

Visualizing a Sub-Salt Field With Image Logs: Image Facies, Mass Transport Complexes, and Reservoir Implications From Thunder Horse, Mississippi Canyon, Gulf of Mexico*

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Abstract

Thunder Horse is a deepwater asset in the Gulf of Mexico, Mississippi Canyon, with turbidite sandstone reservoirs deposited during the Middle Miocene in the Boarshead Basin. Imaging the reservoirs is difficult because the adjacent salt stock and canopy inhibit seismic imaging, and drilling in deepwater conditions makes coring expensive. Image logs provide an alternate means of high resolution visualization of the reservoir, and through the image facies scheme presented here, reveal the character of sandstone and interbedded mudrock fabric that allows for interpretations of depositional processes. Image logs are interpreted by picking bedding boundaries that represent the dip magnitude and azimuth of the dipping beds. The picked dips follow trends according to the sandstone or mudrock fabric being imaged. Similar dip magnitudes and azimuths in sandstone indicate sediment gravity flows traveling the same direction, like high density turbidity currents. Another pattern in sandstone is dips with similar magnitudes but varying azimuths, indicating that flows are in the same plane but traveling in different directions, like an avulsing channelized system. High variability of dipping beds in mudrock indicates deformation through downslope slumping, and steepening up/shallowing up dip patterns also seen in mudrock indicate slide blocks and folds. Correlating image logs across northwest Thunder Horse reveals that slumps, slides, and folds built up mass transport complexes that eroded underlying sandstone in the proximal side of the Boarshead Basin. The mass transport complexes built a 200 m+ thick mounded feature that ponded another sandstone reservoir behind it, locally increasing the reservoir thickness. Previously, all mudrock at Thunder Horse was thought to be planar-bedded shale deposited from hemipelagic settling or low density turbidity currents, but

high resolution image logs were the keystone in confirming the deformed, resedimented nature and erosive capability of the mass transport complexes. This level of detail is highly valuable to a sub-salt field where stratigraphic features such as erosion or amalgamation are not always visible through seismic imaging. As a case study this type of high-resolution data has wide applicability to other deepwater, sub-salt reservoirs, as improved depositional interpretations inform reservoir performance and impact future well planning.

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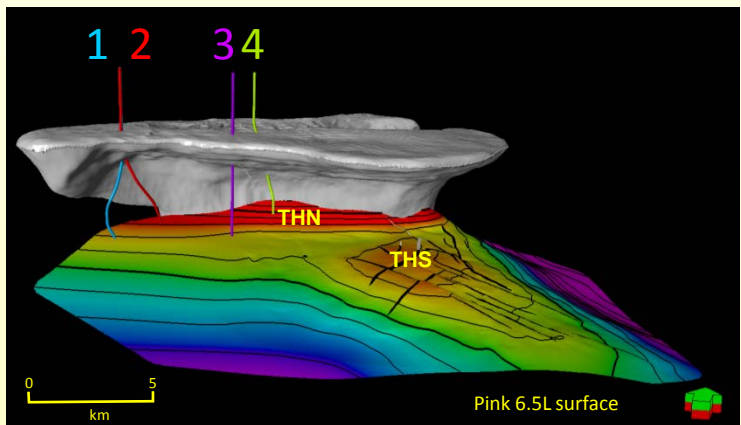
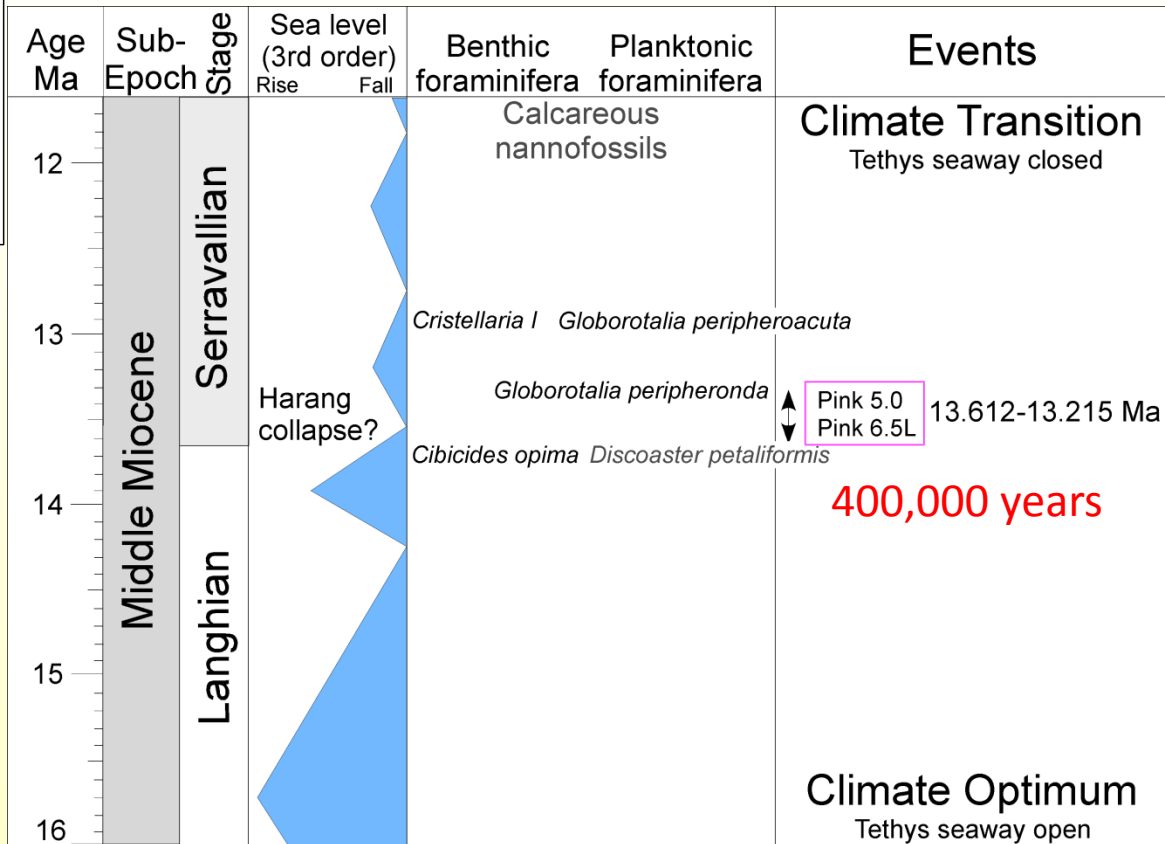
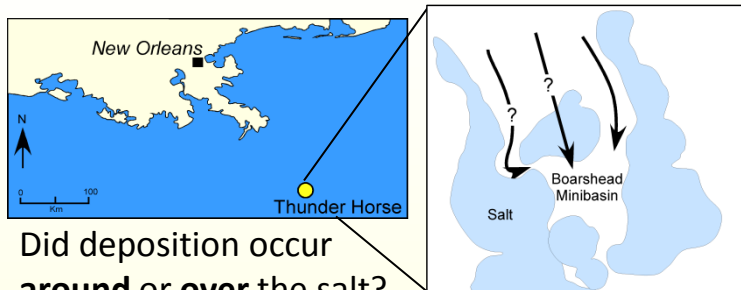
Thunder Horse



- Partnership BP 75% ExxonMobil 25%
- Discovered 1999 in Mississippi Canyon
- Produces from three stacked Miocene reservoirs: Pink, Brown, and Peach
- Two structures: North and South
- To date has produced 320 million barrels oil
- **Production Drilling Quarters**



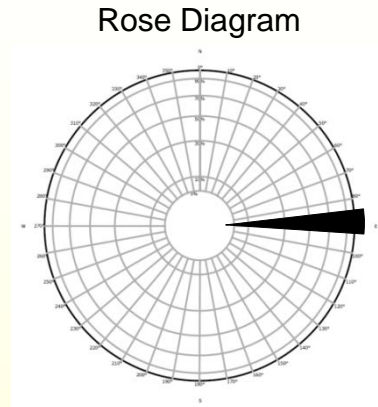
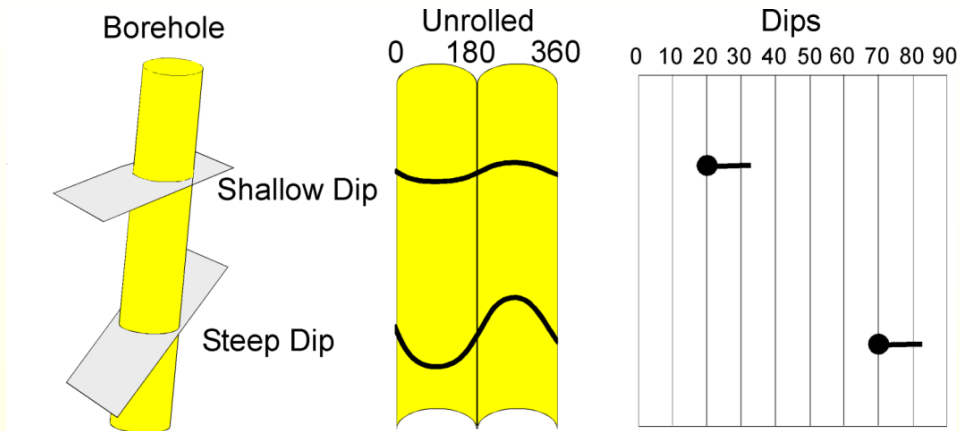
Study Focus: Northwest Thunder Horse, Middle Miocene



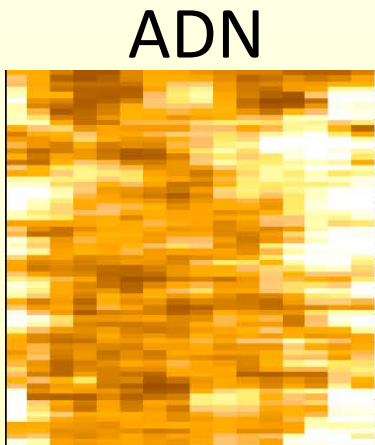
Value of Image Logs



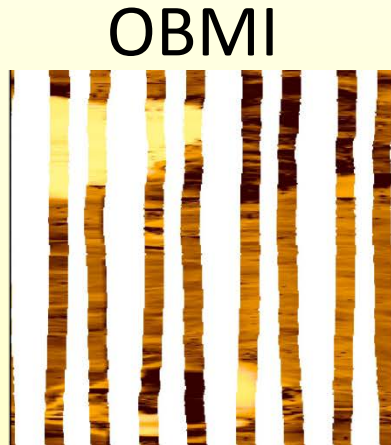
Dip Analysis



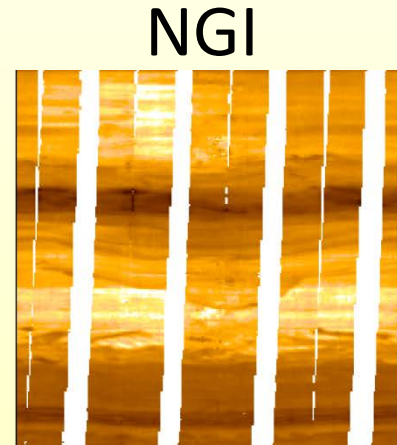
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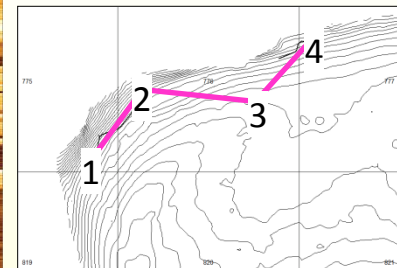
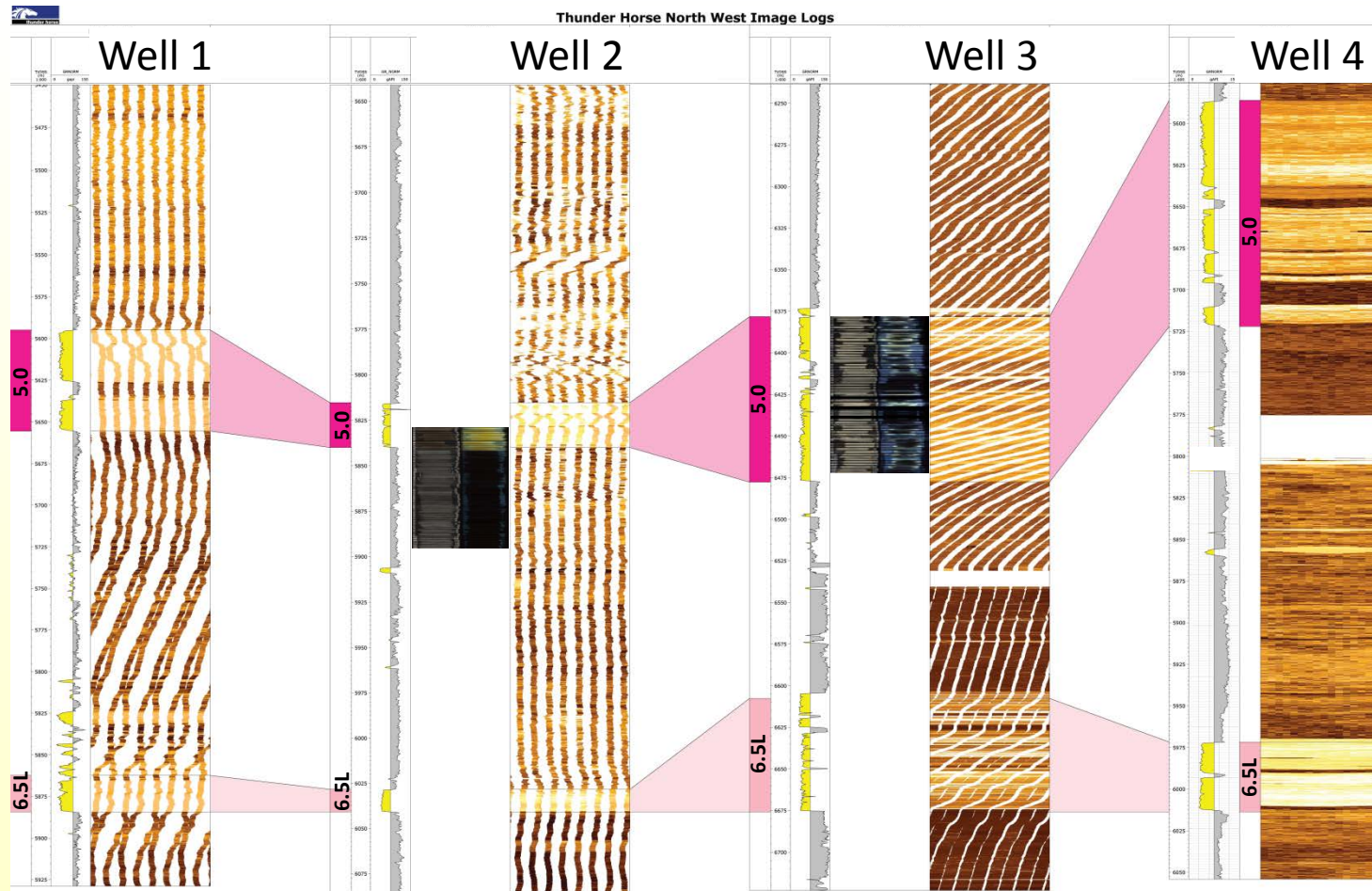
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(\$\$)



(\$\$\$)



A right triangle is shown with a vertical leg labeled 150 ft and a horizontal leg labeled 4 mi. The legs meet at a right angle at the top-left vertex.

Facies	Sub-Salt Seismic	ADN/OBMI	NGI	Core		
Mudrock	Parallel continuous	M1	iMm	Mm		
			iMI	MI		
			iMb	Mba		
		Mb				
		Mab				
M2		iMds	Mds			
M3		iMf	mcMM			
Heterolithic				siM		
				iH	SSI	
					Hm	
				iHb	Hsb	
				iHirr	Hsd	
Sandstone			S1	iSds	Hmd	
				iSm	Sm	
				iSdw	Sdw	
				iSI	Sdw1	
				iSwv	Sdw2	
					Sdw3	
				iSi	Si	
					Smp	
					MS/ccMS	
				iSb	Sb	
				iScon	Sc	
					mcS	
				iSI	SI	
				iScem	Sba	
				S2	iSx	Sx
					iSb	Sr
					iScl	Sr-cl
						Sr-s
S3	iSds	Sds				
Conglomerate		SC	iCgl	Cgl		
			iCgm	Cgm		



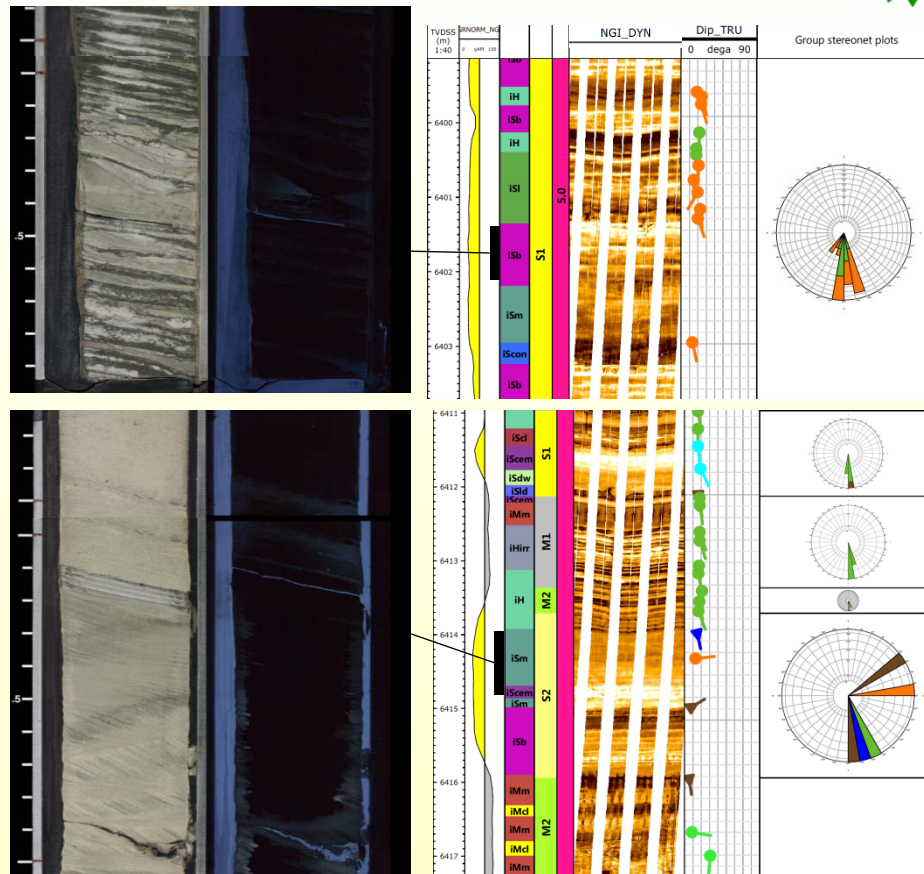
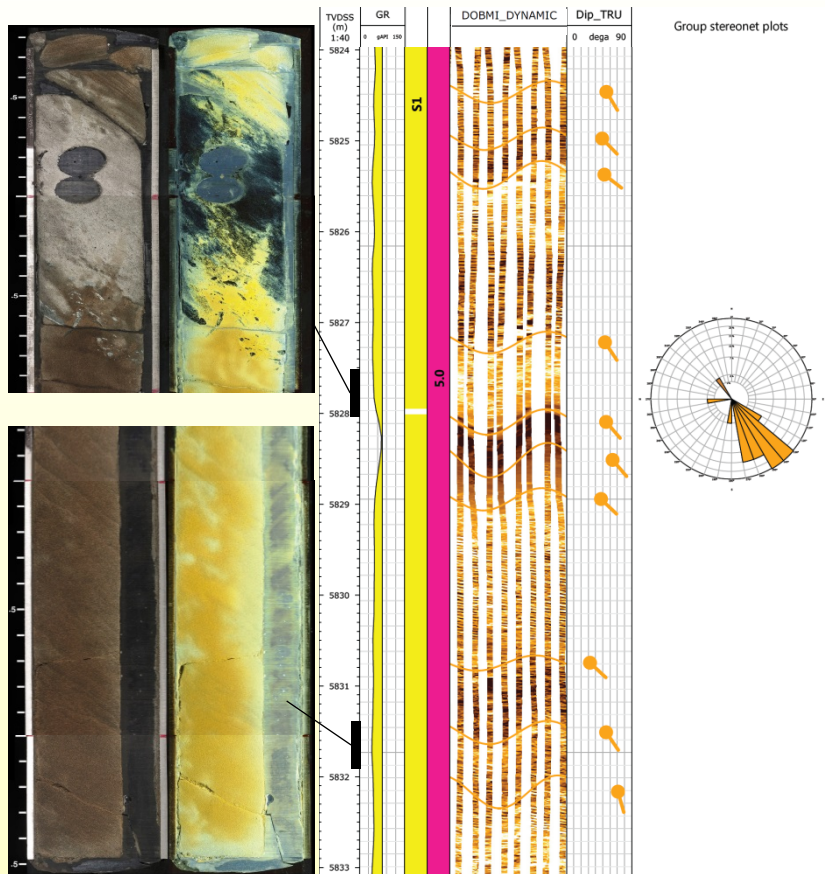
Image/Core Facies: Sandstone

bp



Massive Sandstone/S1

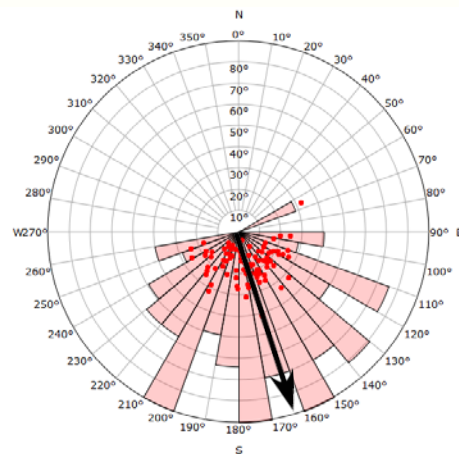
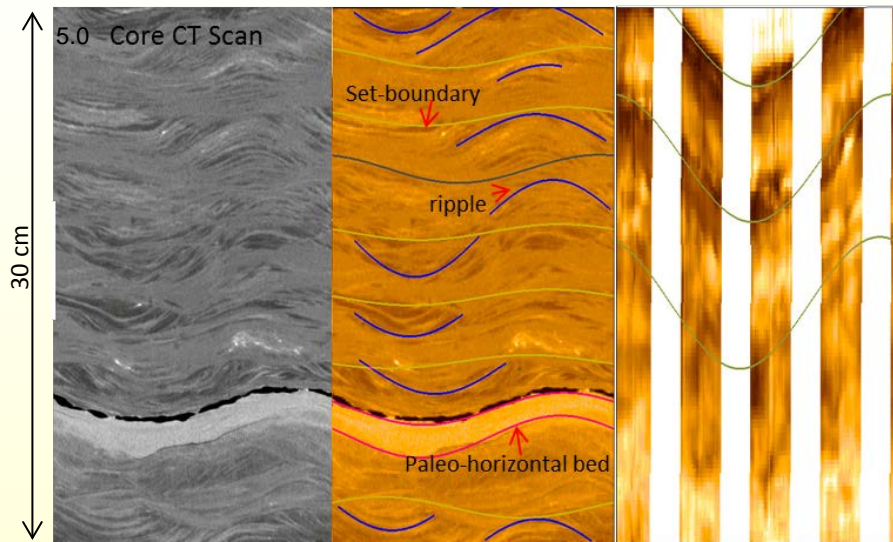
Laminated Sandstone/S1 and S2



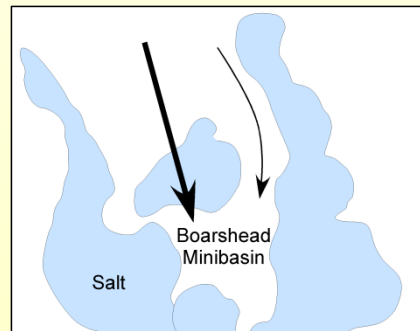
Sandstone Paleocurrent Analysis with Well 3 NGI



5.0 Oriented Core Set Boundary Dips

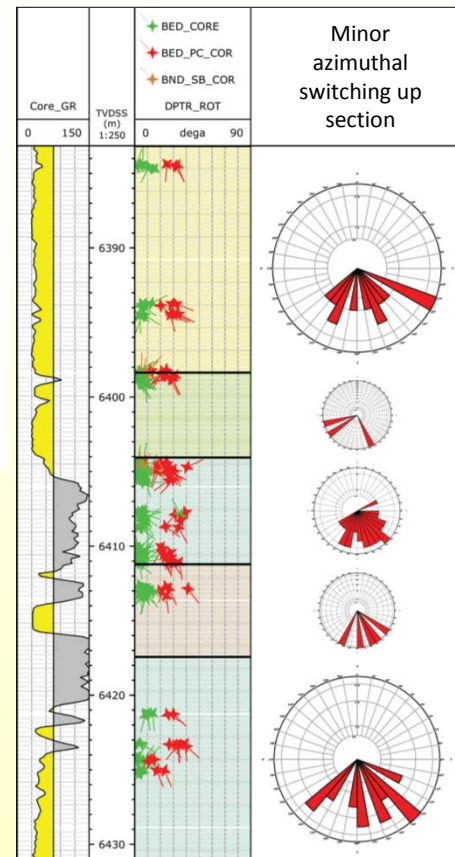


Paleocurrents trend SSE.



Implication:

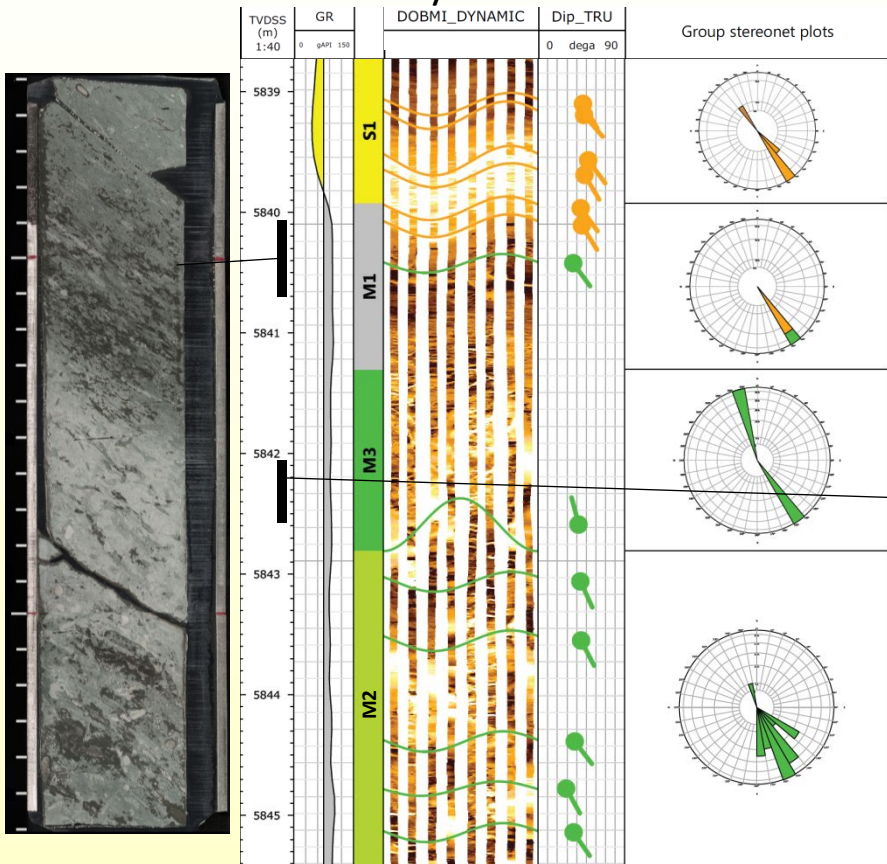
Flows NNW to SSE, over the (incipient?) salt diapir.



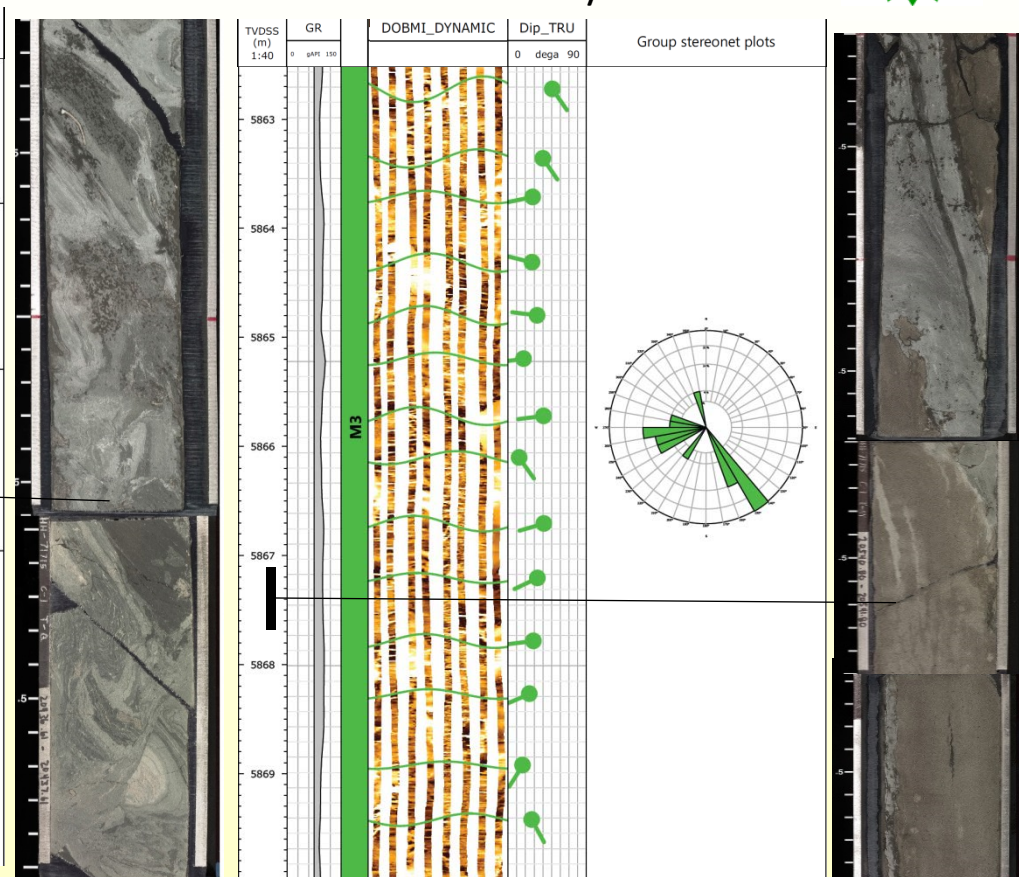
Image/Core Facies: Mudrock



Calcareous Mudrock/M1

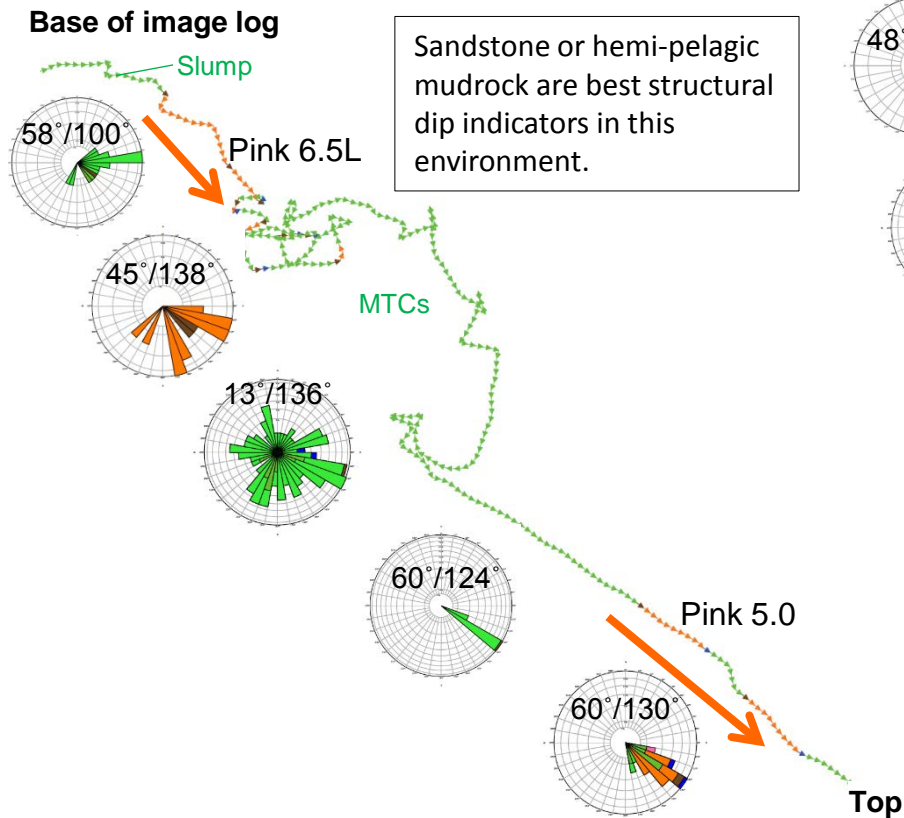


Deformed Mudrock/M2 and M3

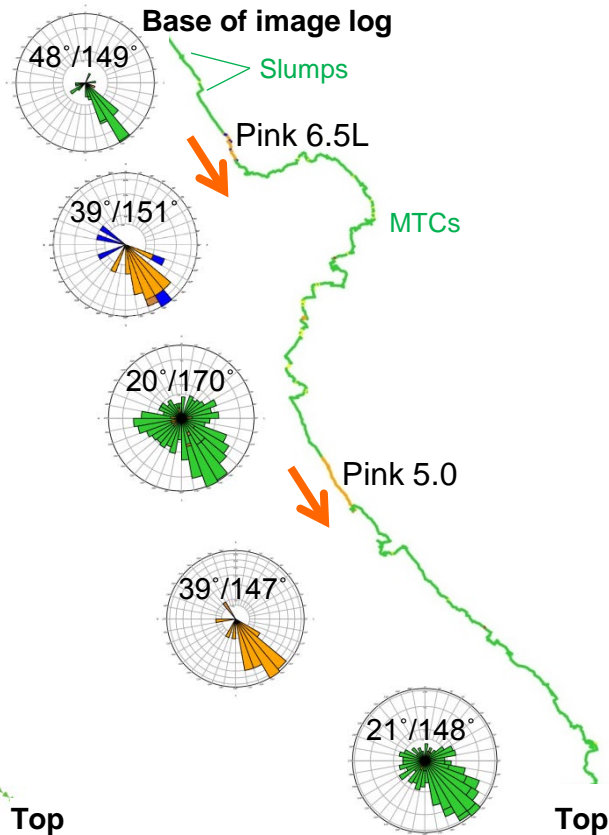


Dip Trends in Mud and Sand

Well 1



Well 2



Well 3

Base of image log

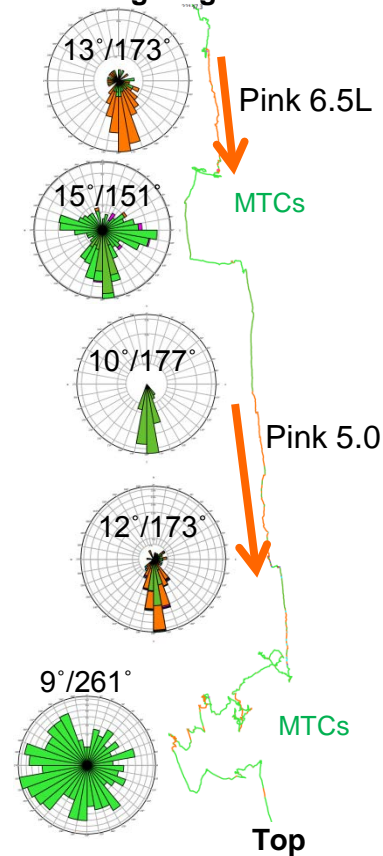
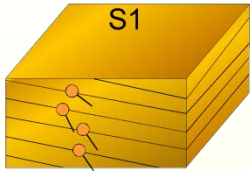
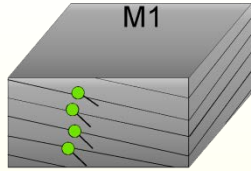


Image Facies

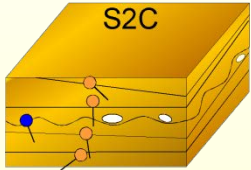
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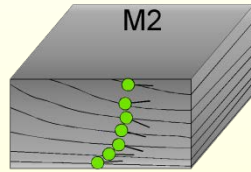
Amalgamating unidirectional turbidite sands



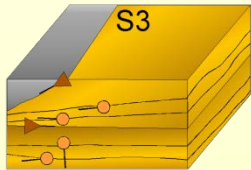
Hemipelagic mud or low density turbidites



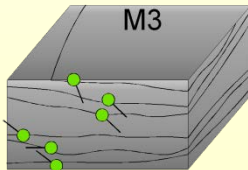
Scouring, avulsing turbidite sands



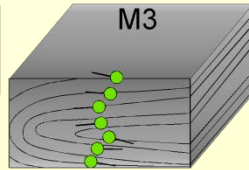
Slide block



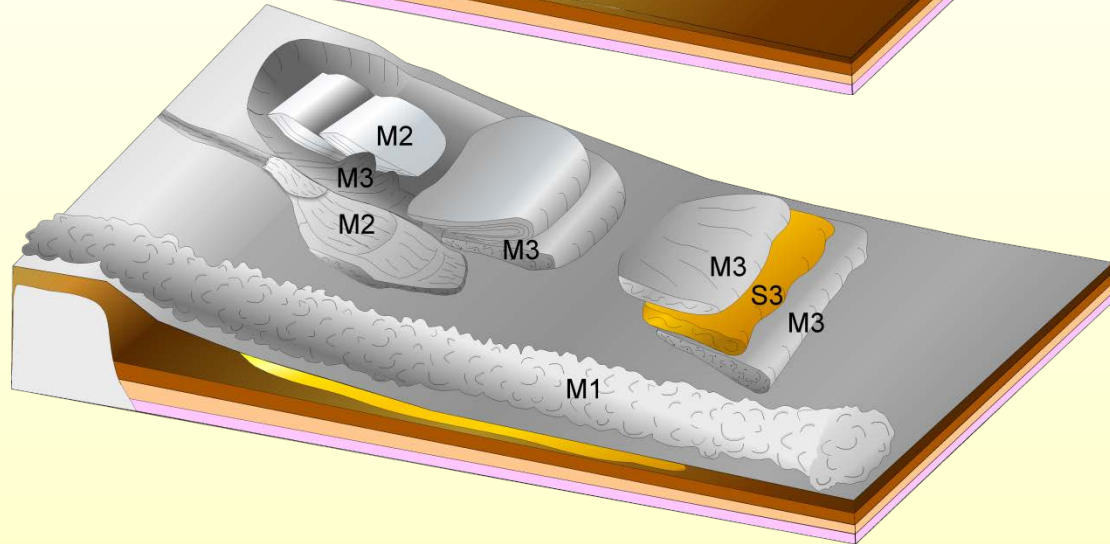
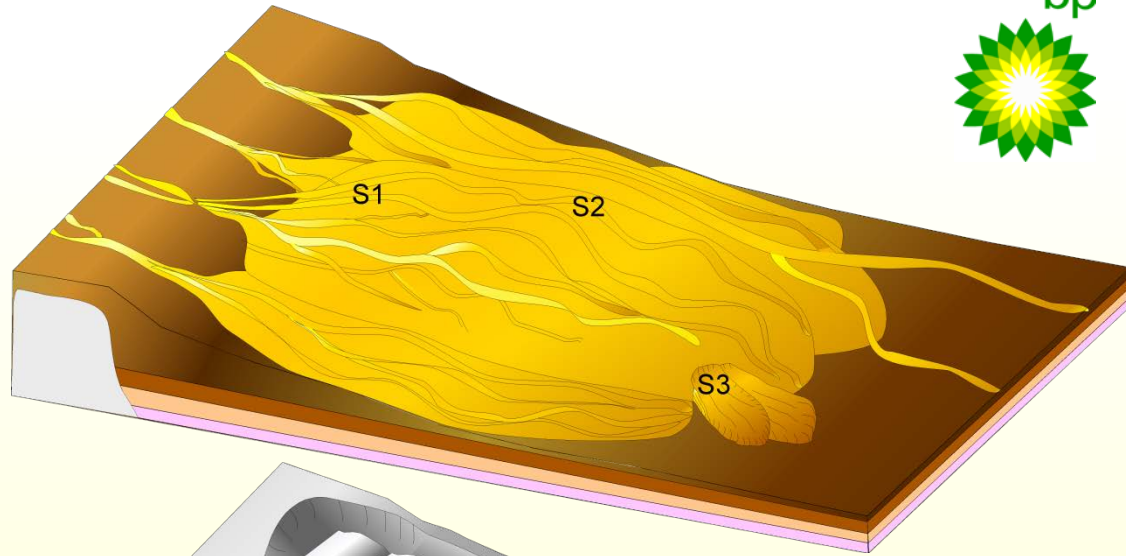
Sandy slump



Muddy slump



Fold





Thunder Horse North West Image Log Dips

MC775.1_ST1

Well 1

MC776.6

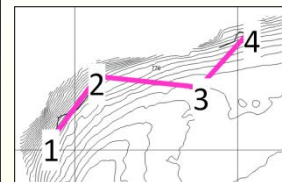
Well 2

MC776.7_BP2

Well 3

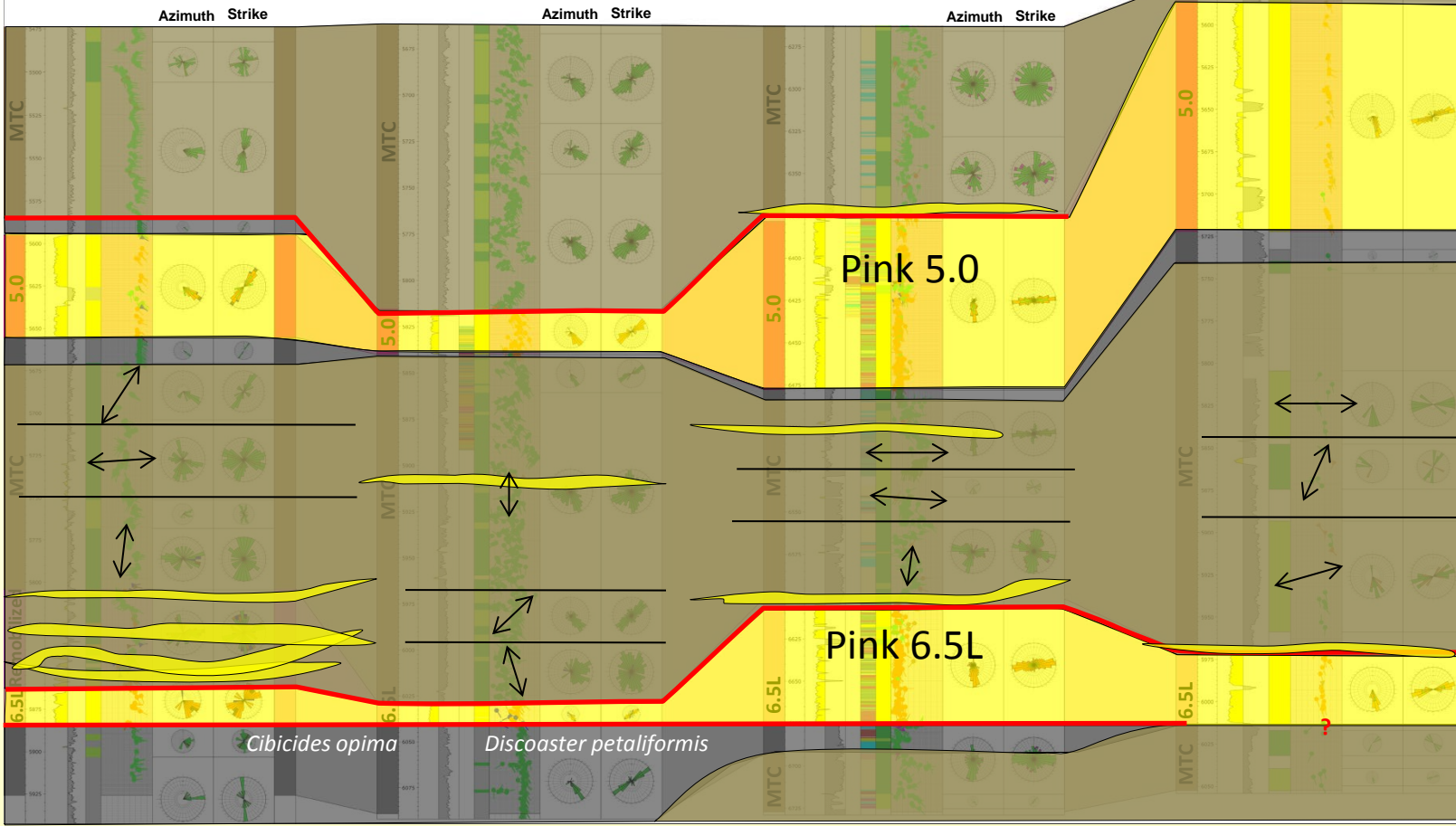
MC777.9

Well 4



150'
4 mi

Strike rose diagrams indicate depositional axes.

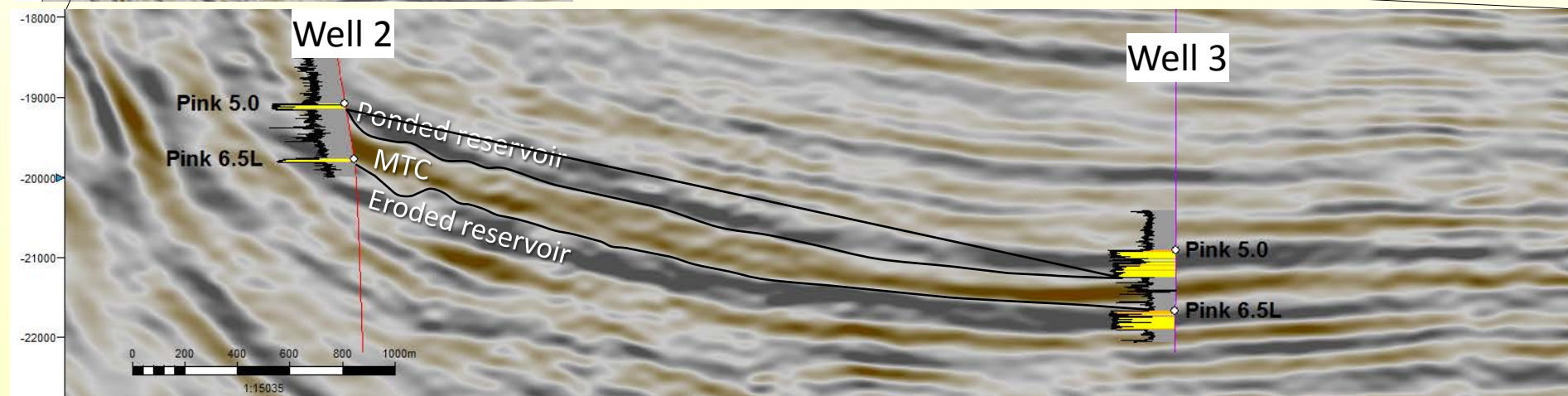
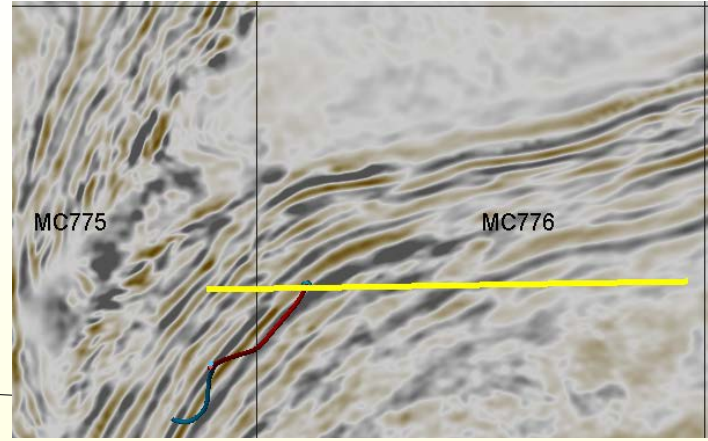
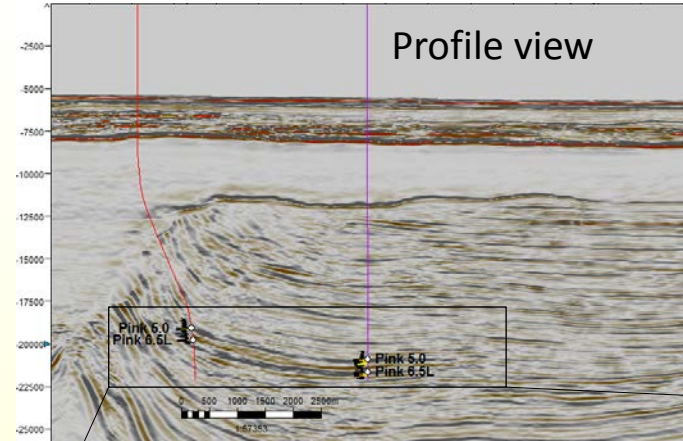


Do MTCs help us or hurt us?



MTC:

- Erosion of Pink 6.5L reservoir
- Built up a topographic high that ponded the Pink 5.0 reservoir



Conclusions: Thunder Horse



- Dips in mudrock show **widely varying dip magnitude and azimuth**, interpreted as slumps, slides, and folds, **building up mass transport complexes**.
- Turbidite sand dips are more likely to be conformable to regional dip and strike.
- Pink 5.0 fairway is **SSE, along the regional axis of lower Mississippi Canyon**.
- MTCs locally **eroded** and **remobilized** the Pink 6.5L and Pink 5.0 reservoirs. In core and on seismic the MTCs also appear to **build up a topographic high and pond** Pink 5.0 reservoir.

Conclusions: MTCs impact on reservoirs



- Can be reliably identified in core and image logs but not always on seismic.
- Can amalgamate as layers that are visualized by seismic as parallel continuous, but are not laterally extensive.
- Can erode underlying reservoirs.
- Can remove biostratigraphic markers.
- May contain sandy components masquerading as turbidite reservoirs.



Can create bathymetric highs as evidenced by hardgrounds in core, which are pronounced enough to cause ponding.

Do MTCs help us or hurt us?

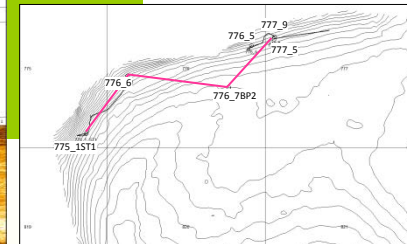
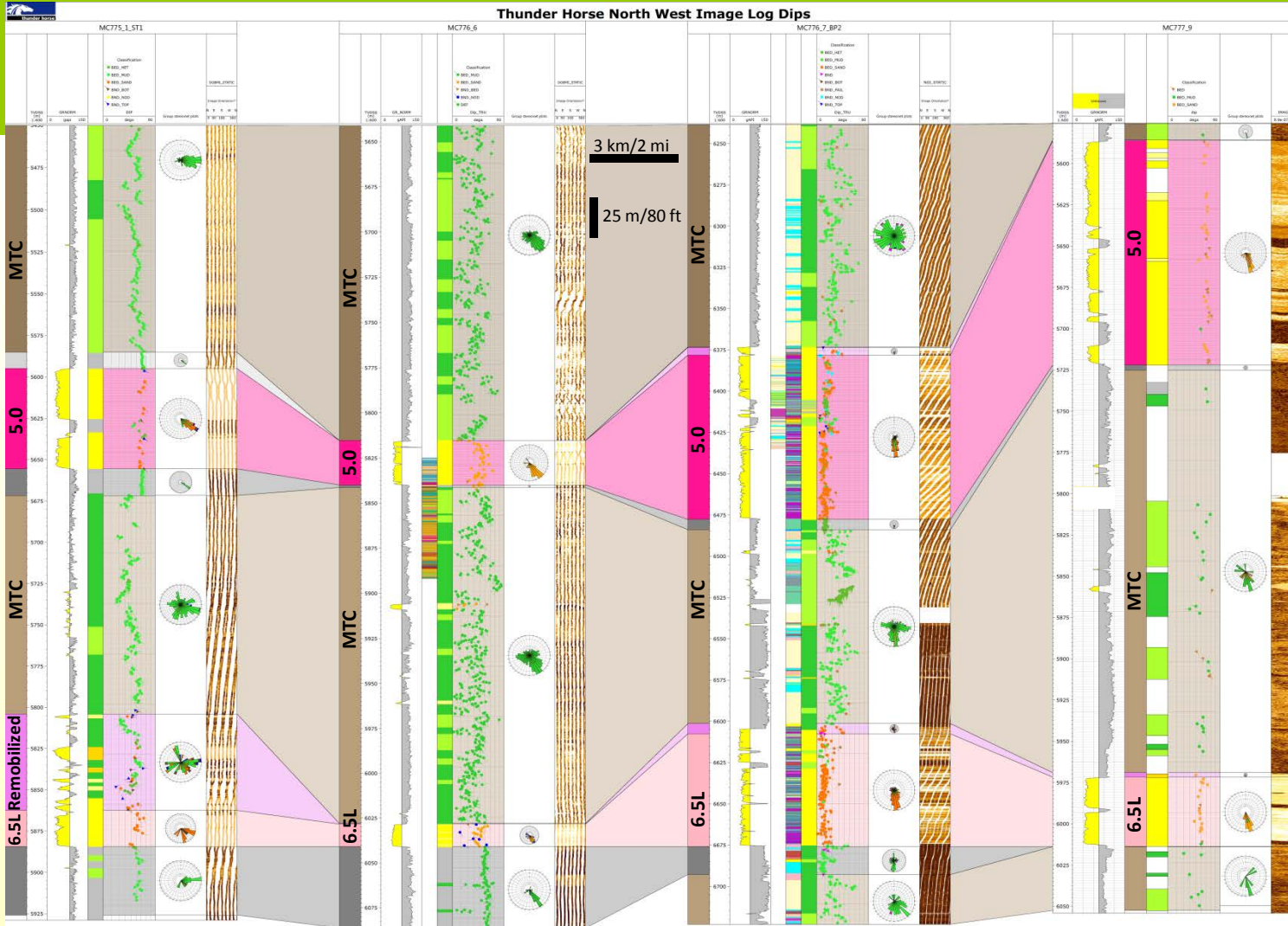
Both.

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Back up





3 km/2 mi

25 m/80 ft

MTCs

- Erode
- Remobilize
- Amalgamate
- Pond