Carbonate-Dominated Hybrid Sediment Gravity Flows Within the Upper Wolfcamp, Delaware Basin, USA: Vectors for Transmitting Terrestrial Organics Into a Deep Marine Basin*

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Abstract

The Delaware Permian Basin in southeast New Mexico and west Texas is currently one of the hottest areas for oil and gas exploration in North America. Regional stratigraphic studies within the lower Permian Wolfcamp interval reveal that basin sediments were derived from both siliciclastic and carbonate clastic sources dispersed around the basin. Carbonate deposition within the basin was dominated by sediment gravity flows including mass transport complexes (that can include debris flows, rafted blocks of preexisting slope deposits, and shelf material) and hybrid event beds (HEBs-also known as linked debrites). Carbonate HEBs are common along the western flank of the Central Basin Platform and out into the basin. Single flow events up to 10 meters thick have been recognized in cores obtained from basin floor settings, but most are much thinner. The HEBs are composed of diagenetically altered fusulinid-rich skeletal packstones. Often the packstones are massive but some also exhibit laminated bedding. Silt-size quartz grains are also a component. In a complete succession, the packstones (Ps) will grade upwards to a mostly silty packstone (SLc) that may be weakly laminated. This is then typically sharply overlain by a calcareous argillaceous siltstone (SLca) that is massive but often shows a "clotted" texture that may represent fluid escape structures that were sheared during final deceleration of the deposit. The SLca grades upward into a calcareous silty mudstone (Mcs) that is also massive. A slightly calcareous to non-calcareous massive to laminated mudstone (Mm/Ml) sharply to gradationally overlies the calcareous mudstone. The massive calcareous muddier portions of the HEBs (SLca, Mcs) exhibit TOC values that can range from 0.6% to 3.5%, whereas the carbonate-dominated basal portions (Ps, SLc) generally contain less than 1%. The non-calcareous mudstones (Mm/Ml) that cap the event beds contain as much as 8% TOC. Within the condensate window, the more organic rich uppermost parts of the HEBs constitute the reservoir facies. A significant proportion of the TOC within the calcareous mudstones and non-calcareous mudstones may have been derived from terrestrial organics as evidenced by well-preserved fern-like plants with fully articulated leaves (Germaropteris martinsii). Their presence within the HEB indicates that the Central Basin Platform was subaerially exposed during their deposition with plants growing on shelf-edge islands.

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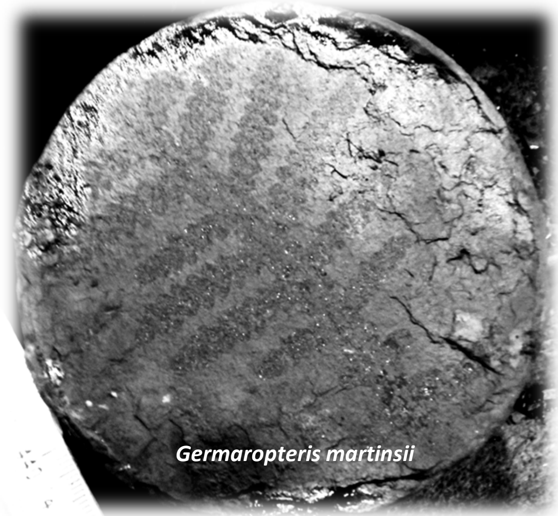
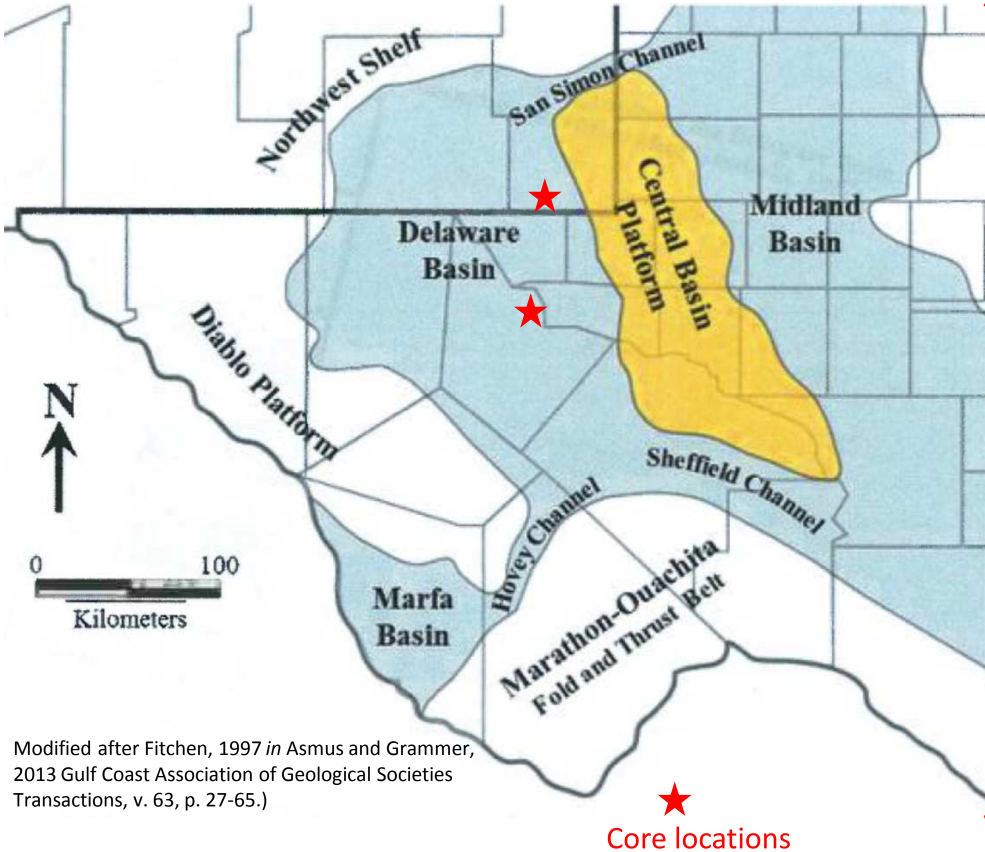
Presentation Outline

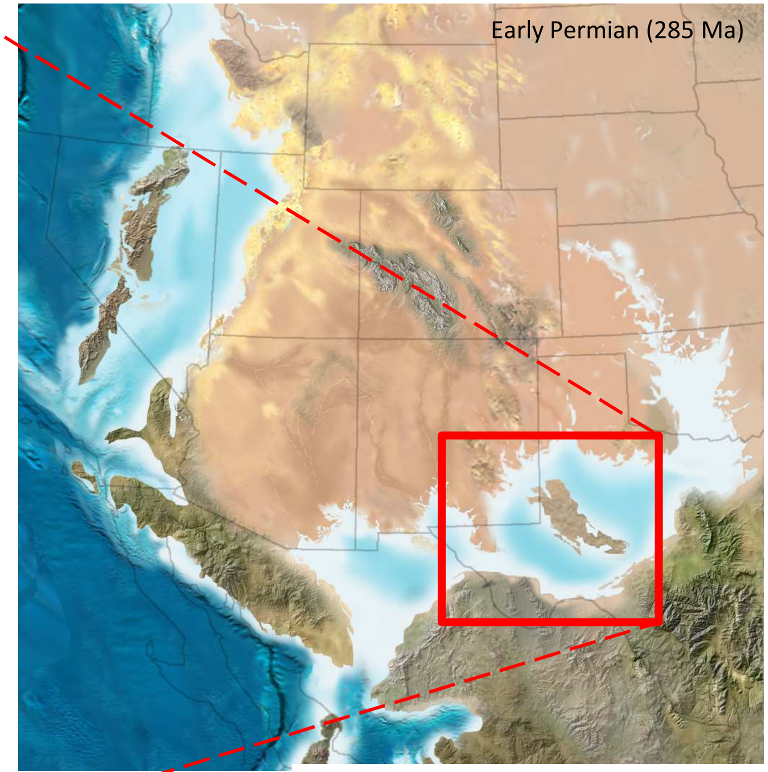
- Geologic context
- Discuss Wolfcamp A facies within Delaware Basin and challenges for petrophysics
- Demonstrate the intricate relationship between terrestrial flora and deepwater marine carbonate sediments
- Identify depositional processes and environments of deposition
- Present implications for mapping
- Conclusions



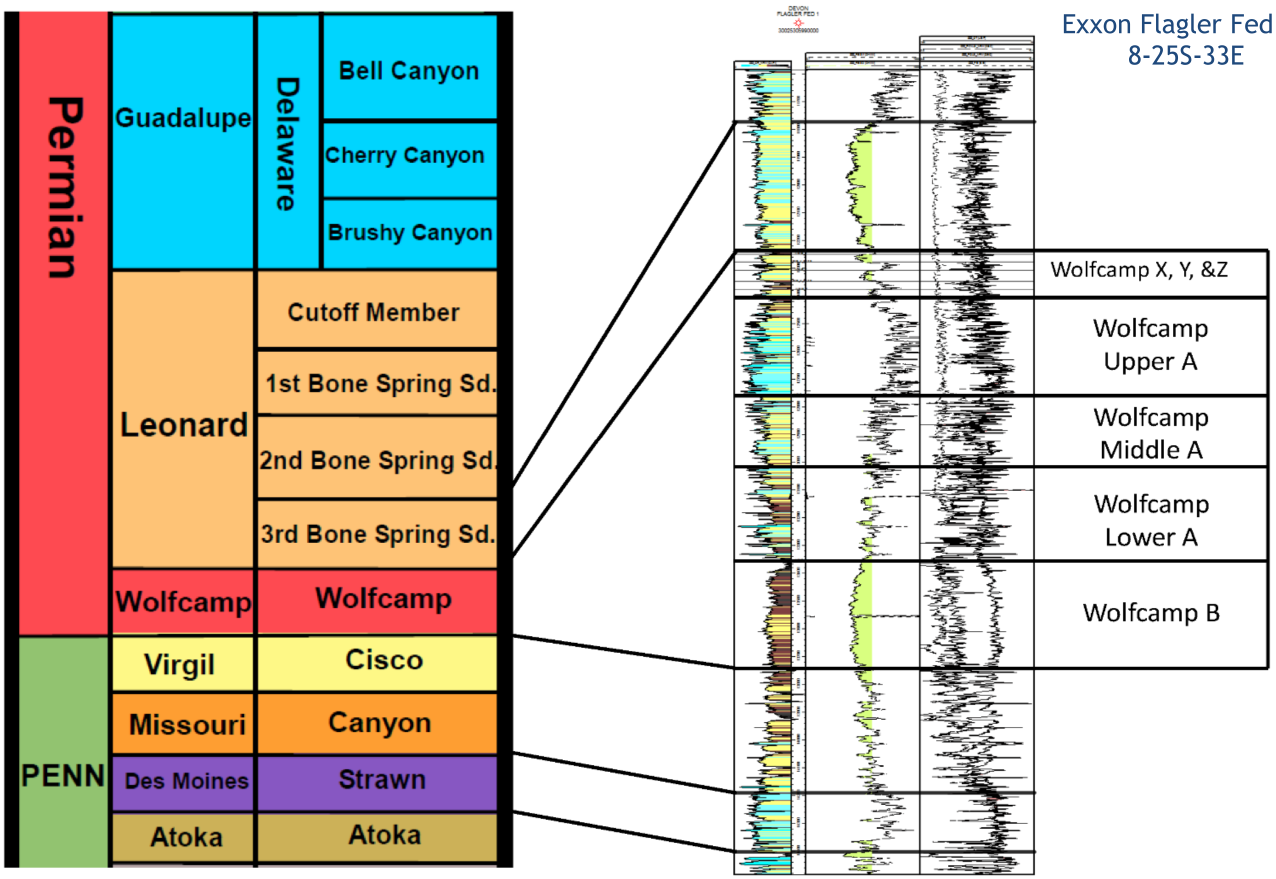
Geologic Context



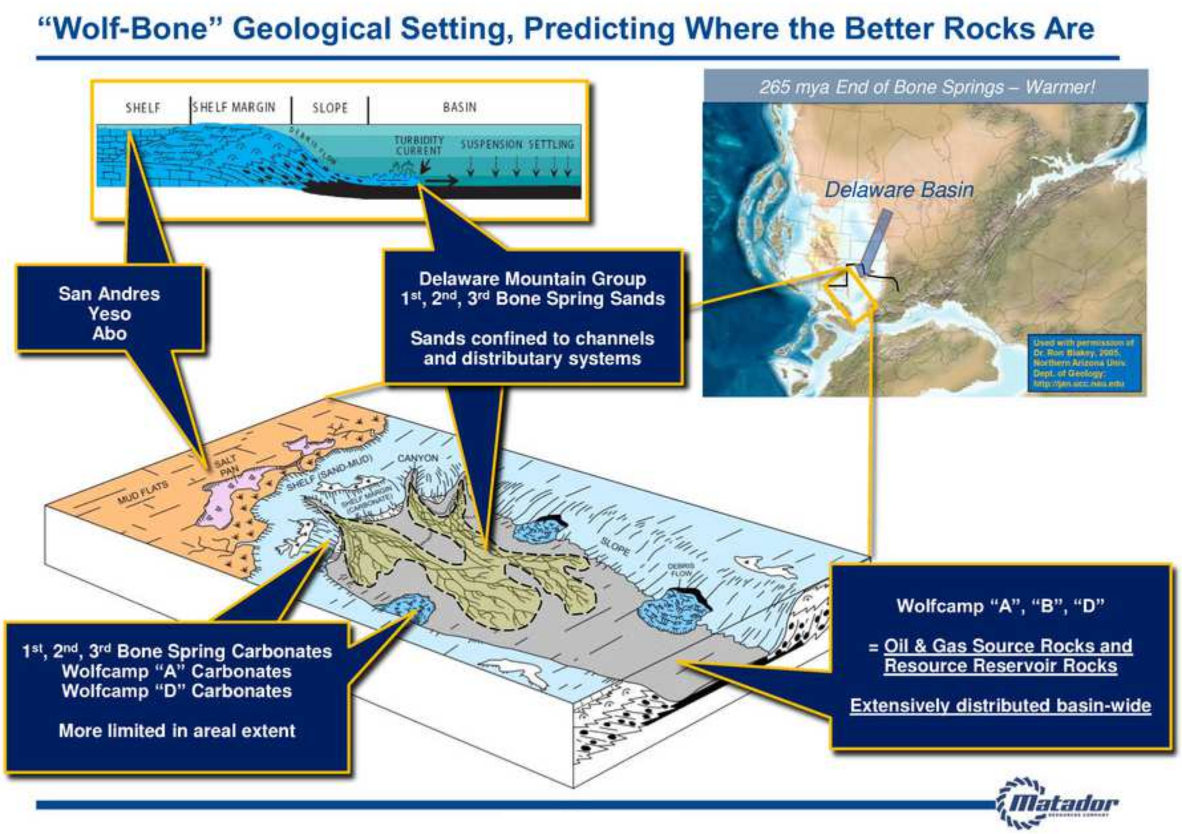
Modified after Fitchen, 1997 *in* Asmus and Grammer, 2013 Gulf Coast Association of Geological Societies Transactions, v. 63, p. 27-65.)



Stratigraphy



Depositional Paradigm

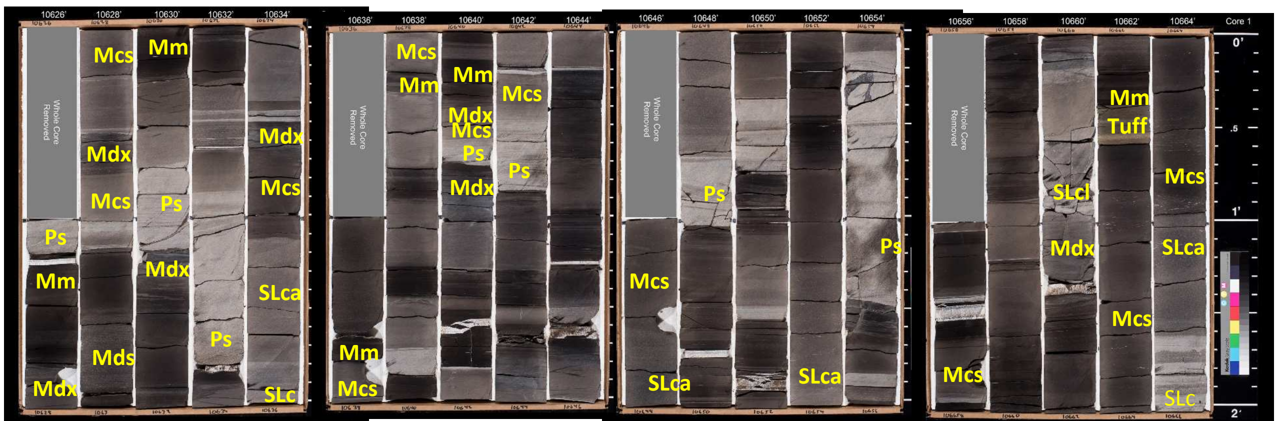


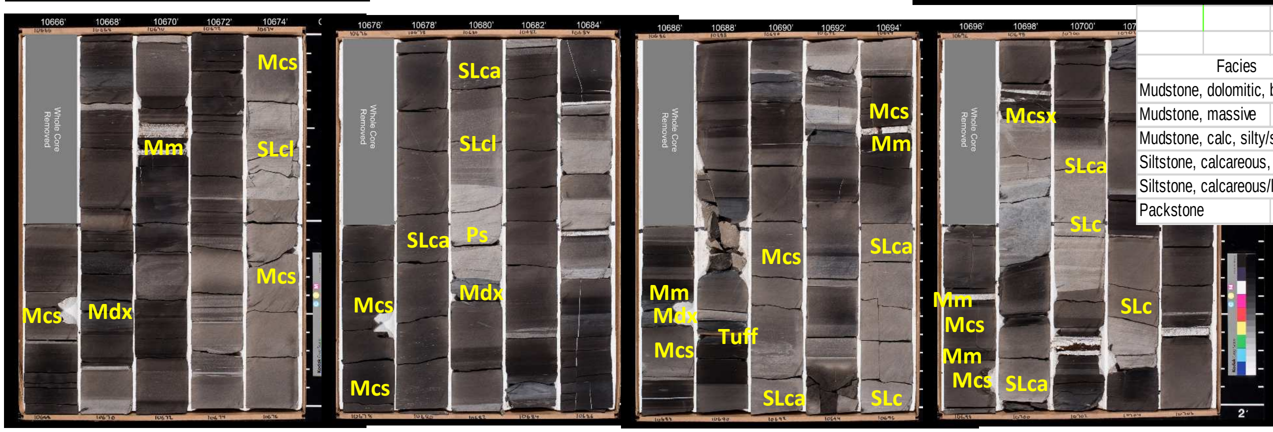
Paradigm:

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.

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

Wolfcamp A Facies Variability





Petrophysicist

How well would cuttings or RSWC capture/predict lithologic variability within this core interval?

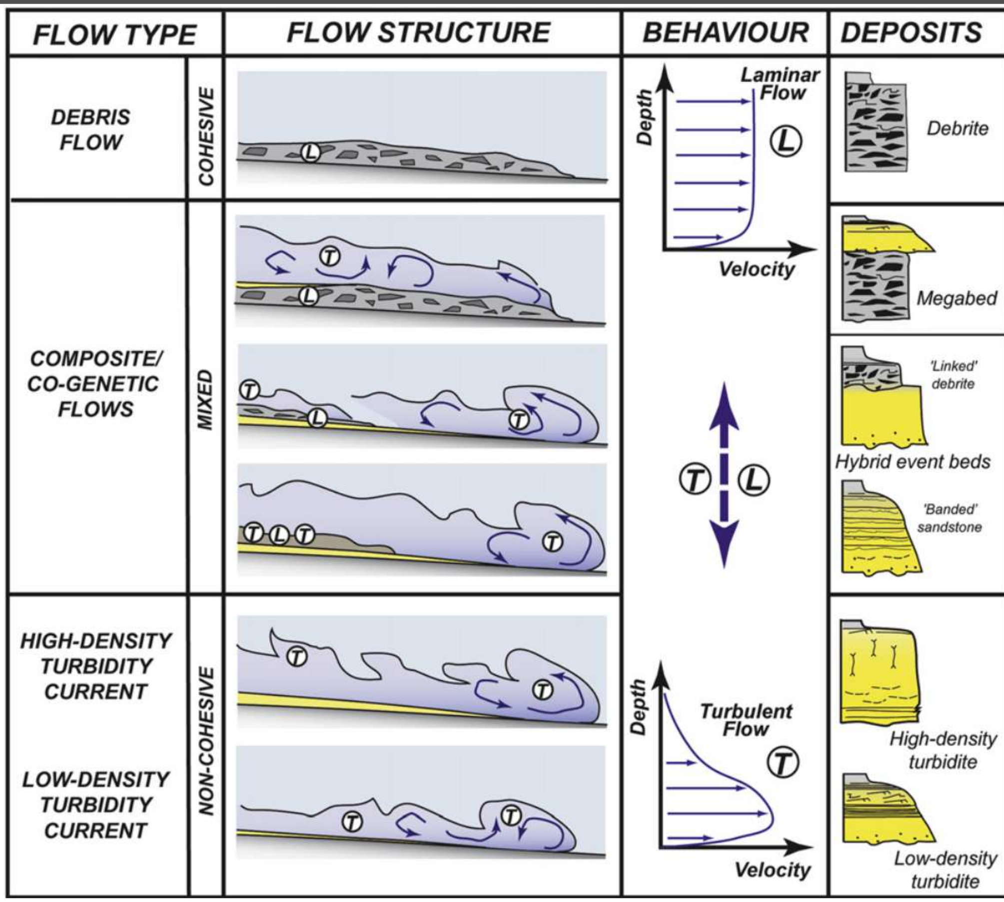
Facies	Facies Code	Clay	Calcite	Dolomite	Other	TOC	Dry, Pres Decay md Perm	Dry Helium Porosity
		Average Percent						
Mudstone, dolomitic, bioturb.	Mdx	38.50	2.00	2.50	57.00	1.04	0.00331	12.207
Mudstone, massive	Mm	33.00	1.00	2.50	55.25	2.59	0.002117	11.1626
Mudstone, calc, silty/sandy	Mcs	27.13	19.27	4.93	48.67	1.66	0.002005	9.68418
Siltstone, calcareous, argillac.	SLca	25.25	24.00	9.50	41.25	1.35	0.001688	8.41357
Siltstone, calcareous/laminated	SLc/SLcl	5.00	64.17	8.33	22.50	0.60	0.00094	3.50498
Packstone	Ps	2.00	62.50	14.00	21.50	0.20	0.000195	3.47

The Plant Conundrum

Plant fronds (*Germaropteris martinsii)* in the upper Wolfcamp are commonly associated with carbonate-poor mudstones that are intercalated with carbonate beds like packstones and wackestones. Why are they associated with carbonate-dominated systems?

- Studies in Spitsbergen, Norway (Plink-Björklund and Steel, 2004, Sed. Geol., v. 165, p. 29-52) and Kutei Basin, Indonesia (Saller, Lin, and Dunham, 2006, AAPG Bulletin, v. 90, p. 1585-1608) show that turbidites triggered by river-sourced hyperpycnal flows are capable of transporting large quantities of leaves and leaf debris into deep-water (100s of feet)
- Wolfcamp deposits were not linked to large rivers capable of generating hyperpycnal flows

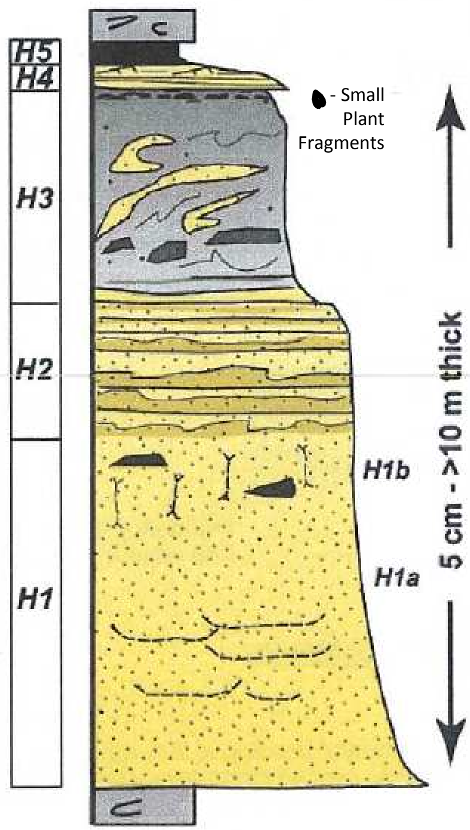
Hybrid Event Beds



The intercalation of Wolfcamp carbonate and siliciclastic facies can be explained in context of "hybrid event beds" unrelated to hyperpycnal flows.

Haughton, *et al* (2009, Marine and Petroleum Geology, v. 26, p. 100-1918)

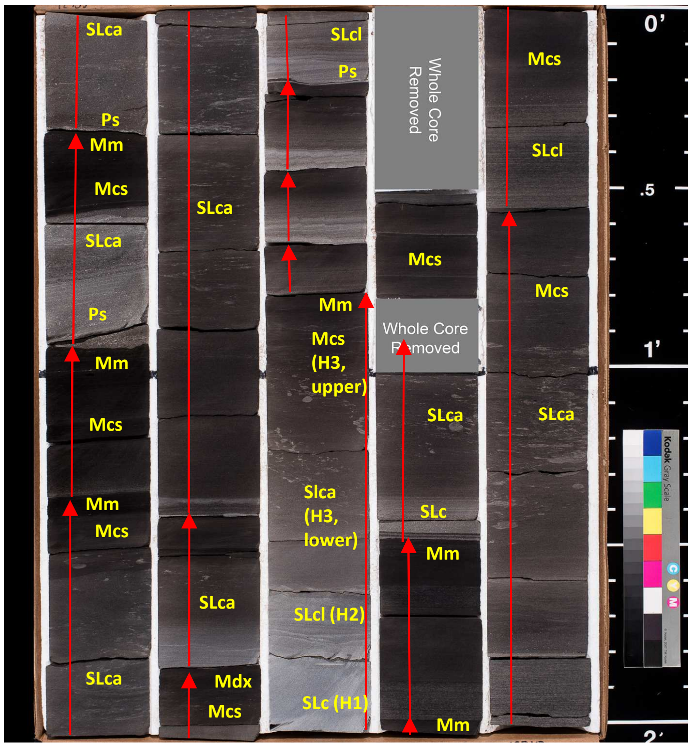
Idealized, Complete Hybrid Bed



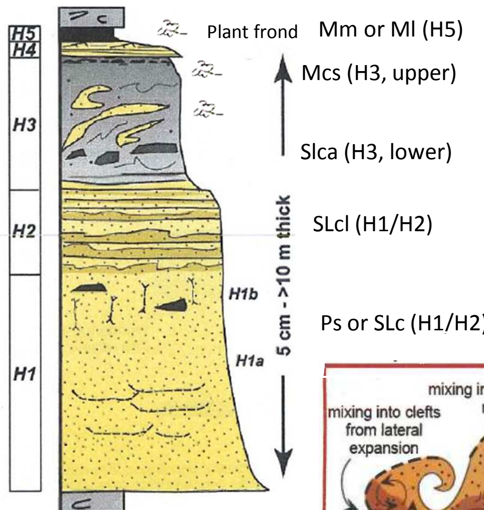
DIVISIONS	INTERPRETATION
Pseudonodular and/or massive mud	Suspension fallout ± shearing
Parallel and ripple cross-lamination	Traction by dilute turbulent wake
Muddy sand ± mudclasts, sand patches, injections, outsized granules, shear fabrics. Often segregation of carbonaceous fragments to top where they can laminated.	Cohesive debris flow, locally modified by sand injection from beneath, and partly reworked at top
Alternating lighter and darker sands, with loading at base of lighter layers. Sheared dewatering pipes and sheets	Transitional flow with intermittent turbulence suppression due to near bed dispersed clay and internal shearing
Isolated mudclasts surrounded by clean sandstone Graded to ungraded, structureless and dewatered, relatively clean sand, commonly with isolated floating mudclasts at top.	Progressive aggradation beneath non-cohesive high-denity turbidity current

Haughton, *et al* (2009, Marine and Petroleum Geology, v. 26, p. 100-1918)

Hybrid Event Beds – Northern Core



Mdx – (burrowing - not always present)



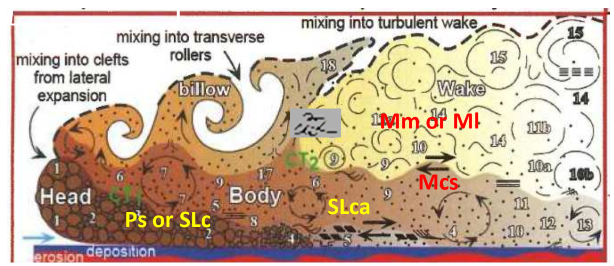
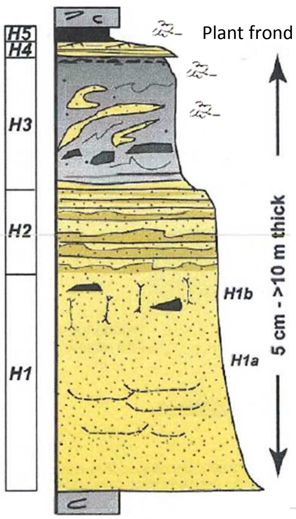


Figure modified from M. Gardner, 2015, Course notes for Nautilus N302: Deepwater Reservoir Presence and Architecture: Permian Brushy Canyon Formation, Guadalupe and Delaware Mountains (West Texas, USA)

Facies	Mean Green Facies Code	Average Percent Clay	Calcite	Dolomite	Other	TOC	Dry, Pres Decay Perm mD	Dry Helium Porosity	Klink. Perm mD	Dry Helium Porosity
Mudstone, dolomitic, bioturb.	Mdx	17.2	3.0	28.6	51.0	1.5	0.002228	6.3		
Mudstone, massive, laminated	Mm/Ml	36.1	1.0	2.8	60.1	4.5	0.002893	10.6		
Mudstone, calc, silty/sandy	Mcs	24.6	18.9	3.8	52.7	2.7	0.002313	8.1		
Siltstone, calcareous, argillac.	SLca	22.3	22.0	4.6	51.1	2.6	0.002397	6.9	0.0322	4.1
Siltstone, calcareous/laminated	SLc/SLcl	8.0	50.4	4.6	36.6	1.6	0.0010	5.0	0.0045	5.0
Packstone	Ps	3.5	72.0	1.5	23.0	0.9			0.1914	2.3
Wackestone	Ws	6.5	62.3	2.0	29.3	1.0	0.001154	2.9	0.0001	2.4

Hybrid Event Beds – Southern Core



Mdx/Mmx – burrowing - not always present

Note: H4 is usually missing

Rapid deposition and rheologically/compositionally stratified flows

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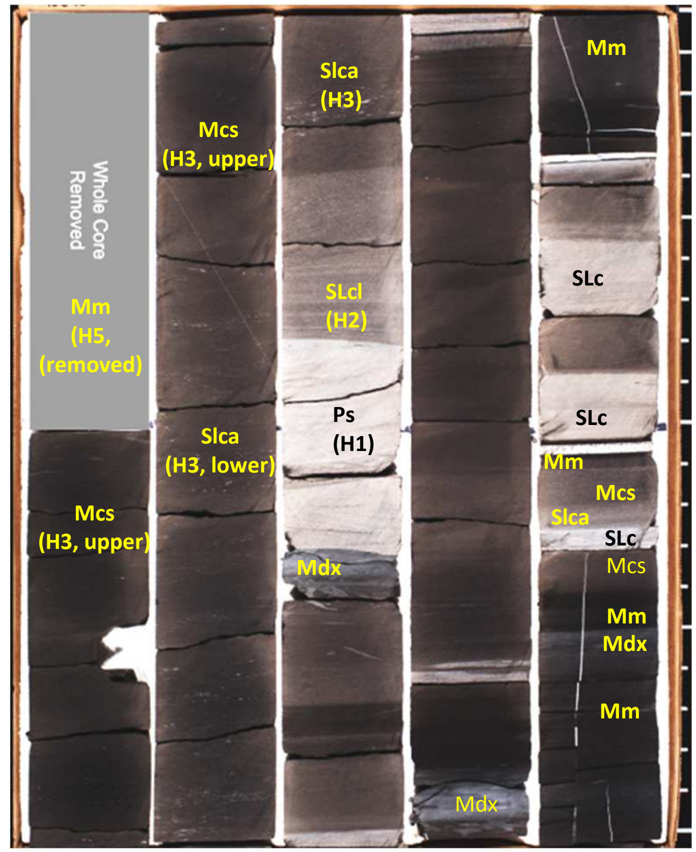
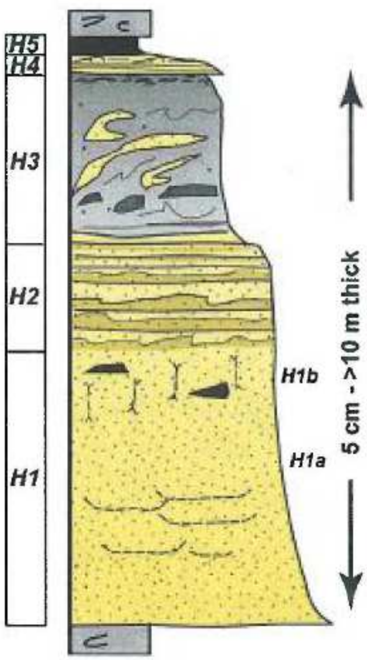


Reservoir Quality

Sub-facies in Hybrid Event Beds

Reservoir Quality of sub-facies for unconventional systems with Ro>0.9



Haughton et al. (2009)

H5 – 10X increase over H1 Kh values

H3 - commonly 0.01Kh of associated H1 sub-facies, unless it is relatively sandy

2X to 10X increase over H1 Kh values

H2 - Banded, overall poorly sorted sand-silt-mud mix ~0.1Kh of H1 Kh values

H1 - Highest Kh values, often best in the entire reservoir

Lowest Kh values (with important exceptions)

H2 may have a sand log response but low Kh, and H3 may be thin, particularly if it is a slurry facies - in these cases the overall log response may indicate sand and the low Kh sub-facies may be hidden

Comments on reservoir quality (in black) might be valid for sandstone/siltstones HEB's but not for the Wolfcamp carbonate HEB's. For Wolfcamp HEB's (red comments), H3 and H5 facies are the best reservoirs within the condensate and gas windows.

Modified from Pulham and Evans, 2016, Course notes for Nautilus N009: Sedimentology, Stratigraphy and Reservoir Geology of Deepwater Clastic Systems (County Clare, Ireland)

Potential Distribution of Key Types of Hybrid Beds

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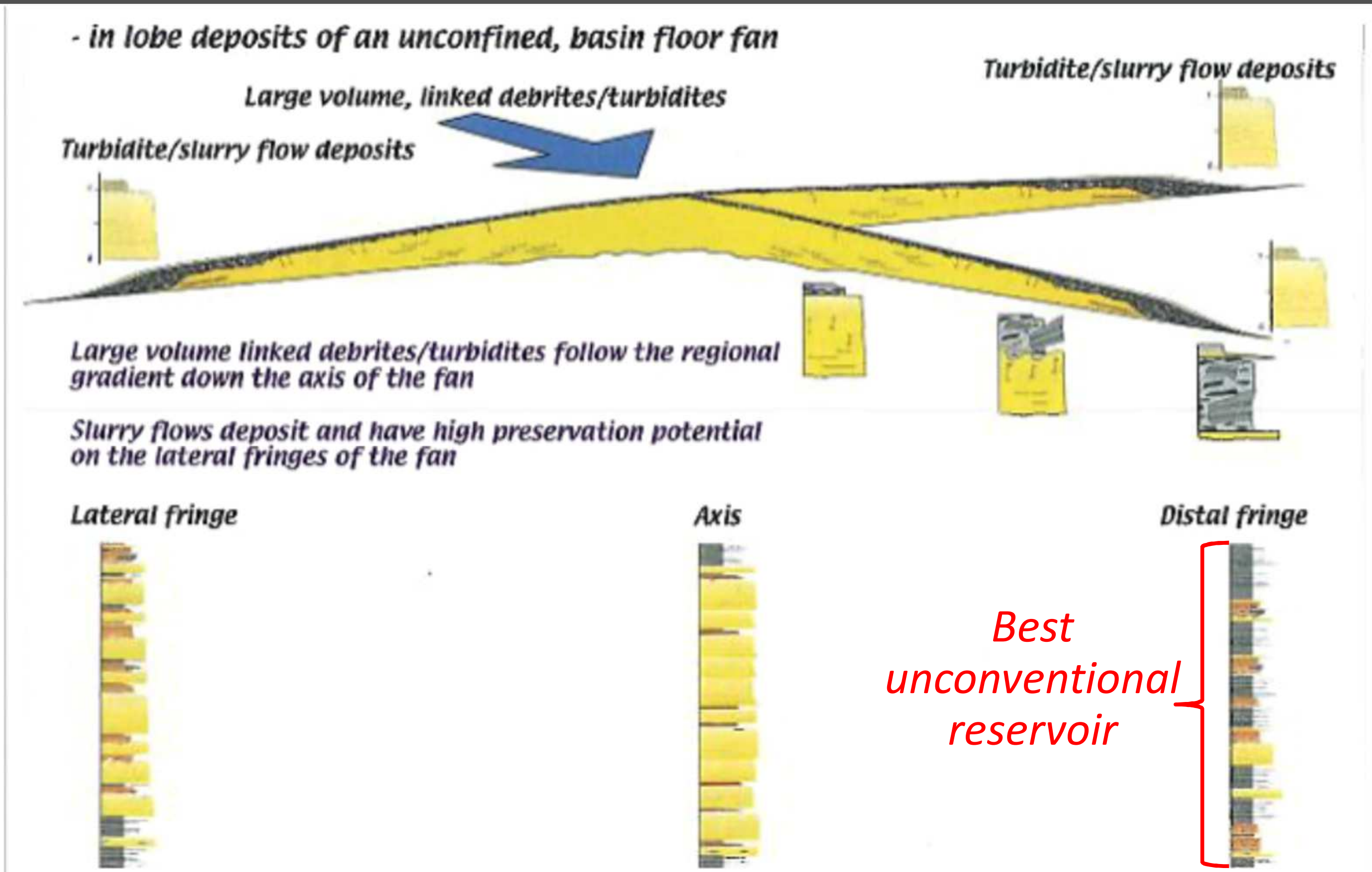
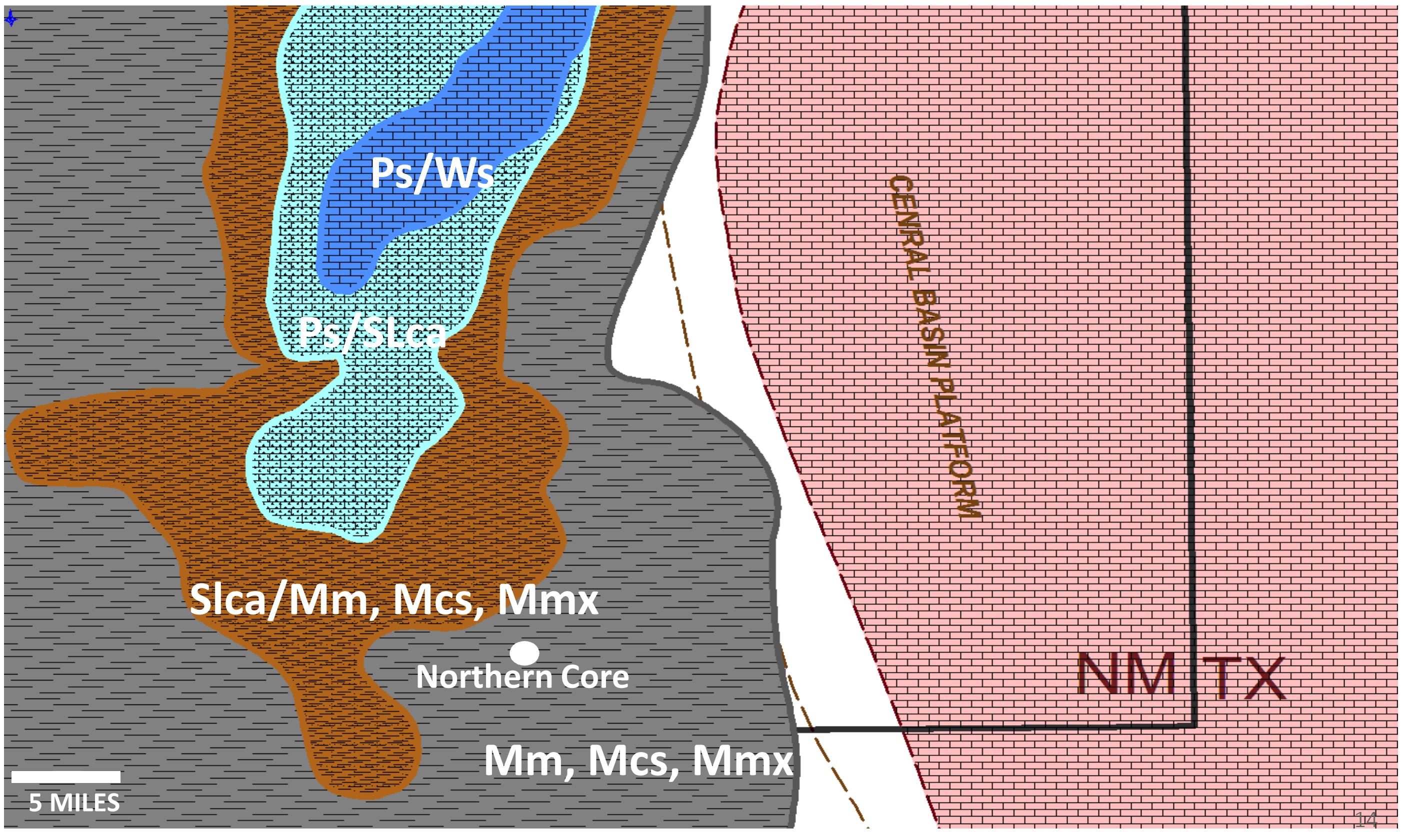


Modified from Haughton and others (2009, Marine and Petroleum Geology, v. 26, p. 100-1918) and Haughton, Barker, and McCaffrey (2003, Sedimentology, v. 50,p. 459-482).

Wolfcamp A Example

Dominant facies types within a ~250 ft. thick Wolfcamp A fan complex



The Plant Conundrum

So how did the fronds get into a deep water realm?

Conceptual Image

devon

Conclusions

- **Significant volumes of carbonates and siliciclastic sediments can be co-deposited in deep marine settings within single hybrid event beds.**
- **Petrophysical models and logs, by themselves, do not necessarily explain or predict depositional processes.**
- **Good depositional models can help with mapping strategies.**
- **Significance of terrestrial organic input into deep water systems from carbonate reef complexes may be under-appreciated.**

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