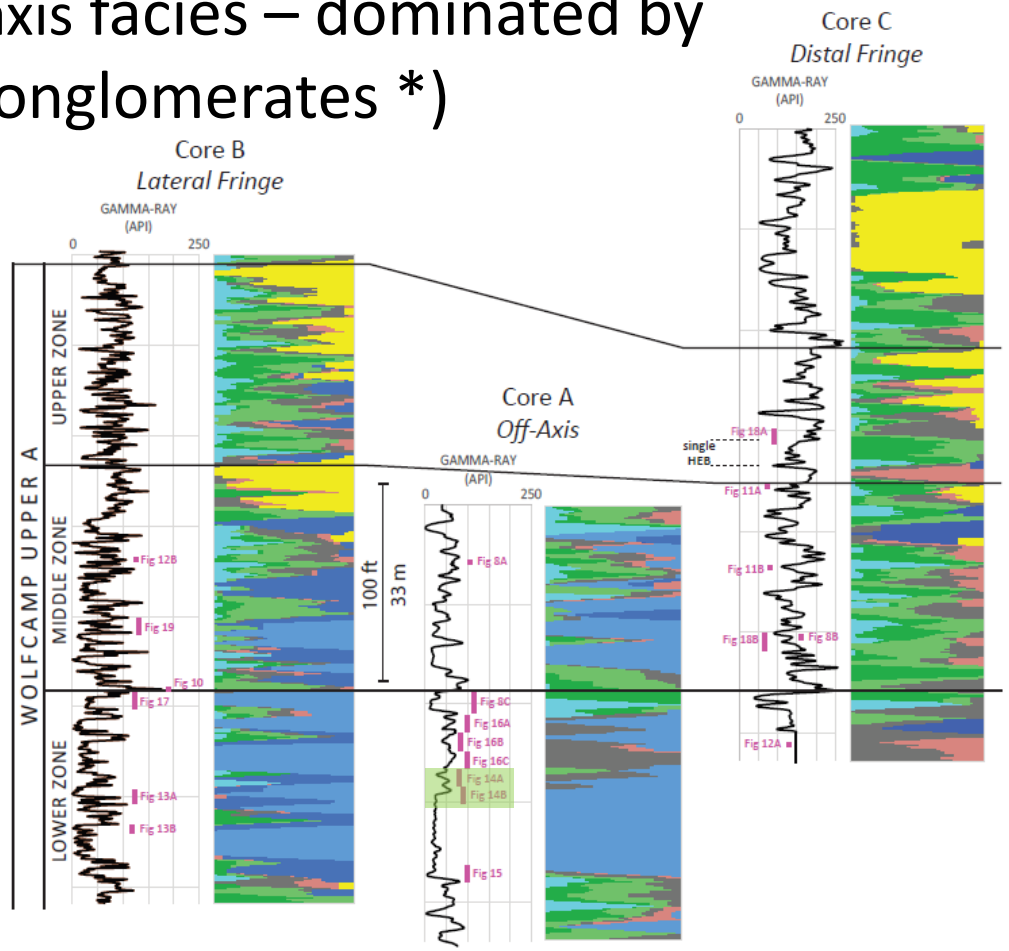


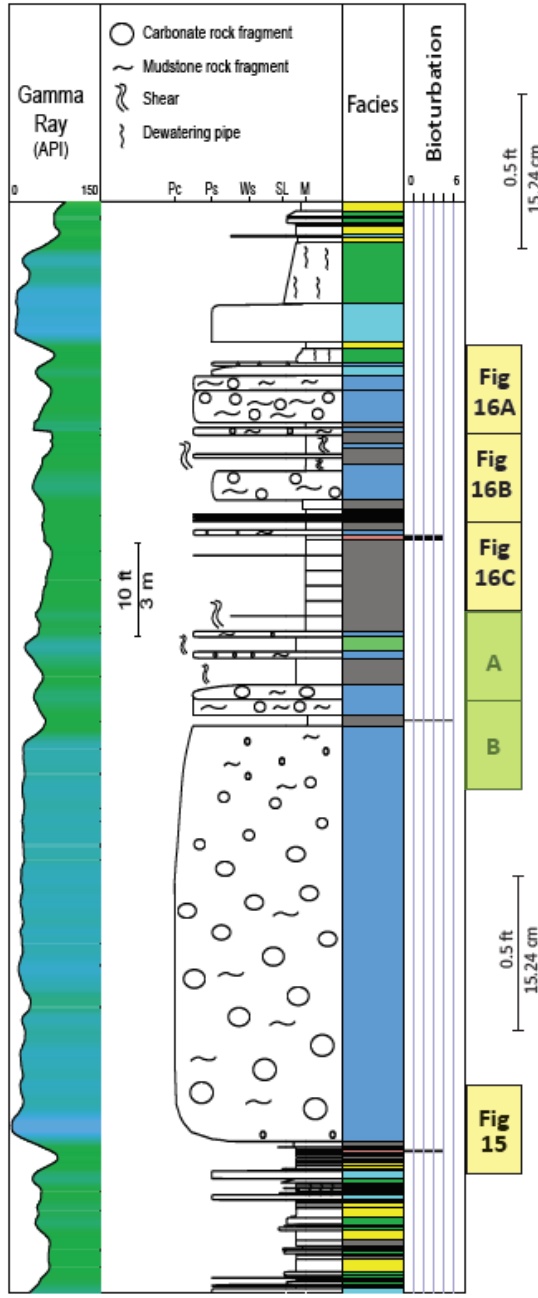


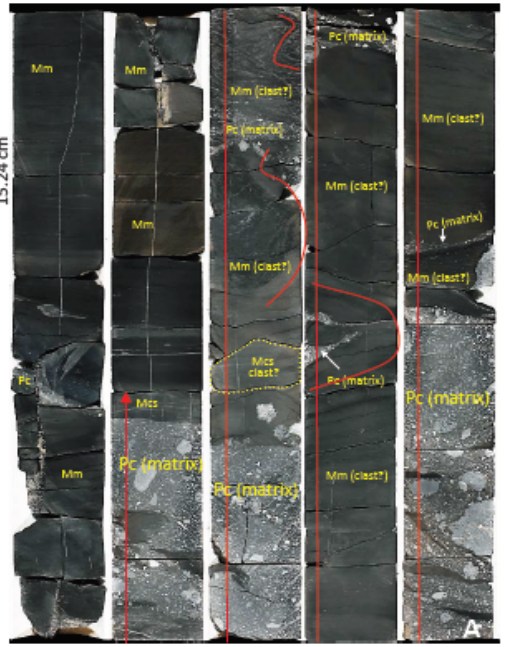
From Haughton et al., 2009, Hybrid sediment gravity flow deposits – classification, origin and significance: Marine and Petroleum Geology, v. 26, p. 1900-1918.

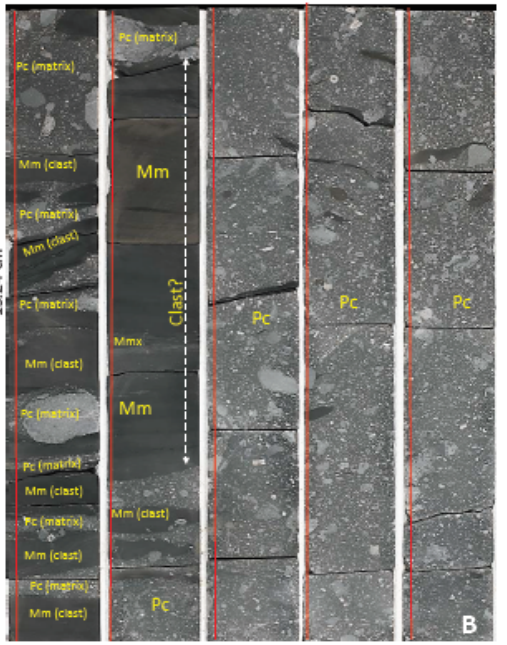
Core axis/near-axis facies – dominated by debrites (paraconglomerates *)











* Conglomerate not formed from normal aqueous flow but rather through mass transport or glacial processes – clasts not necessarily in contact

HEB FACIES
- Packstone (Ps/SLc/SLcl)
- Calcareous argillaceous siltstone (SLca)
- Calcareous silty mudstone (Mcs)
- Mudstone (Mm)

DEBRITE FACIES
- Paraconglomerate (Pc)
- Wackestone (Ws)
- Bioturbated mudstone (Mmx/Mdx)
- Bone Spring Fm. sands and silts

From Kvale et al., in press, AAPG Bull.

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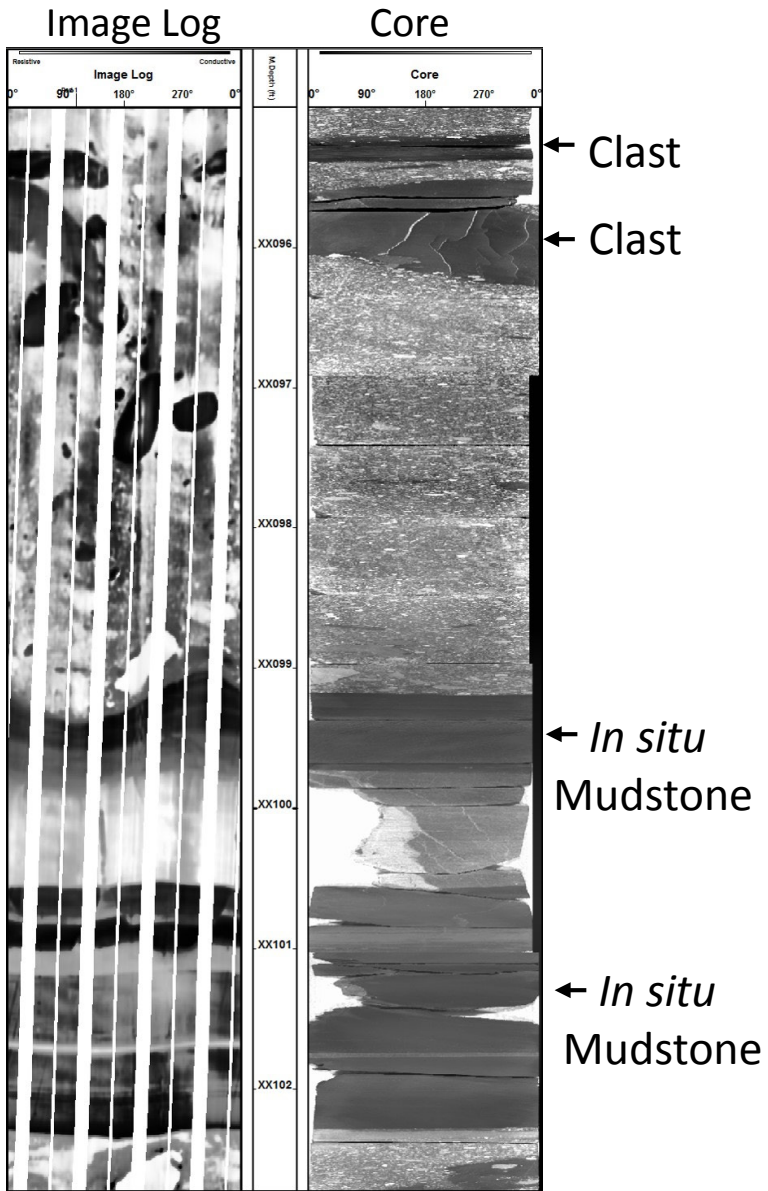
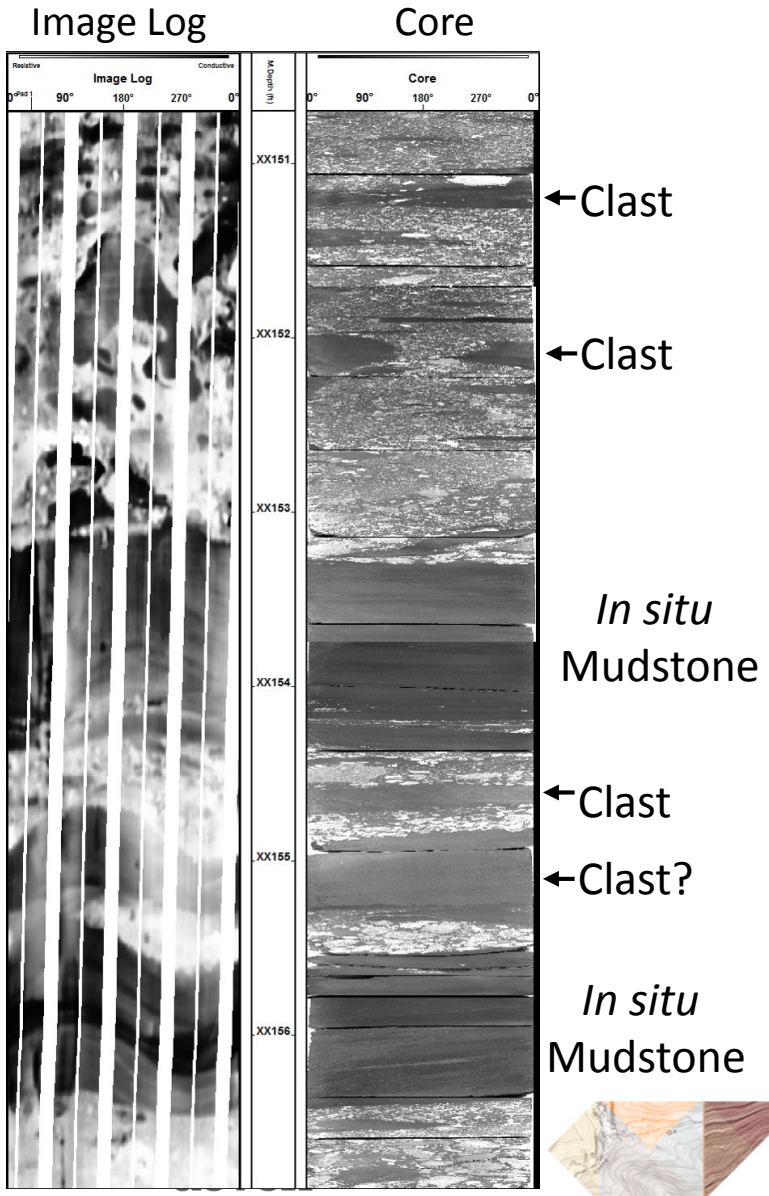
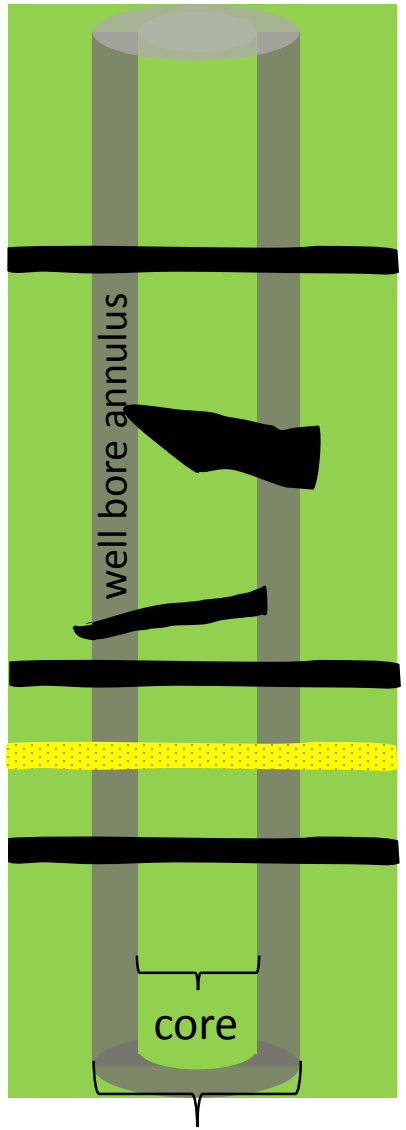
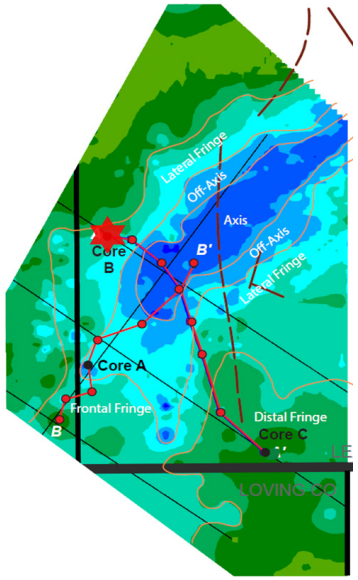
Paraconglomerate with mud and carbonate clasts - image logs help to differentiate between clay clasts and background bedding

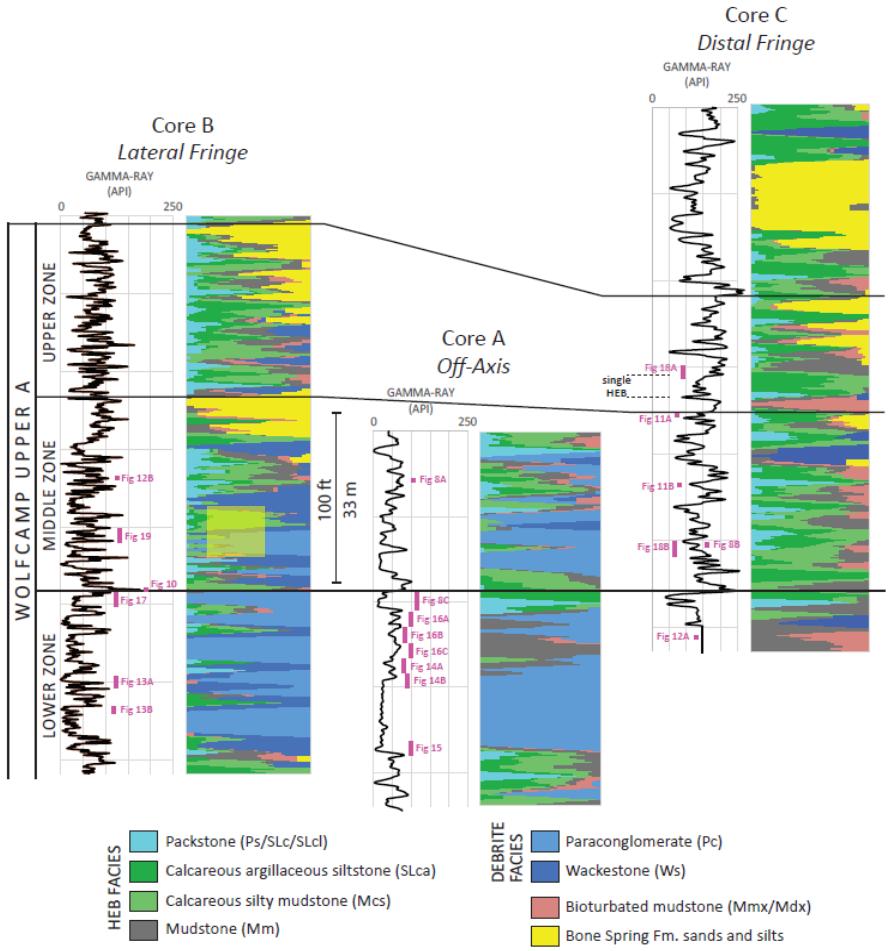


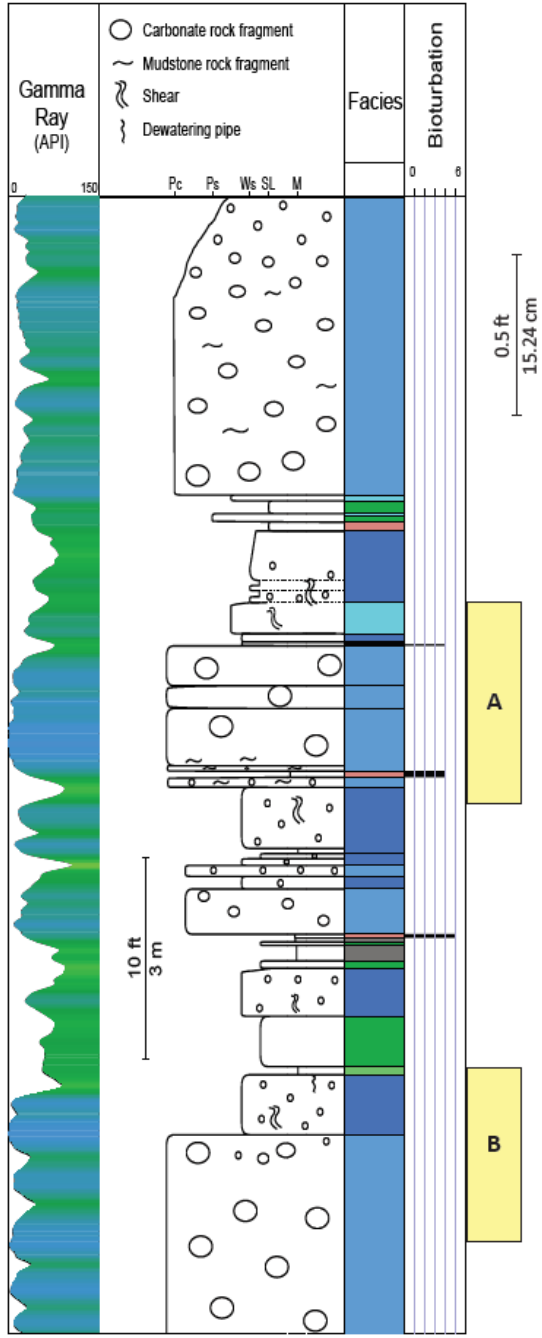


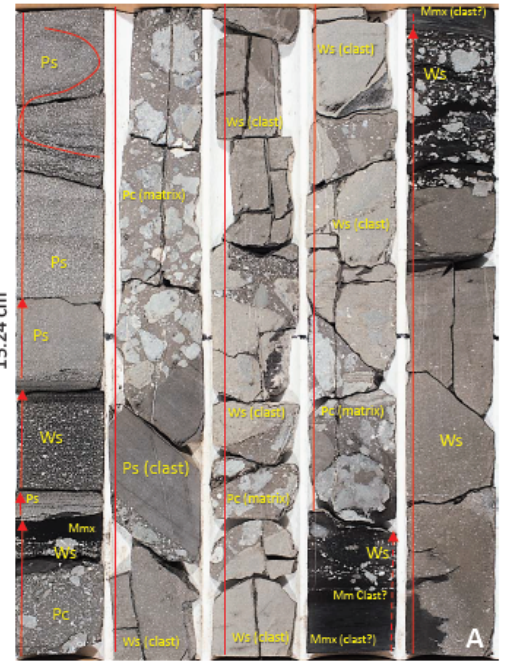


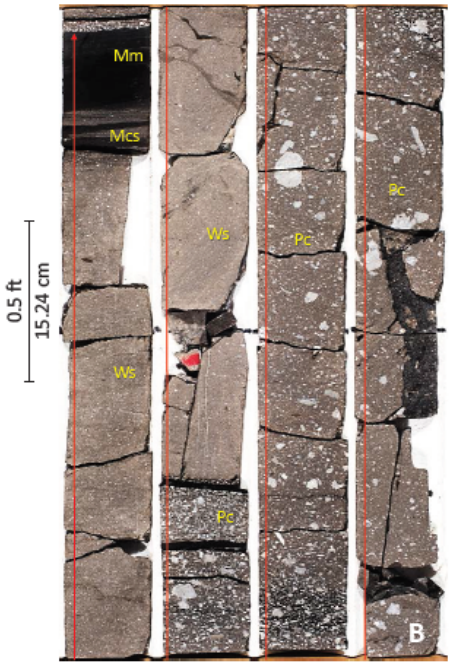
Lateral fringe – wackestones (muddy debrites) and some paraconglomerates (fewer than fan axis)



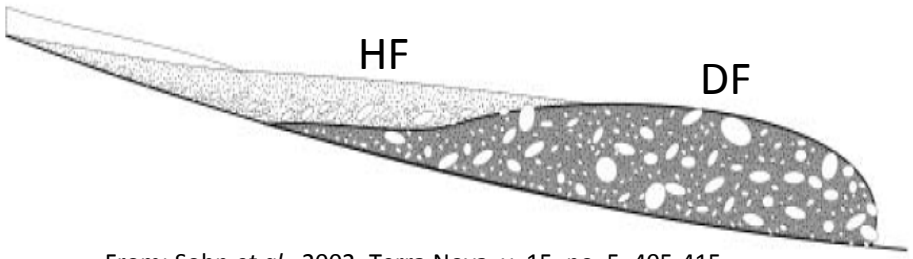






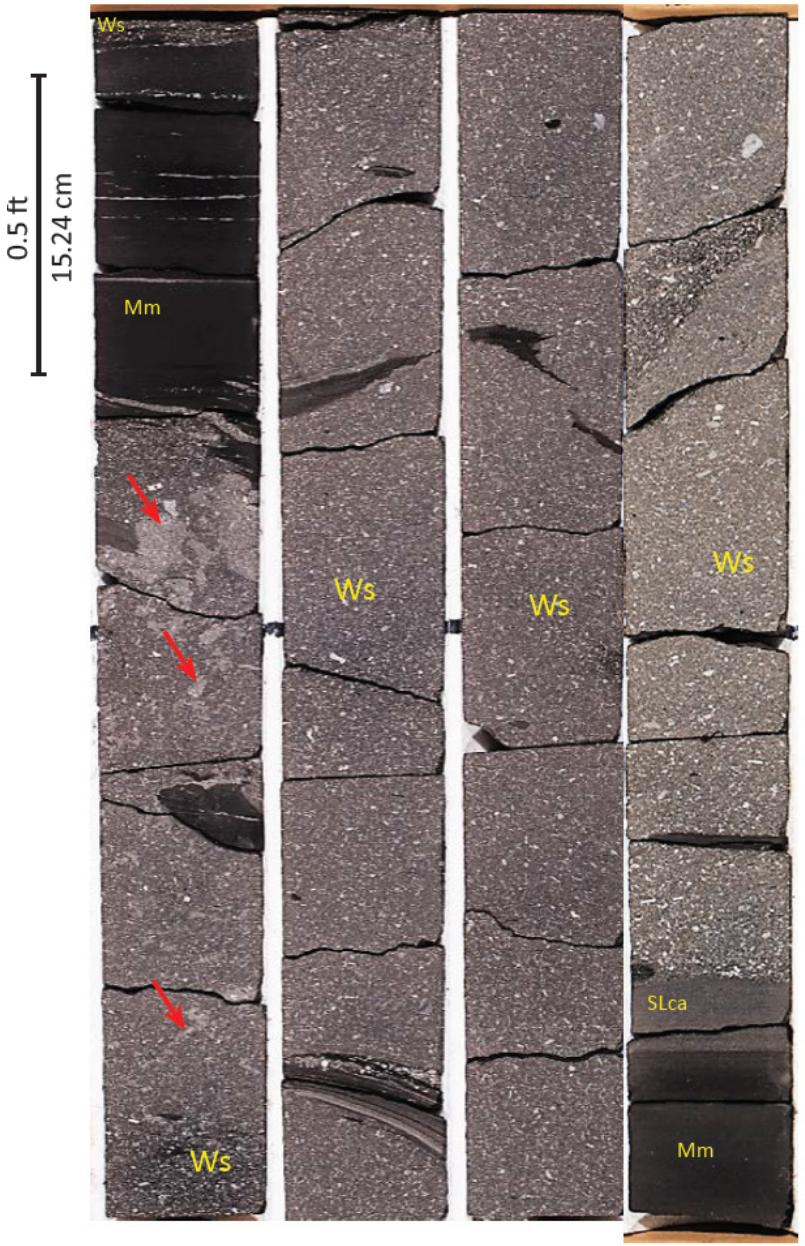


- Lateral fringe – wackestones and packstones are commonly stacked and appear to be genetically linked
- Suggests rheologically stratified flow

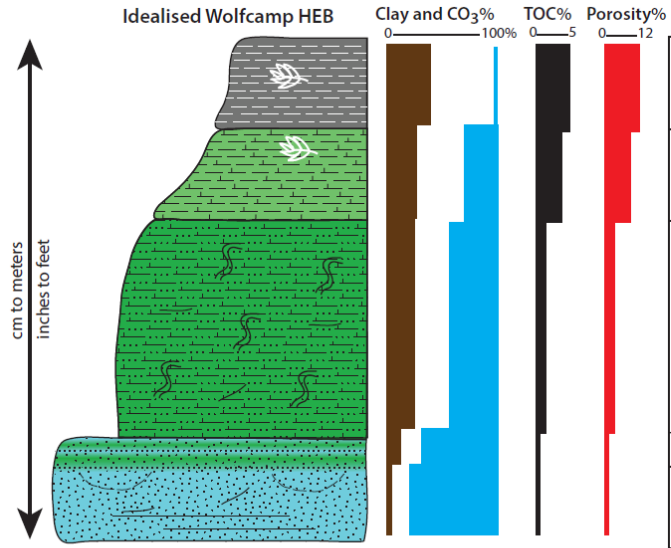


From: Sohn *et al.*, 2002, Terra Nova, v. 15, no. 5, 405-415

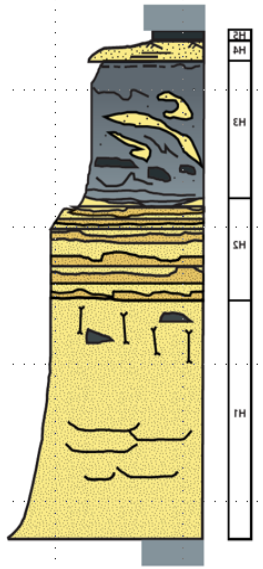
Short red arrows (right-hand figure) point to possible fluid escape structures



Frontal to distal fringe – Dominated by mixed carbonate-siliciclastic hybrid event beds (HEBs); exhibit features very similar to siliciclastic HEBs

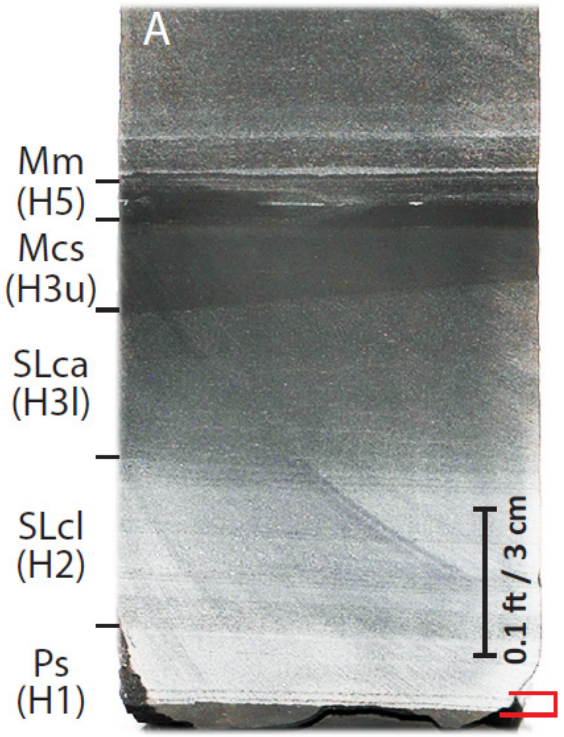


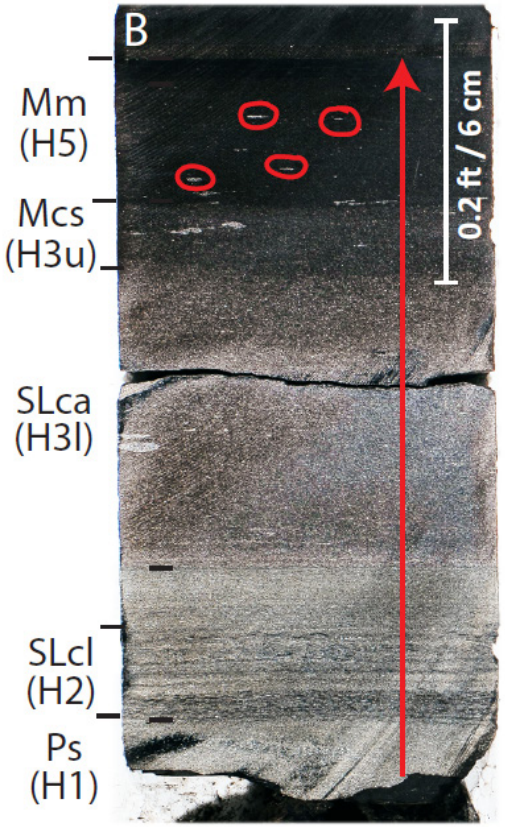
HEB Divisions	Interpretation	WFCP Facies
H5 - Structureless to faintly laminated organic siliceous mudstone, common plant fronds	Suspension fallout and/or hemipelagic settling	Mm
H3 upper - Structureless calcareous silty mudstone, organic-rich with occasional plant fronds and uncommon sheared dewatering structures	Cohesive flow with general absence of elutriation features	Mcs
H3 lower - Calcareous argillaceous siltstone with clotted texture and dewatering pipes; isolated dark gray mudstone clasts sometimes present	Cohesive flow with sand-silt concentrations from dewatering and elutriation coupled with internal shearing from within unit	SLca
H2 - Alternating lighter and darker bands of packstone and silty wackestone	Transitional flow with turbulence suppression	SLcl
H1 - Structureless to laminated bioclastic packstone, isolated dark gray mudstone clasts common, occasional dish structures at the top	Progressive aggradation beneath turbidity current	Ps/SLc



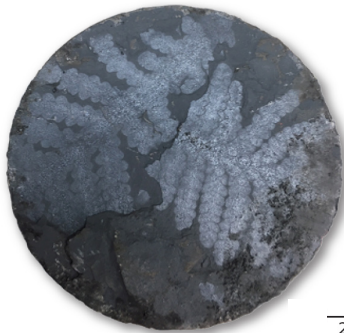
Facies	Hybrid Beds	Facies Code	Average Percent Clay	Calcite	Dolomite	Other	TOC	Dry, Pres Decay Perm mD	Dry Helium Porosity
Mudstone, dolomitic, bioturb.		Mdx	17.2	3.0	28.6	51.0	1.5	0.00223	6.3
Mudstone, massive, laminated	H5	Mm	36.1	1.0	2.8	60.1	4.5	0.00289	10.6
Mudstone, calc, silty/sandy	H3U	Mcs	24.6	18.9	3.8	52.7	2.7	0.00231	8.1
Siltstone, calcareous, argillac.	H3L	SLca	22.3	22.0	4.6	51.1	2.6	0.00240	6.9
Siltstone, calcareous/laminated	H2	SLcl	8.0	50.4	4.6	36.6	1.6	0.00096	5.0
Packstone	H1	Ps/SLc	3.5	72.0	1.5	23.0	0.9		2.3

From Kvale et al., in press, AAPG Bull.





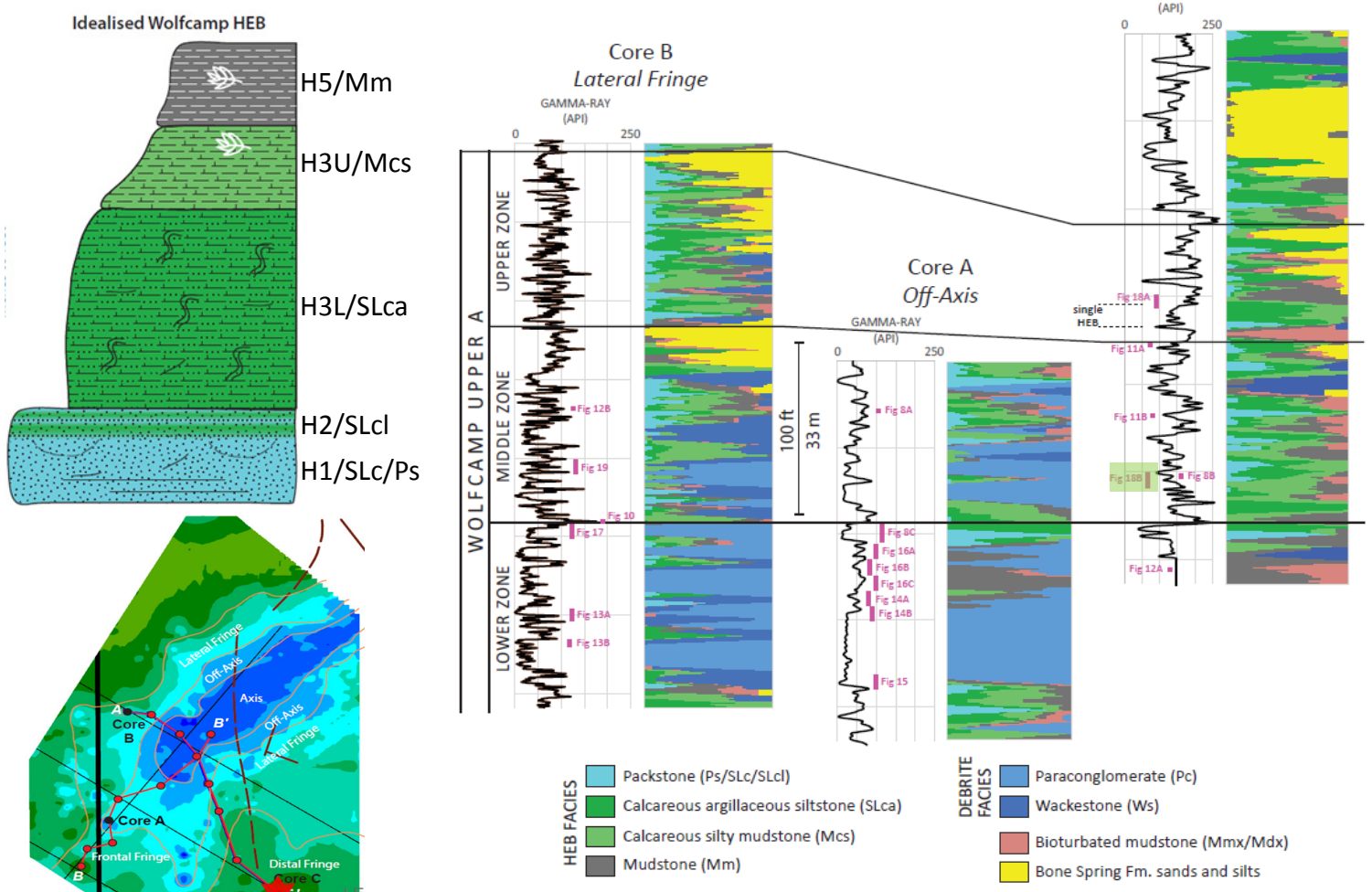
1 inch/
2.5 cm

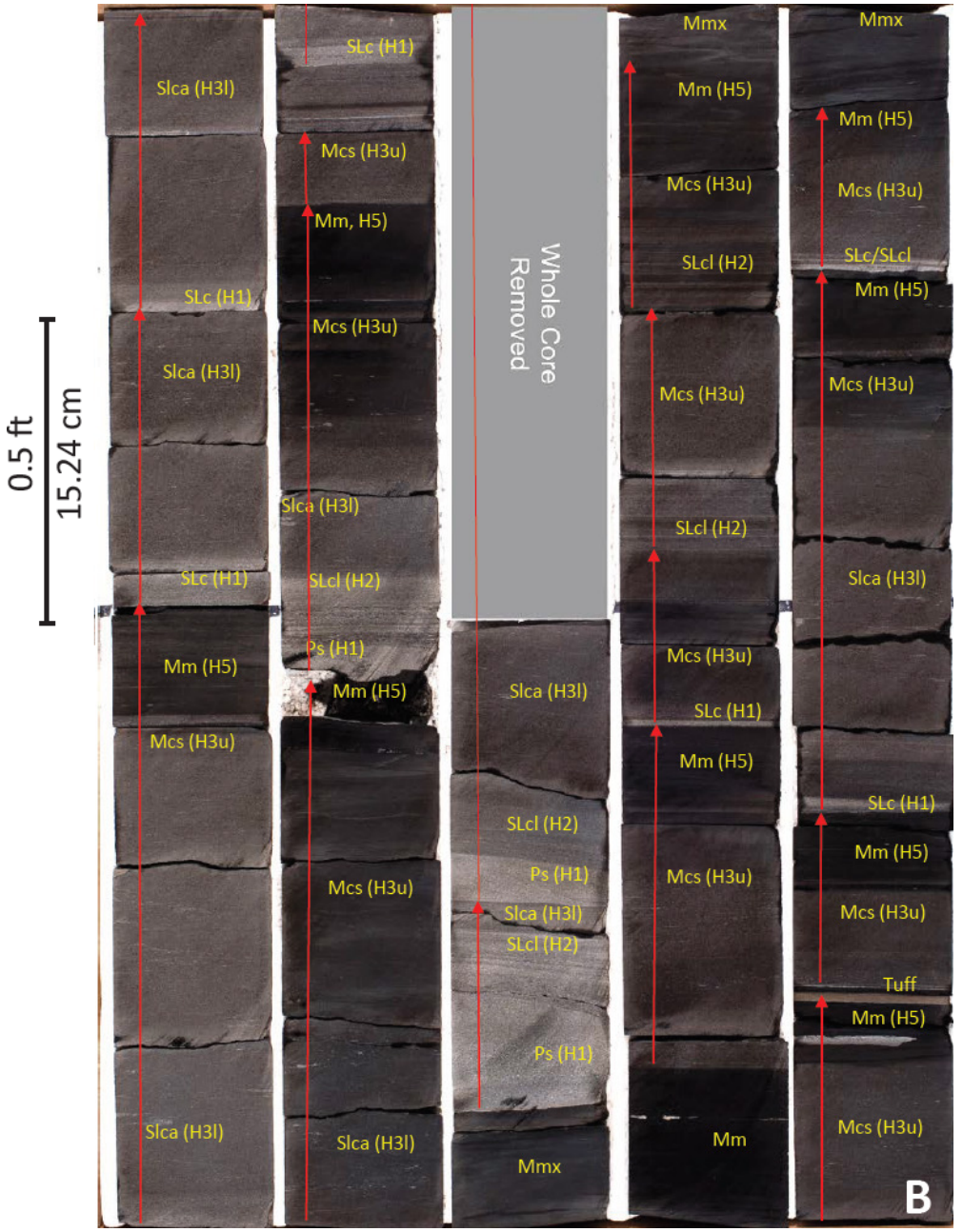


Germaropteris martinsii

Red circles indicate carbonate "coatings" that formed around terrestrial plant leaves

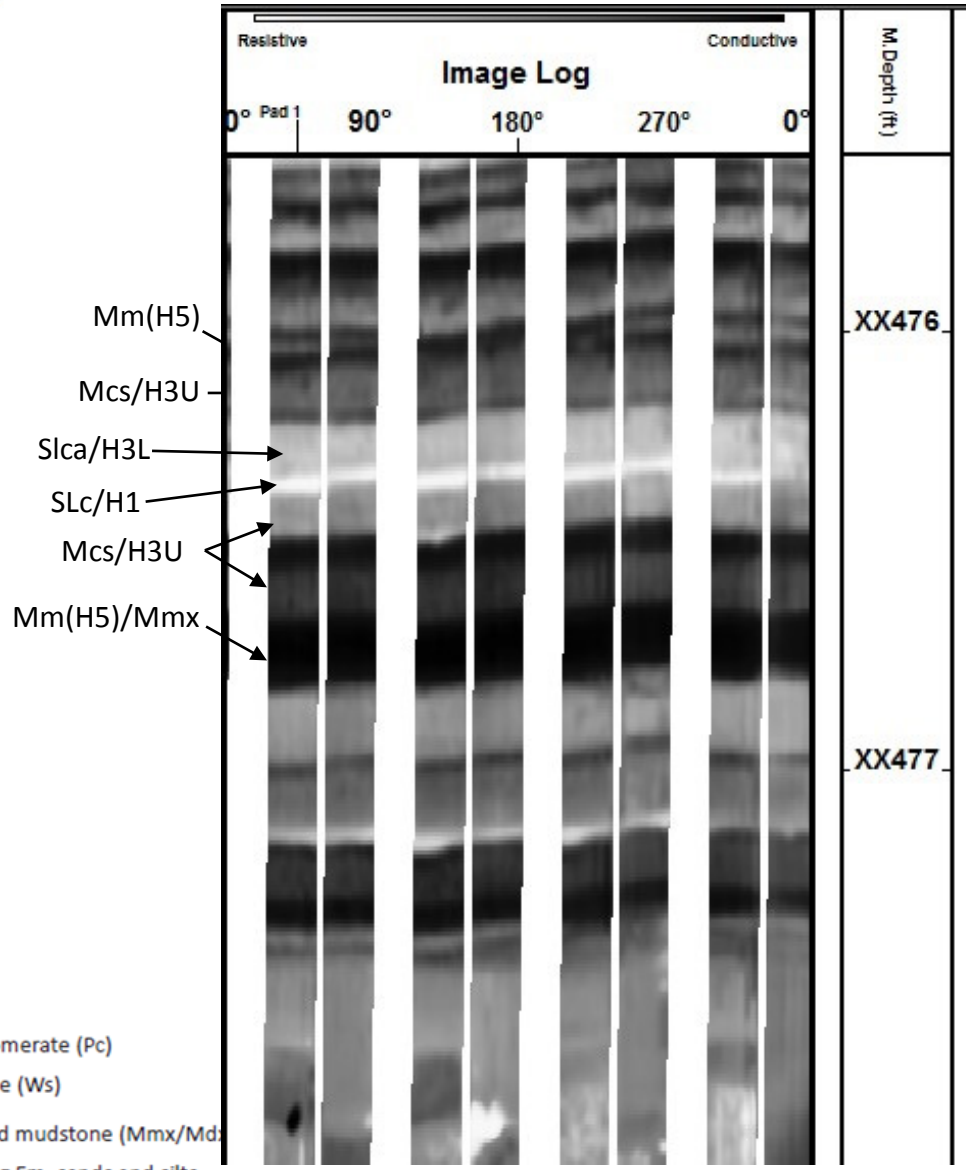
HEBs vary in completeness of divisions



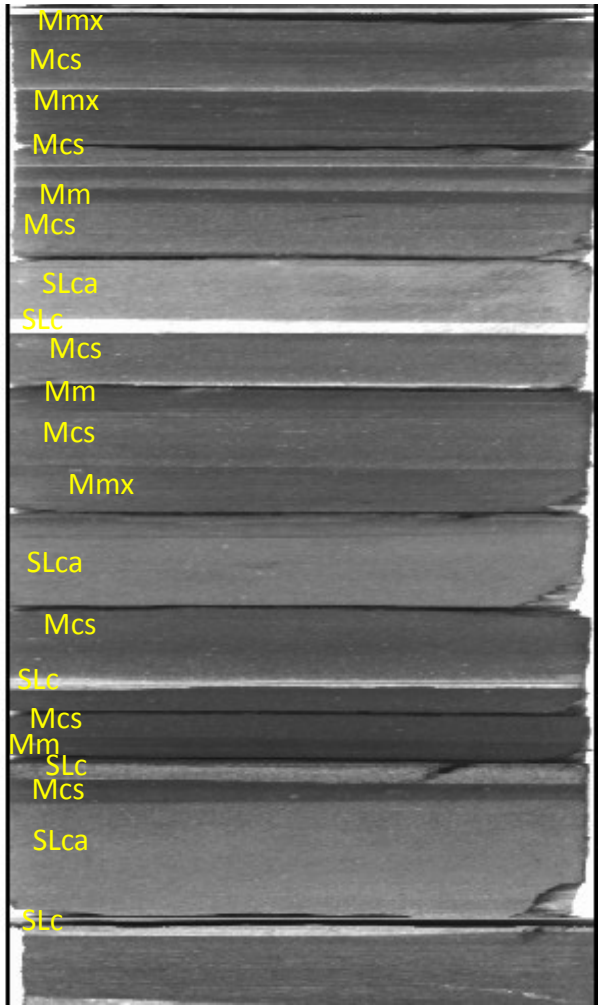


HEB facies can be recognized on image logs but need core to calibrate initially

- The brighter (more resistive) the image log, the more carbonate within the facies
- At least 4 facies can be distinquished in this image



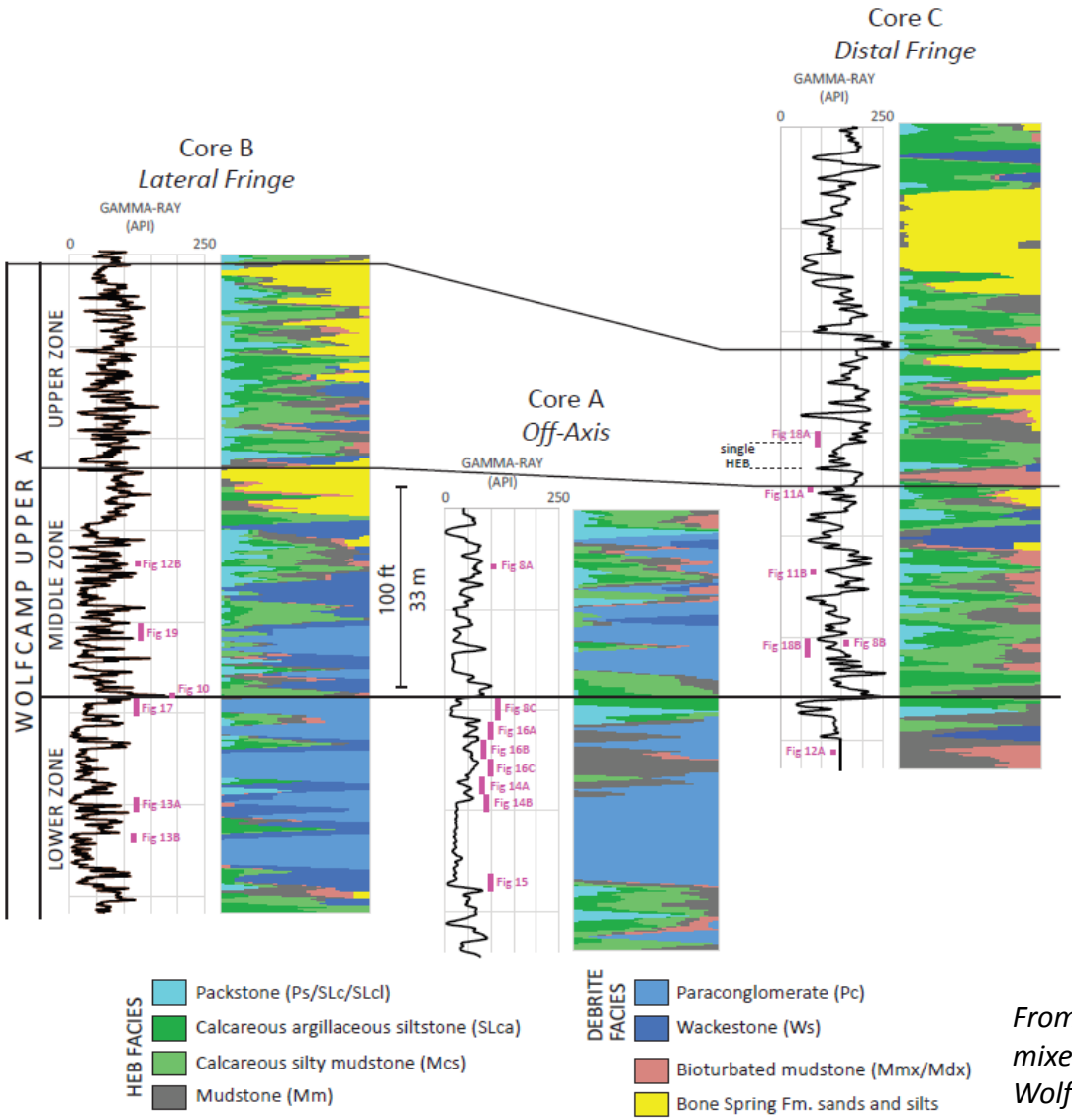
Core image

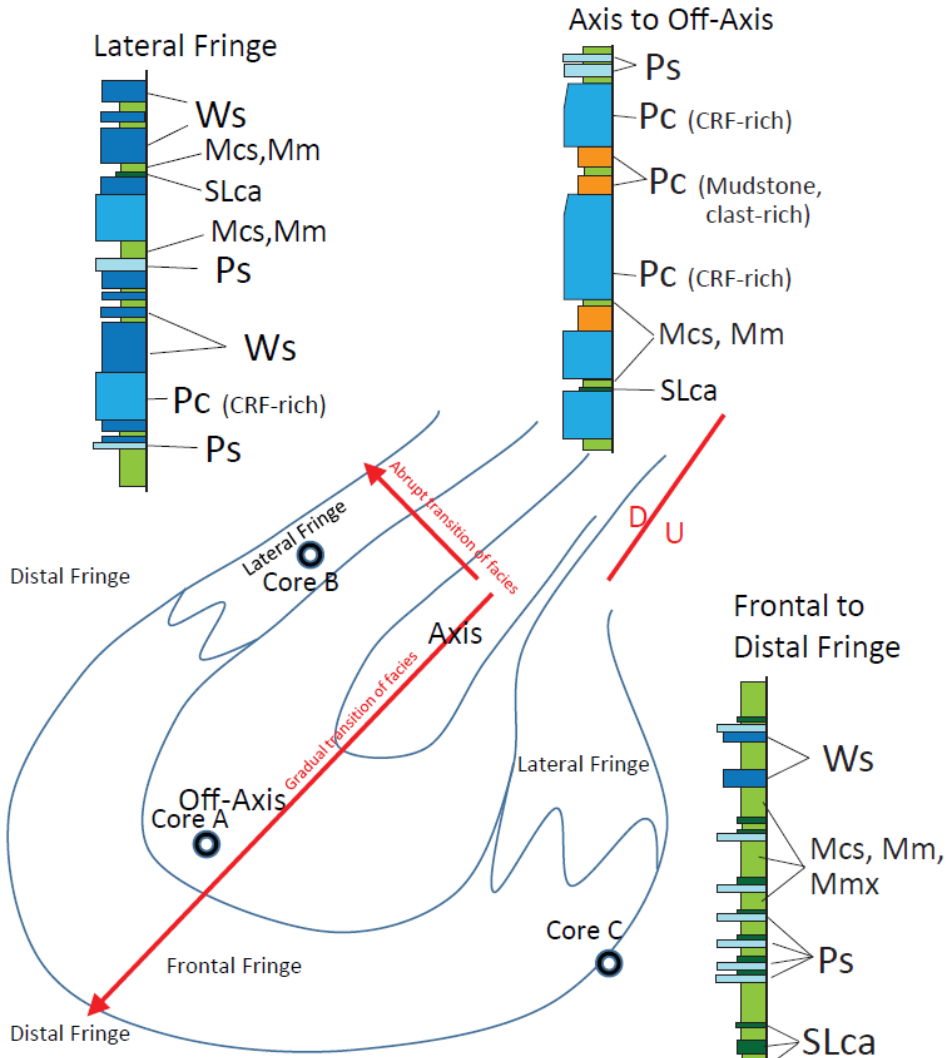


HEB FACIES
- Packstone (Ps/SLc/SLcl)
- Calcareous argillaceous siltstone (SLca)
- Calcareous silty mudstone (Mcs)
- Mudstone (Mm)

DEBRITE FACIES
- Paraconglomerate (Pc)
- Wackestone (Ws)
- Bioturbated mudstone (Mmx/Md
- Bone Spring Fm. sands and silts

Wolfcamp fan facies summary





From Kvale et al., in press, Facies variability within a mixed carbonate-siliciclastic sea-floor fan (upper Wolfcamp Fm., Permian, Delaware Basin, New Mexico). AAPG Bull.

Axis to Off-Axis (core A)
- Dominated by paraconglomerates (Pc) (debrites)
- Debrites can be carbonate- or mudstone-clast rich
- Relatively minor HEBs
- Turbidites are rare!

Lateral Fringe (core B)
- Abundant wackestones (Ws) (muddy debrites)
- Debrites are rheologically stratified (linked Pc and Ws)
- Fewer beds of Pc
- Increase in mud-dominated HEBs over Off-axis core

Frontal to Distal Fringe
- Dominated by HEBs
- Debrites are thin and uncommon
- Bioturbation more common

devon

Acknowledgements

- Devon Energy for permission to present
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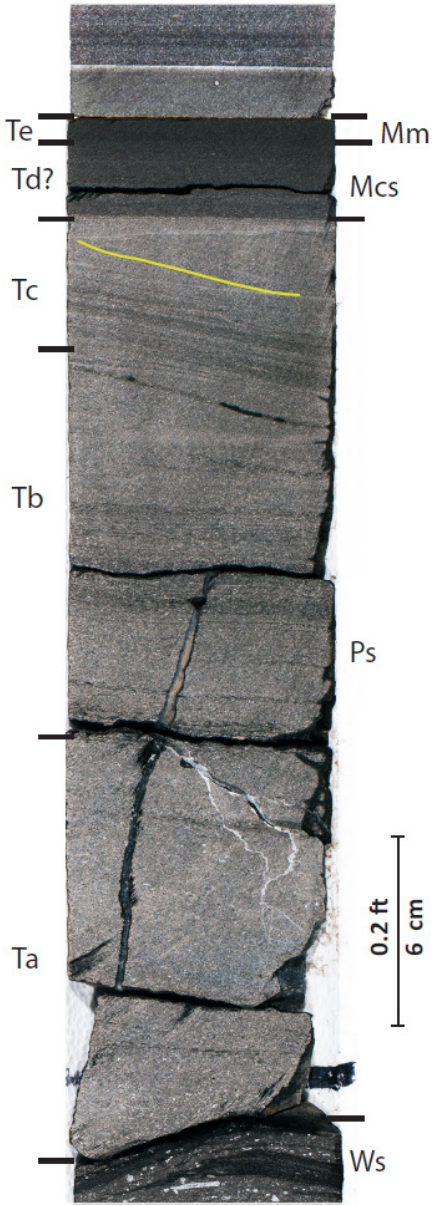
- Mr. Sloan Anderson for Petrel image of Wolfcamp fan
- Additional information will be presented Tuesday afternoon 2-5 pm, P92, Pore System Characterization of Wolfcamp Lithofacies, Delaware Basin, J.J. O'Brien *et al*.



One of two turbidites identified in the three cores used in the study – boundary between HEB and turbidite classification appears to be diffuse…