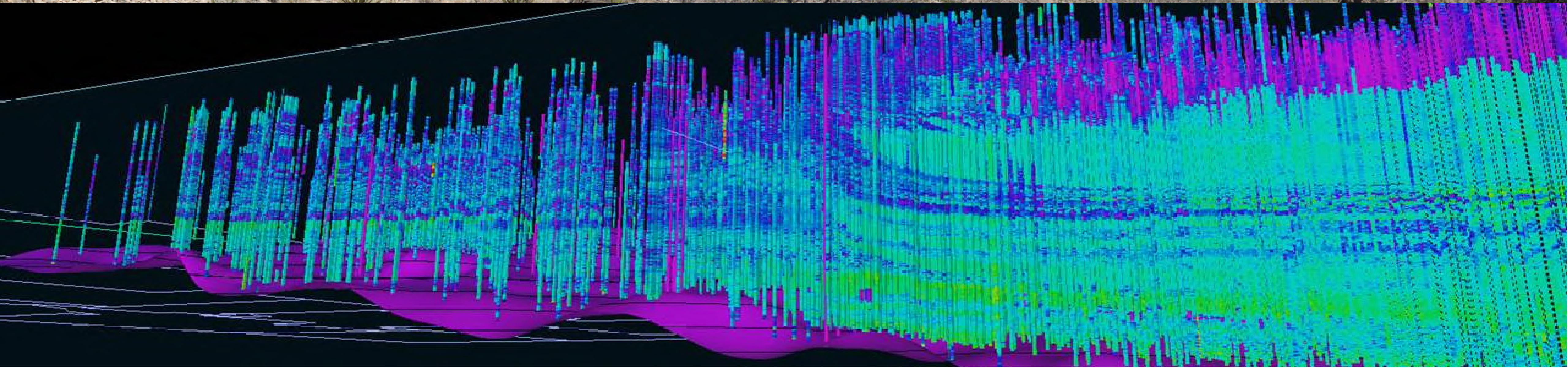
Reinterpretations of Re-sedimented Deepwater Carbonates: Examples from the Permian Basin, Southeast New Mexico and West Texas, U.S.A.



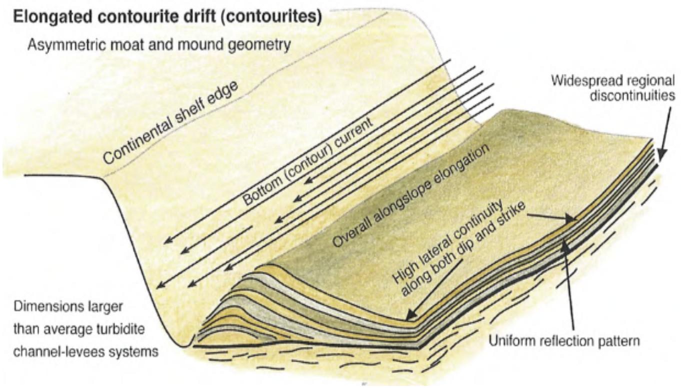
TEXAS Geosciences
Bureau of Economic Geology
Jackson School of Geosciences
The University of Texas at Austin

Buddy Price

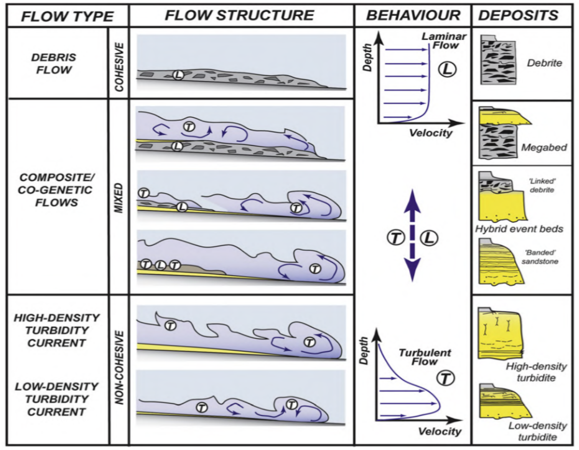
Roswell Geological Society, April 12, 2022

Reservoir Characterization Research Laboratory

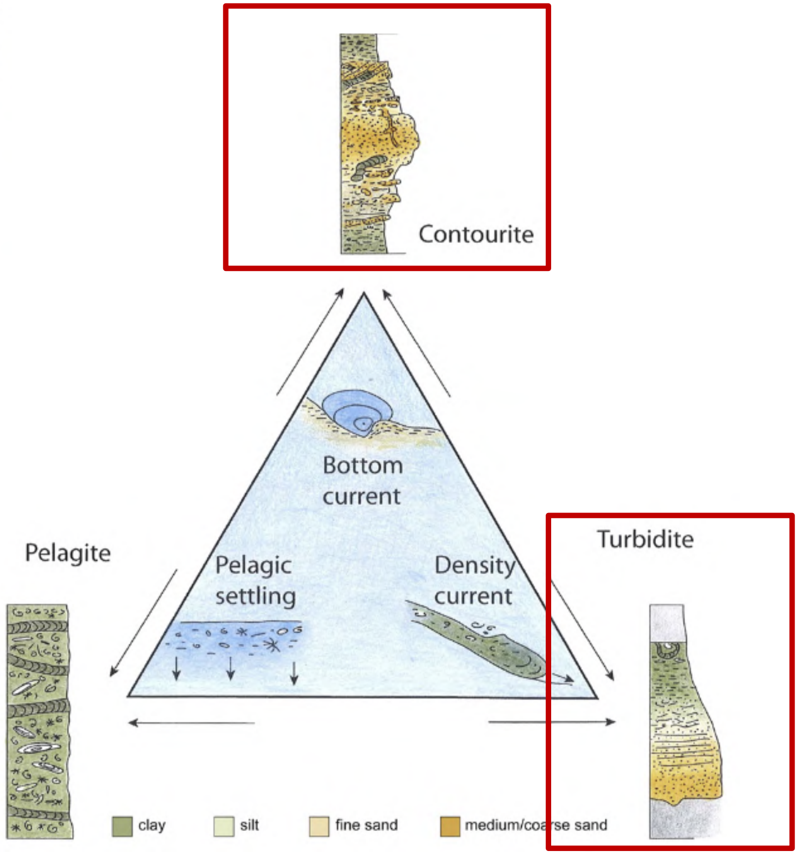
Basinal Sedimentation Processes



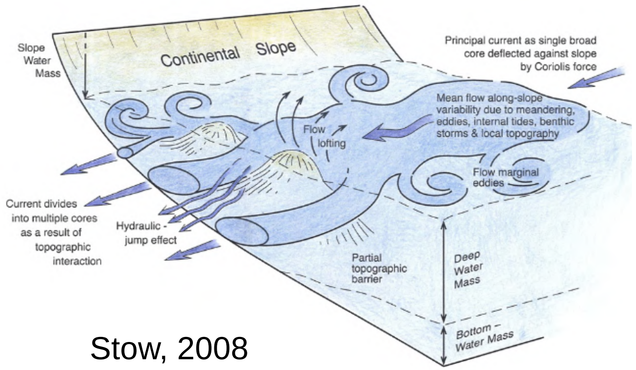
Rebesco, 2005



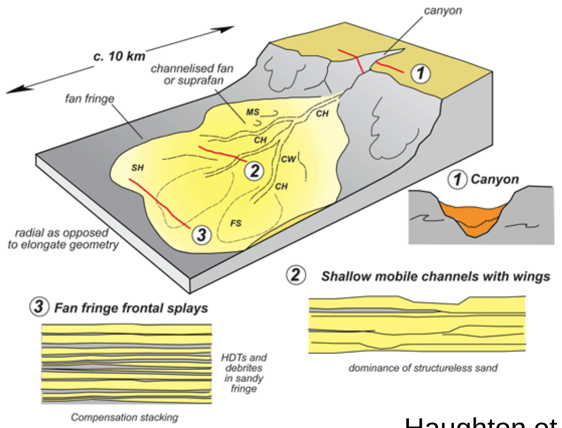
Haughton et al., 2009



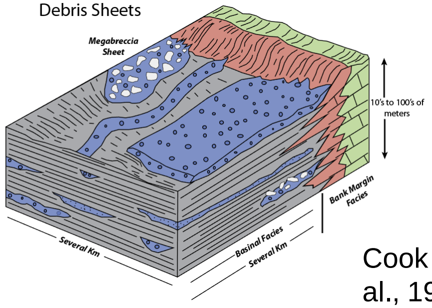
Rebesco et al., 2014



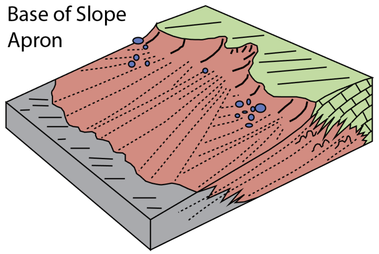
Stow, 2008

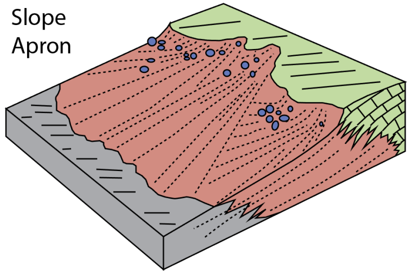


Haughton et al., 2006



Cook et al., 1972





Mullins and Cook, 1986

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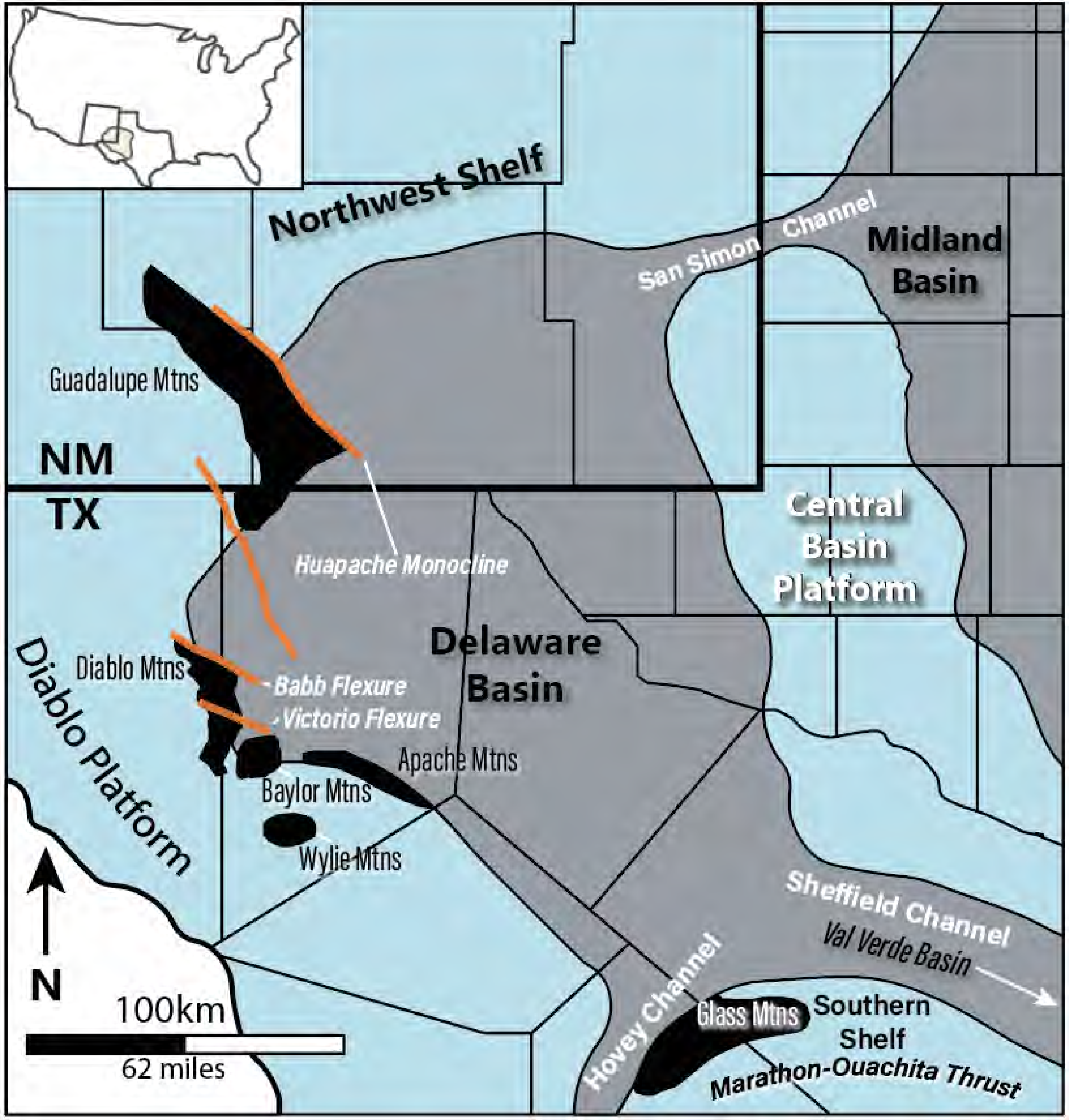
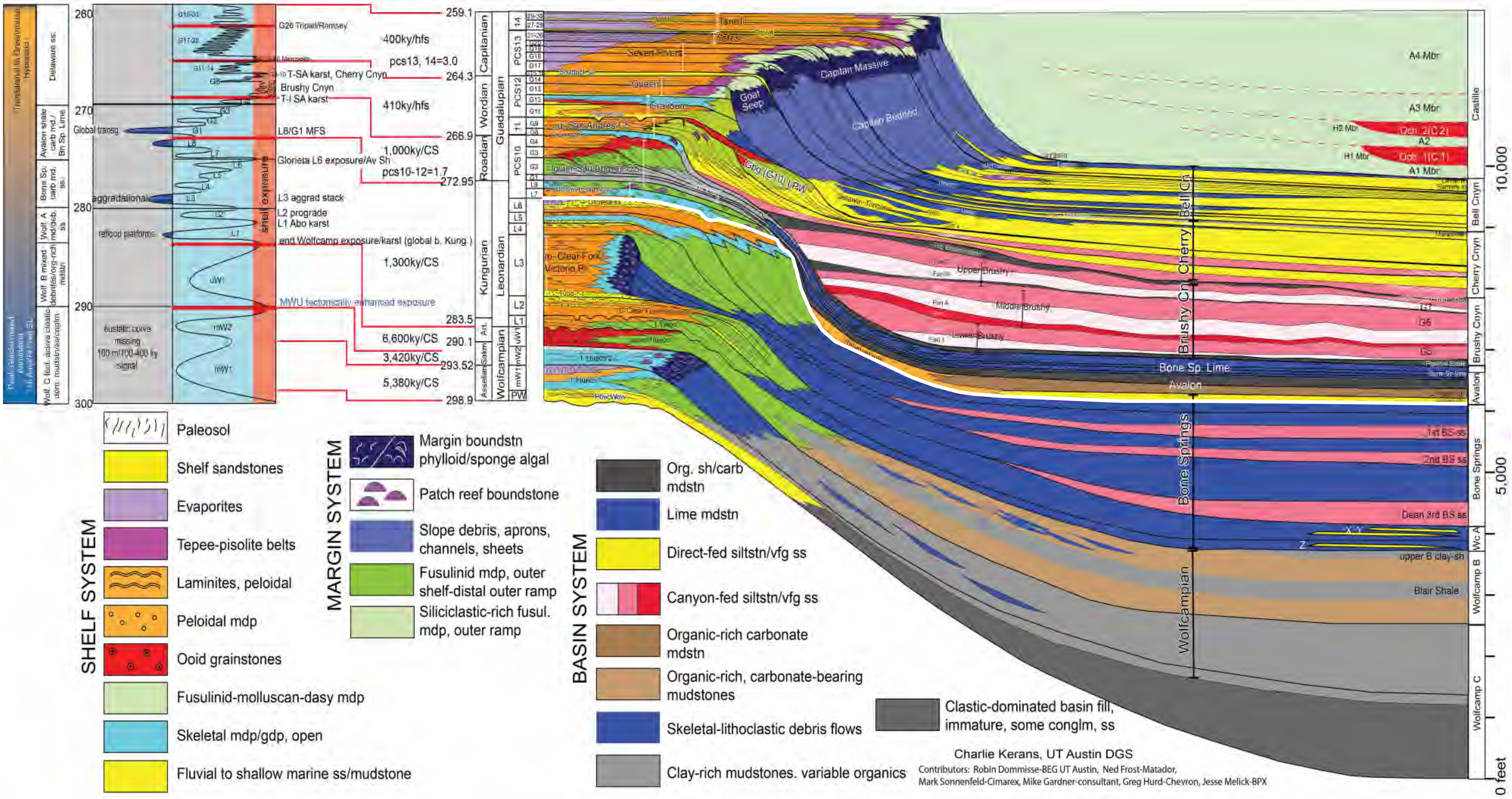


Early Leonardian Paleo-reconstruction

Modified from Fitchen et al., 1995

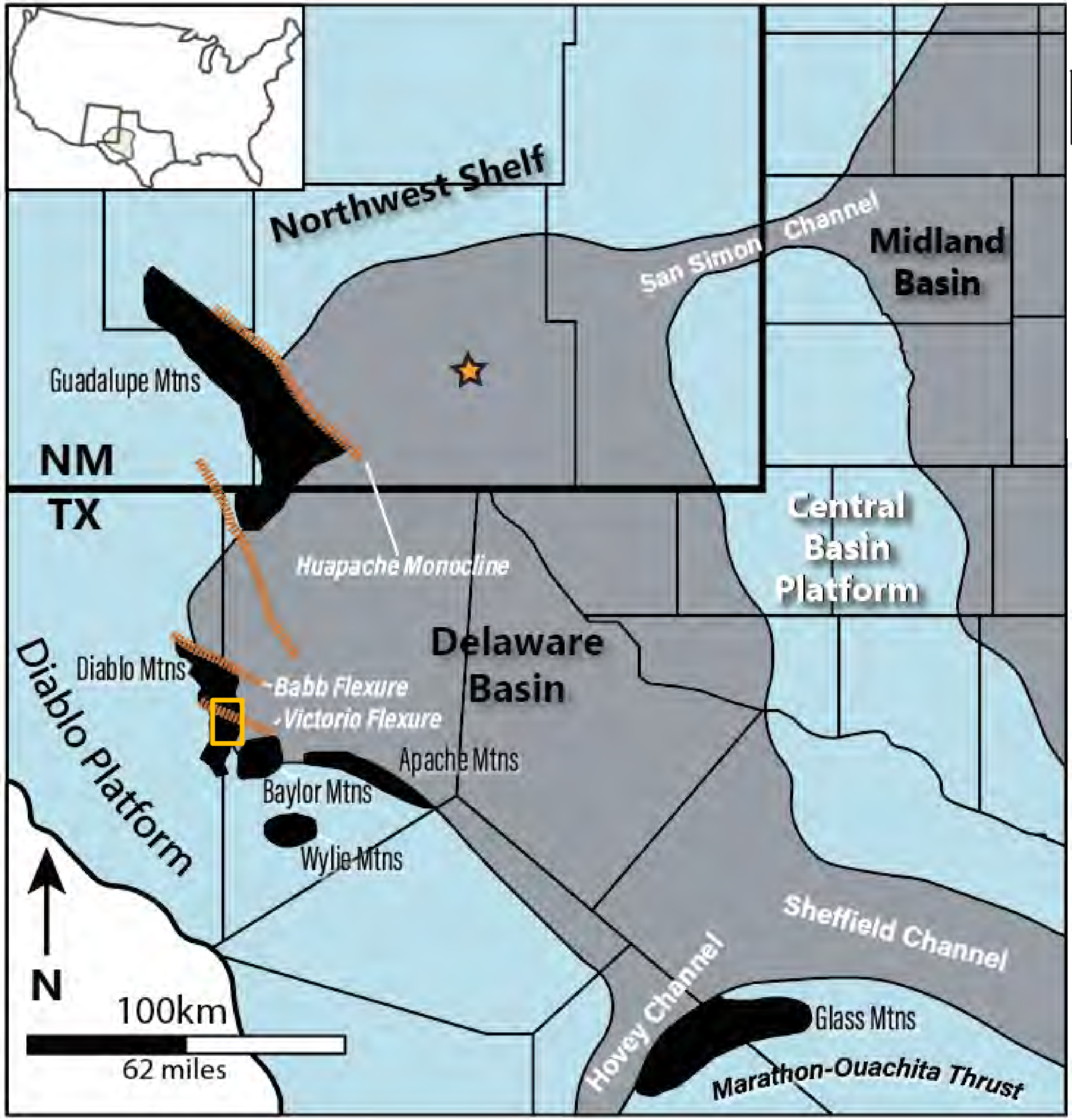
Delaware Basin

- Deep basinal settings rimmed by variable carbonate platforms and slopes
  - *Source and route sediment gravity flows*
- Connecting straights or gateways to adjacent water bodies
  - *Present possibility of bottom current circulation*
- Decades of research from Permian-aged outcrops and subsurface
  - *provides a constrained Permian stratigraphic framework*



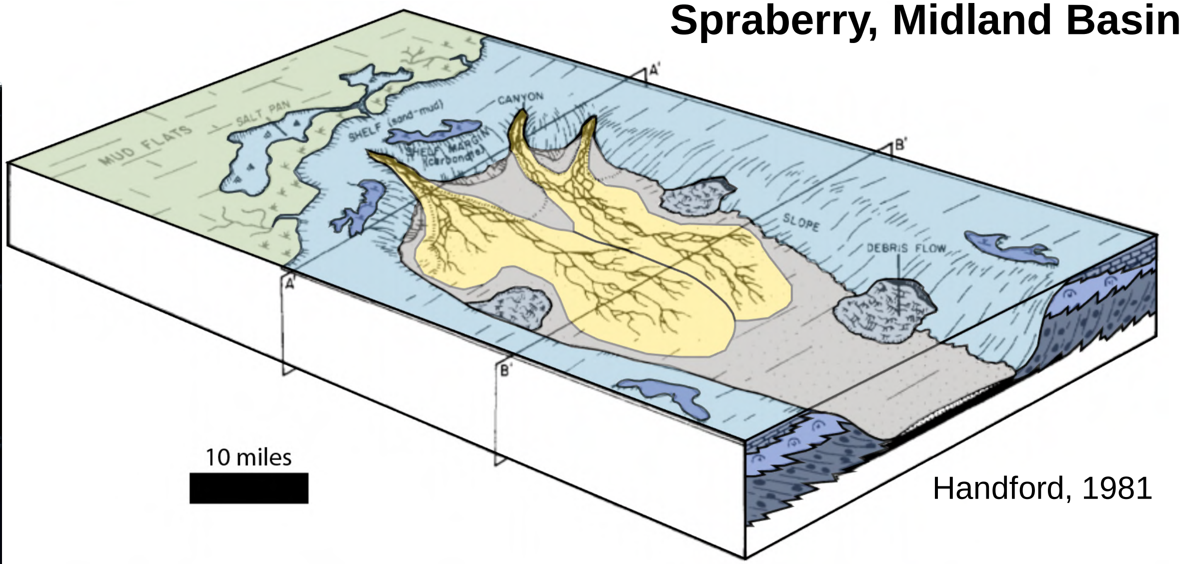
Kerans, RCRL 2019-2021

Permian Basin



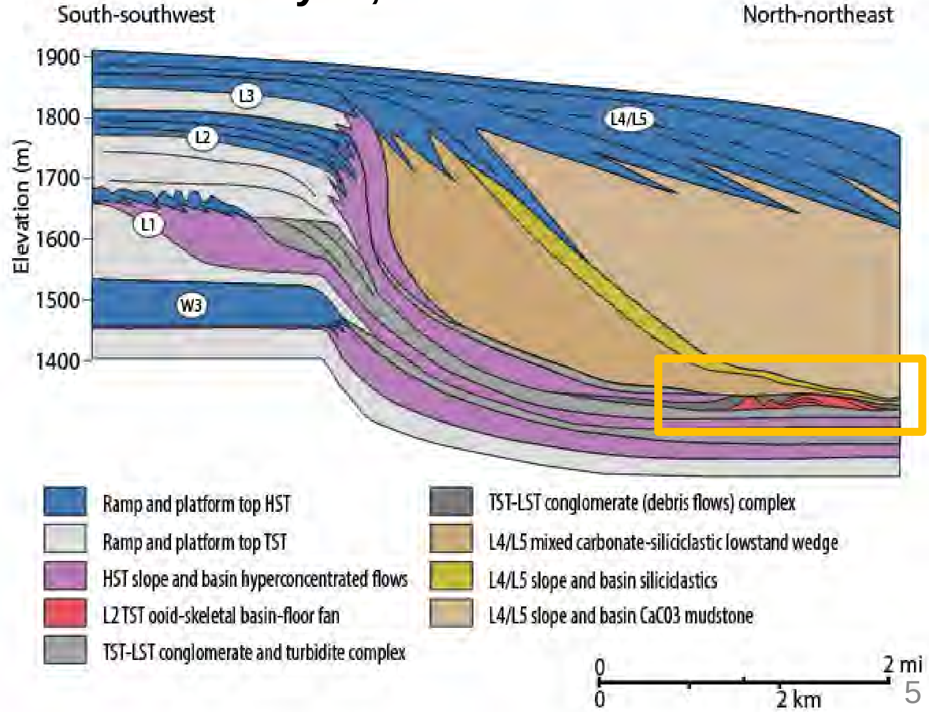
Modified from Fitchen et al., 1995

Spraberry, Midland Basin



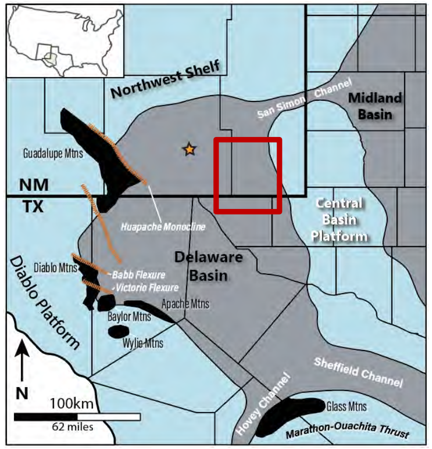
Handford, 1981

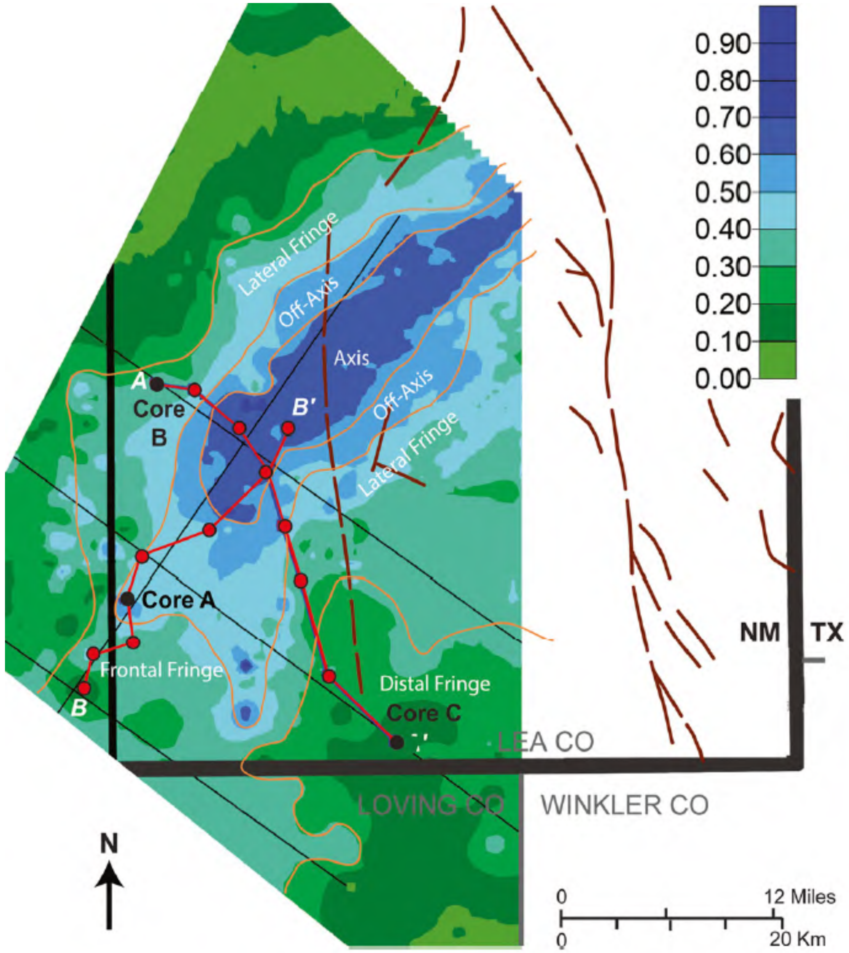
Victorio Canyon, Sierra Diablo Mountains

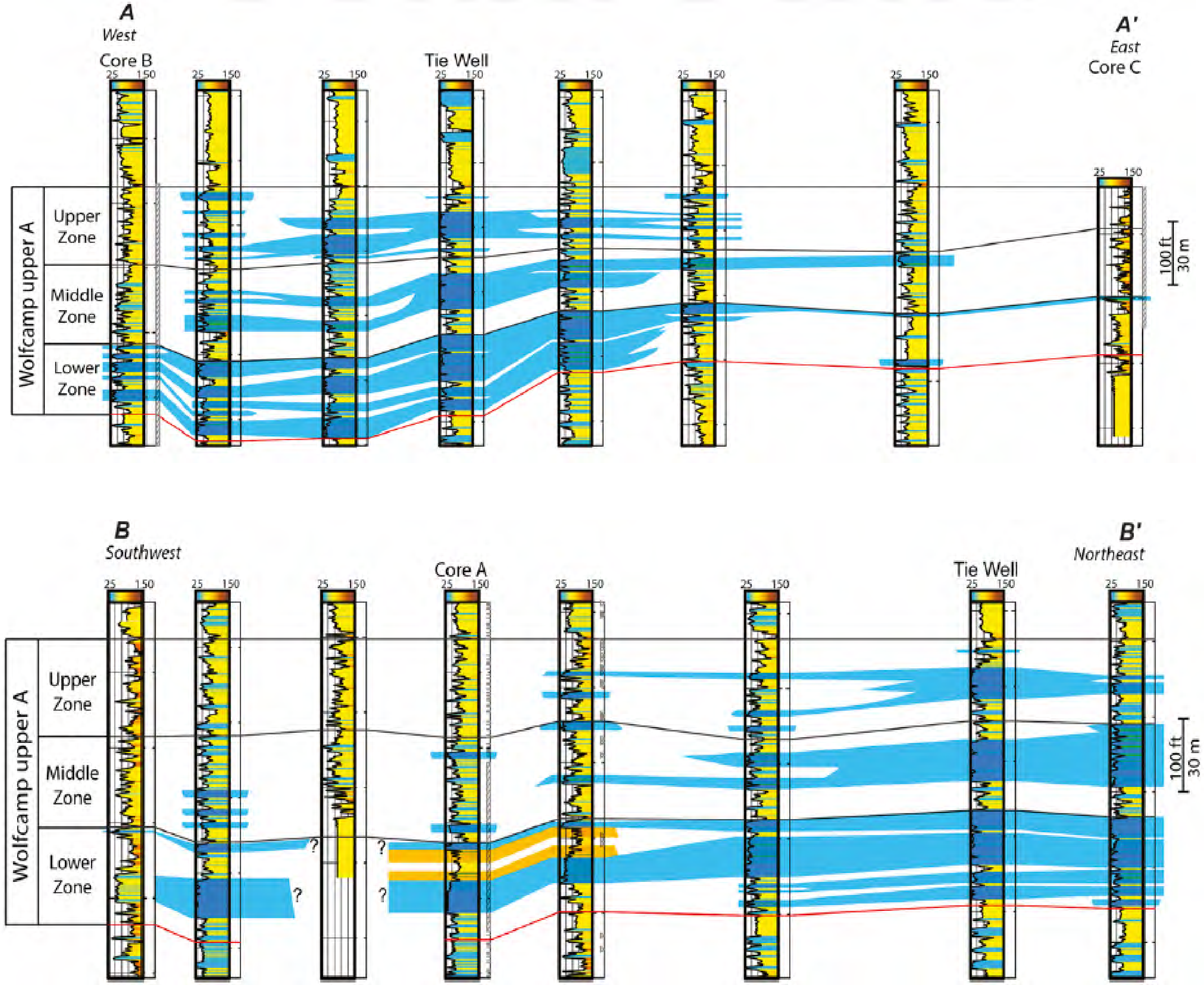


Kerans, 2001; Janson et al., 2007

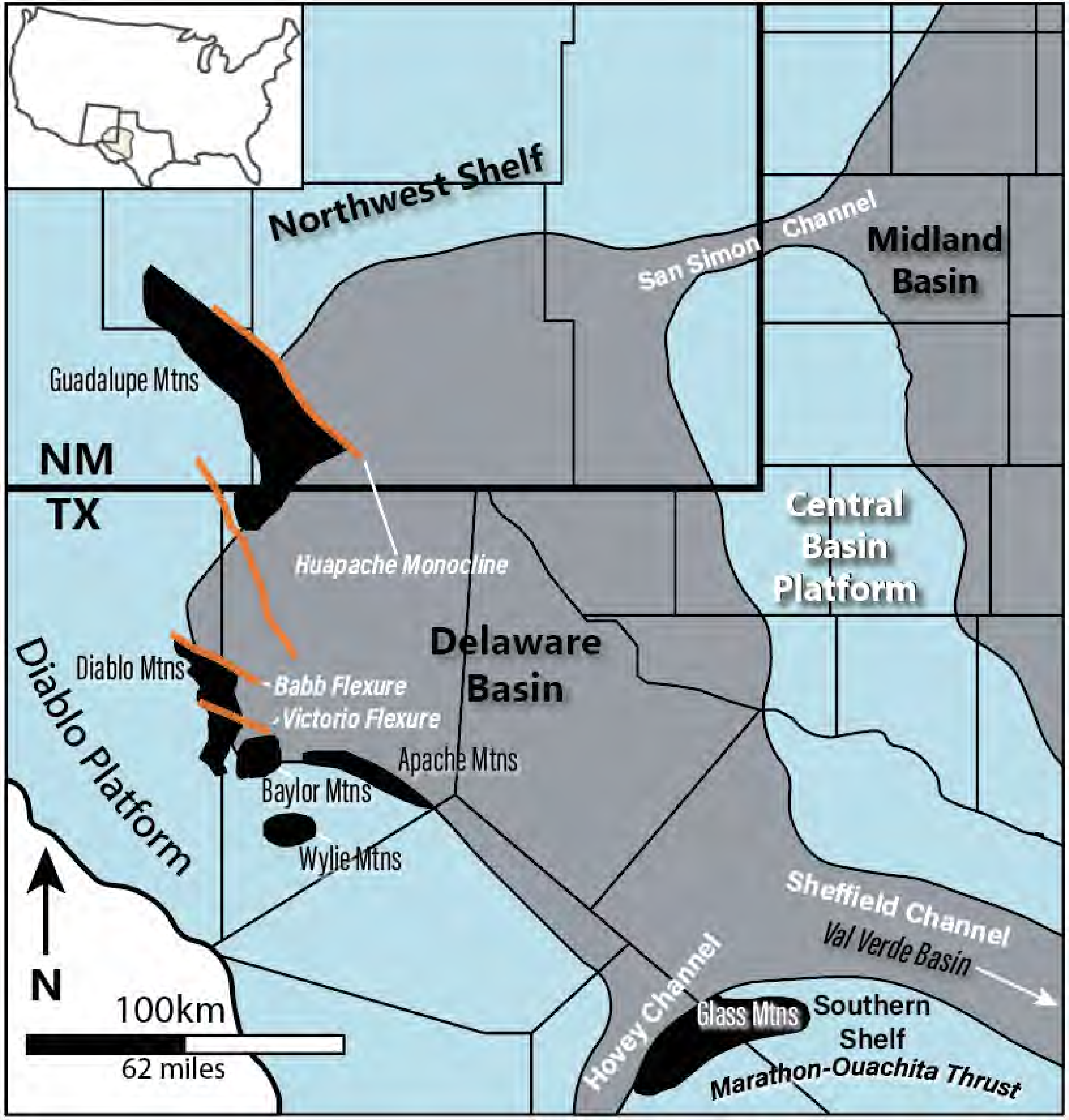
Permian Basin Basinal Depositional Models







Kvale et al., 2020



Problems and Questions

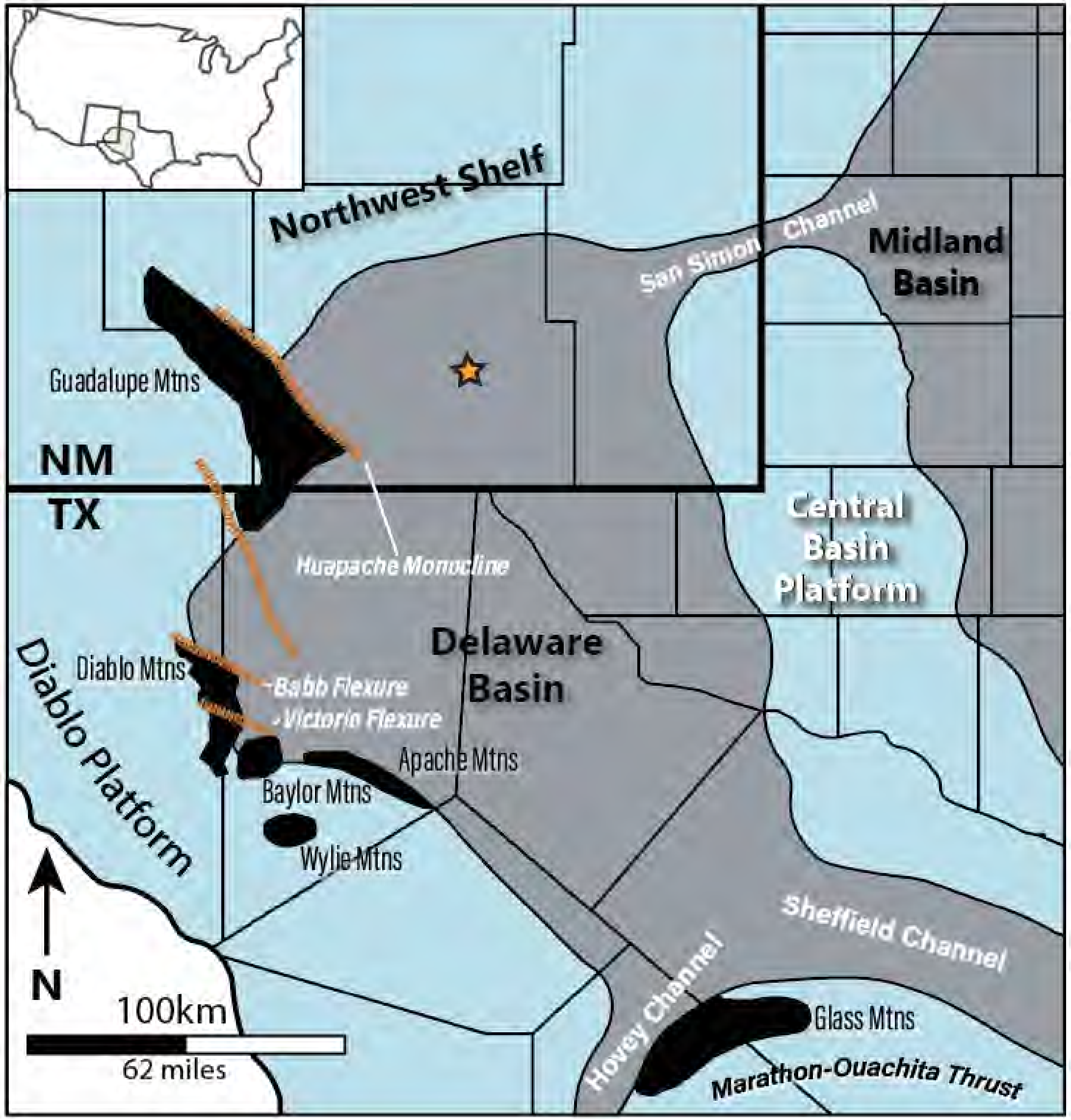
Some existing basinal depositional models appear to be outdated.

New interpretations of calciclastic fans are shedding light on the need for regional re-assessment.

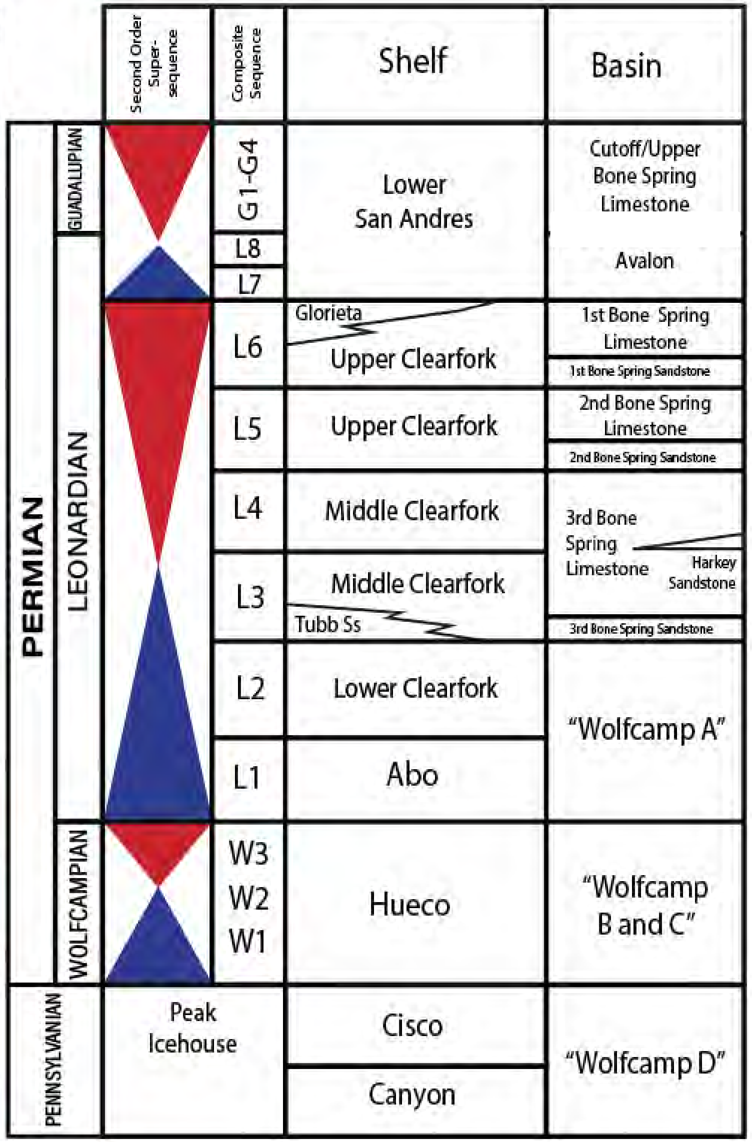
1) Can the combination of regional subsurface studies and insight from new models lead to updated interpretations of the basinal stratigraphy?

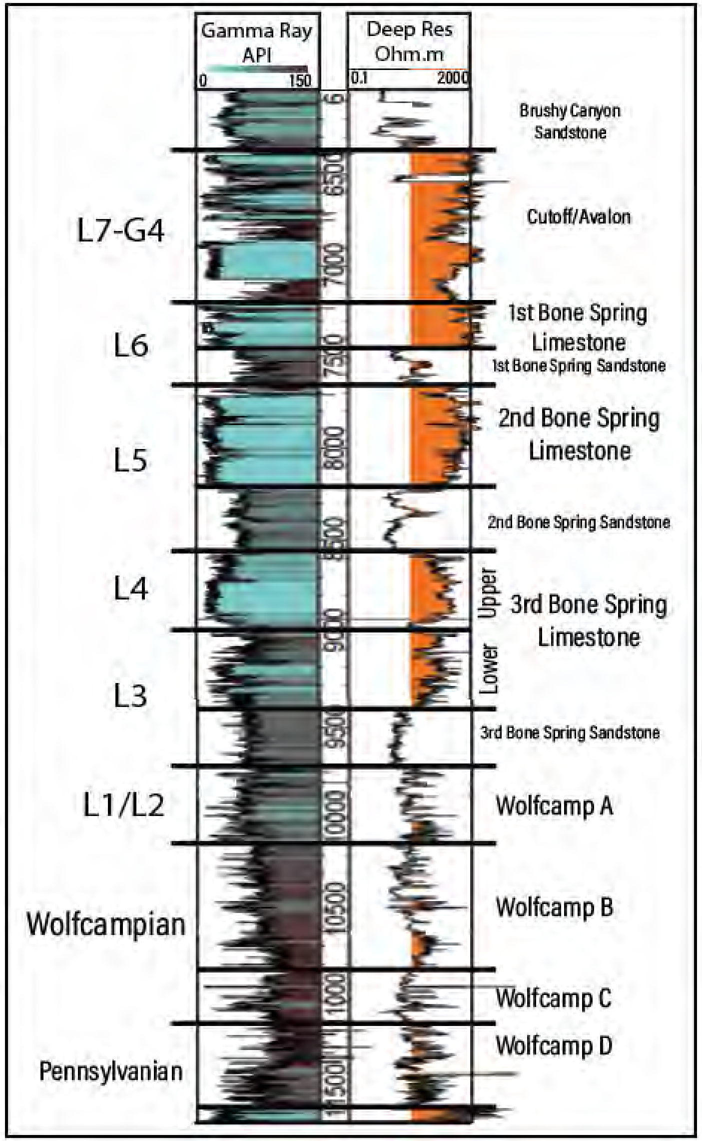
2) Can new models increase the predictability of facies architecture and subsequent reservoir and non-reservoir distribution in the subsurface?

Study Intervals



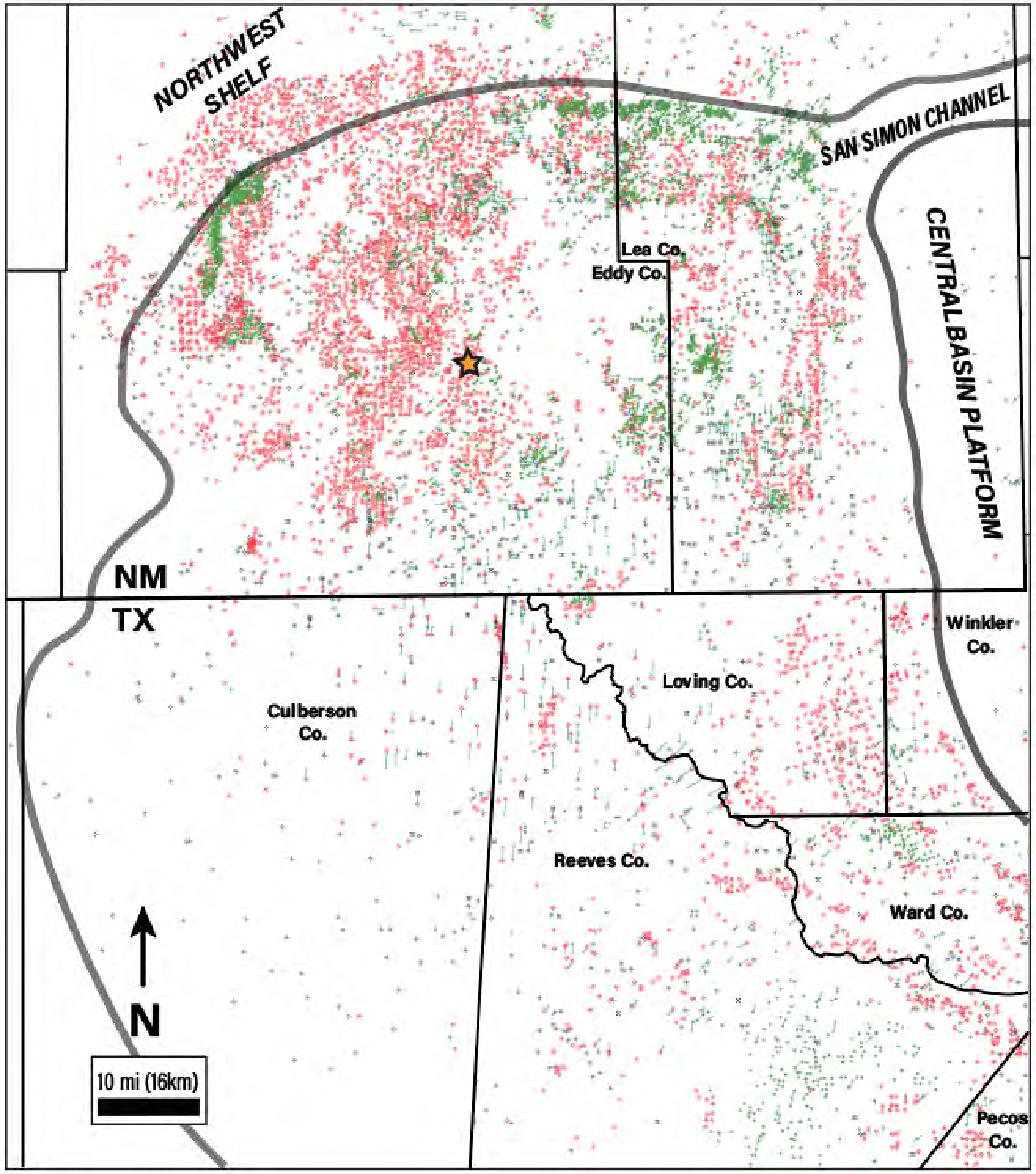
Price et al., in review

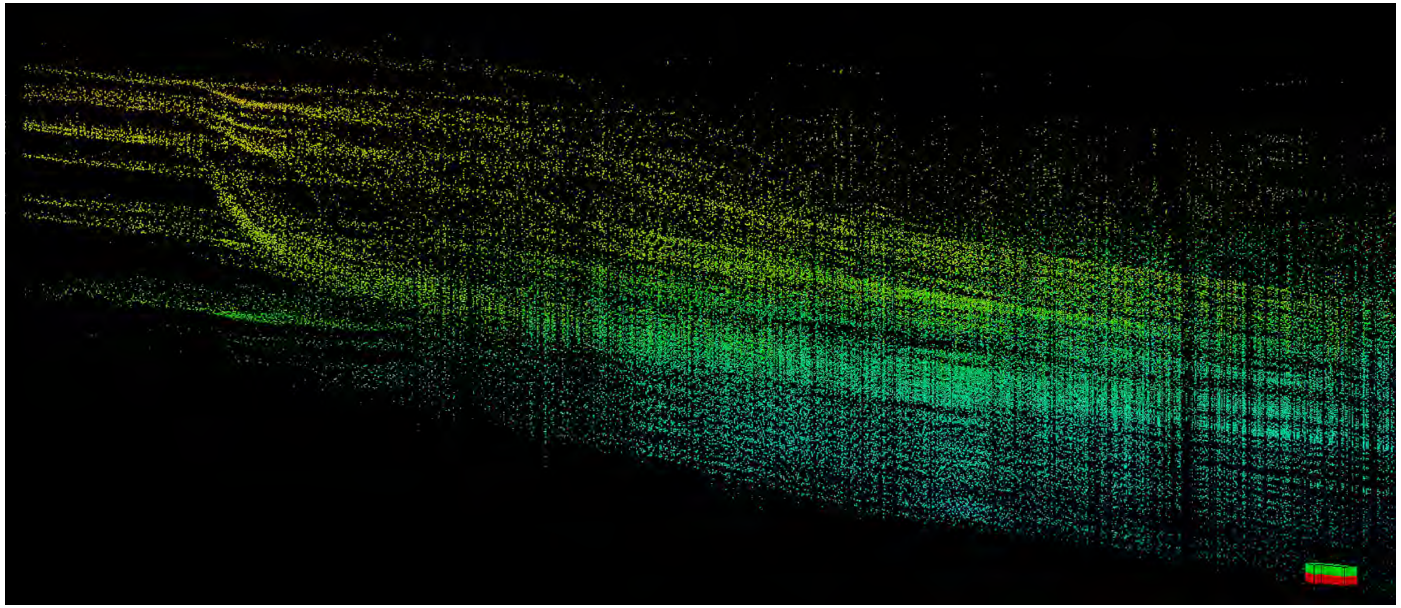




(Modified from Fitchen et al., 1995; Kerans, 2001; Janson et al., 2007)

Methods

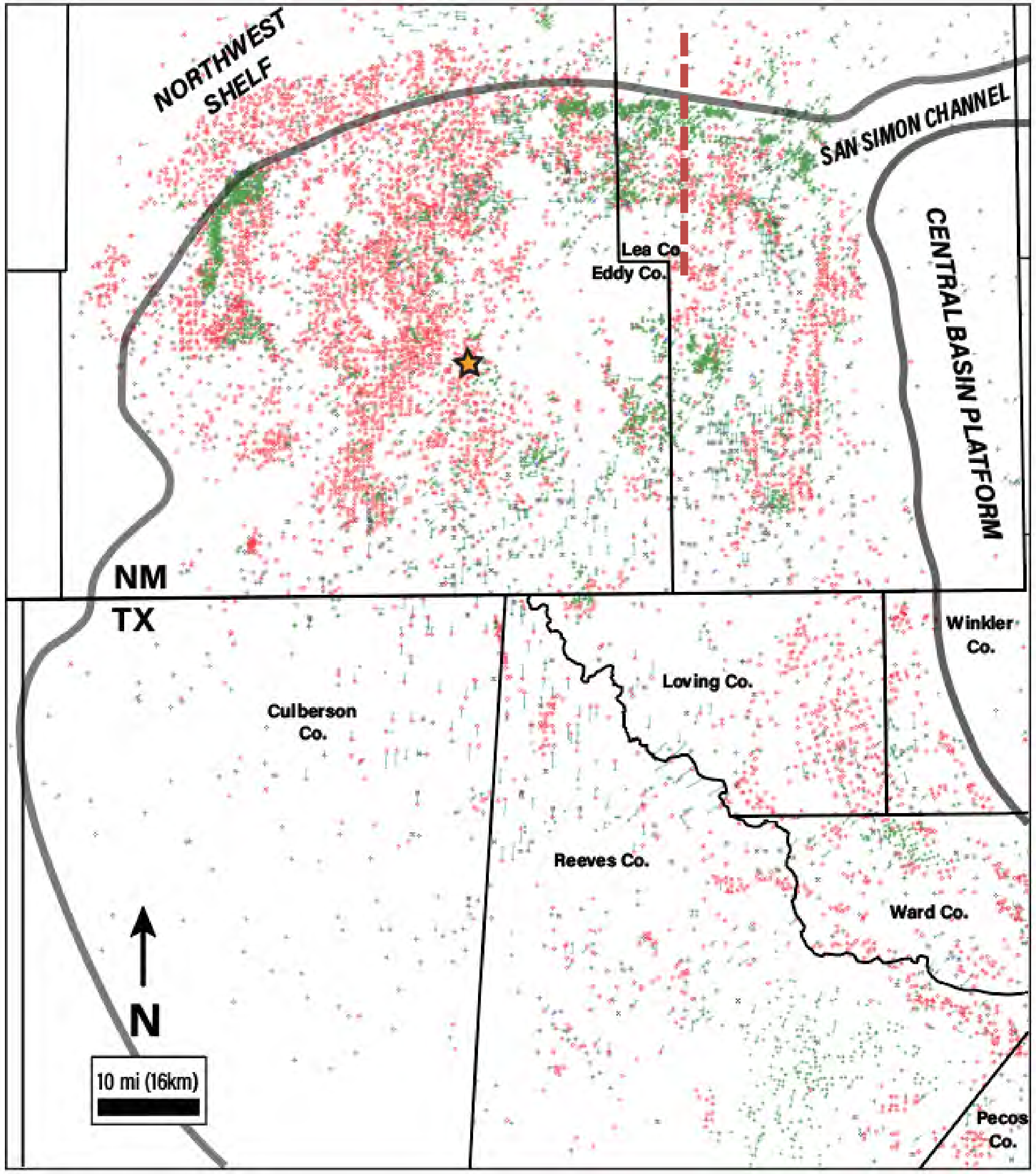


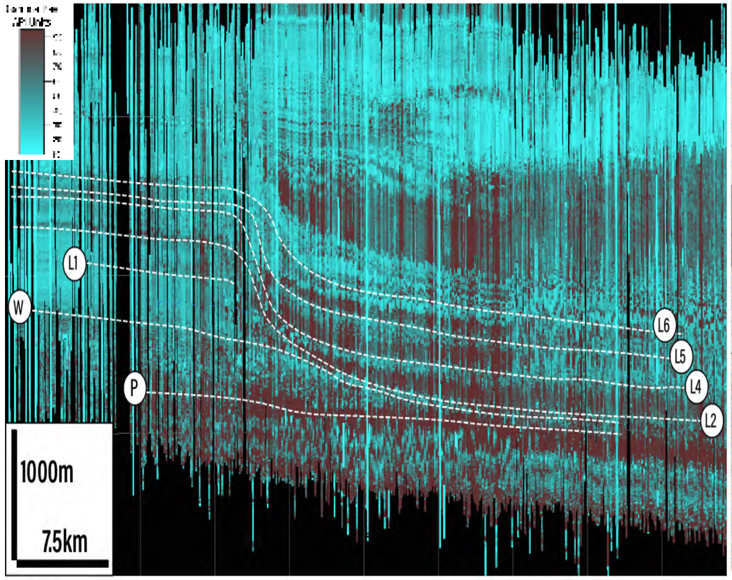


Three-dimensional view of subsurface well tops

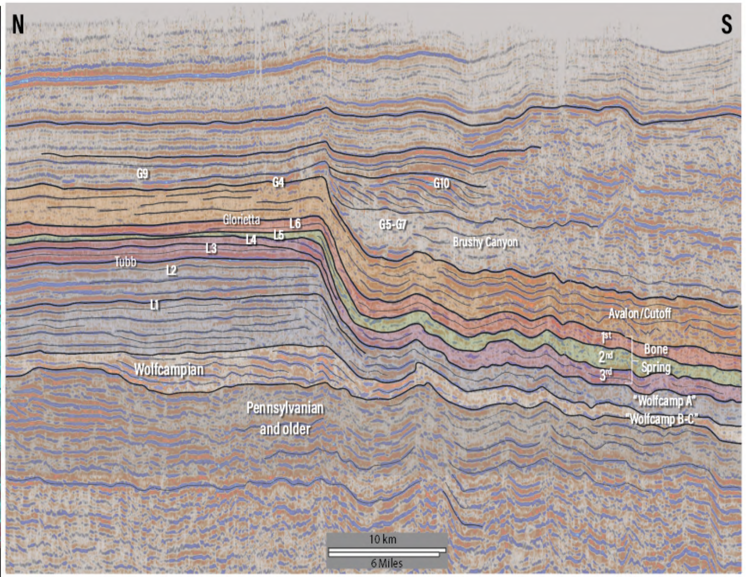
- Regional manual well-log mapping incorporating approximately 8000 well logs (approximately 125,000 top picks)
- Platform to Basin correlation to constrain slope geometry and trends in offbank sedimentation
- Using core-refined log cutoffs to identify varying scales of slope and basinal carbonate accumulations

Methods





3-D intersection visualization of spatially referenced well logs



2-D seismic courtesy of Seismic Exchange

- Regional manual well-log mapping incorporating approximately 8000 well logs (approximately 125,000 top picks)
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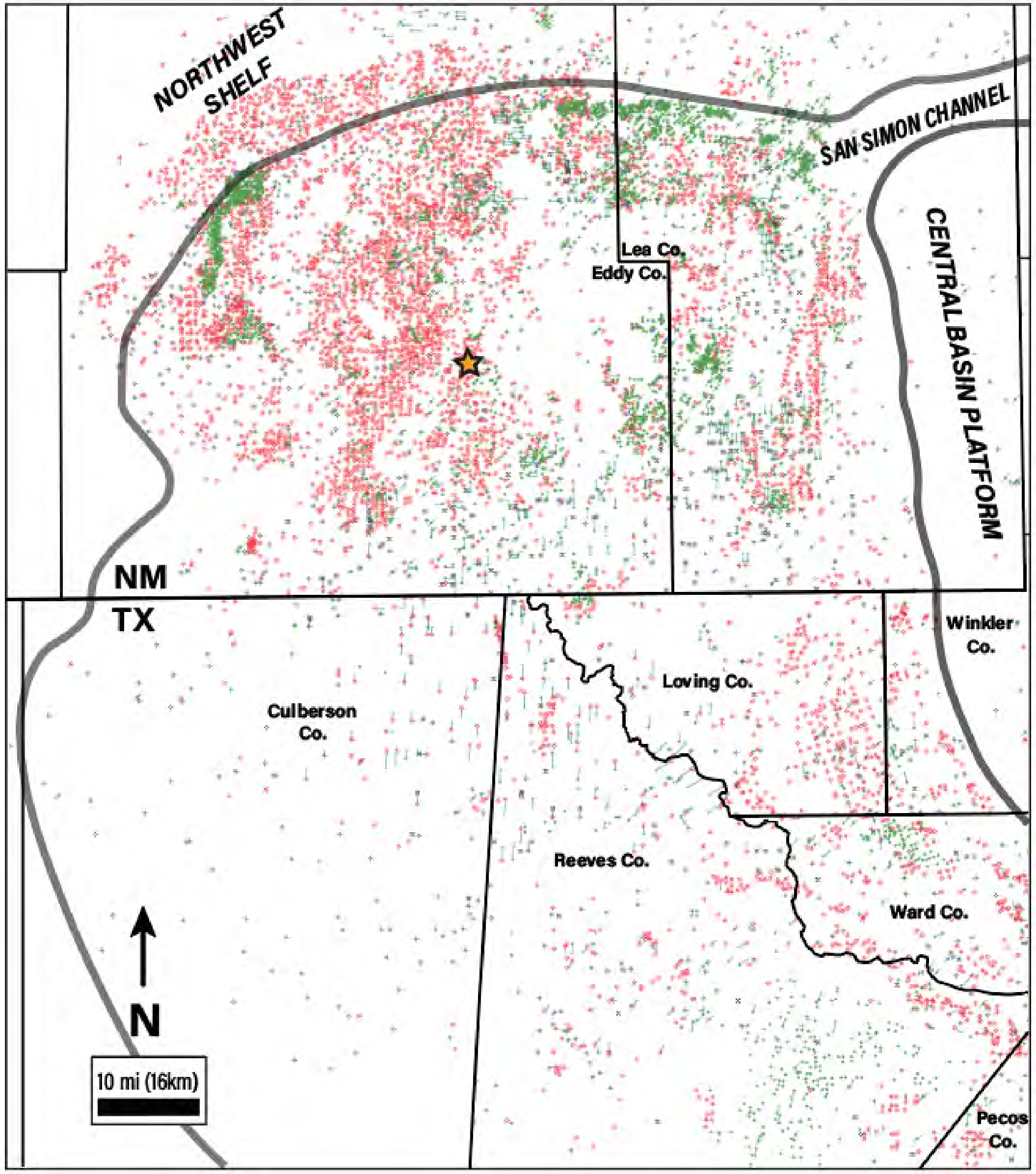
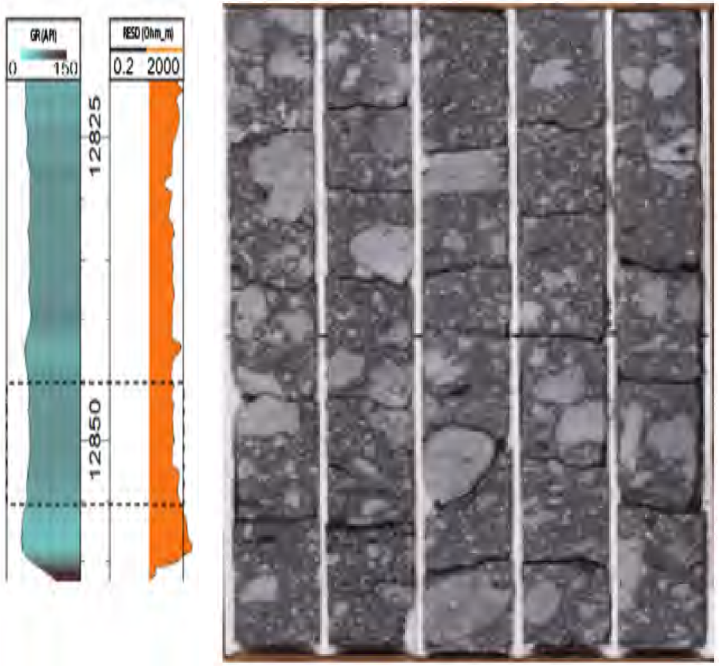
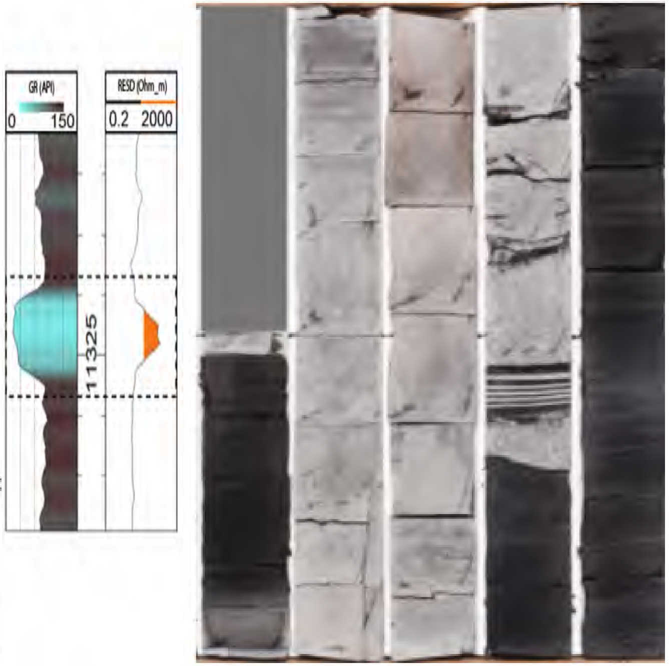
Methods



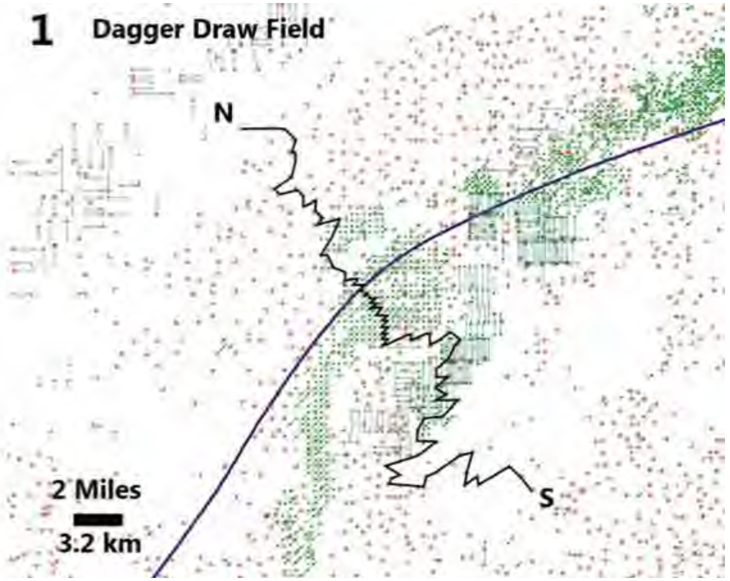


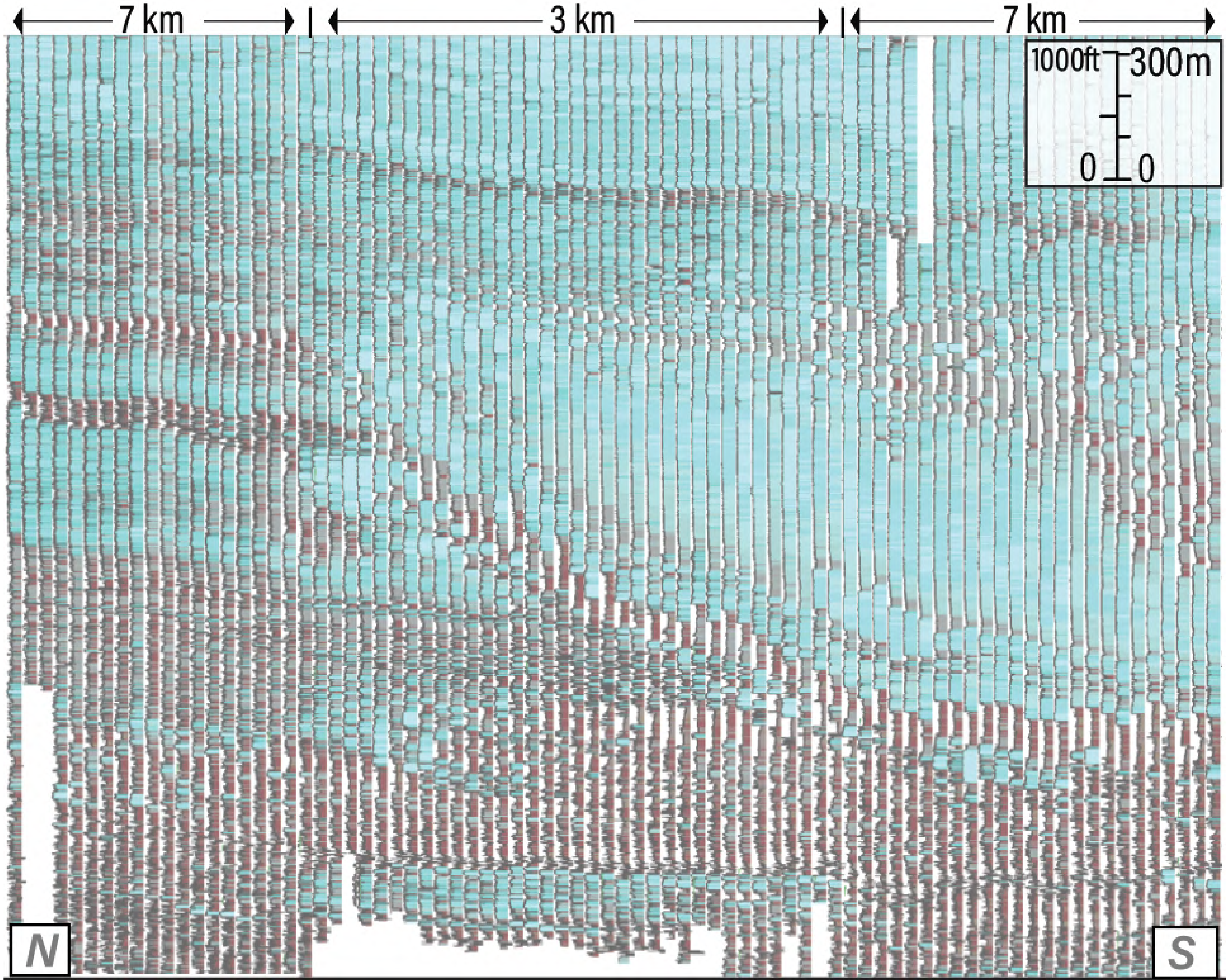


- Regional manual well-log mapping incorporating approximately 8000 well logs (approximately 125,000 top picks)
- Platform to Basin correlation to constrain slope geometry and trends in offbank sedimentation
- Using core-refined log cutoffs to identify varying scales of slope and basinal carbonate accumulations

Platform to Basin Architecture

Northwestern Portion of the Delaware Basin





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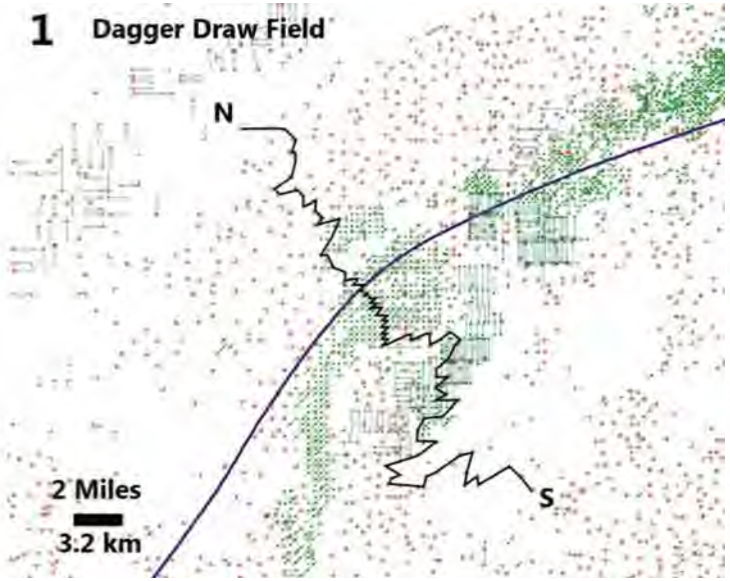
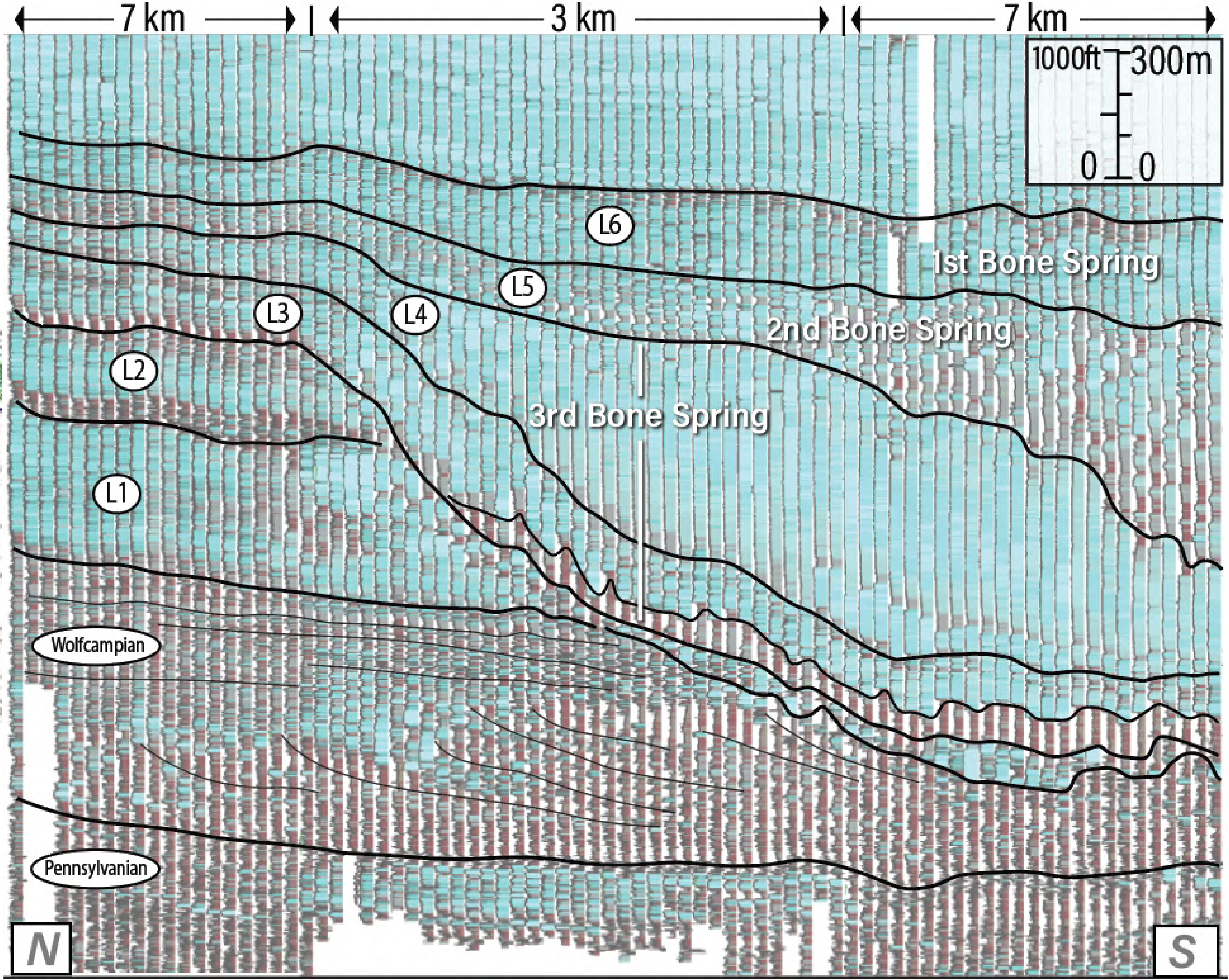
Northwestern Portion of the Delaware Basin

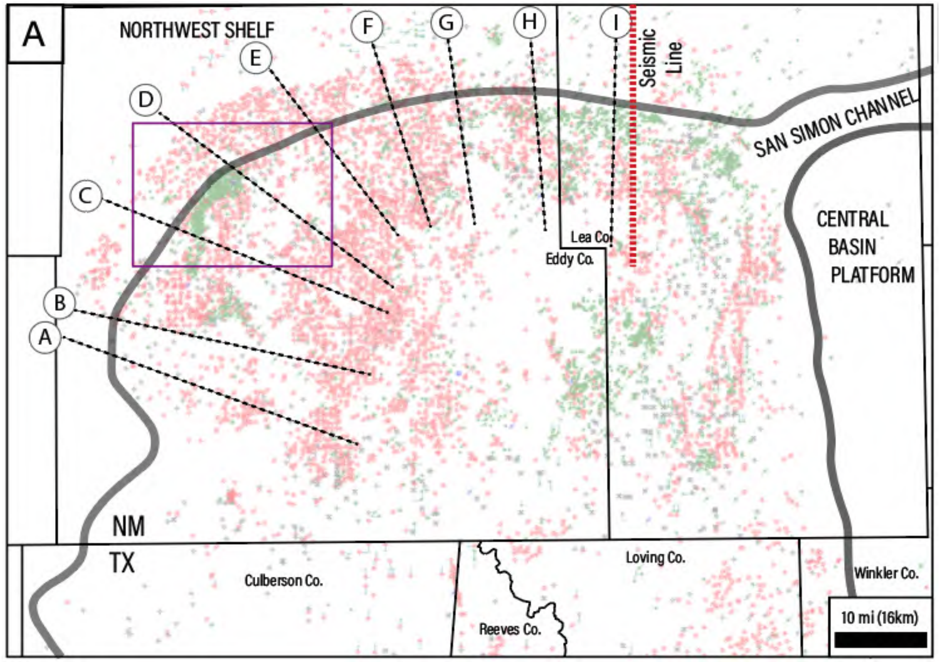


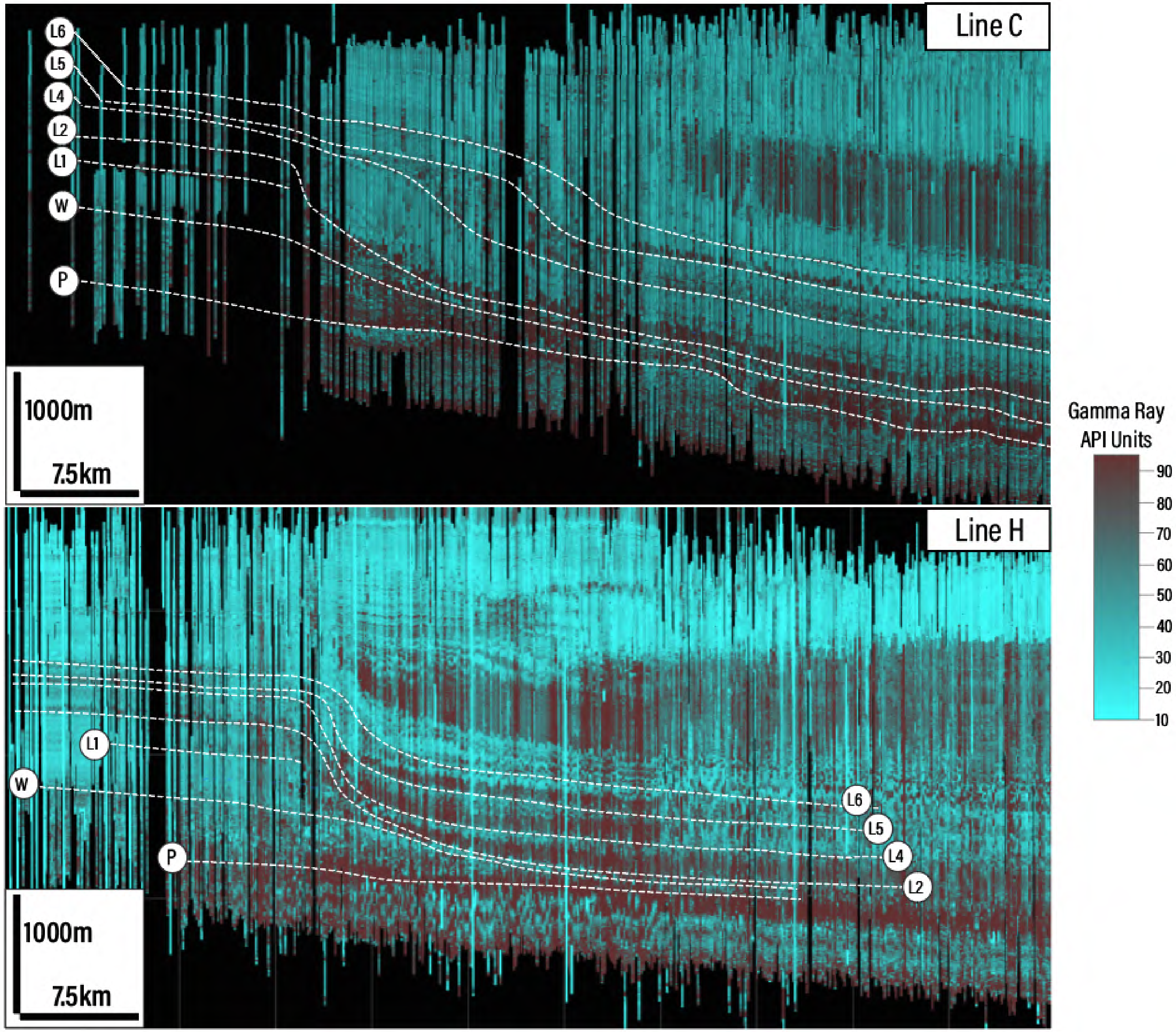


Wolfcampian: Lower gradient, highly complex stratigraphy

L1-L2: Steeper Aggradational-retrogradational margin and slope, Comparable profiles to west and north

L4-L6: Lower gradient and progradational to west, steeper progradational-aggradational to the north





Wolfcampian: Lower gradient, highly complex stratigraphy

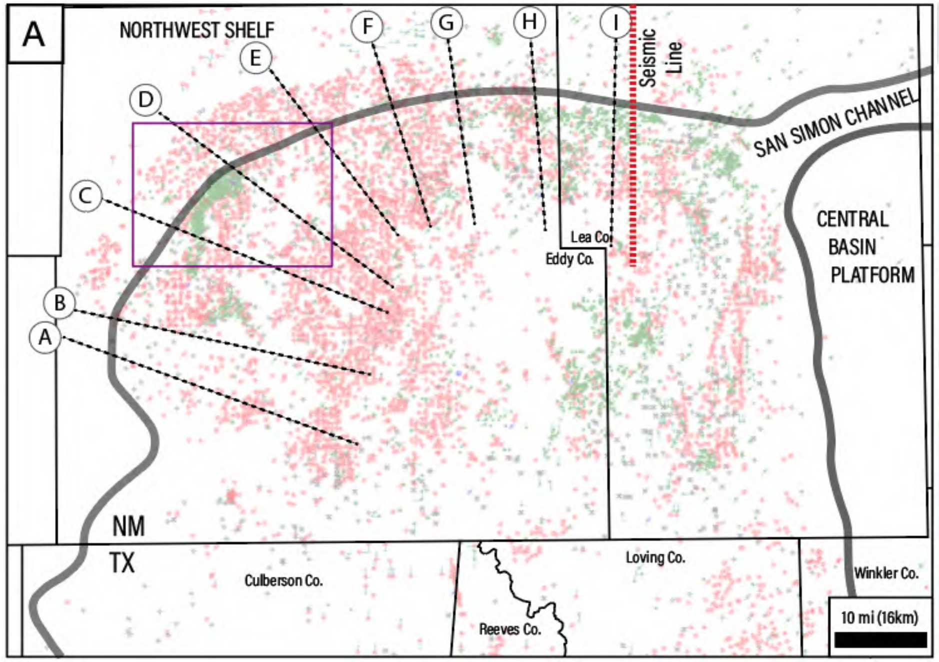
L1-L2: Maintains relatively consistent profile

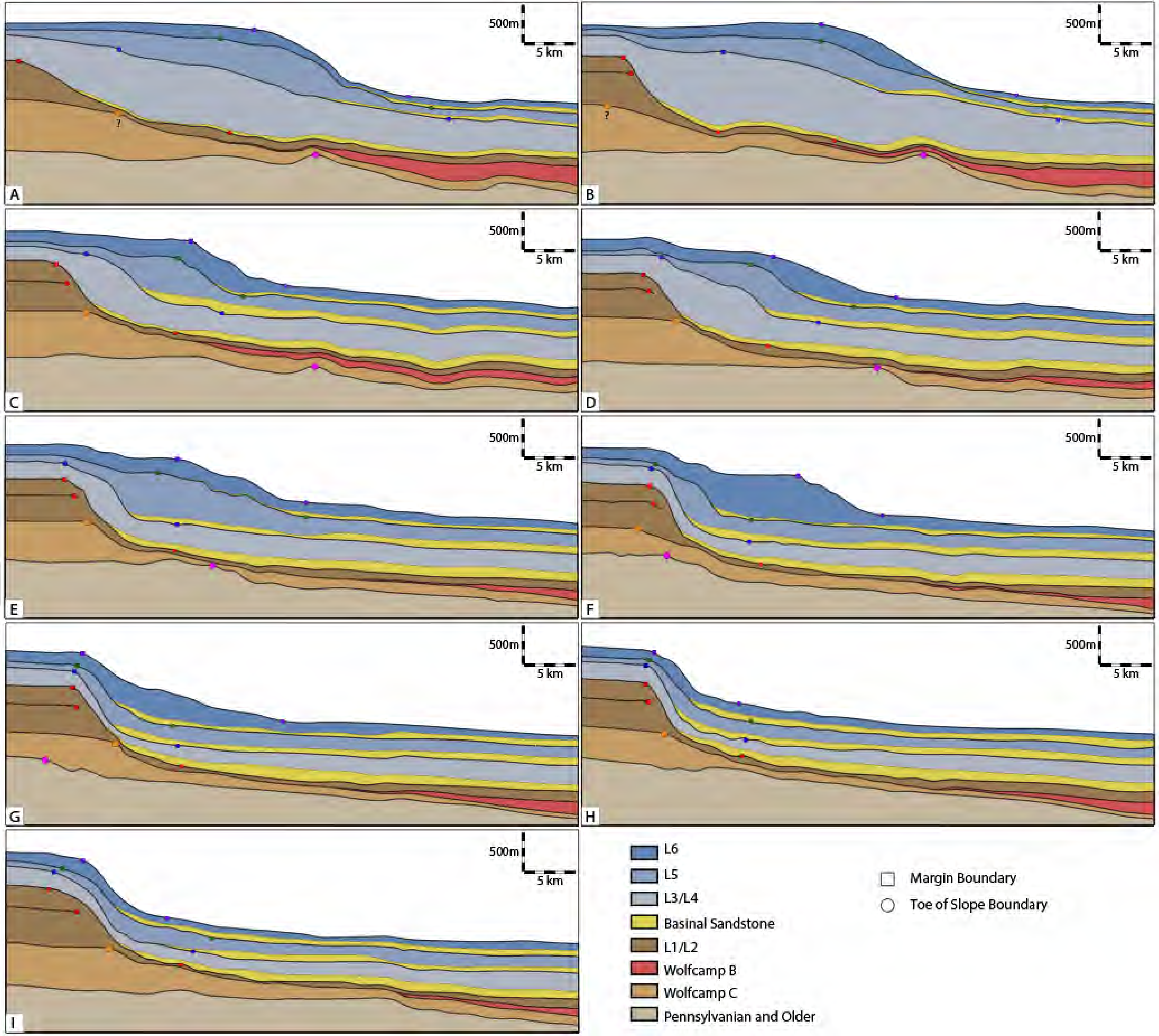
L4-L6: Variations in P/A ratios spatially

L4: P/A 5-35*

L5: P/A 40-110*

L6: P/A 2-80*





Slope Gradient Maps

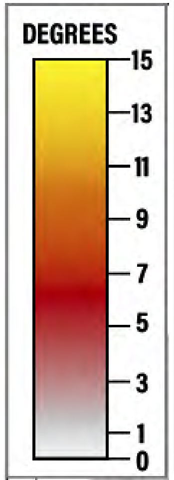
Wolfcampian: Irregular slope profile with 4-10 degree slopes

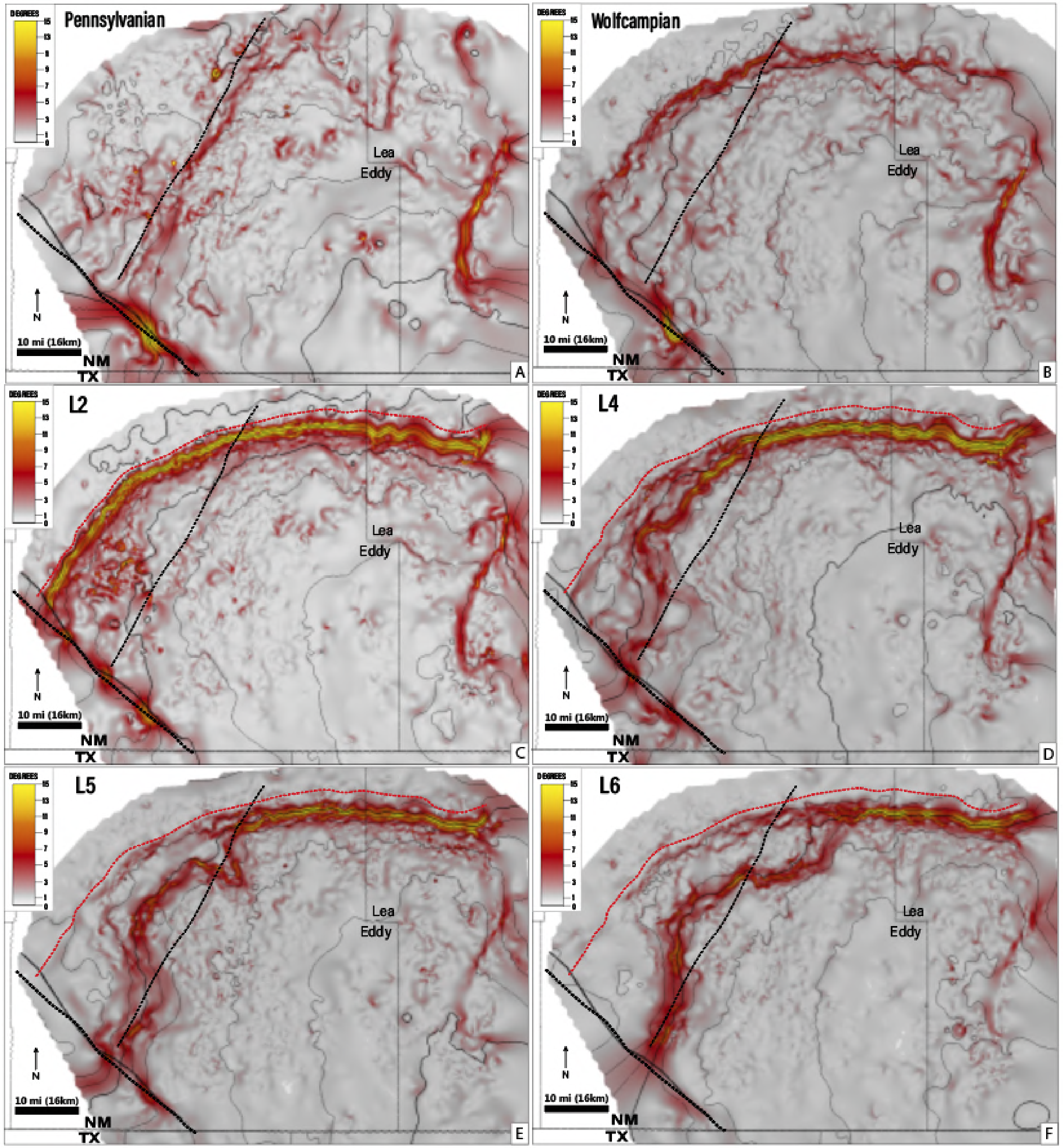
L1-L2: Consistent slope profile of 15-25 degrees

L3-L4: 2-8 degree slopes to the west, 15-20 degree slopes to the north.

L5: 3-8 degree slopes to the west, 10-15 degree slopes to the north

L6: 4-7 degrees to the west,10-15 degrees to the north





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Bottom Currents

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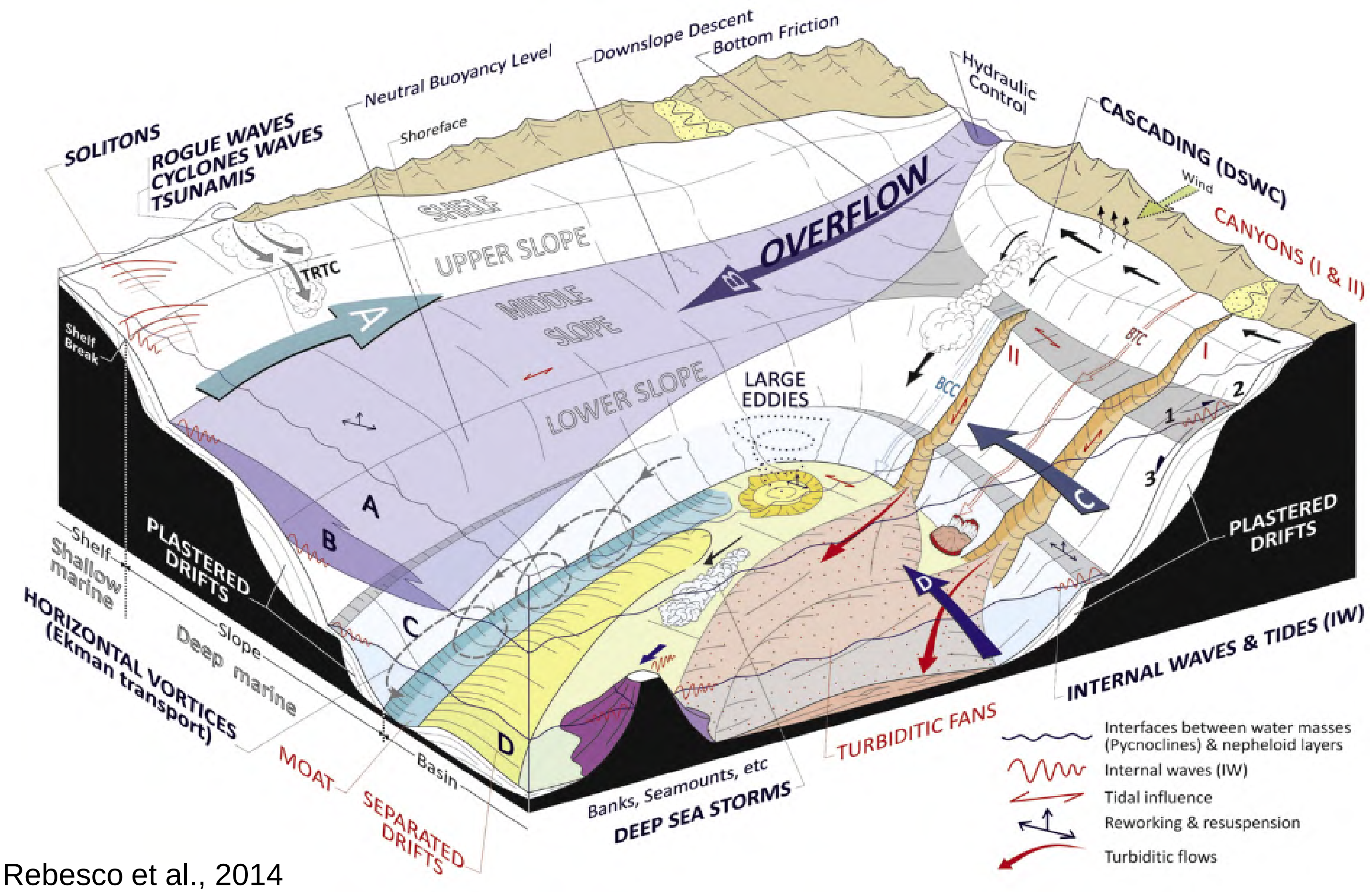
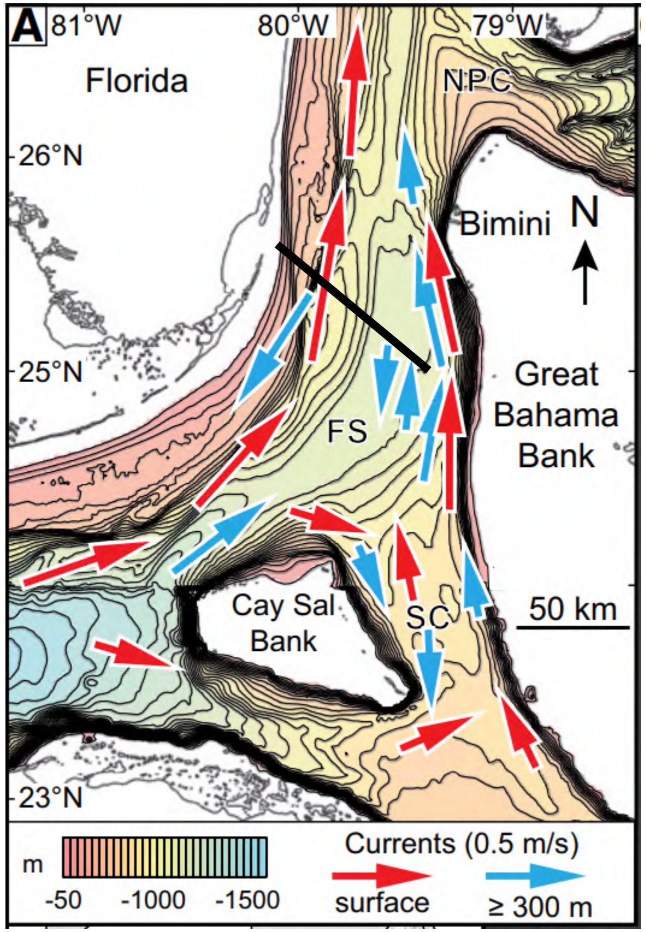
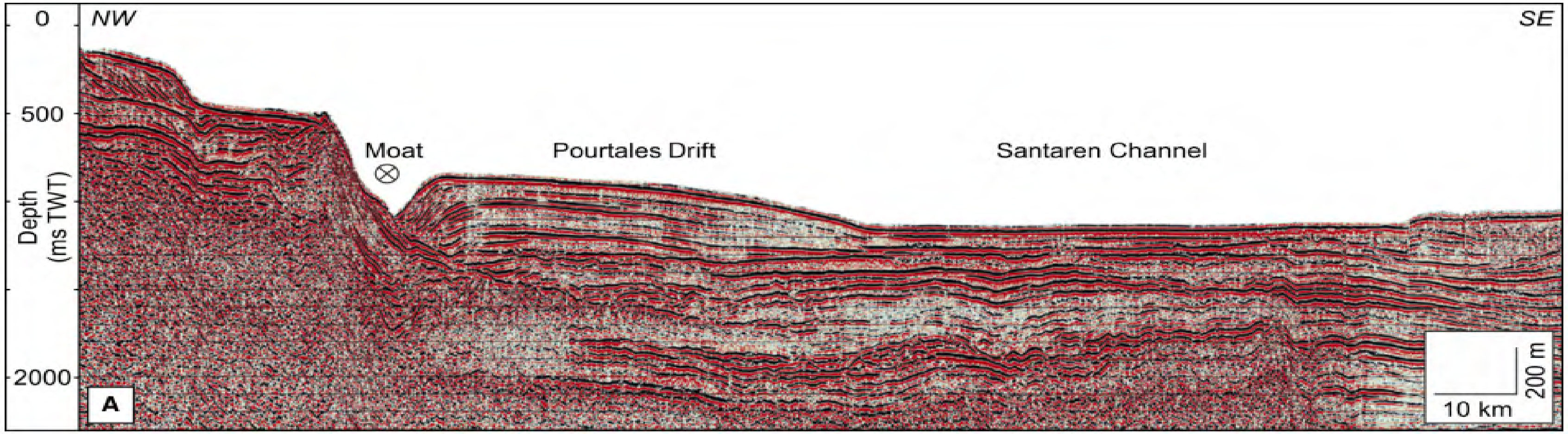


Rebesco et al., 2014

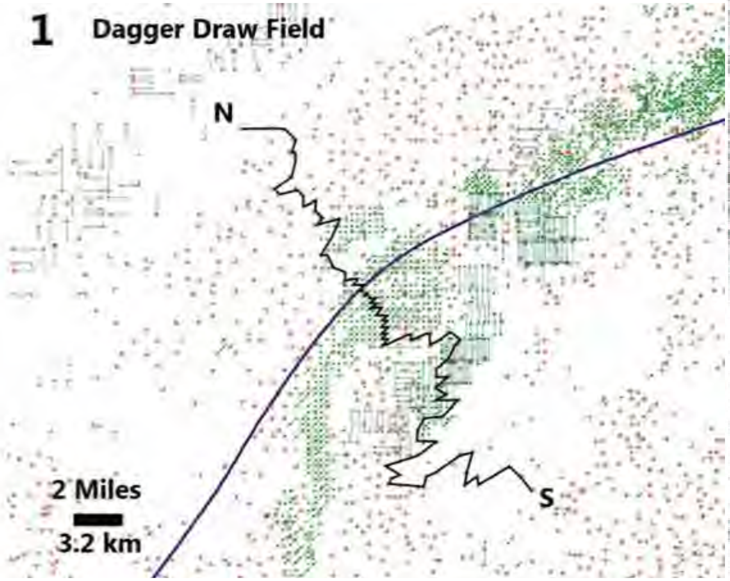


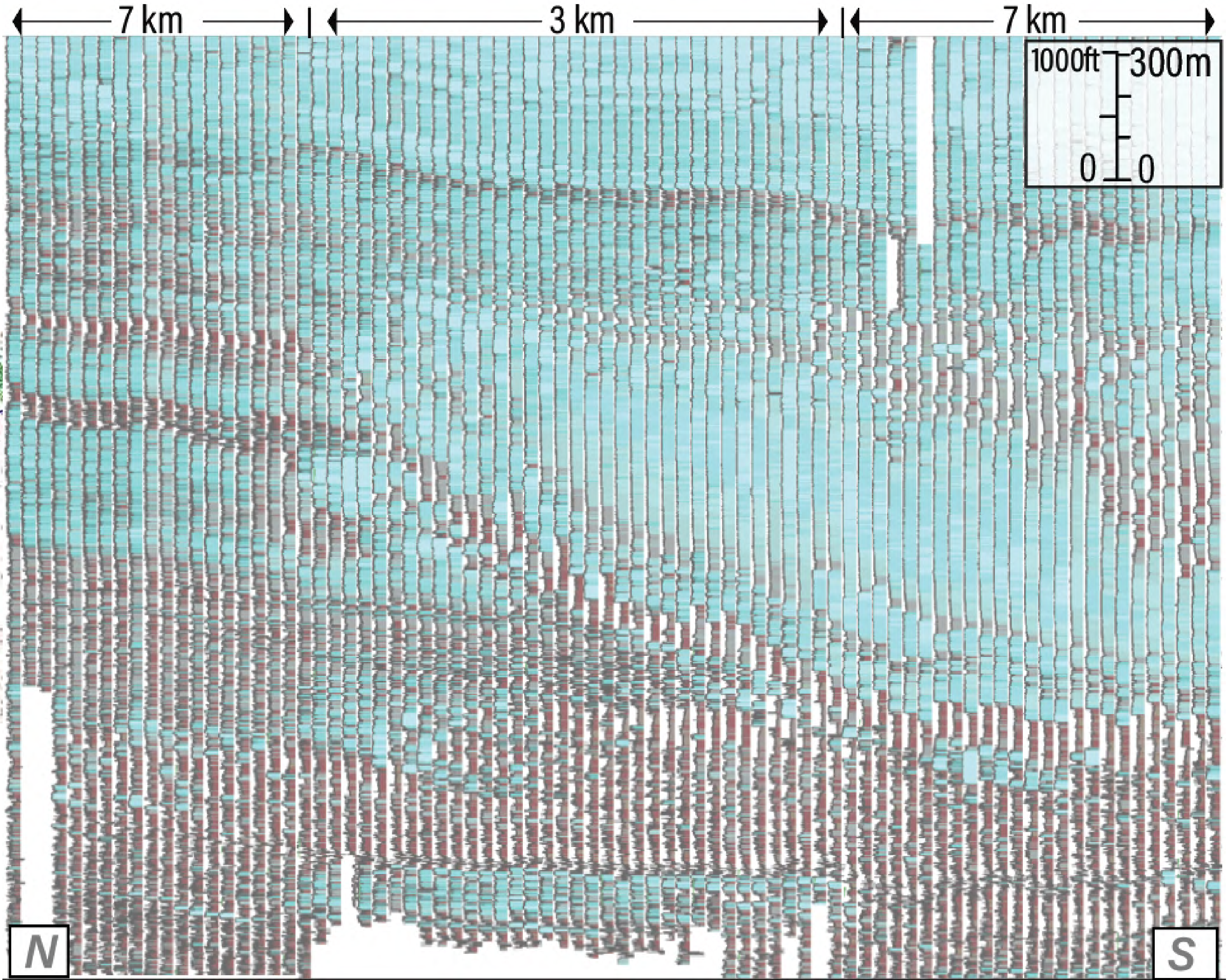
Betzler et al., 2014



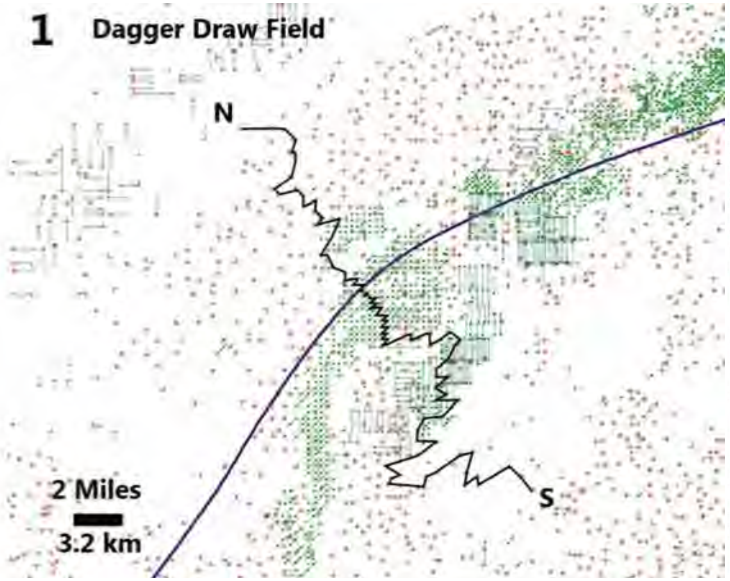
Mulder et al., 2019

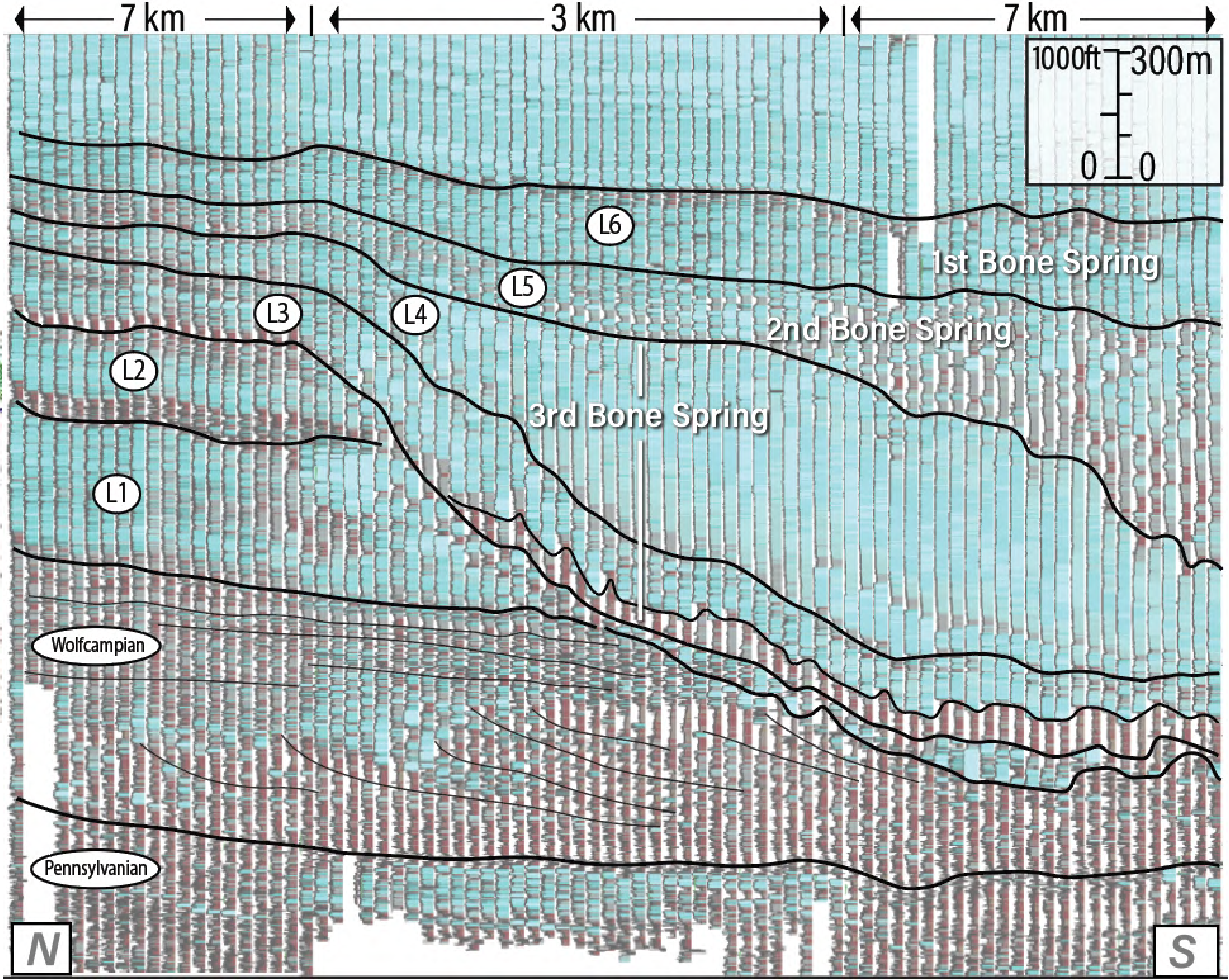
Northwestern Portion of the Delaware Basin



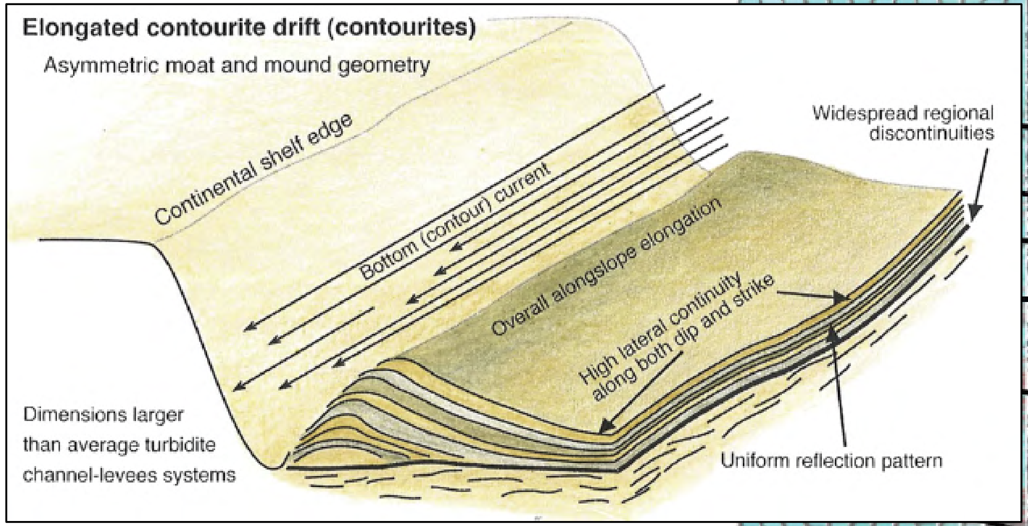


Northwestern Portion of the Delaware Basin





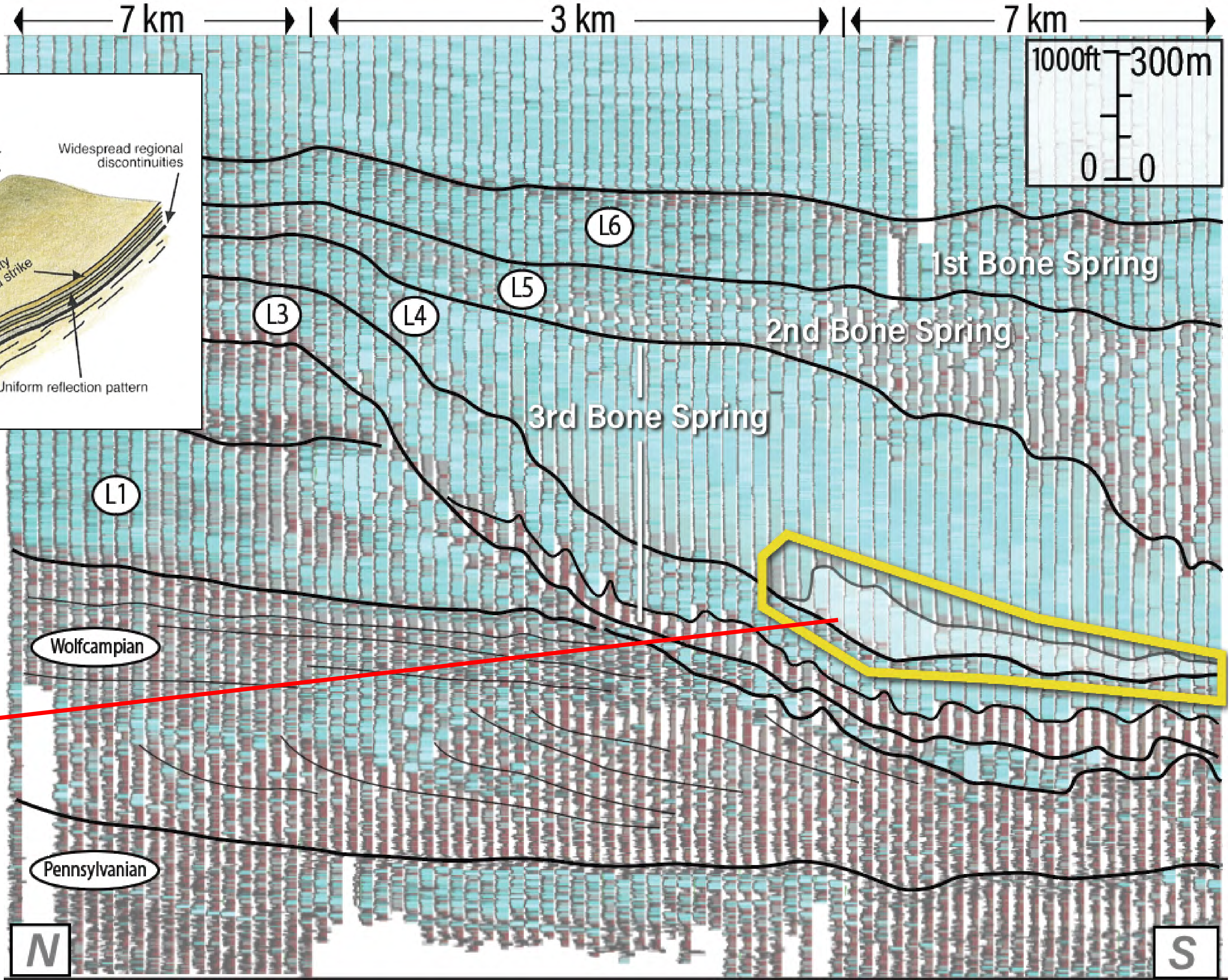
Reservoir Characterization Research Laboratory



Mounded Asymmetric carbonate body at the base of the L4 sequence

Likely not an MTC due to homogeneity and lack of updip scar where failure would initiate

Possible Carbonate Drift



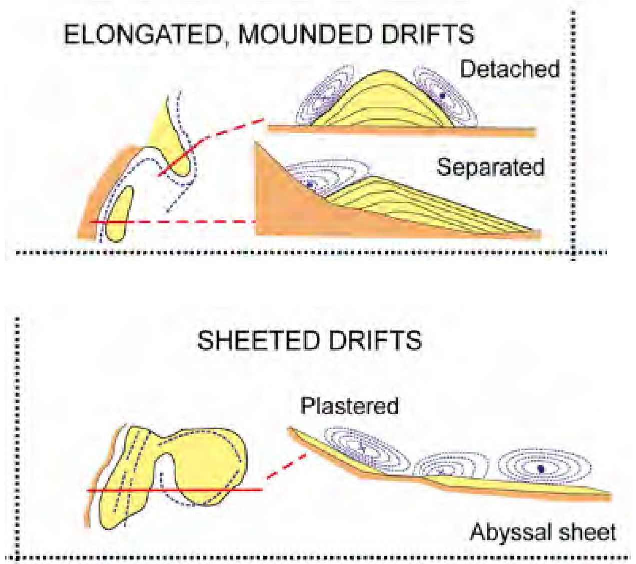
Basal L4 Wedge

Reaches over 800ft /250m thick

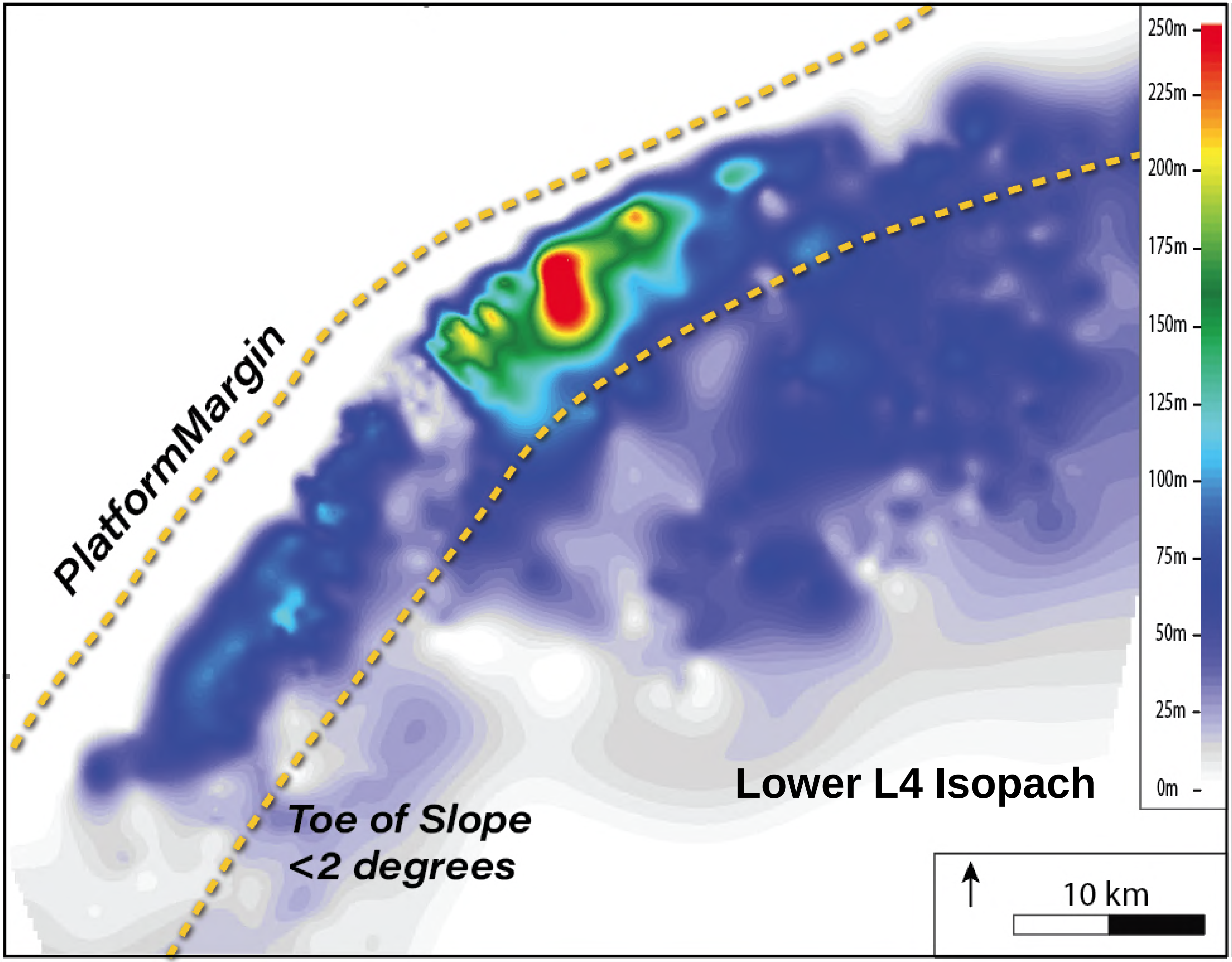
Parallels the slope on the western side of the basin

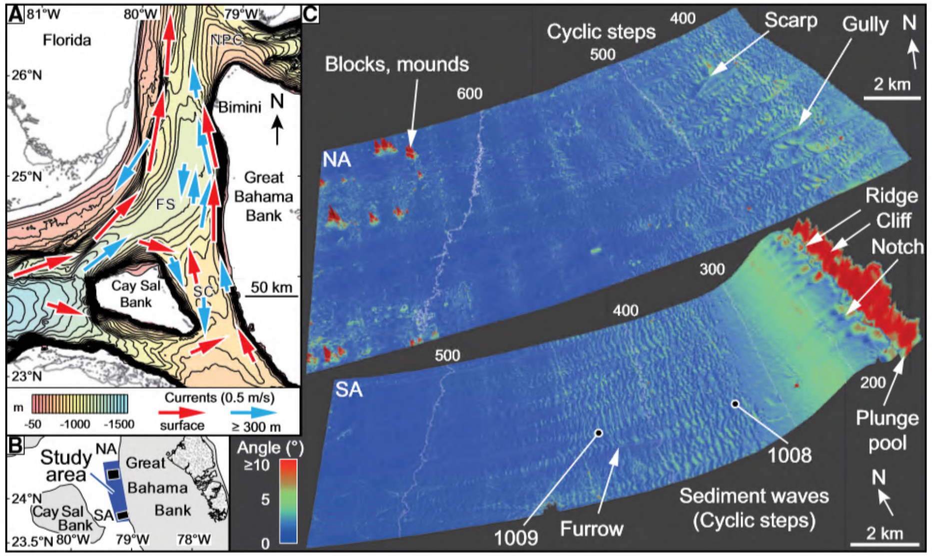
Mounded and asymmetric in cross section

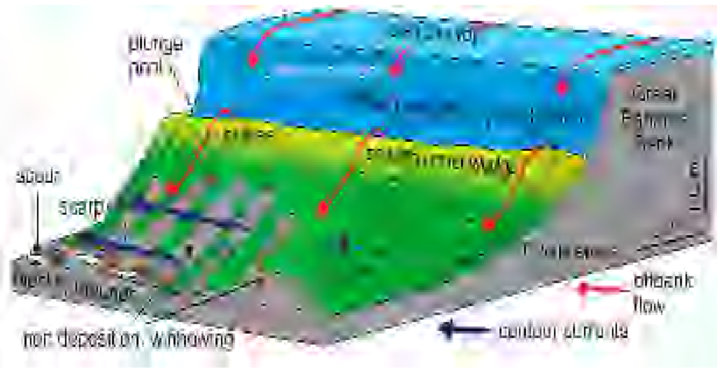
Onlaps and drapes the slope



Rebesco et al., 2014

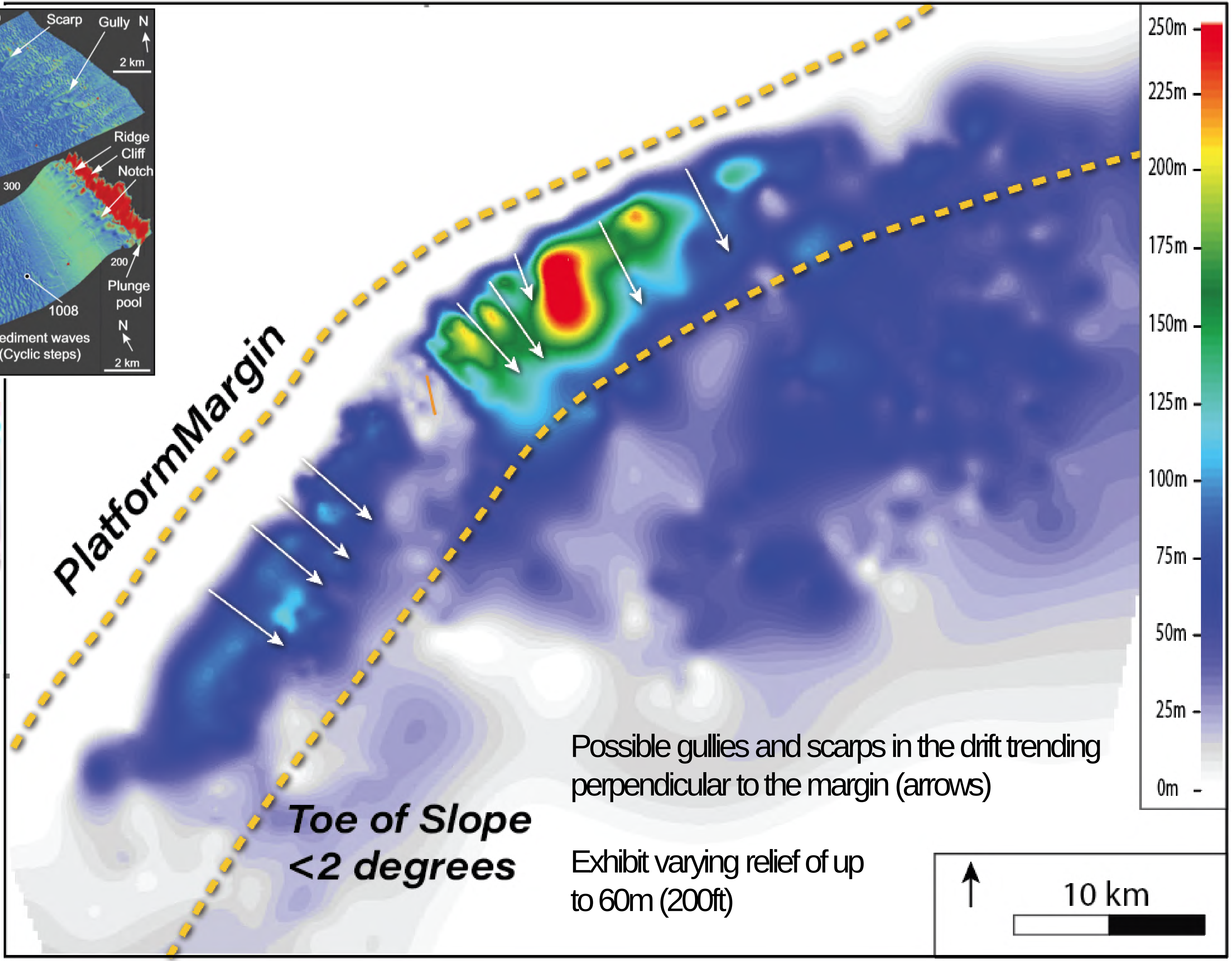






Betzler et al., 2014

Analog: Bahamian Periplatform Drift



Possible gullies and scarps in the drift trending perpendicular to the margin (arrows)

Exhibit varying relief of up to 60m (200ft)

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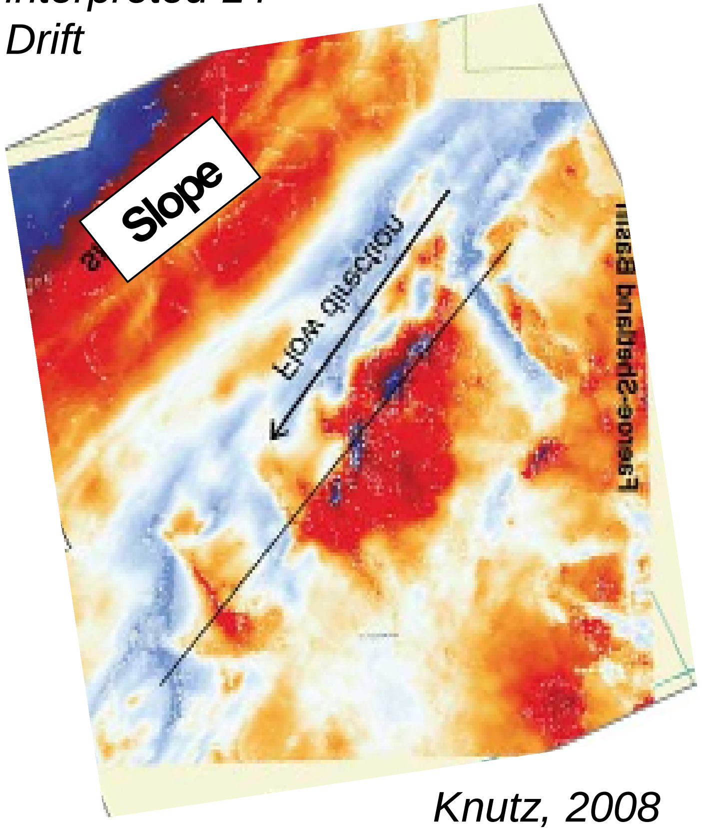
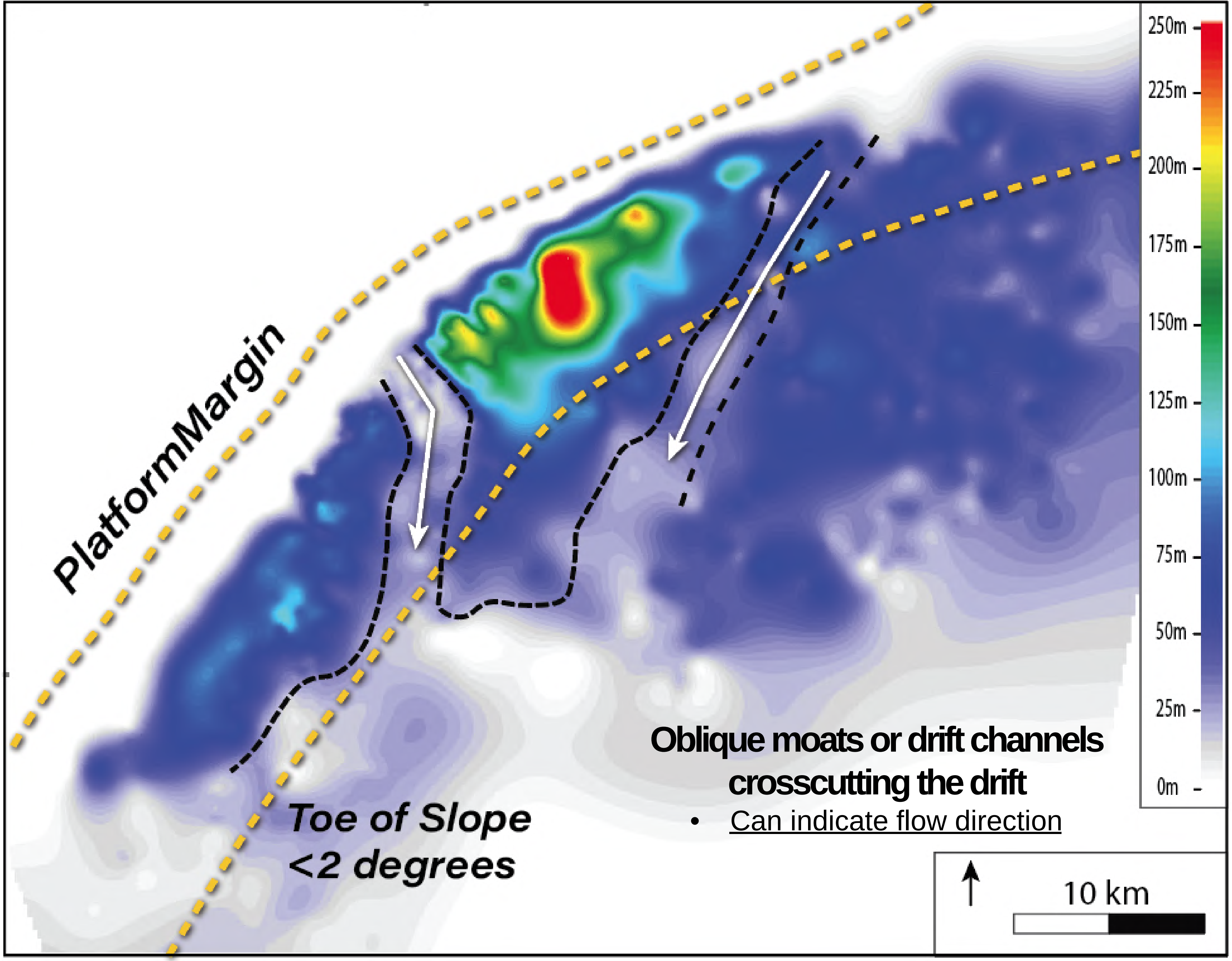
Reoriented and scaled to the interpreted L4 Drift

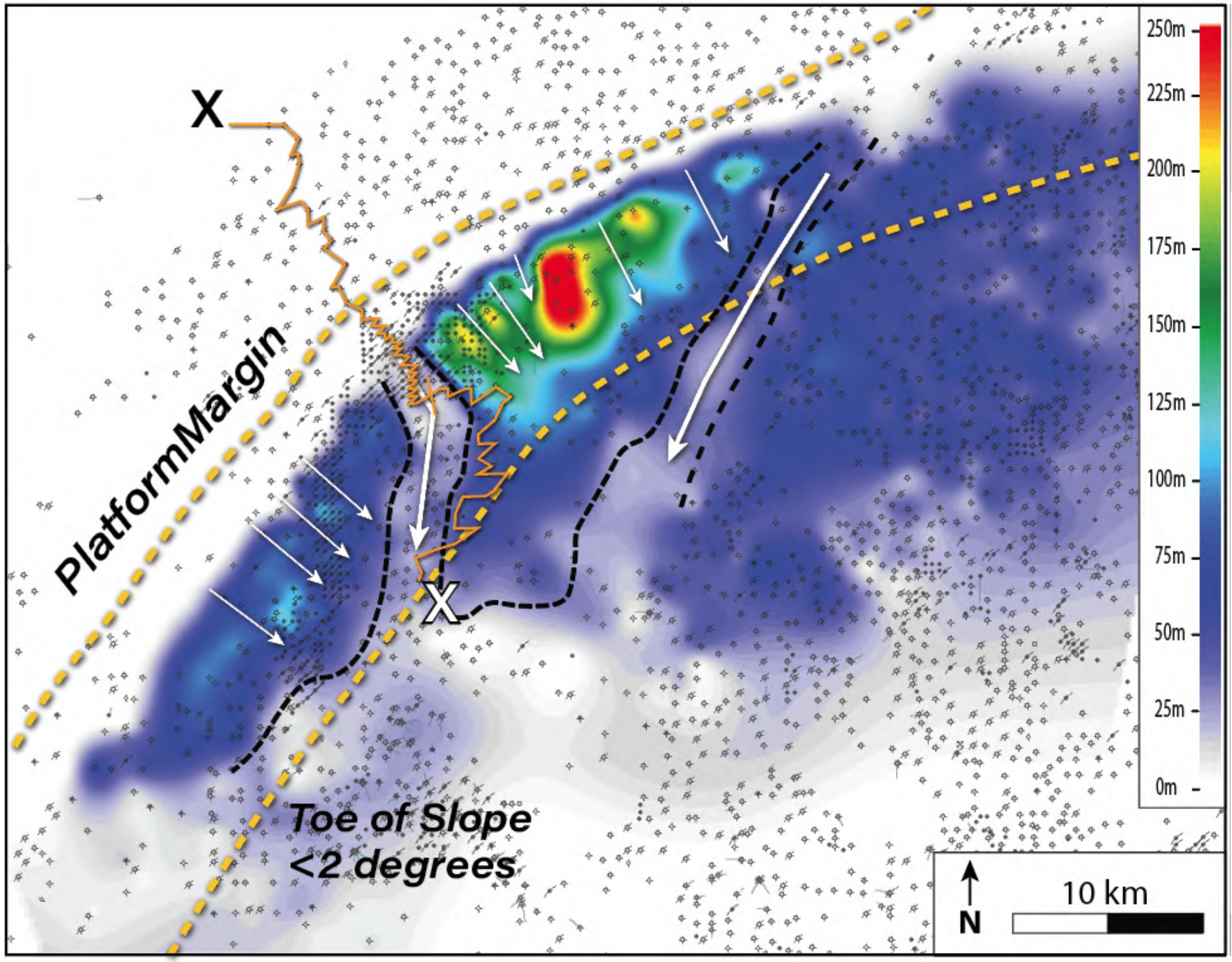


Knutz, 2008

Analog: West Shetland Drift, Seismic Isochron

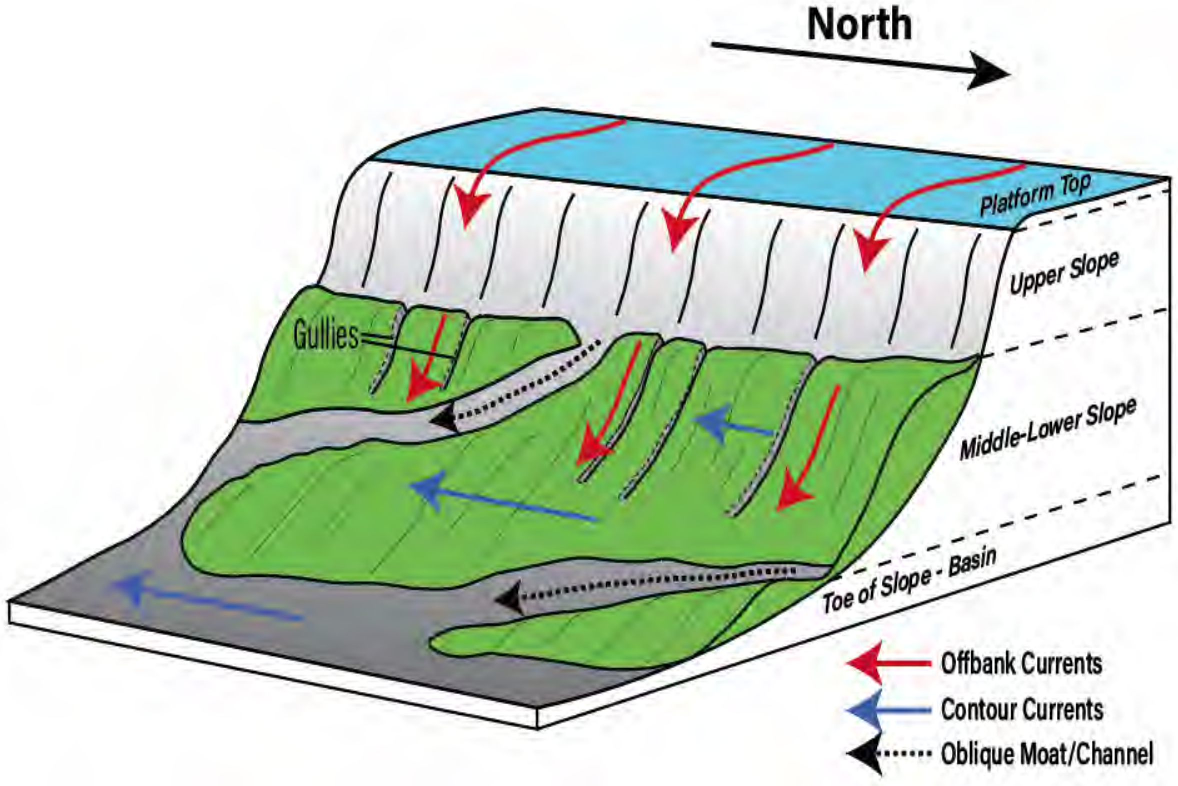


Contourites



Price et al., in press

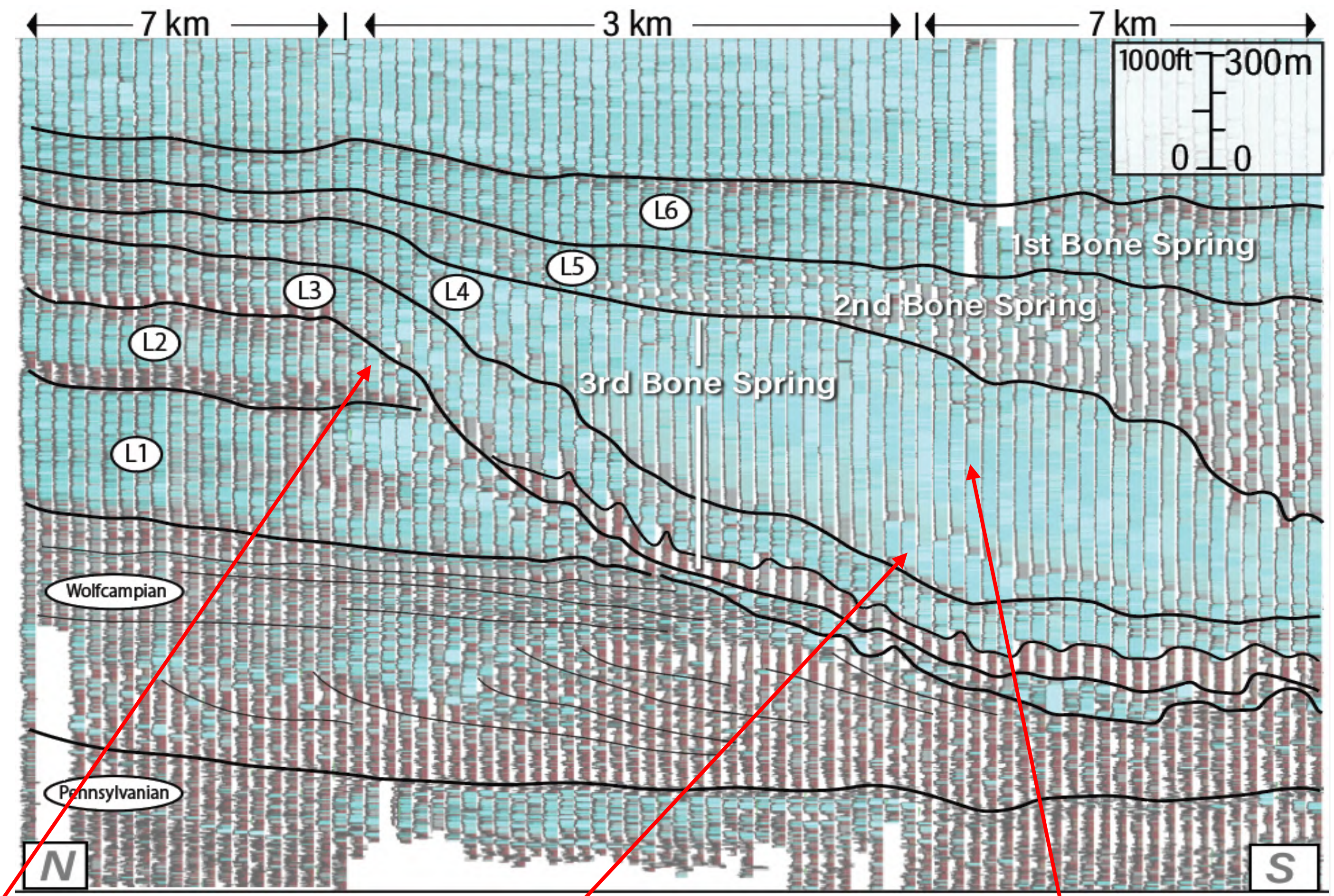
Proposed Model

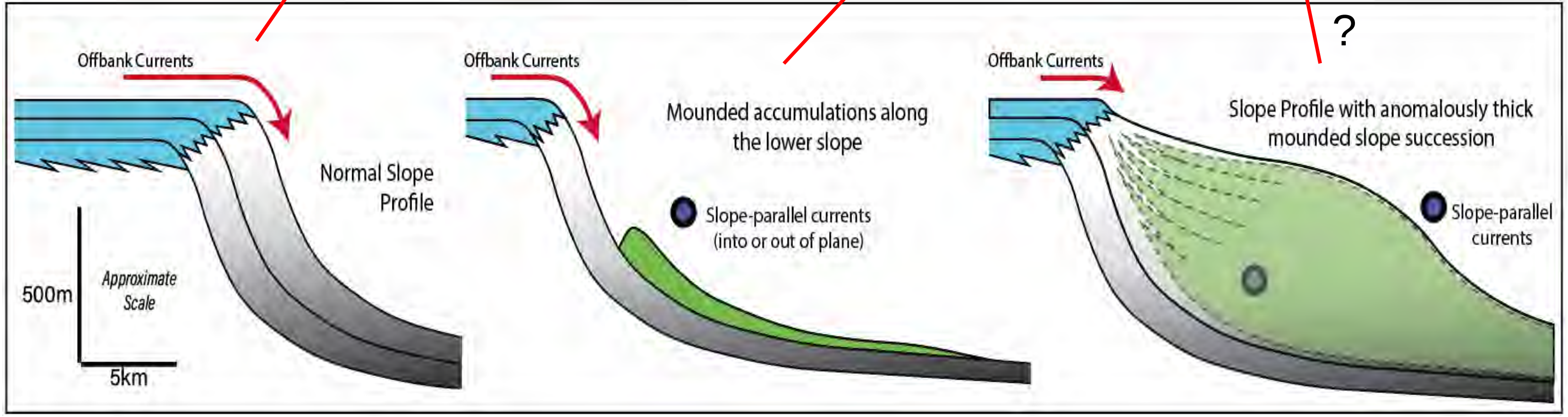


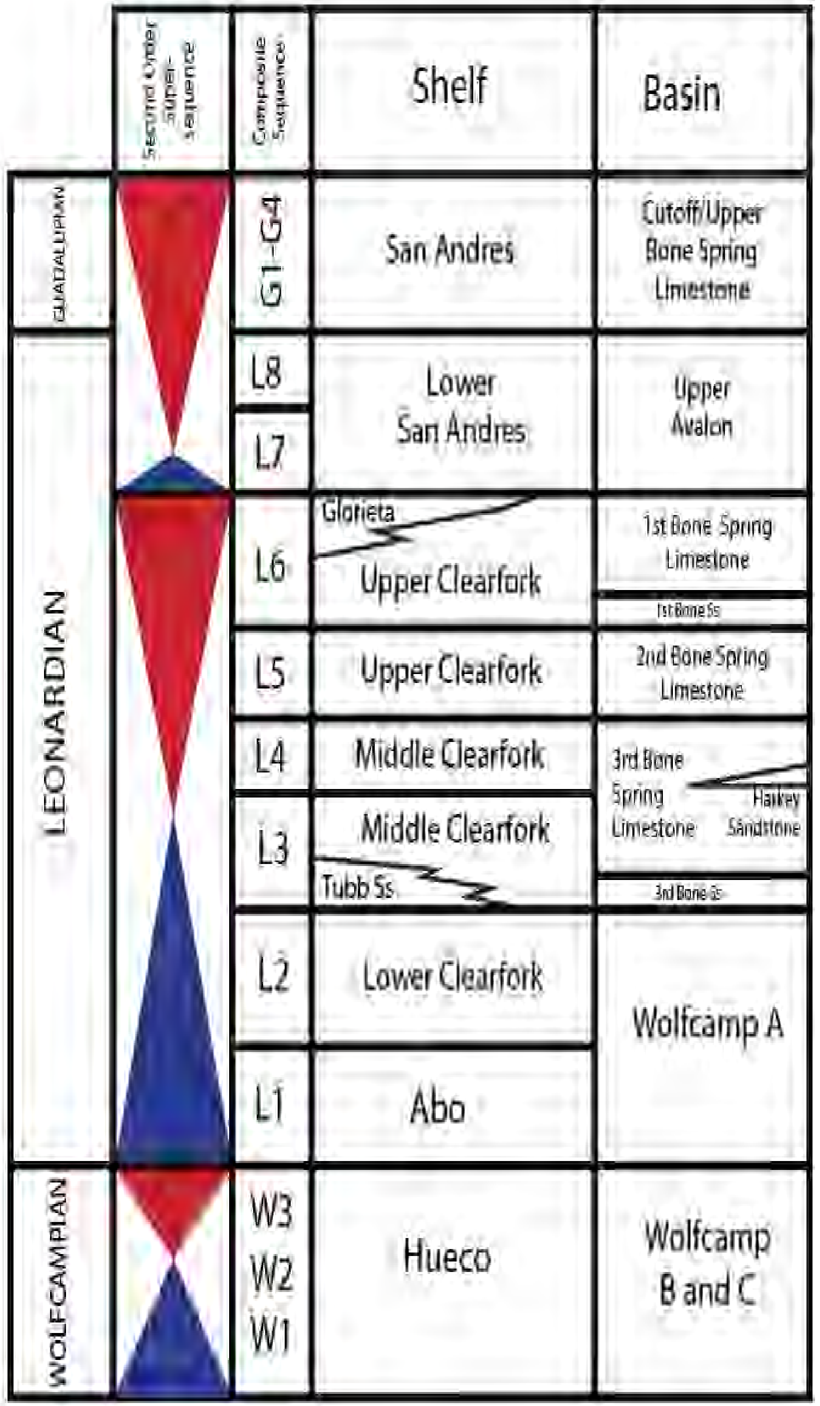
Modified after Betzler et al., 2014

Why does the drift form here?

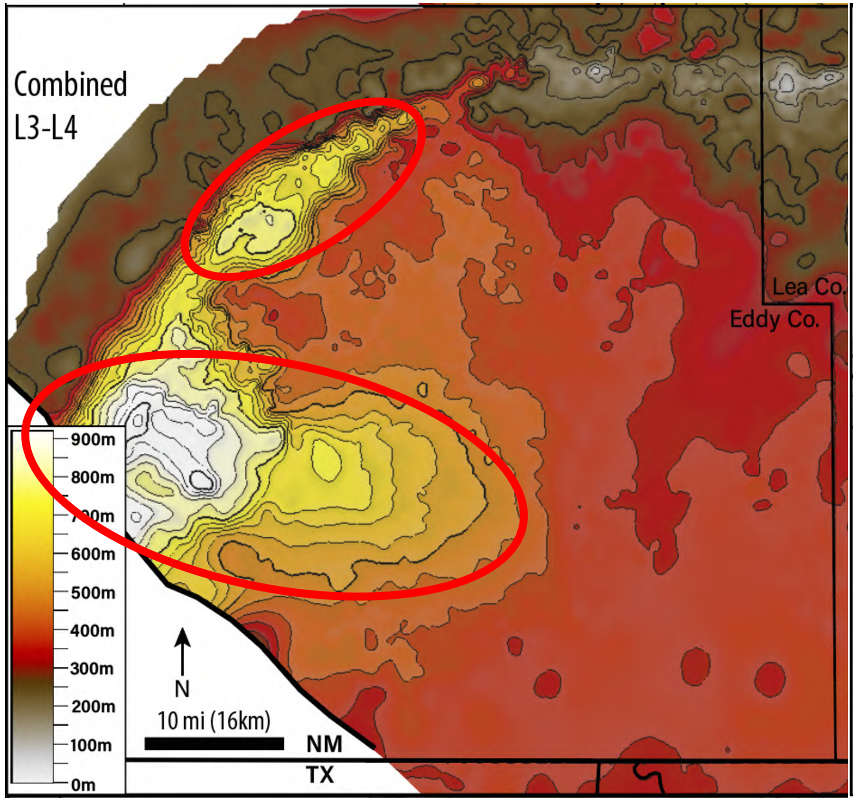
Are there other Drifts?



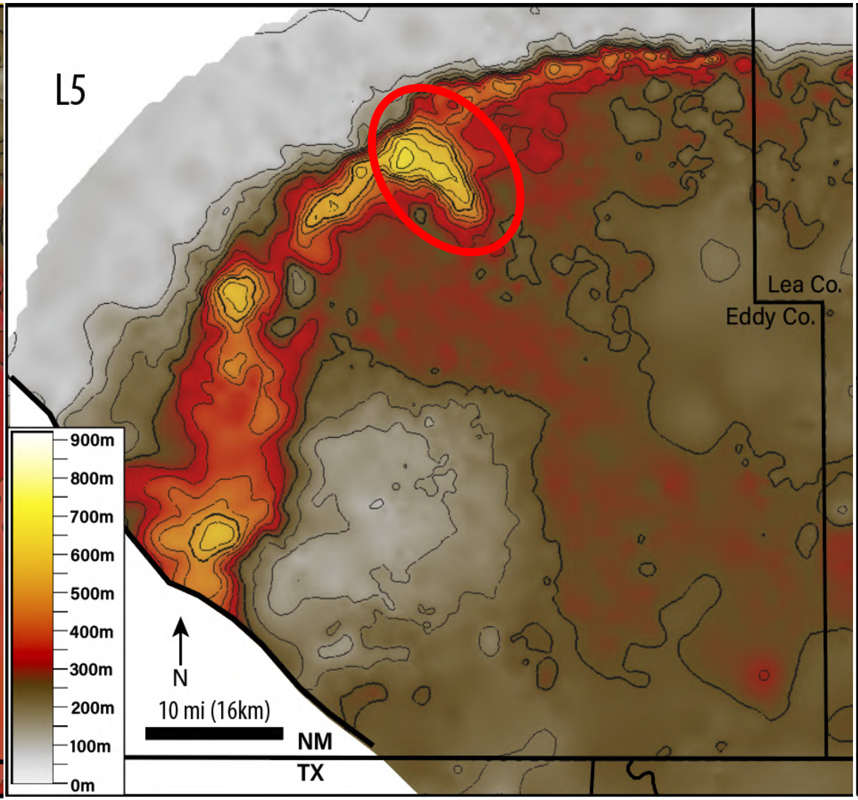




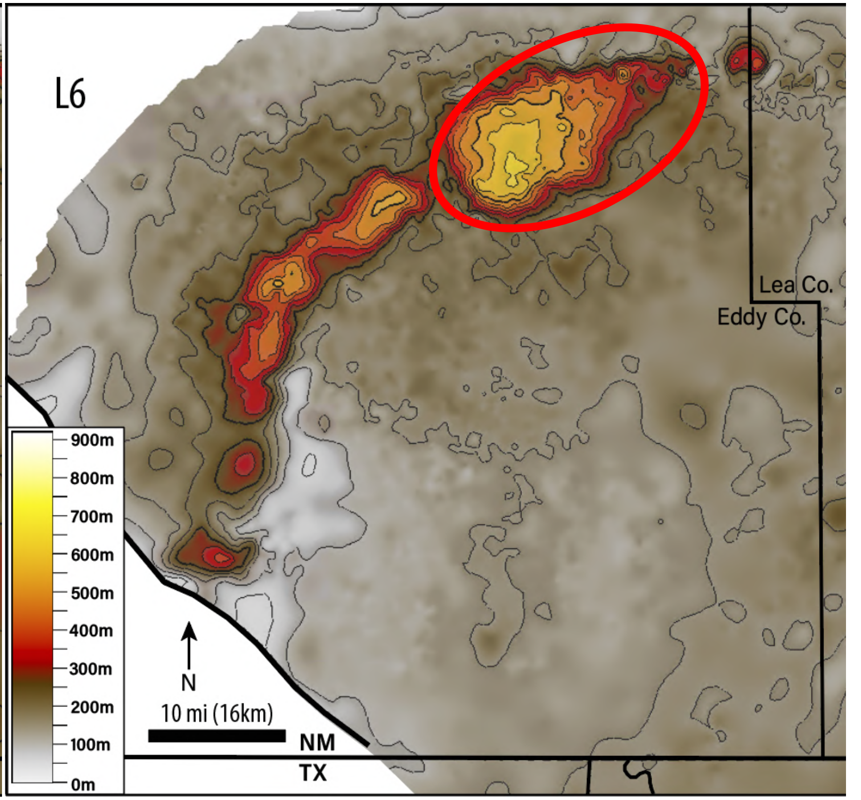
Isopach Thickness Maps



3rd Bone Spring Limestone (L3,L4)



2nd Bone Spring (L5)



1st Bone Spring (L6)

No evidence of sediment focusing from the platform

Anomalous thicknesses along the western slopes could potentially be large drift deposits

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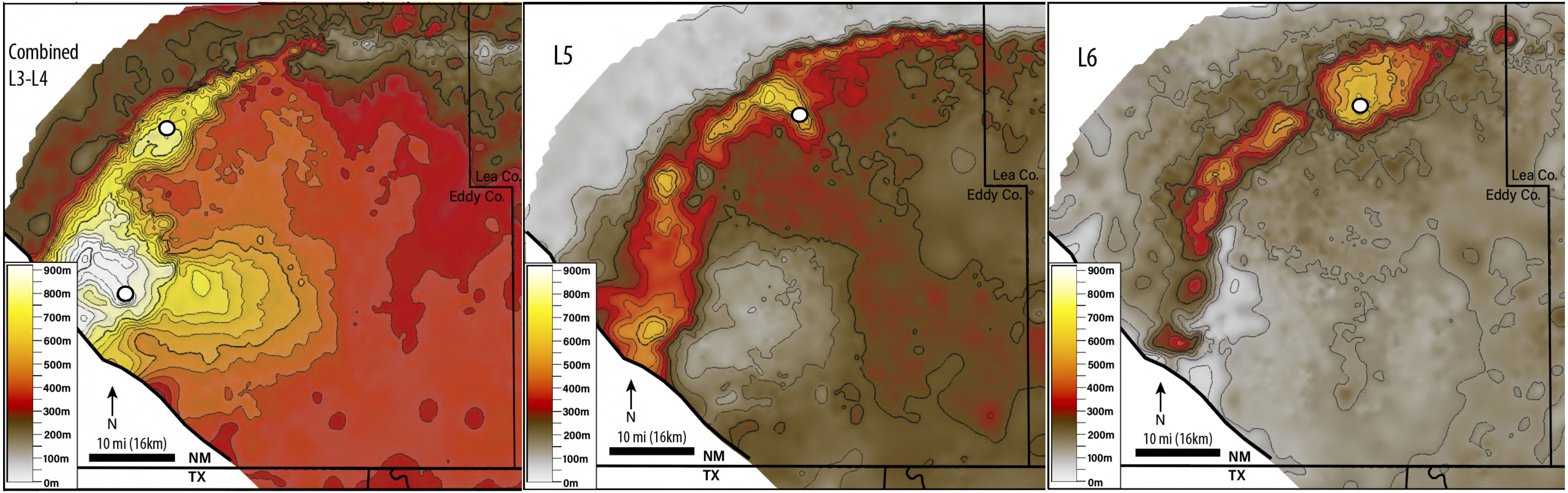
Well Log Character

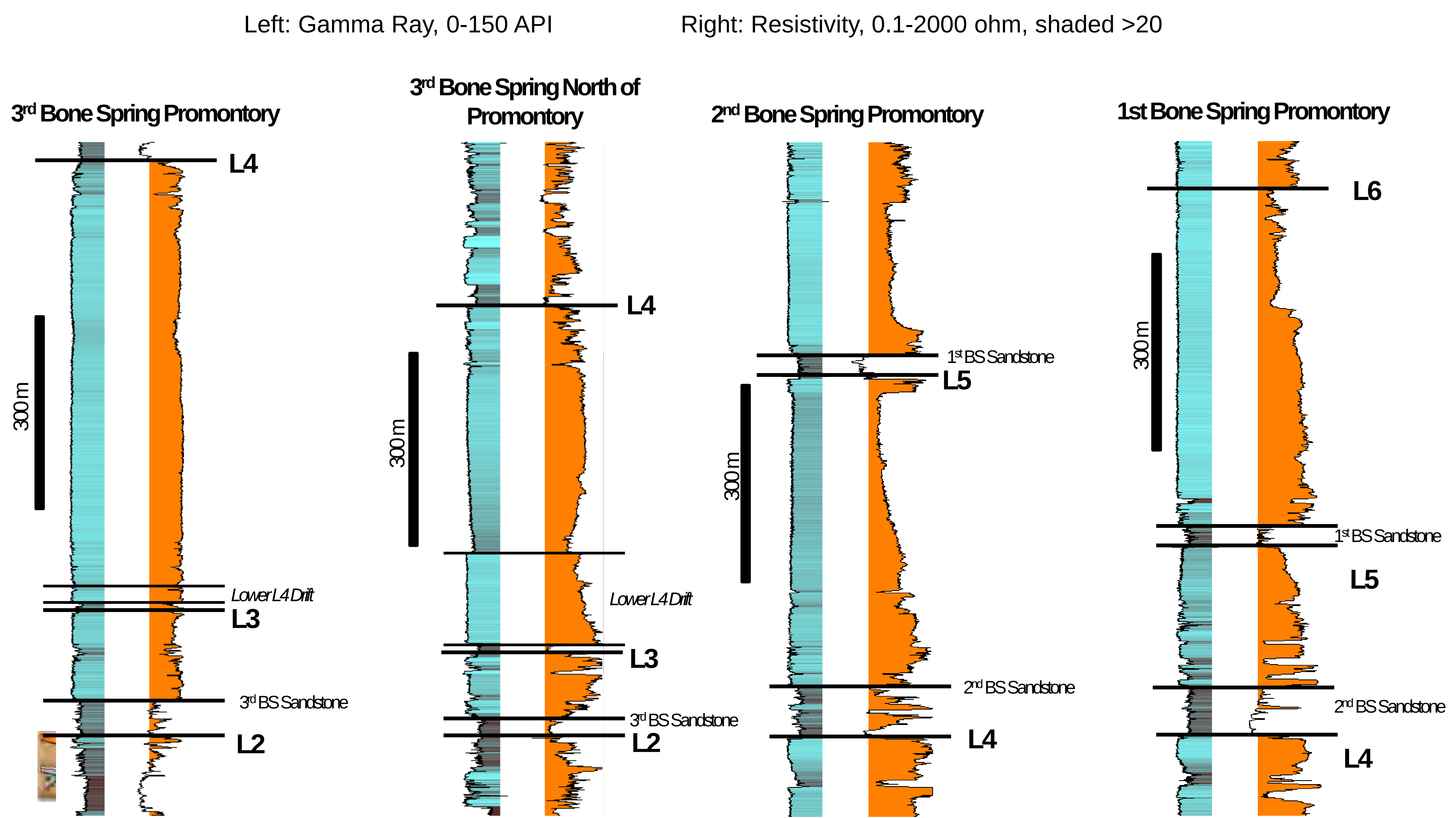


3rd Bone Spring Limestone (L3,L4) **2nd Bone Spring (L5)** **1st Bone Spring (L6)**

Thick accumulations display homogenous well log signatures
Differs from variable, serrate log signatures in other areas representing sediment gravity flow deposits.

Could indicate sedimentation driven by comparatively continuous sedimentation from contour currents (Also could be a stack of dilute muddy turbidites, but we need cores)

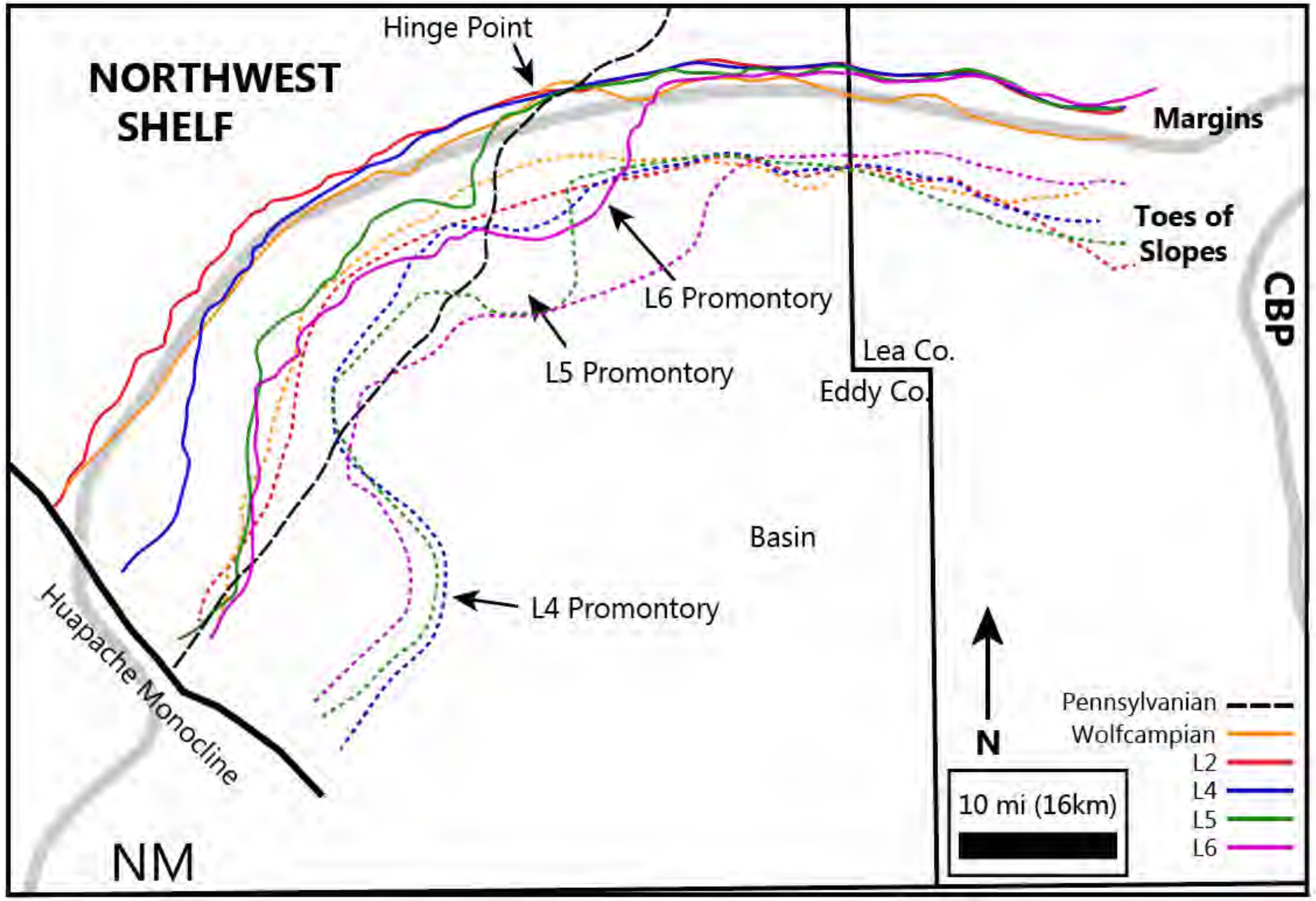
○ Well Log Locations



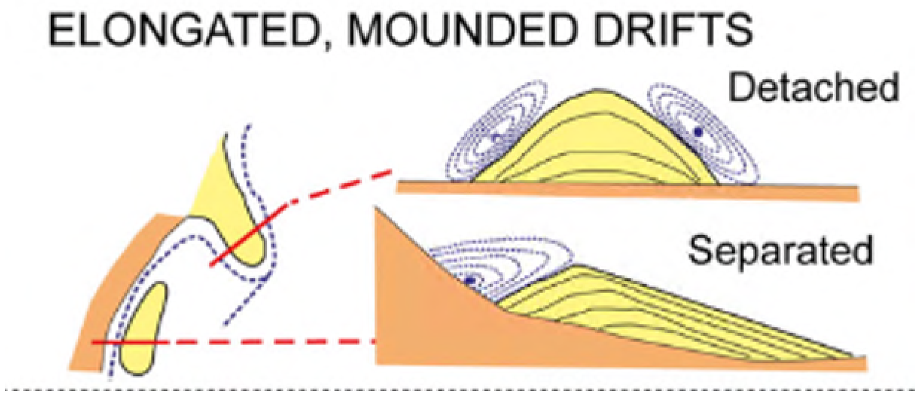
Left: Gamma Ray, 0-150 API
Right: Resistivity, 0.1-2000 ohm, shaded >20
3rd Bone Spring Promontory
3rd Bone Spring North of Promontory
2nd Bone Spring Promontory
1st Bone Spring Promontory
L4
300 m
Lower L4 Drift
L3
3rd BS Sandstone
L2
L4
300 m
Lower L4 Drift
L3
3rd BS Sandstone
L2
1st BS Sandstone
L5
300 m
2nd BS Sandstone
L4
L6
300 m
1st BS Sandstone
L5
2nd BS Sandstone
L4

Carbonate Promontories

3 Slope Promontories previously identified may be large drifts



Mimic relationships of detached drifts (i.e.: Rebesco and Stow, 2001). These drift types typically formed from the interaction of bottom currents with a competing current system or from a significant change in the slope orientation (Rebesco, 2005).



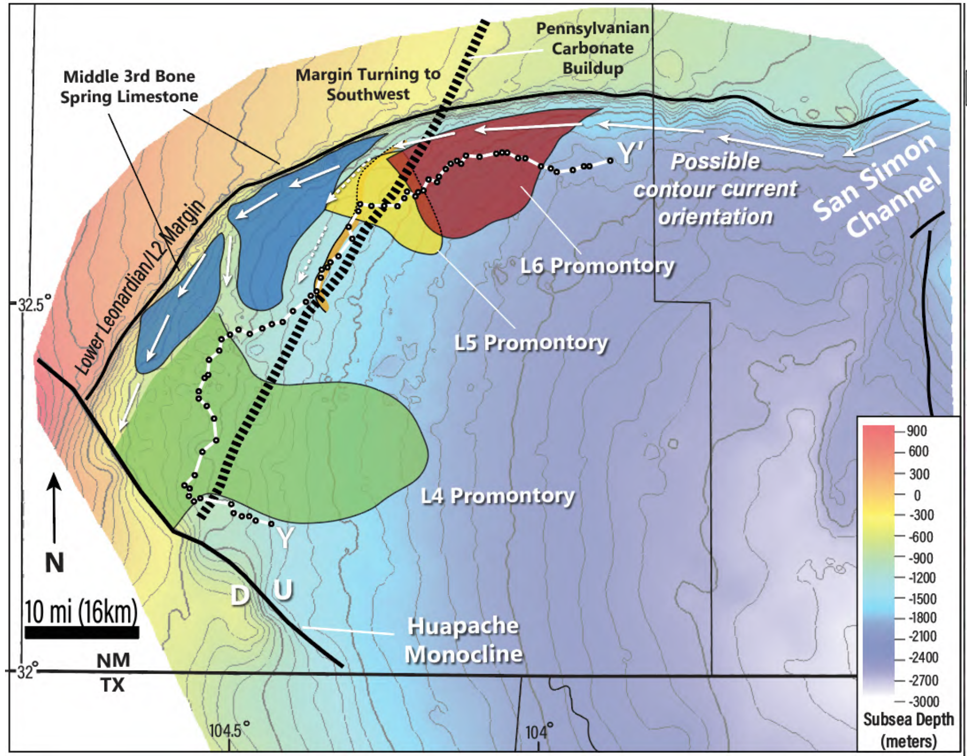
Rebesco and Stow, 2001

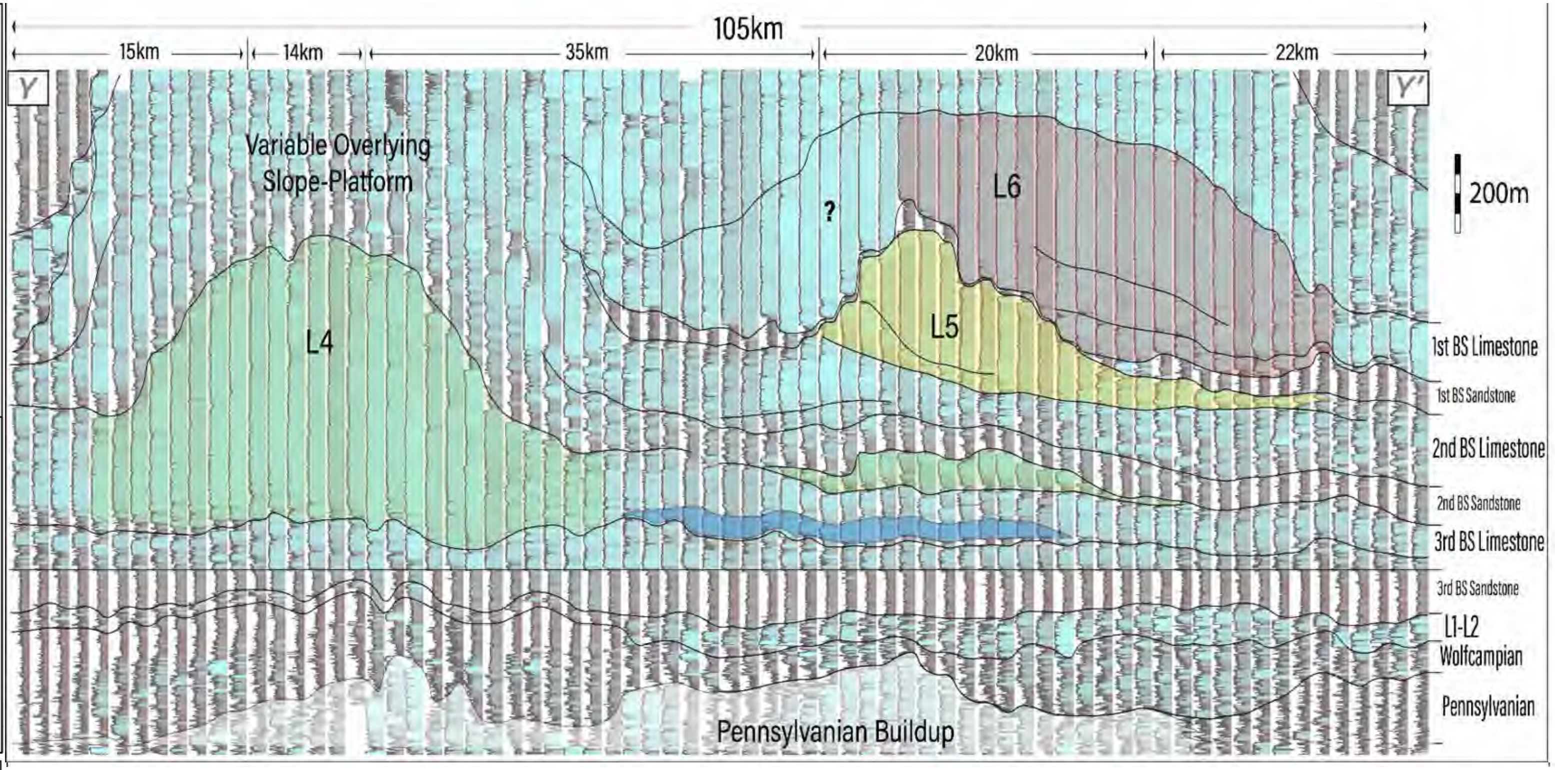
Possible Controls

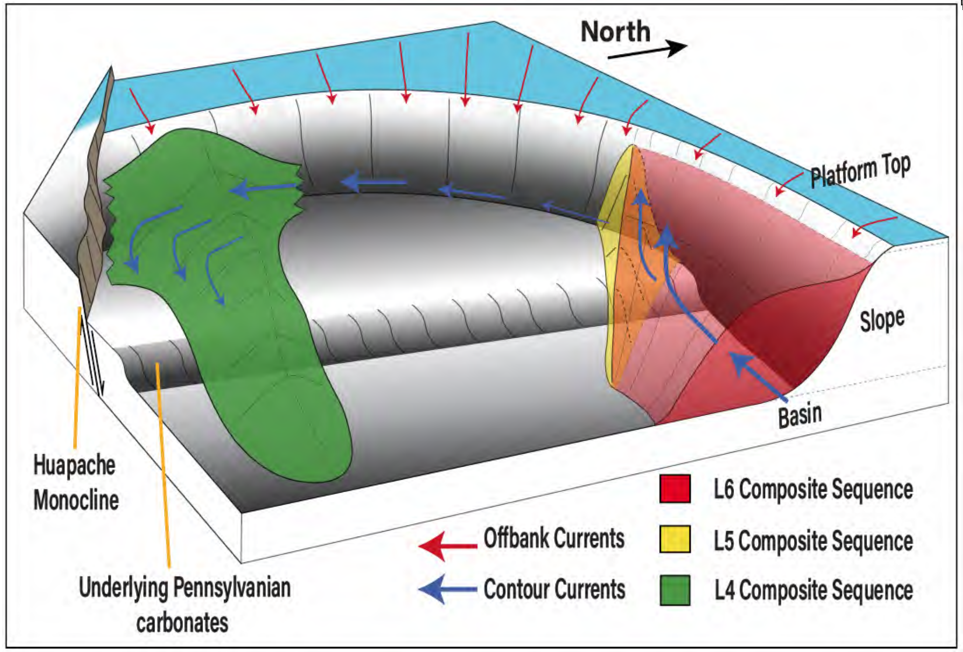
L4: Huapache Monocline and turning of the basin margin

L5: Penn Buildup and turning of the basin margin (hingepoint on the map)

L6: L5 drift geometry (builds off the existing drift)







Large drifts accumulate near significant mapped bathymetric protuberances

Alter platform to basin relief and subsequent progradation rates of overlying platforms

May generate more confined windows along the slopes to point source sediments

Regions of Erosion/ Non-Deposition

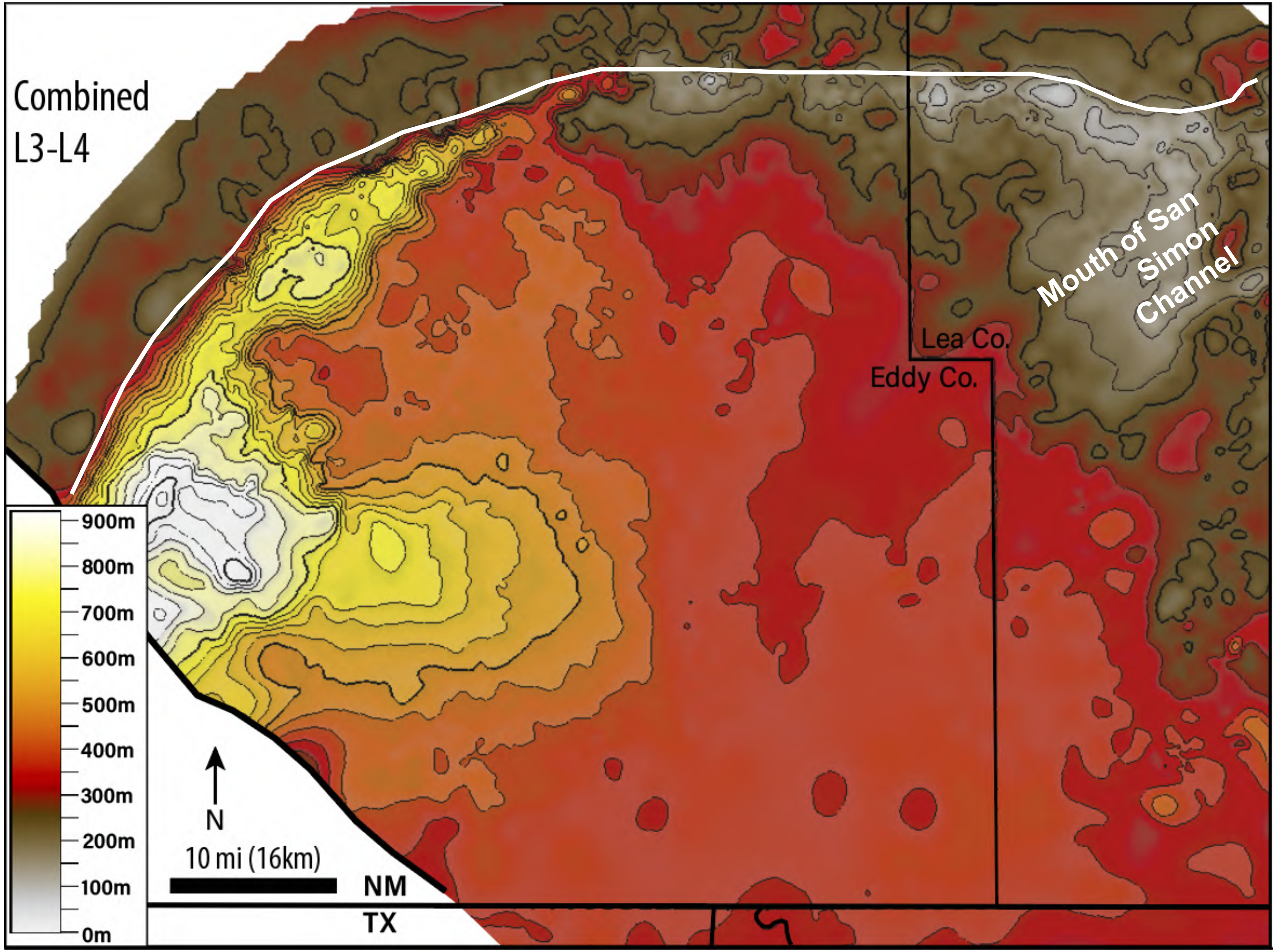
What about where there aren't interpreted drifts?

This is just one example, but there considerable thinning of the combined L3-L4 isopach near the San Simon Channel and along the northern slope, with thickness continually increasing to the west

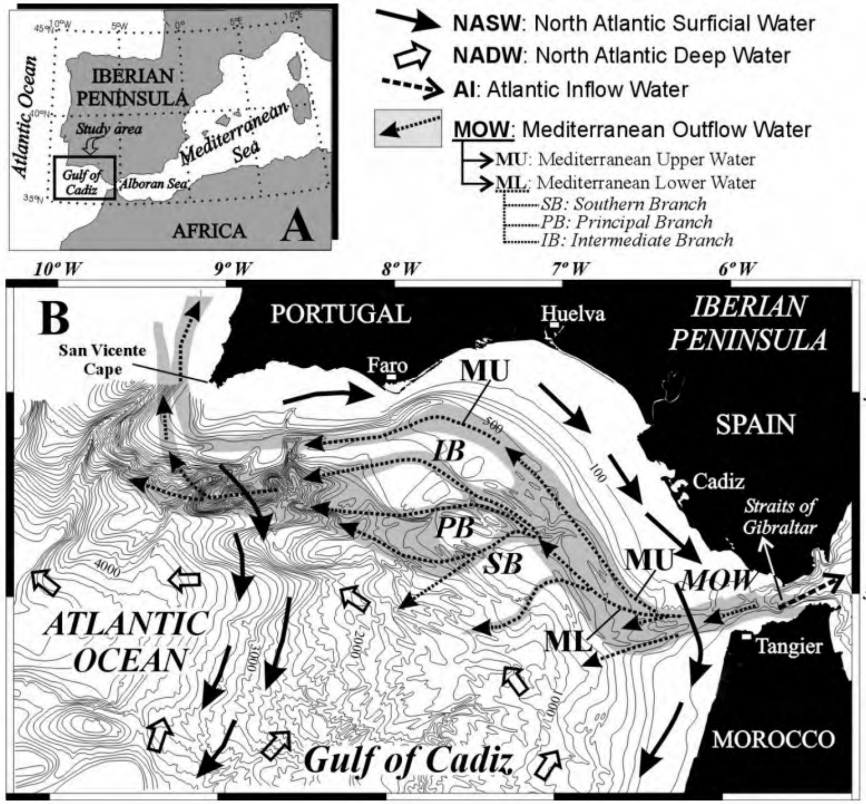
Could be related to volume of offbank transport

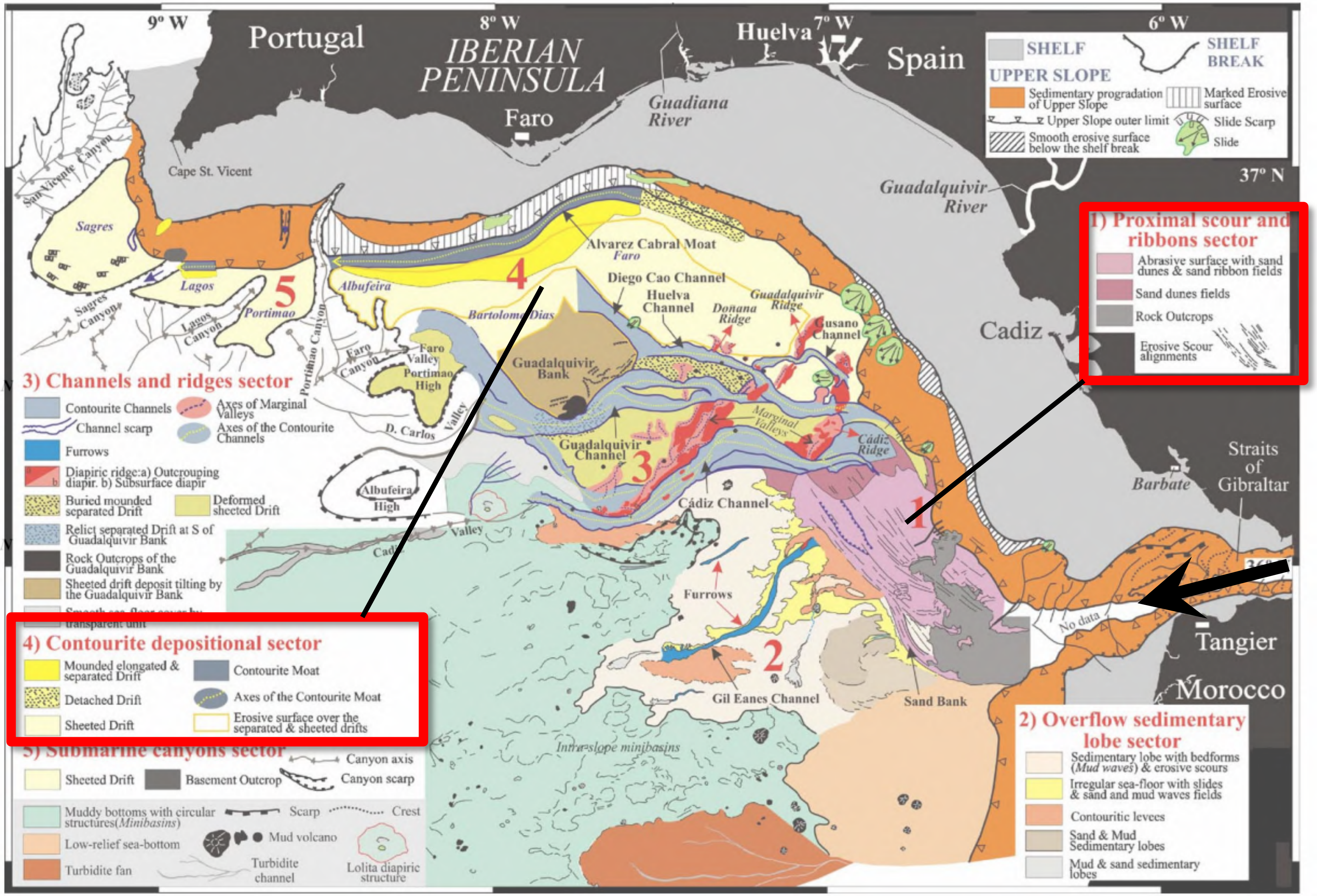
OR

Contour currents could be sweeping sediments from east to west from the San Simon Channel and plastering them on the western slopes.



L4/ 3rd Bone Spring Isopach





Possible Analog: Faro Drift, Gulf of Cadiz

Hernandez-Molina et al., 2003

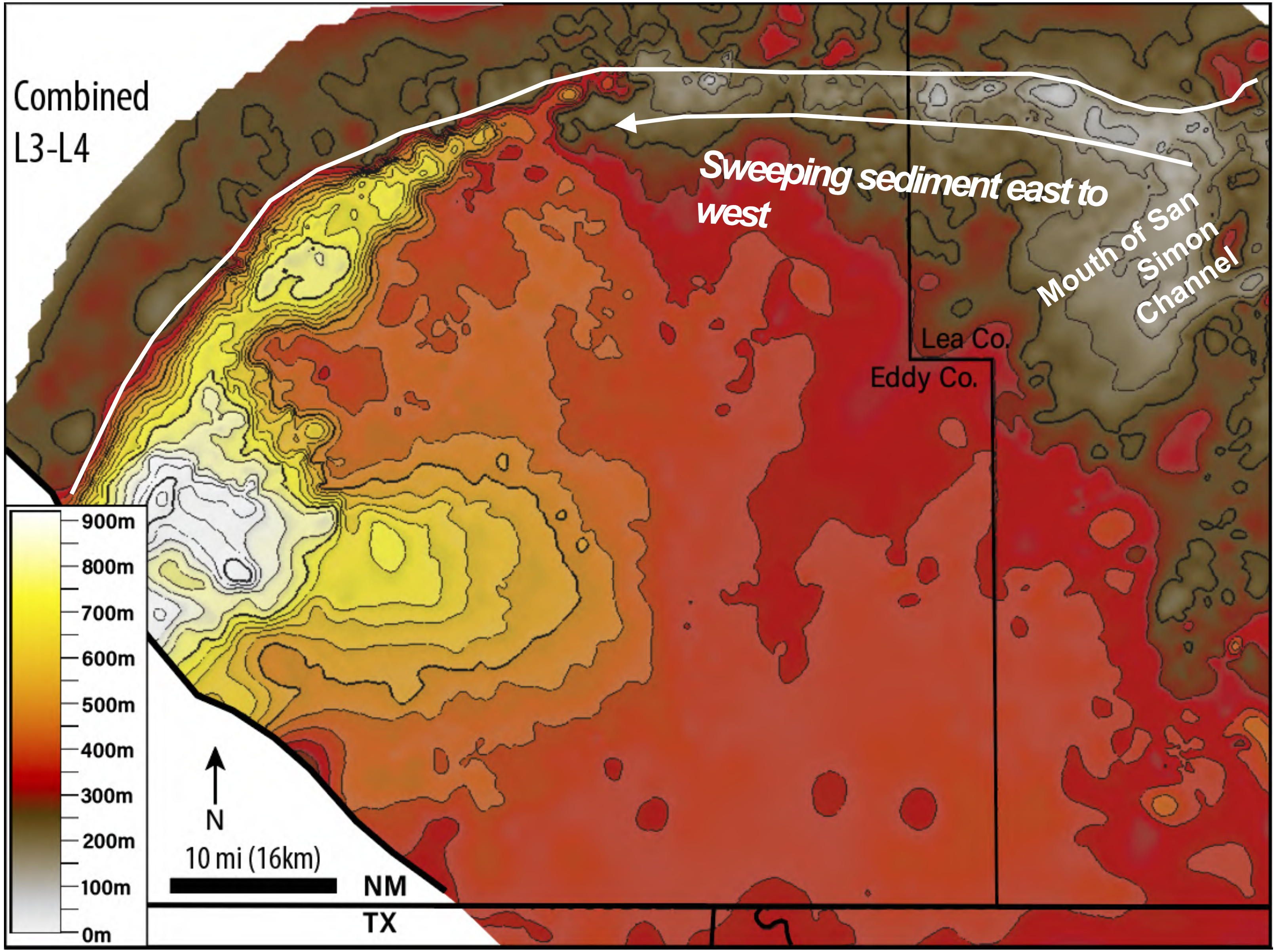
Regions of Erosion/ Non-Deposition

Deposition of Carbonate Mud

Could be related to volume of offbank transport

<u>OR</u>

Contour currents could be sweeping sediments from east to west from the San Simon Channel and plastering them on the western slopes.



L4/ 3rd Bone Spring Isopach

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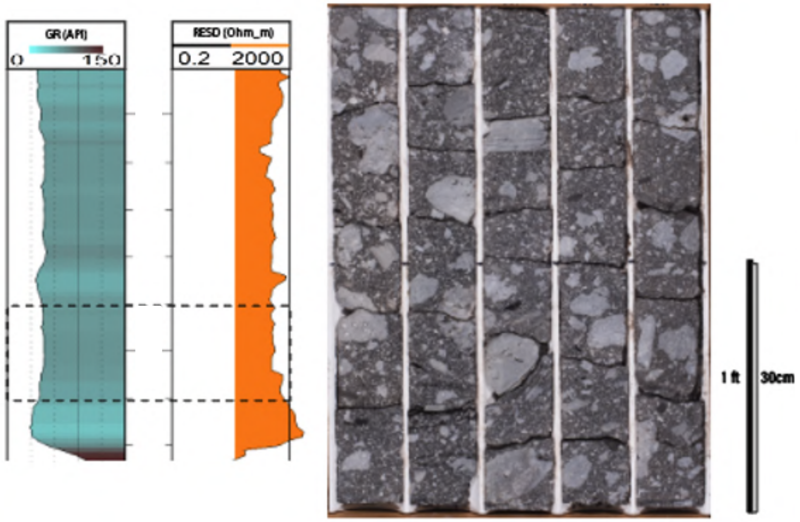
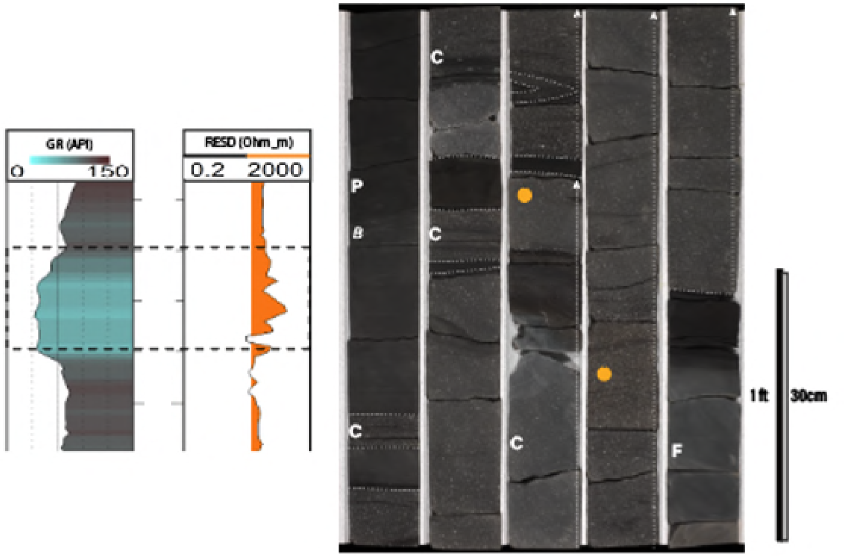
Basinal Deposition

Log Motifs

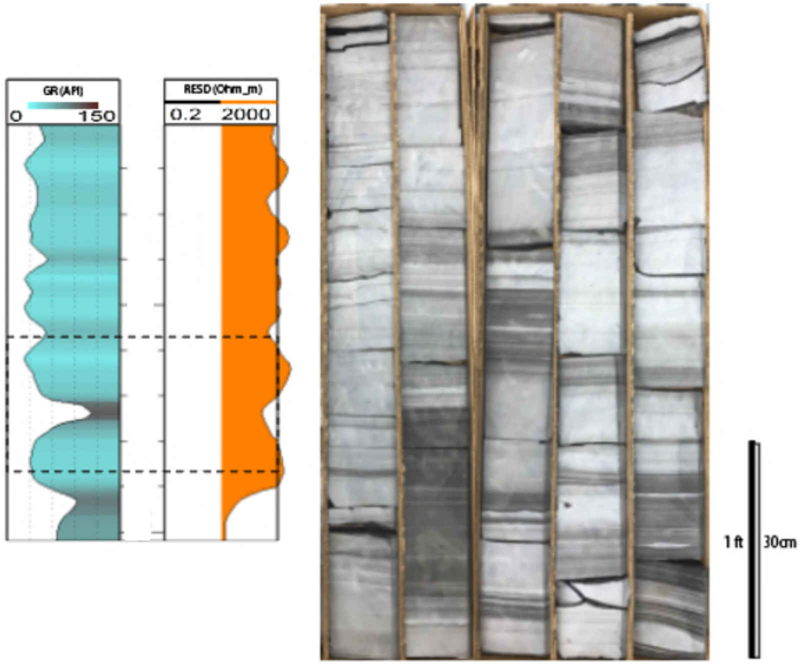
- Gamma ray logs provide a proxy for carbonate content
- Carbonate intervals most often represent the coarser material within gravity flow deposits
- Siliciclastic material often represents dilute portions of flows or hemipelagic muds



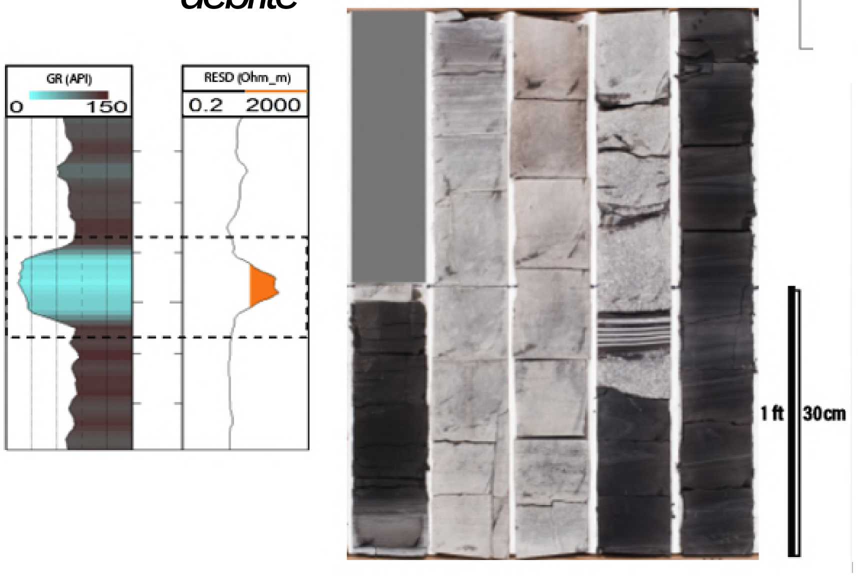
Clast-supported carbonate debrite



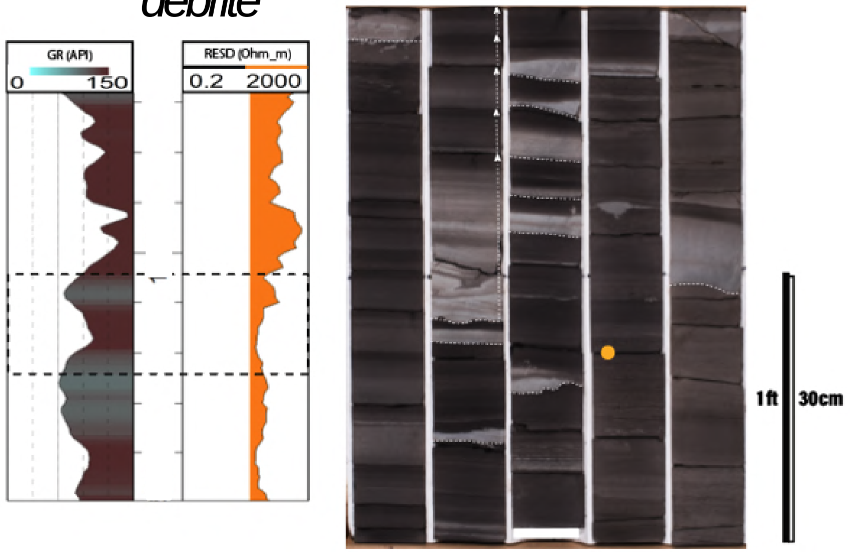
Matrix-supported carbonate debrite



Mud-rich carbonate turbidites

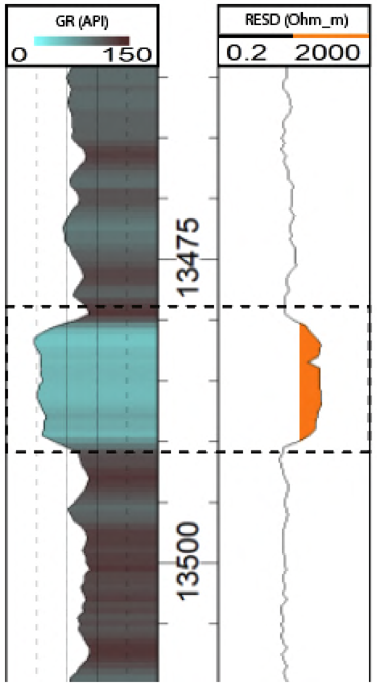


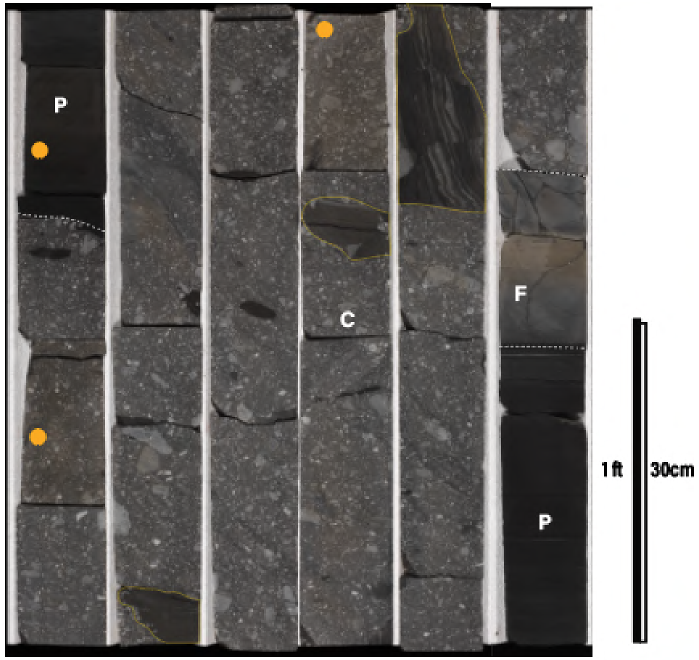
Grain-rich carbonate turbidite

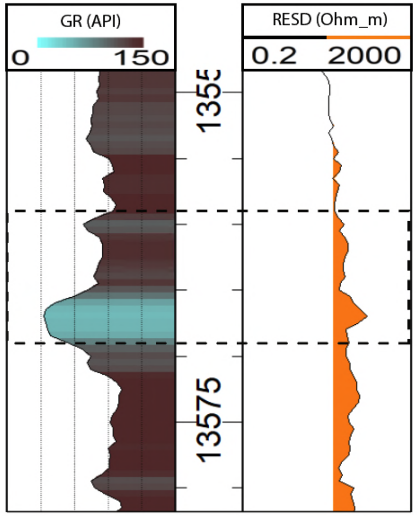


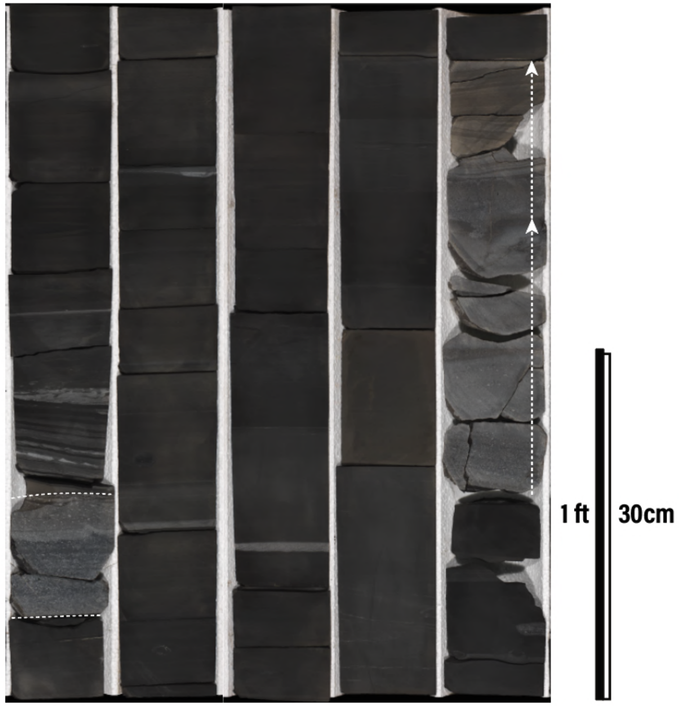
Mixed turbidites

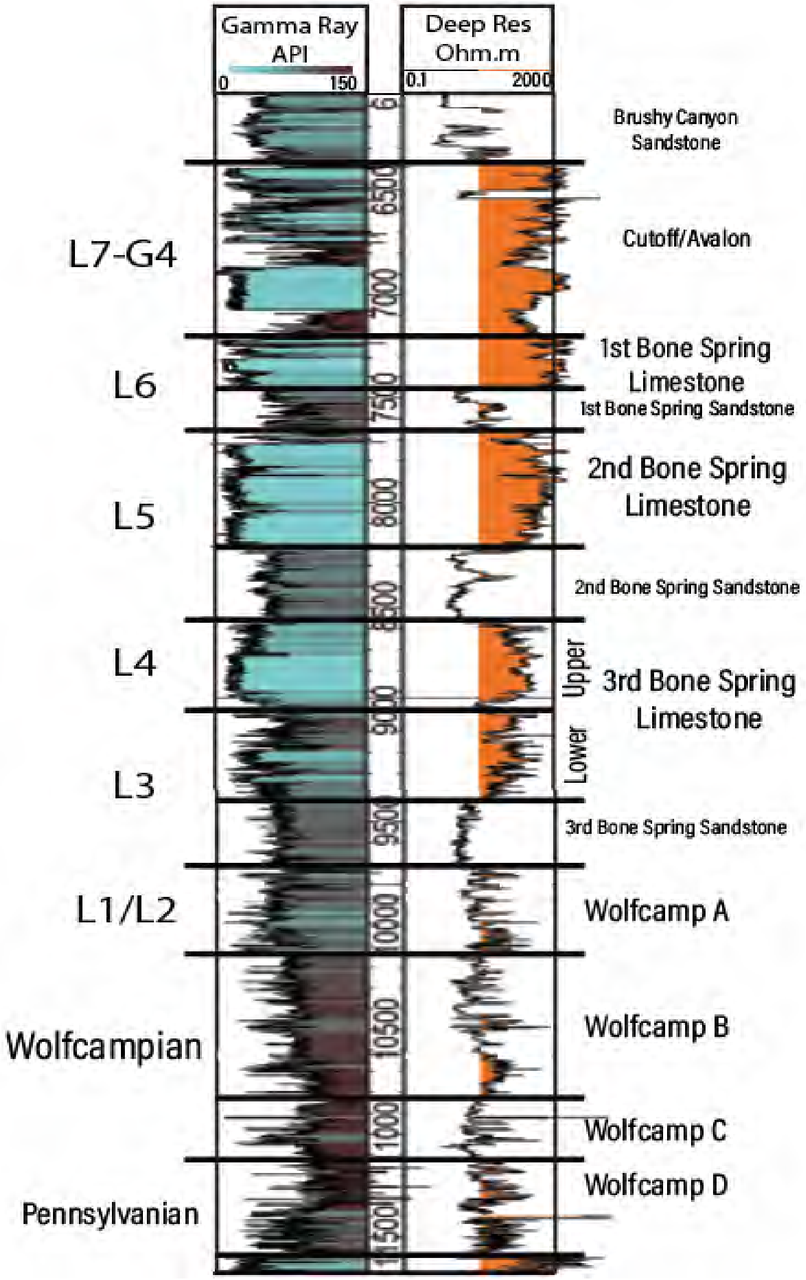
Potential Calciclastic Submarine Fans



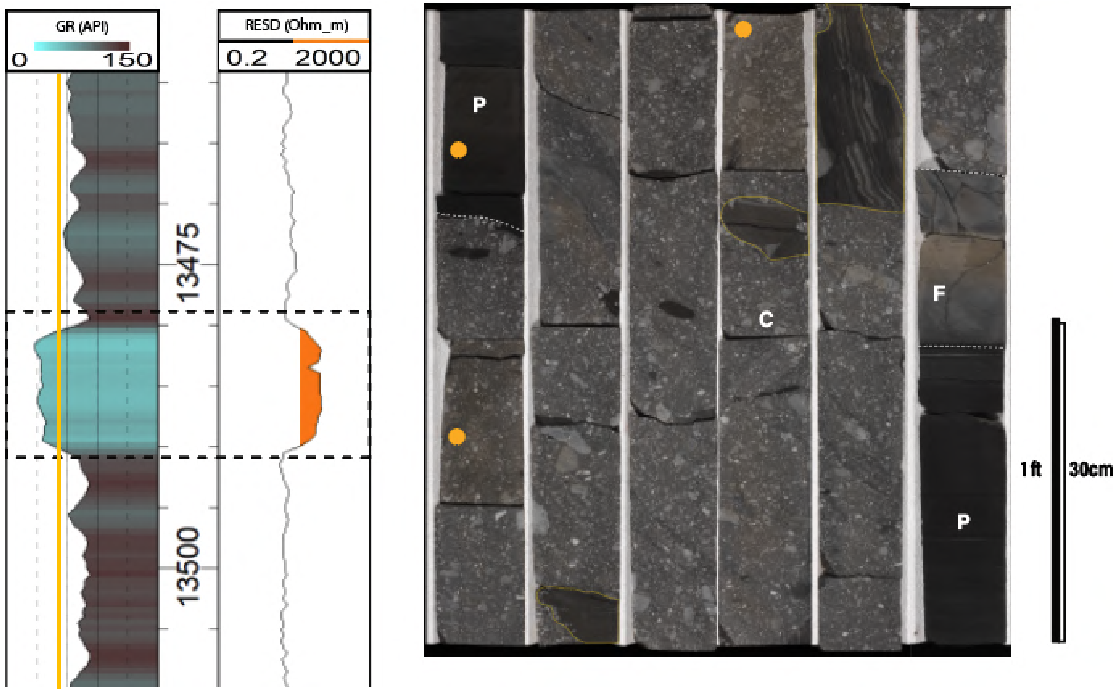


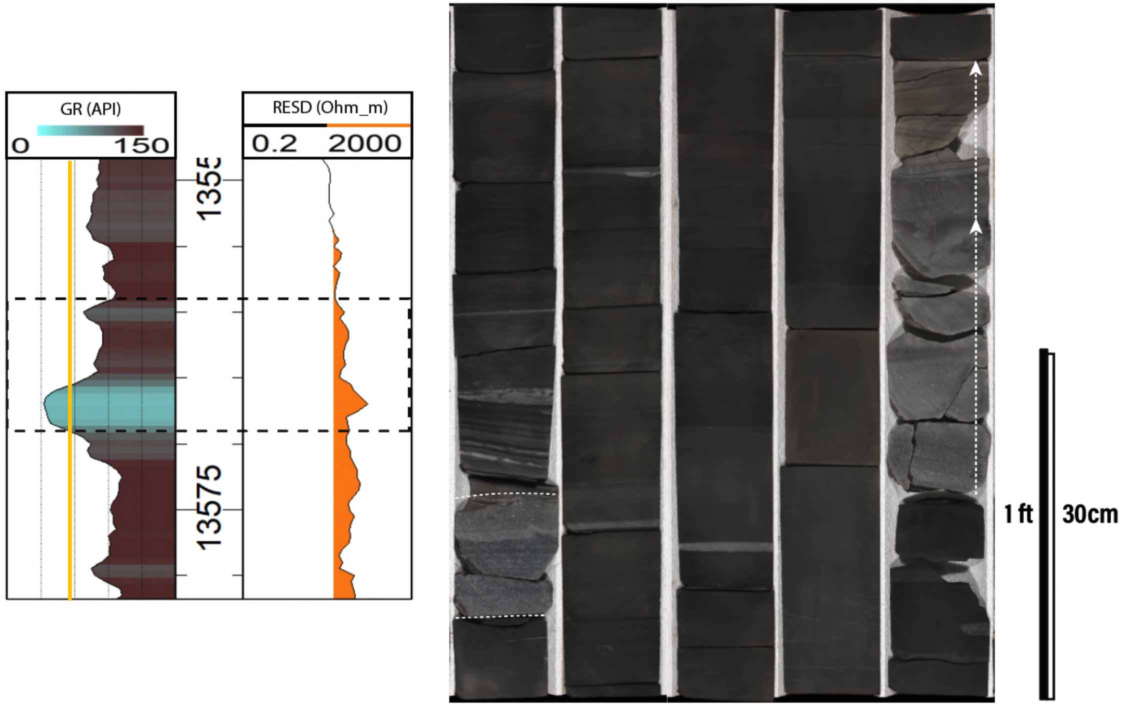


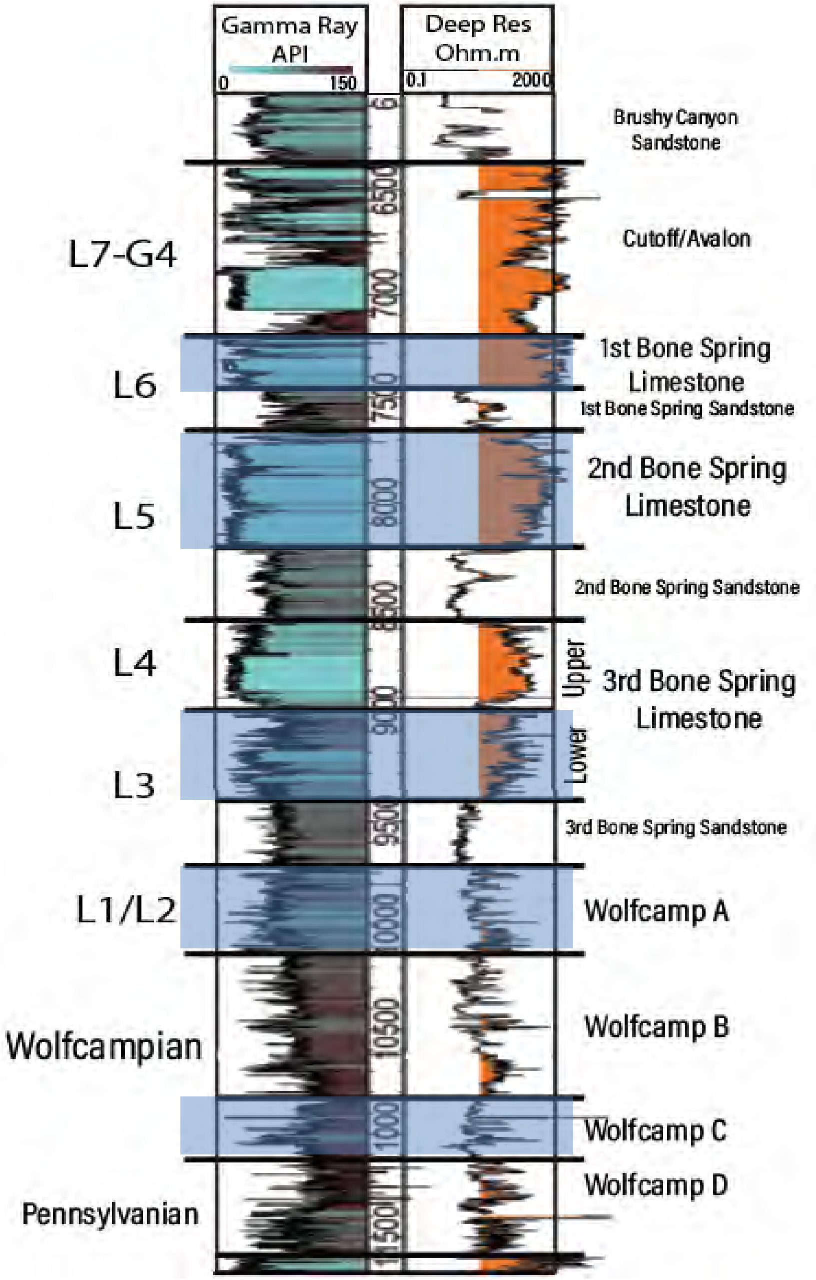




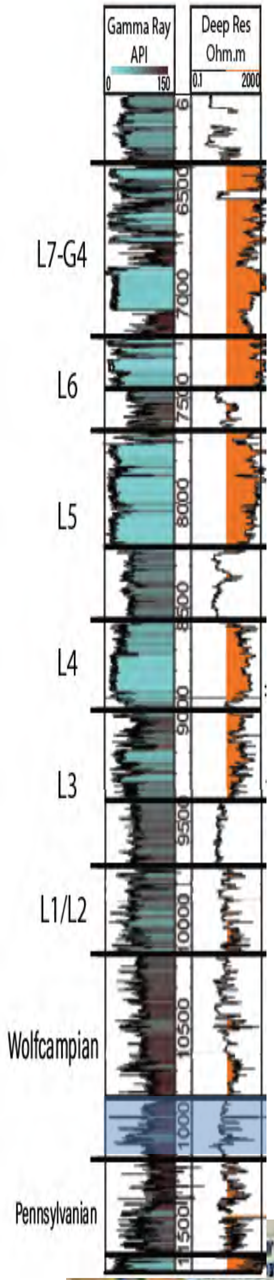
Potential Calciclastic Submarine Fans

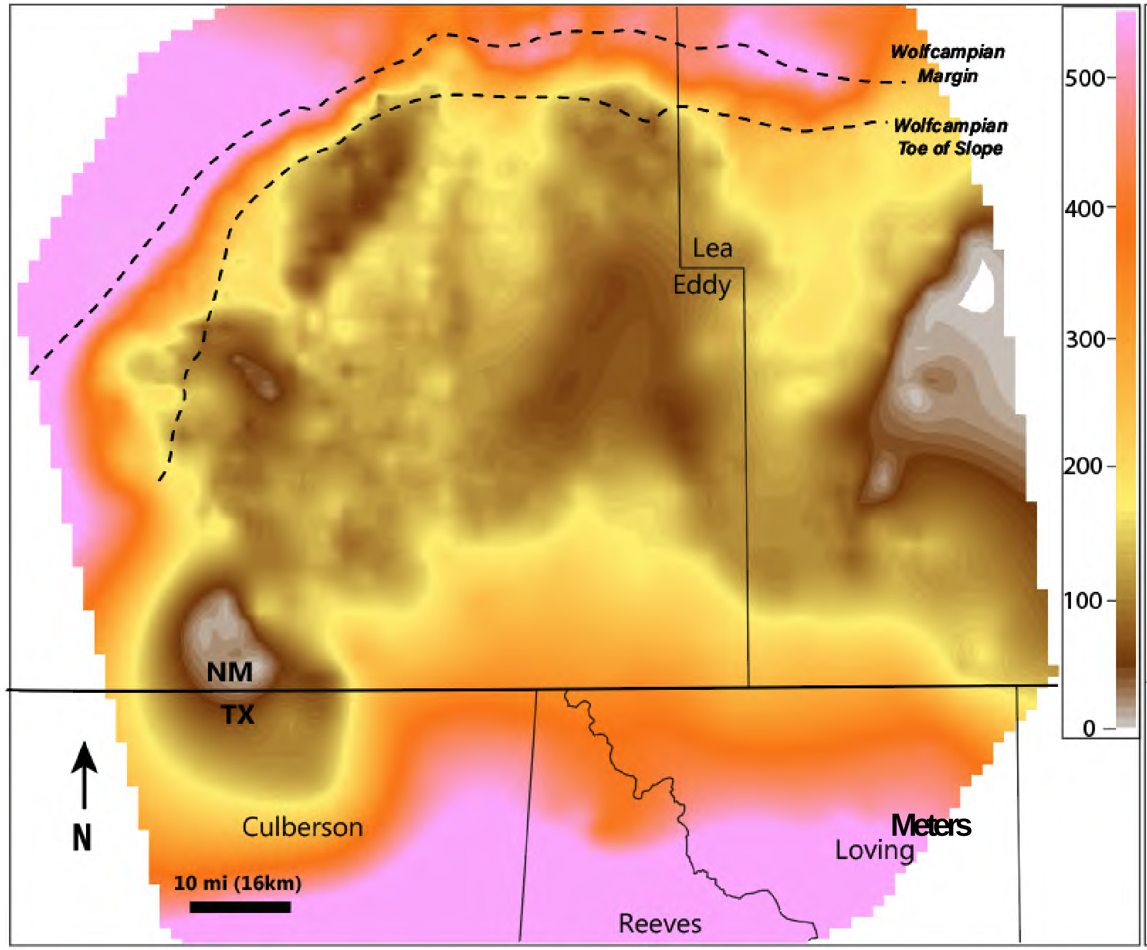




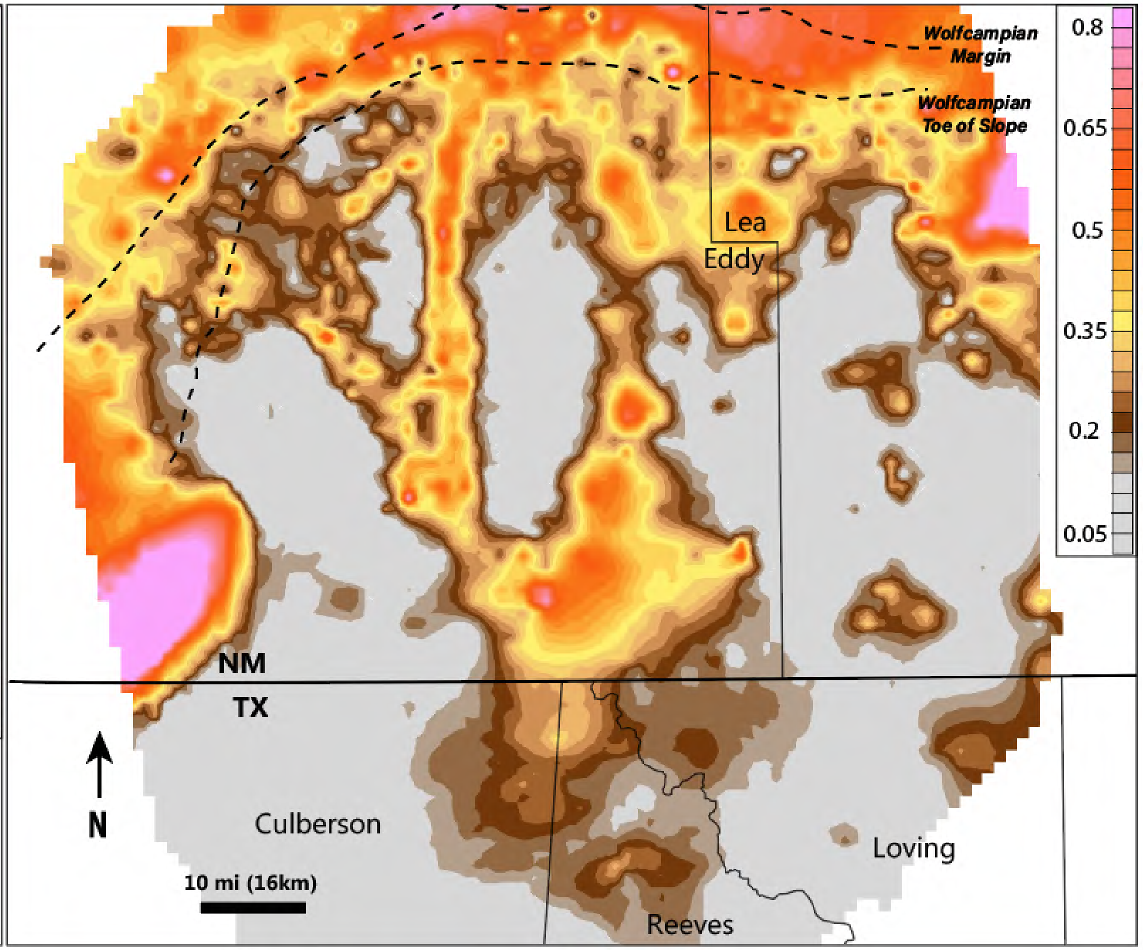


Interpreted Calciclastic Fan: *“Wolfcamp C”*





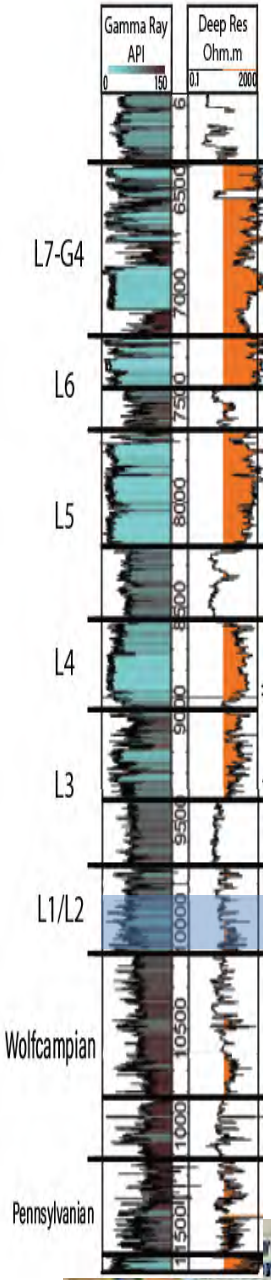
Isopach Thickness Map

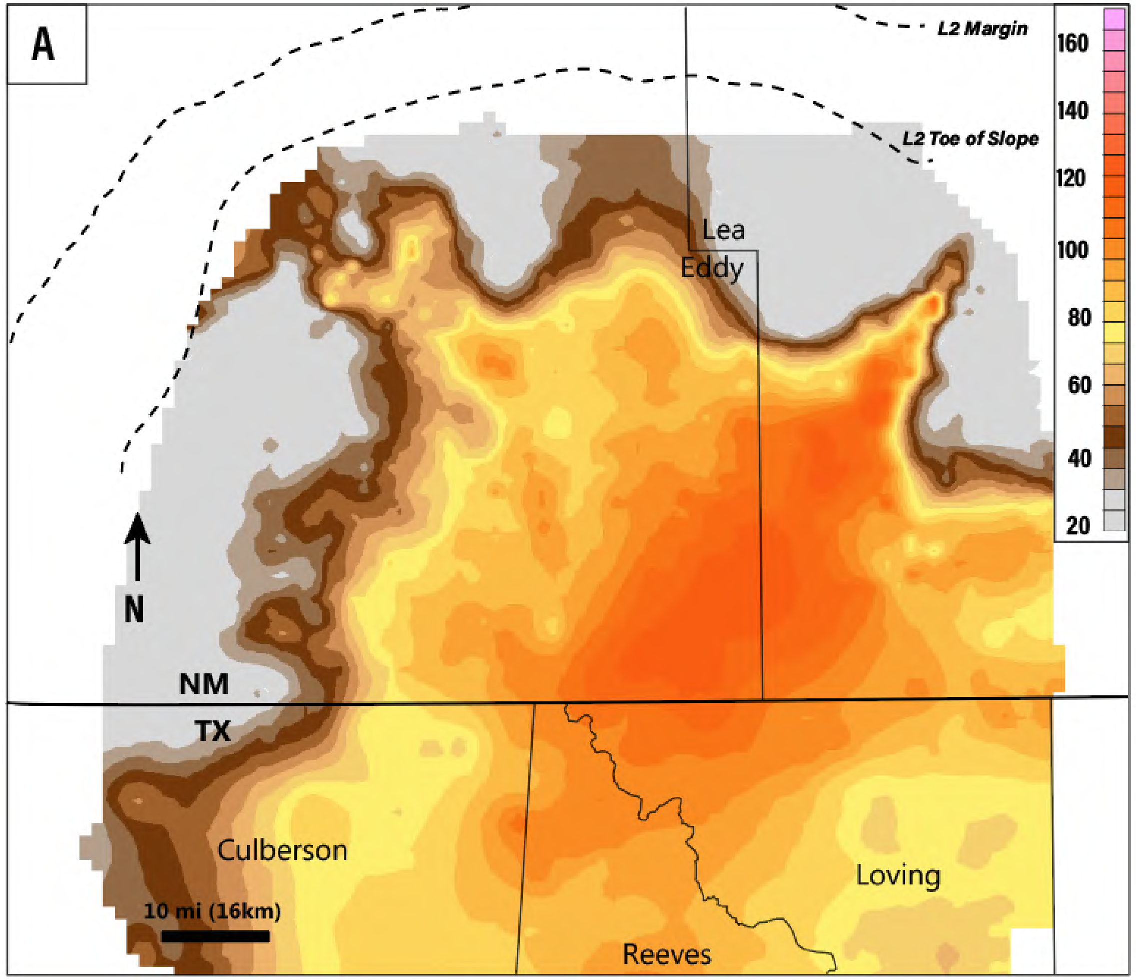


Net-to-Gross Thickness Map

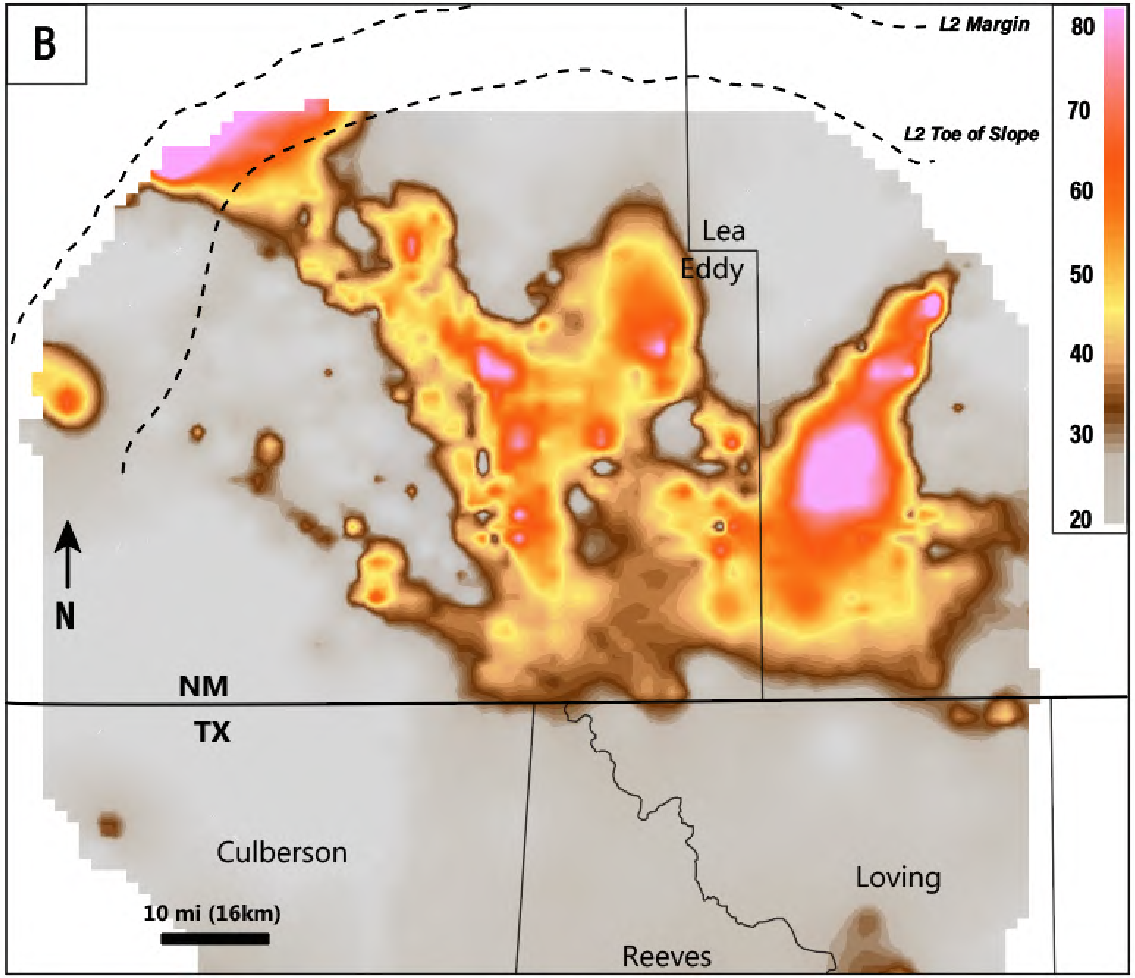
Thickness in meters

Interpreted Calciclastic Fan: *L1-L2 Carbonate*





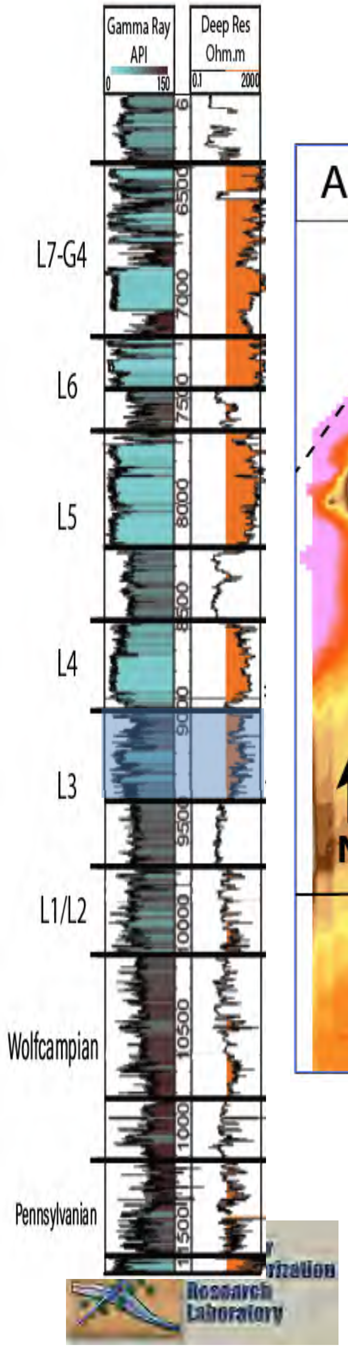
Isopach Thickness Map

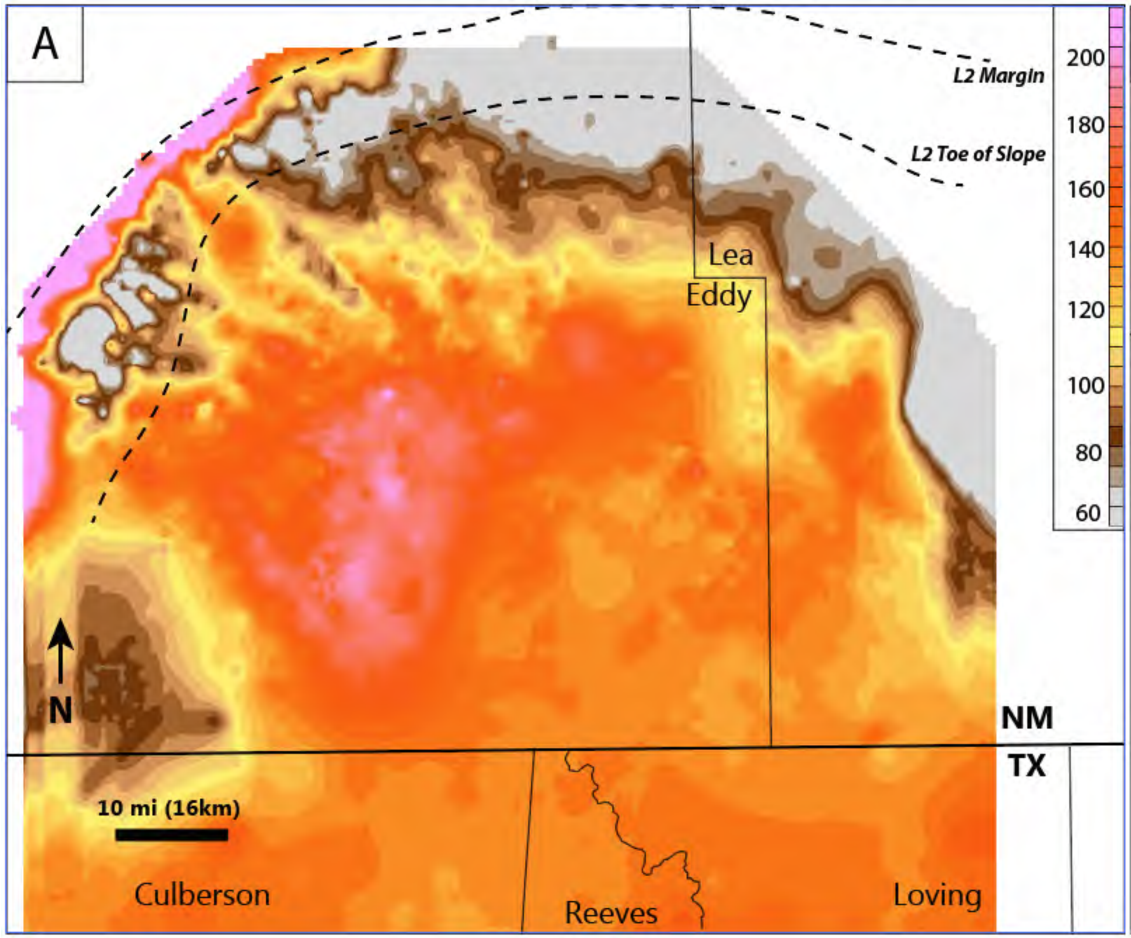


Net Thickness Map

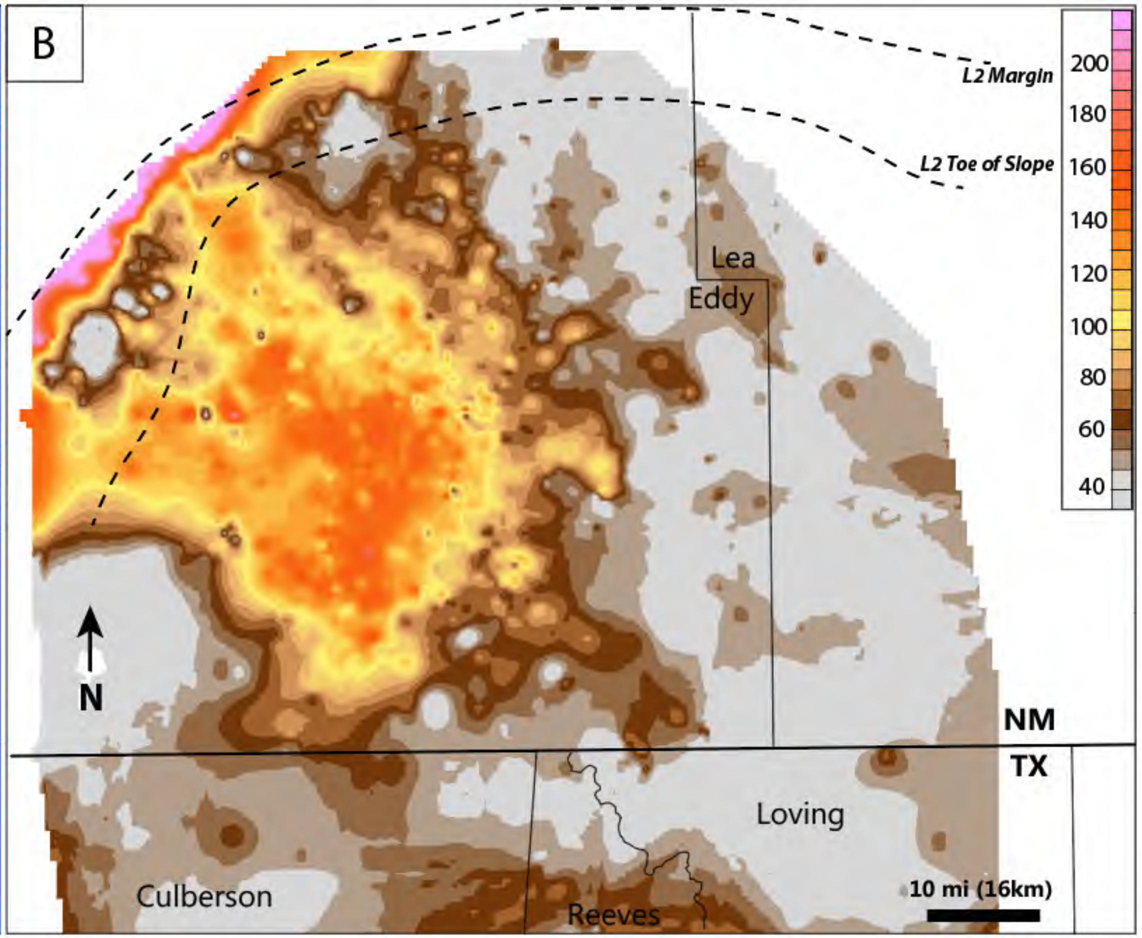
Thickness in meters

Interpreted Calciclastic Fan: *L3 Carbonate*





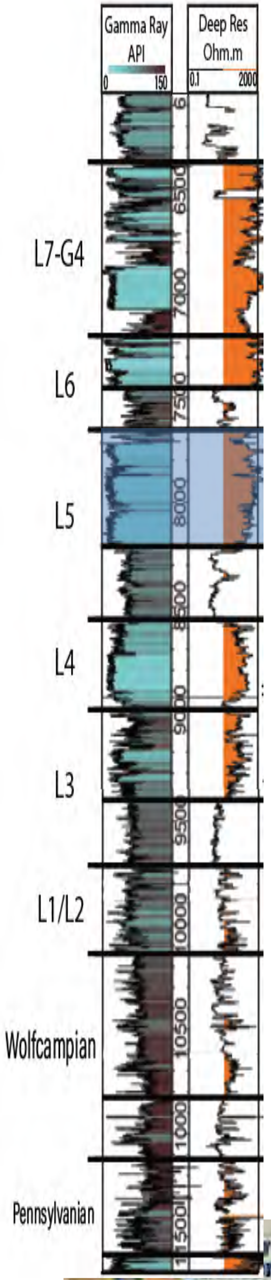
Isopach Thickness Map

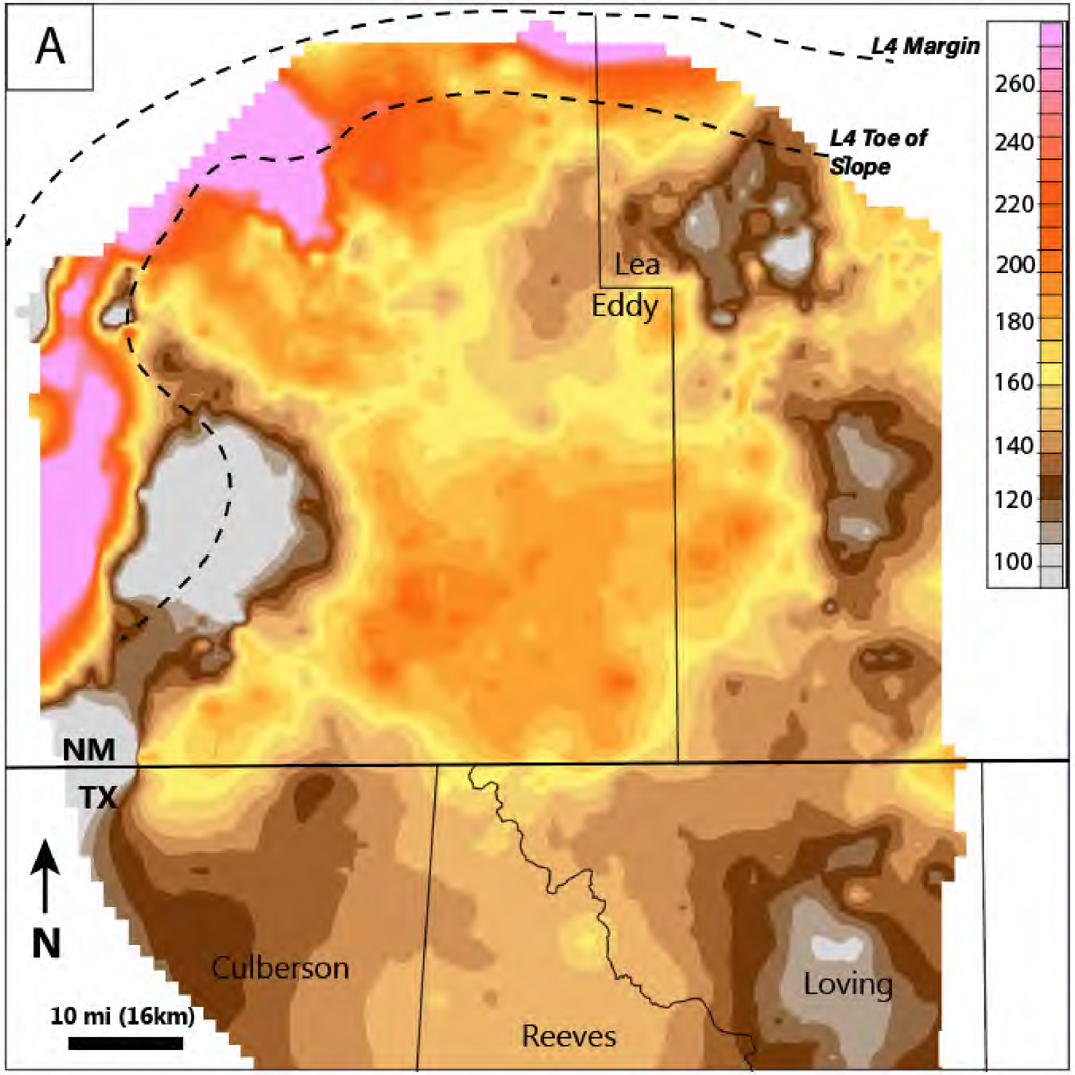


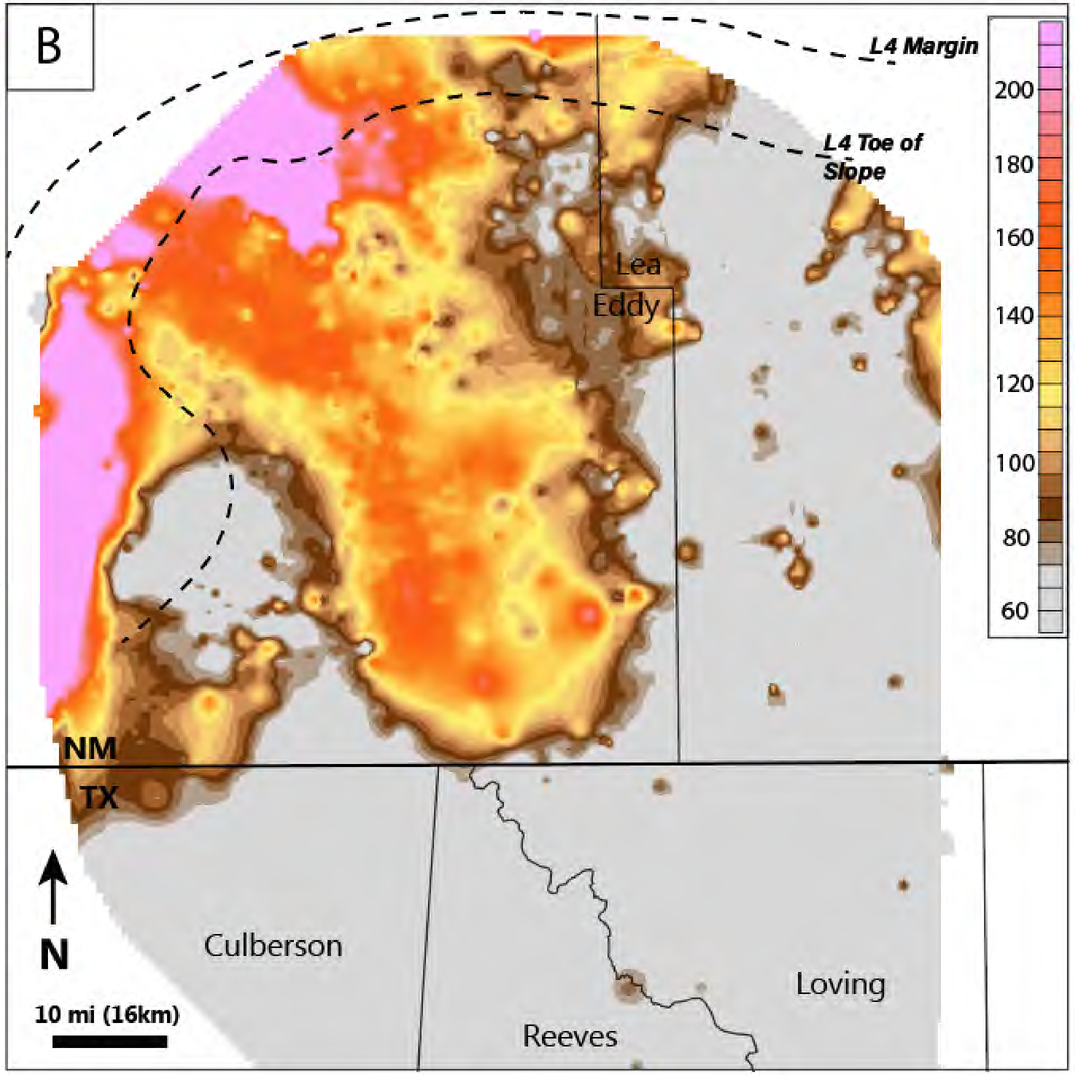
Net Thickness Map

Thickness in meters

Interpreted Calciclastic Fan: *L5 Carbonate*





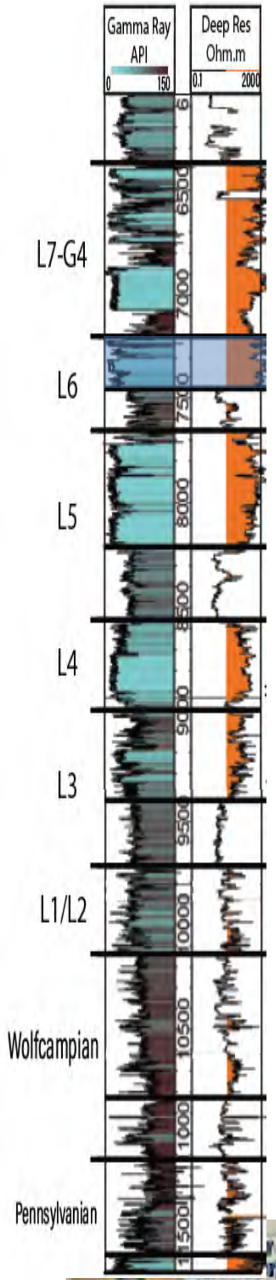


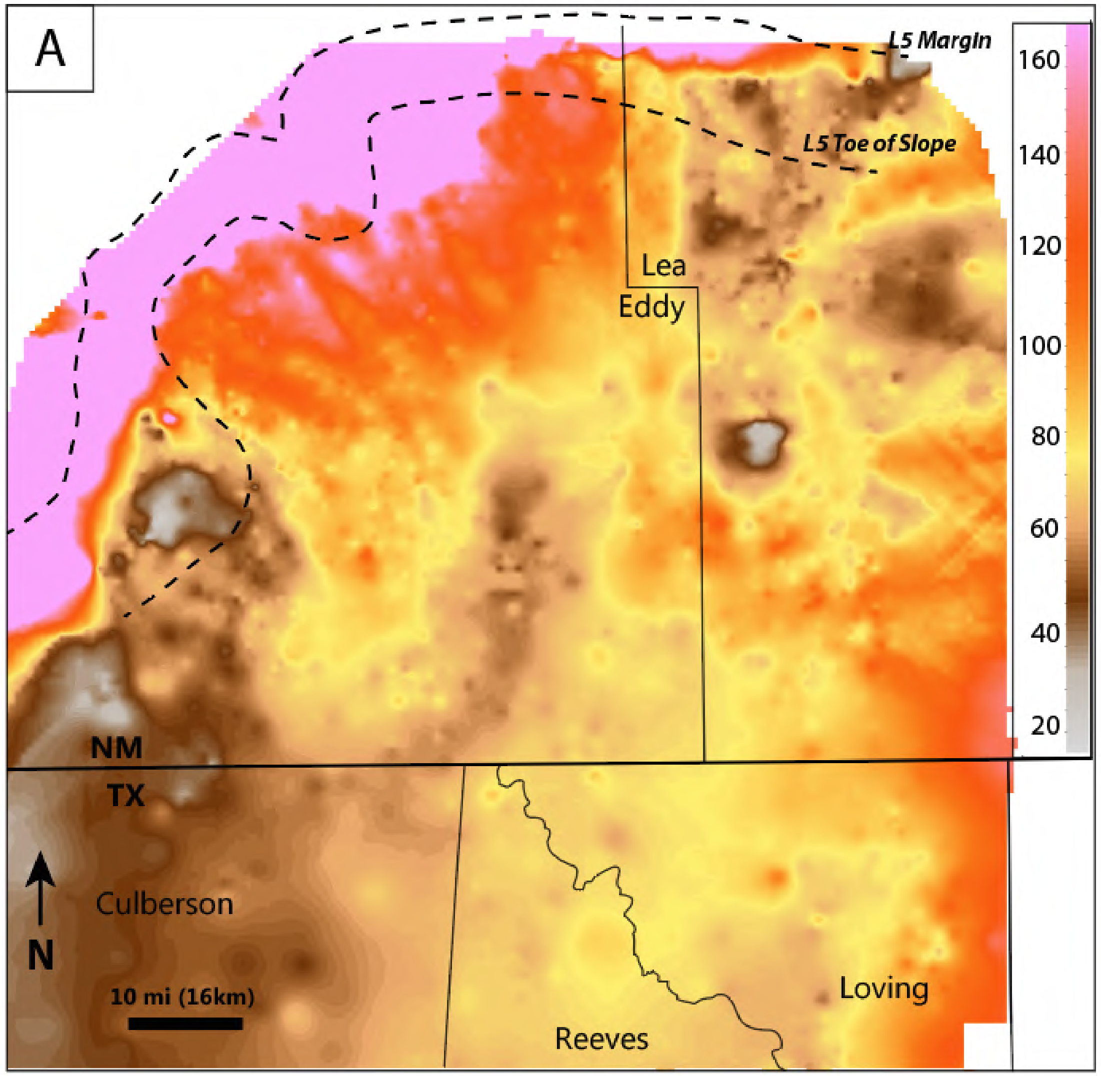
Isopach Thickness Map

Net Thickness Map

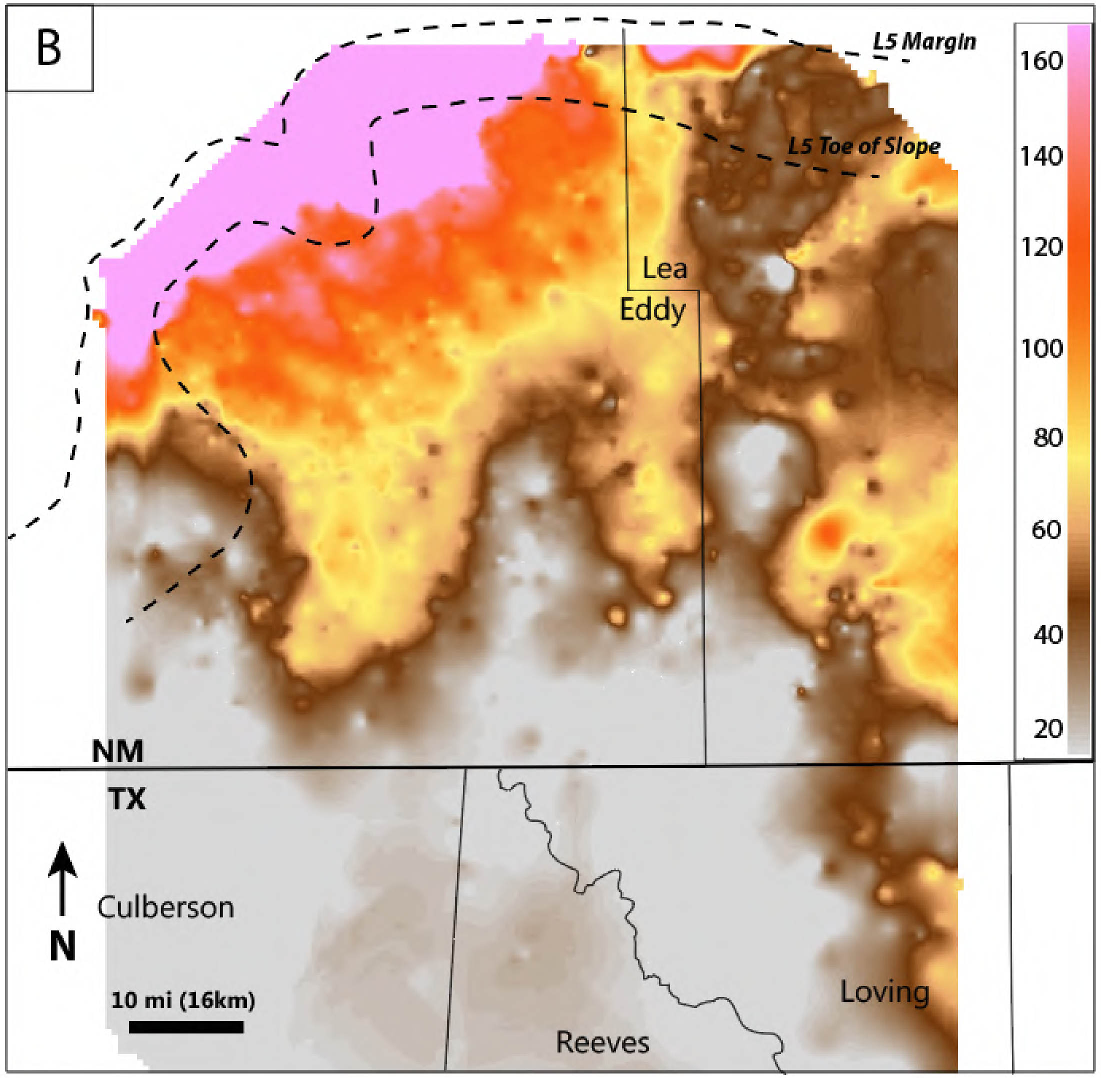
Thickness in meters

Interpreted Calciclastic Fan: *L6 Carbonate*





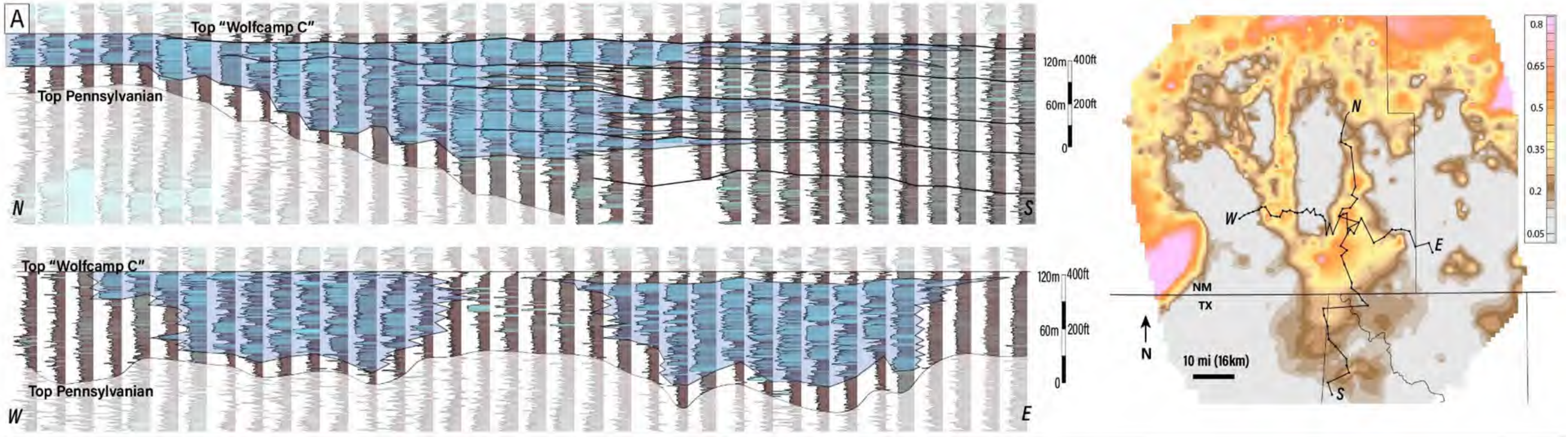
Isopach Thickness Map

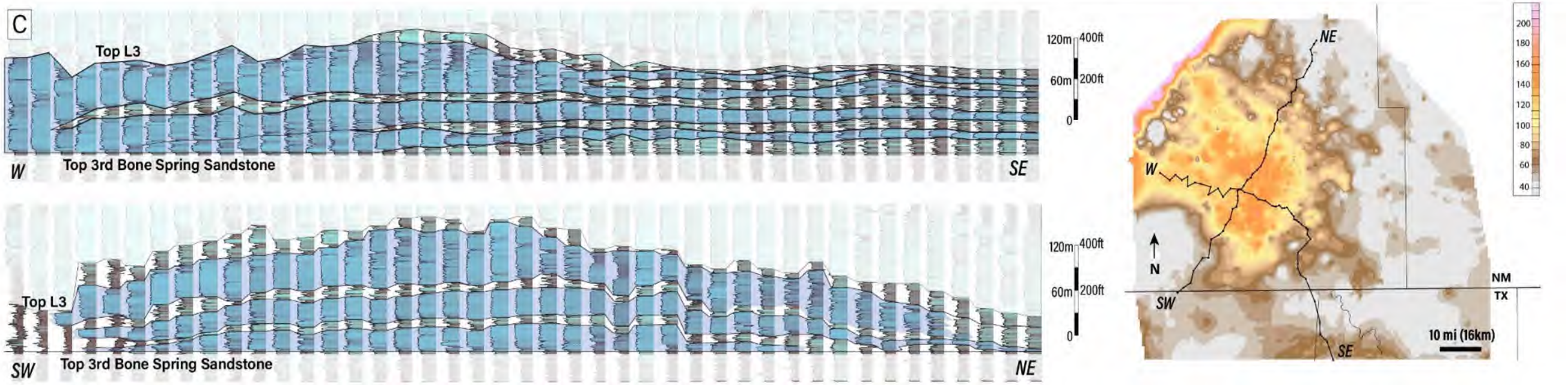


Net Thickness Map

Thickness in meters

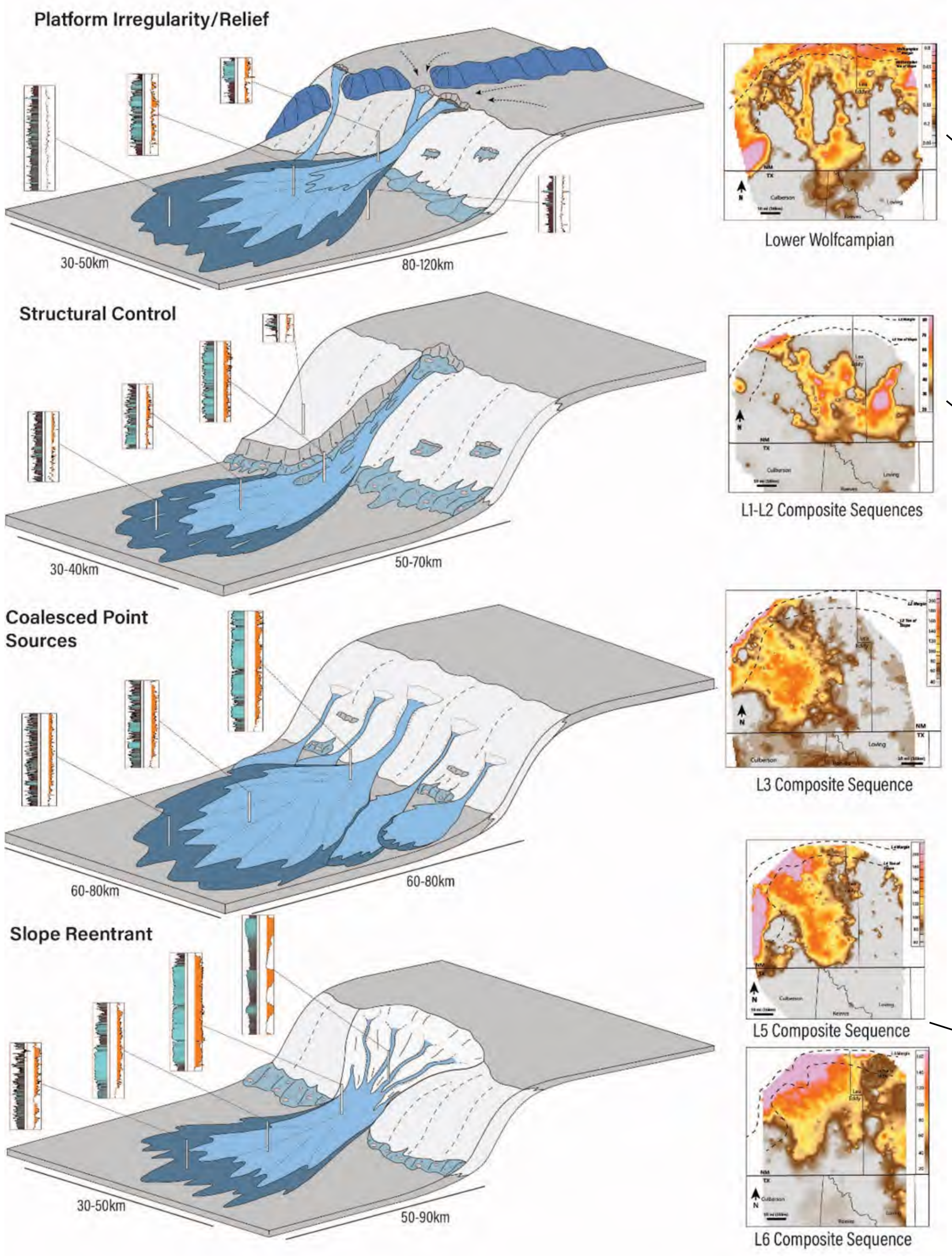
Well Log Response

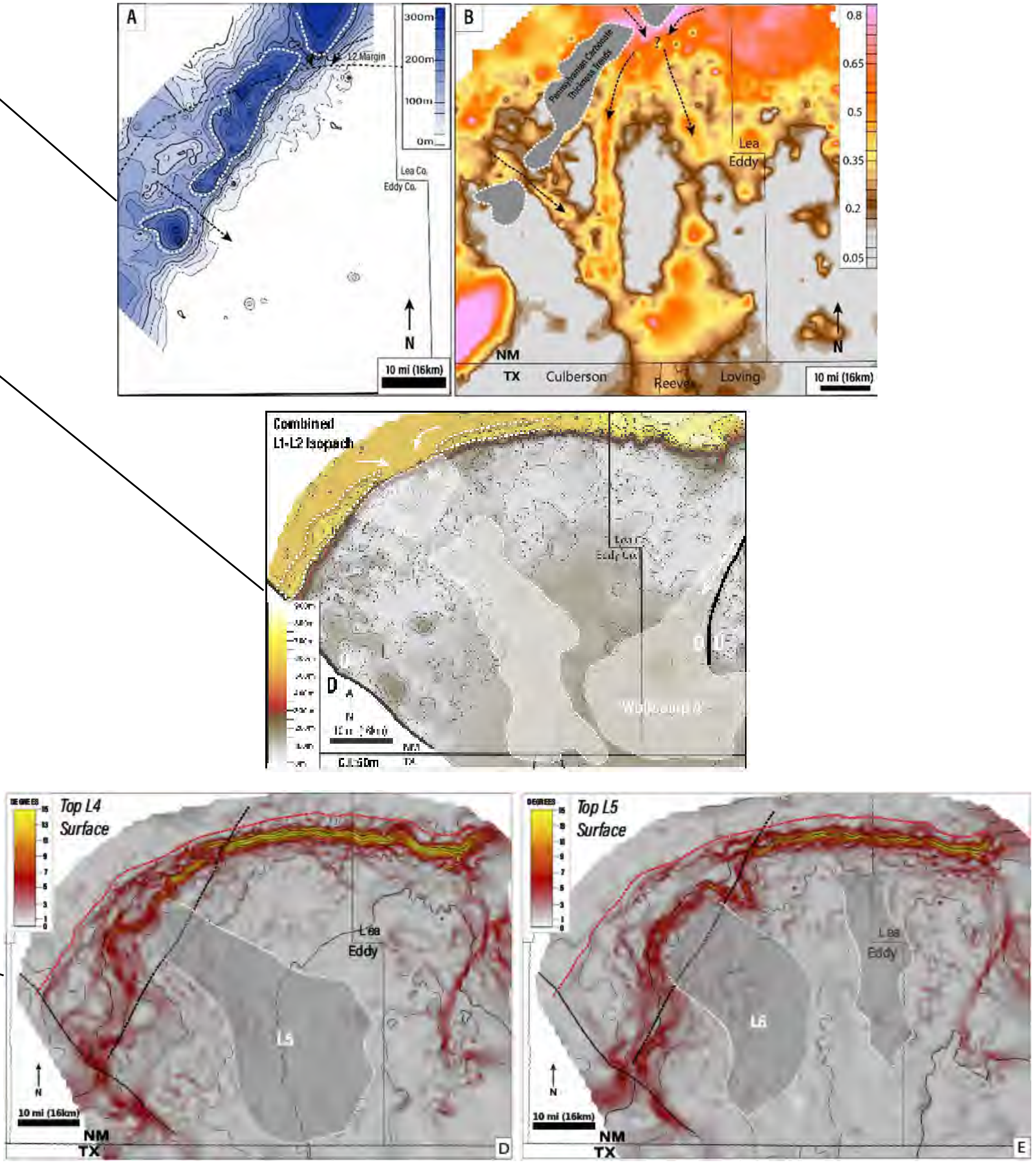


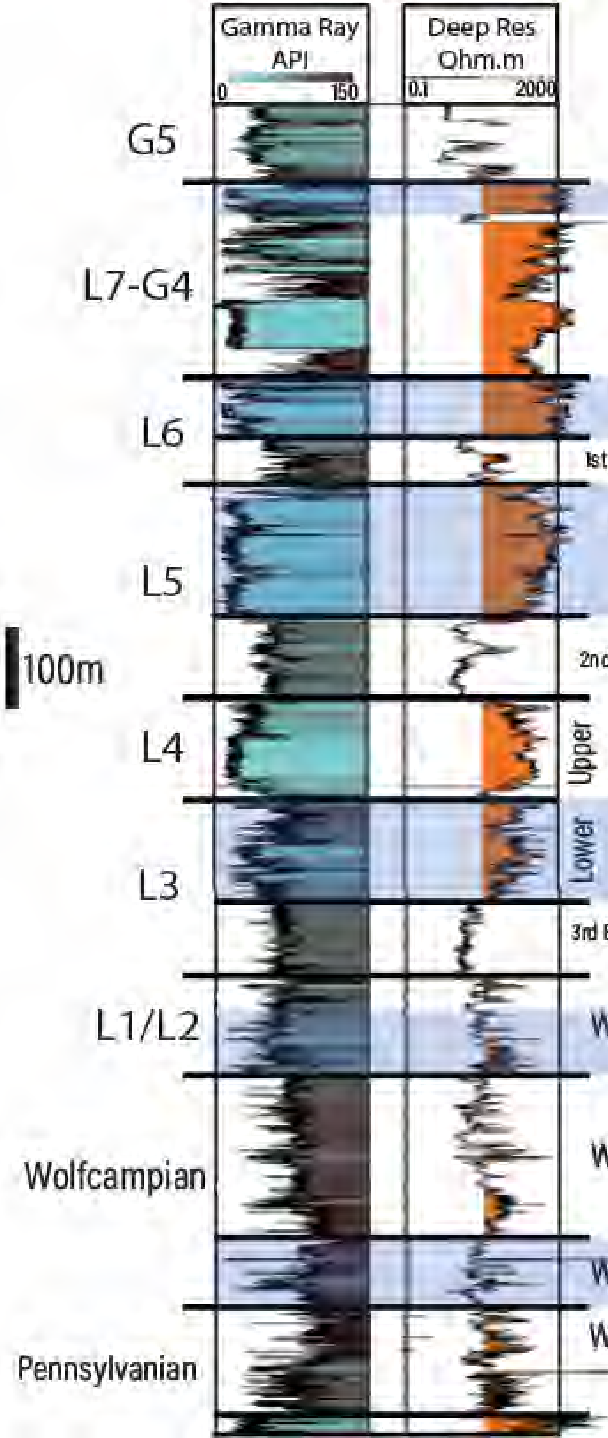


- Gradational electrofacies transition off frontal fringe
- Rapid electrofacies shifts off lateral fringes
- Enriched in siliciclastics with continued gravity flow runout

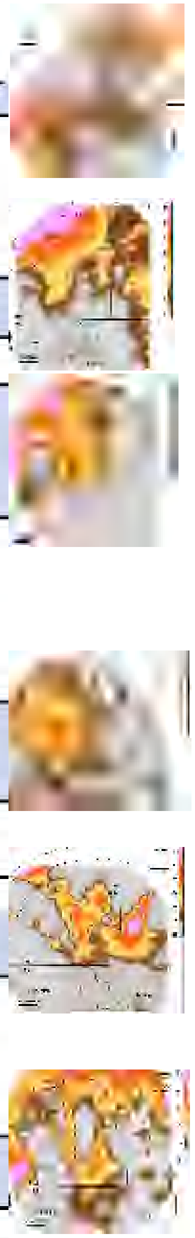
Fan Growth Controls







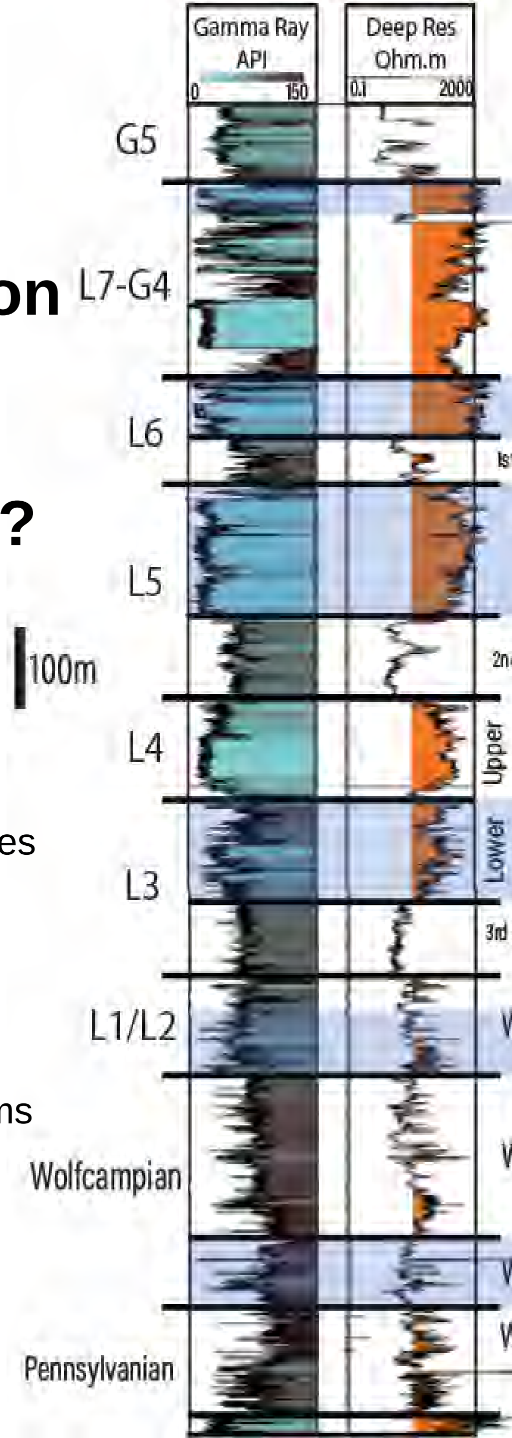
Interval	Composition	Platform	Slope	Confinement Mechanism	Duration (Approximate)
Brushy Canyon Sandstone					
	Multiple Compositions	Retreated platform	Variable	Local/Coalesced Point Sources	1 MY
Cutoff/Avalon					
1st Bone Spring Limestone	Mud-dominated	Progradational broad mud-dominated	3-8 degrees	Antecedent bathymetry and structural	1.0-1.3 MY
1st Bone Spring Sandstone					
2nd Bone Spring Limestone	Mud-dominated	Progradational broad mud-dominated	3-8 degrees	Antecedent bathymetry	1.0-1.3 MY
2nd Bone Spring Sandstone					
3rd Bone Spring Limestone	Mud-dominated	Retrogradational, broad mud-dominated	15-20 degrees	Coalesced Point Sources	1.0-1.3 MY
3rd Bone Spring Sandstone					
Wolfcamp A	Debris-Dominated, mixed composition	Aggradational, tectonically modified	15-20 degrees	Structural	1.3-2.5 MY
Wolfcamp B					
Wolfcamp C	Debris-Dominated, mixed composition	Irregular, tectonically modified	6-10 degrees	Antecedent bathymetry	8-10 MY
Wolfcamp D					



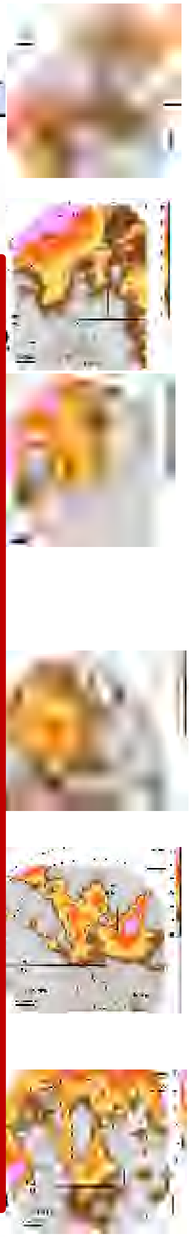
Sedimentation Rates and Organic Enrichment?

Long duration and aggradational-retrogradational profiles likely conducive to condensed sedimentation

Short duration and progradational systems may dilute organic



Interval	Composition	Platform	Slope	Confinement Mechanism	Duration (Approximate)
Brushy Canyon Sandstone					
Cutoff/Avalon	Multiple Compositions	Retreated platform	Variable	Local/Coalesced Point Sources	1 MY
1st Bone Spring Limestone	Mud-dominated	Progradational broad mud-dominated	3-8 degrees	Antecedent bathymetry and structural	1.0-1.3 MY
1st Bone Spring Sandstone					
2nd Bone Spring Limestone	Mud-dominated	Progradational broad mud-dominated	3-8 degrees	Antecedent bathymetry	1.0-1.3 MY
2nd Bone Spring Sandstone					
3rd Bone Spring Limestone	Mud-dominated	Retrogradational, broad mud-dominated	15-20 degrees	Coalesced Point Sources	1.0-1.3 MY
3rd Bone Spring Sandstone					
Wolfcamp A	Debris-Dominated, mixed composition	Aggradational, tectonically modified	15-20 degrees	Structural	1.3-2.5 MY
Wolfcamp B					
Wolfcamp C	Debris-Dominated, mixed composition	Irregular, tectonically modified	6-10 degrees	Antecedent bathymetry	8-10 MY
Wolfcamp D					

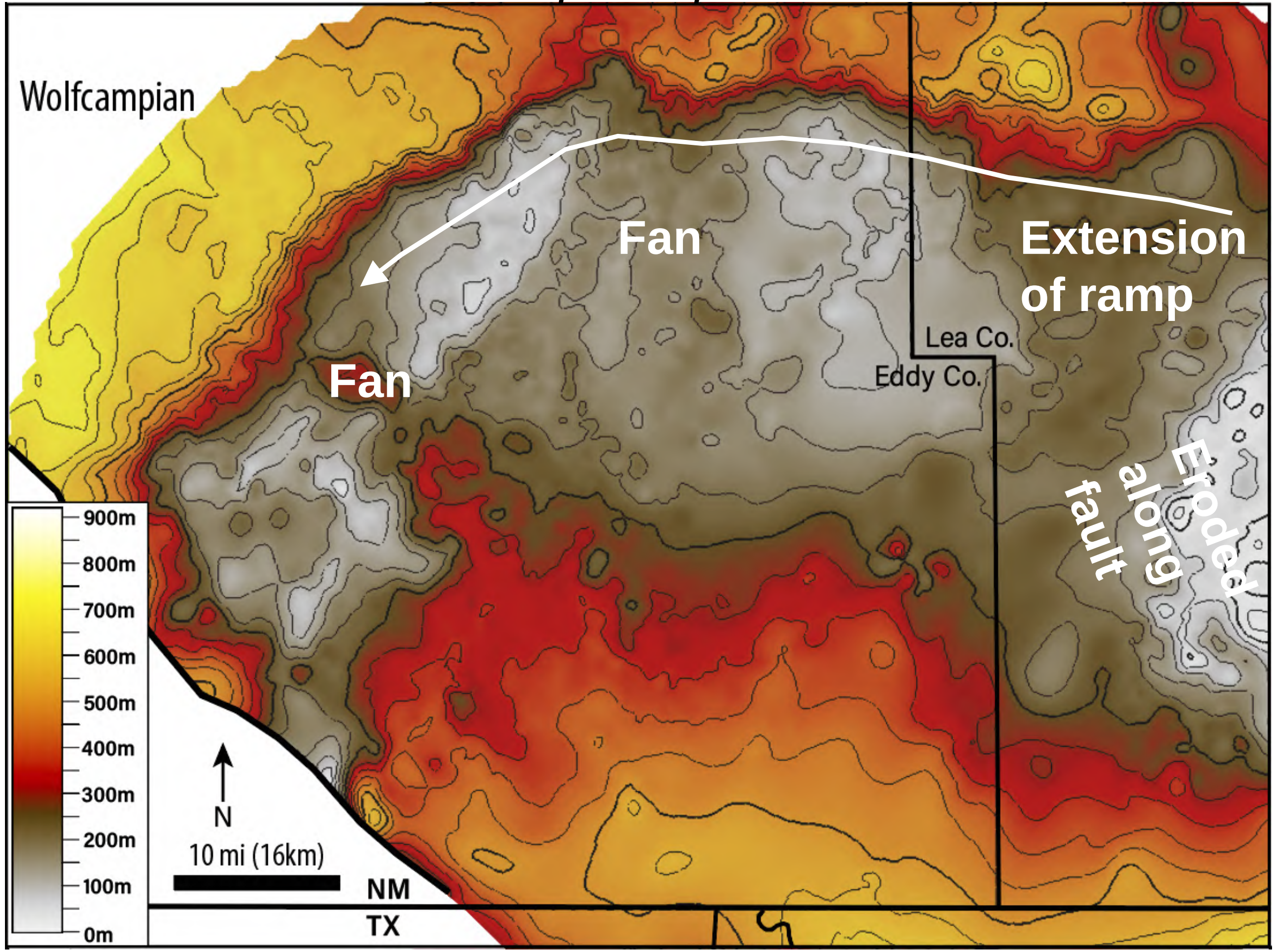


Transport of Fine-Grained Material

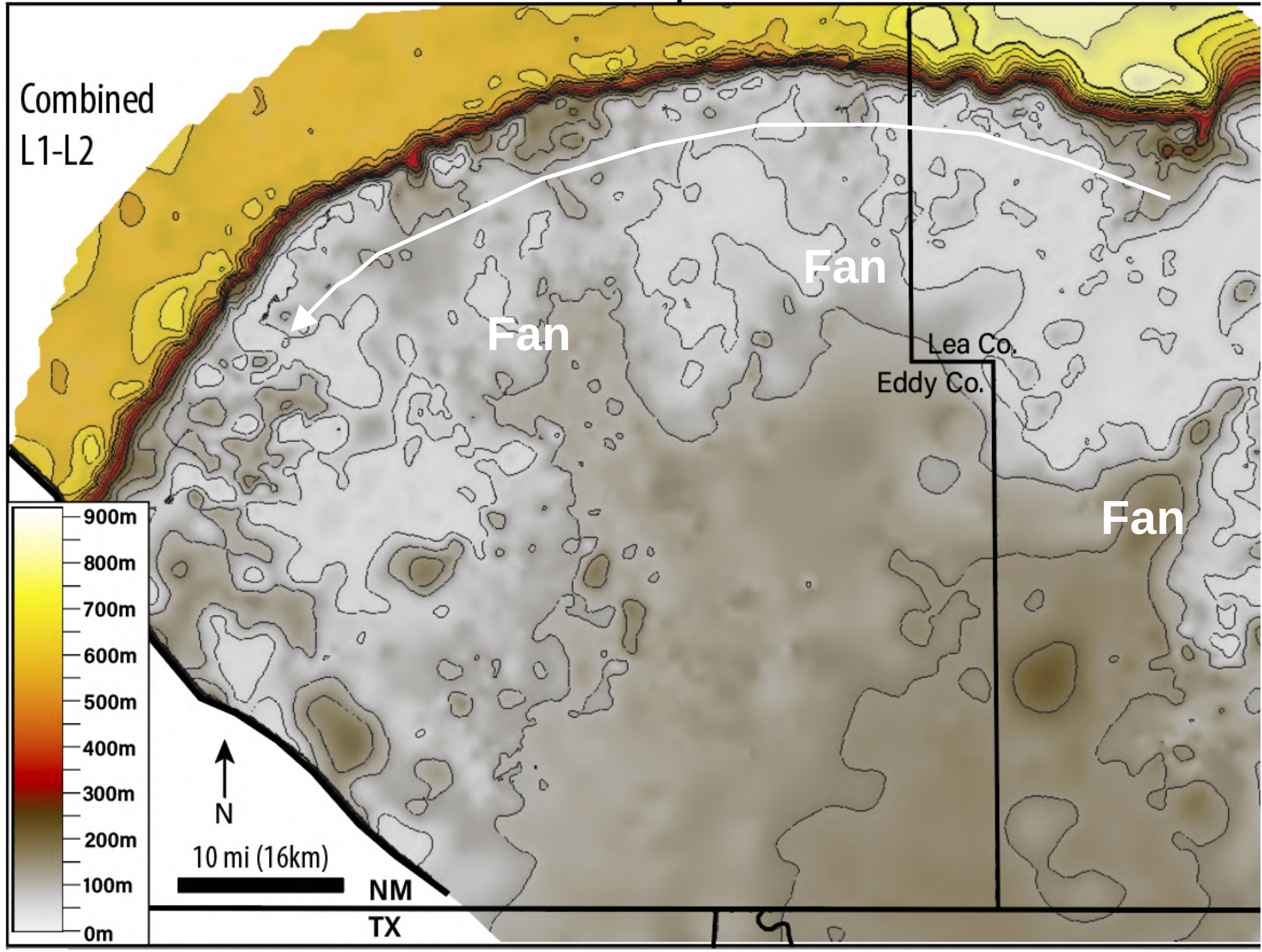
Wolfcampian and L1-L2 sequences have significant thinning at the toe of slope and proximal basin floor

- Could be driven by slope bypass, or non-deposition (but thinning extends beyond the slope)
- May also be influenced by contour currents winnowing finer sediment, resulting in thinning (coarser proximal axes or fans aren't as affected?)

Wolfcampian Isopach



L1-L2 Isopach



Conclusions and Implications

- Carbonate contourite drifts accumulate along the slopes of the northern Delaware Basin in response to counter-clockwise bottom currents
- Significant calciclastic submarine fans exist in the Delaware Basin that control large portions of the basinal stratigraphic architecture

Both impart significant control on slope and basinal facies architecture and subsequent reservoir distribution

- Interpretations required extensive regional characterization, not localized studies
- These finding represent a paradigm shift in the understanding of the basinal deposits in the Permian Basin as they have been previously undocumented

Influence of bottom currents and point sourcing of carbonate material in basinal sedimentation patterns has been overlooked or uninterpreted in one of the most data-rich geologic regions in the world

Calciclastic drifts and fans are likely more common in the ancient rock record

Reservoir Characterization Research Laboratory

Thanks to the RCRL Sponsors for supporting this research

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ارامكو السعودية Saudi Aramco
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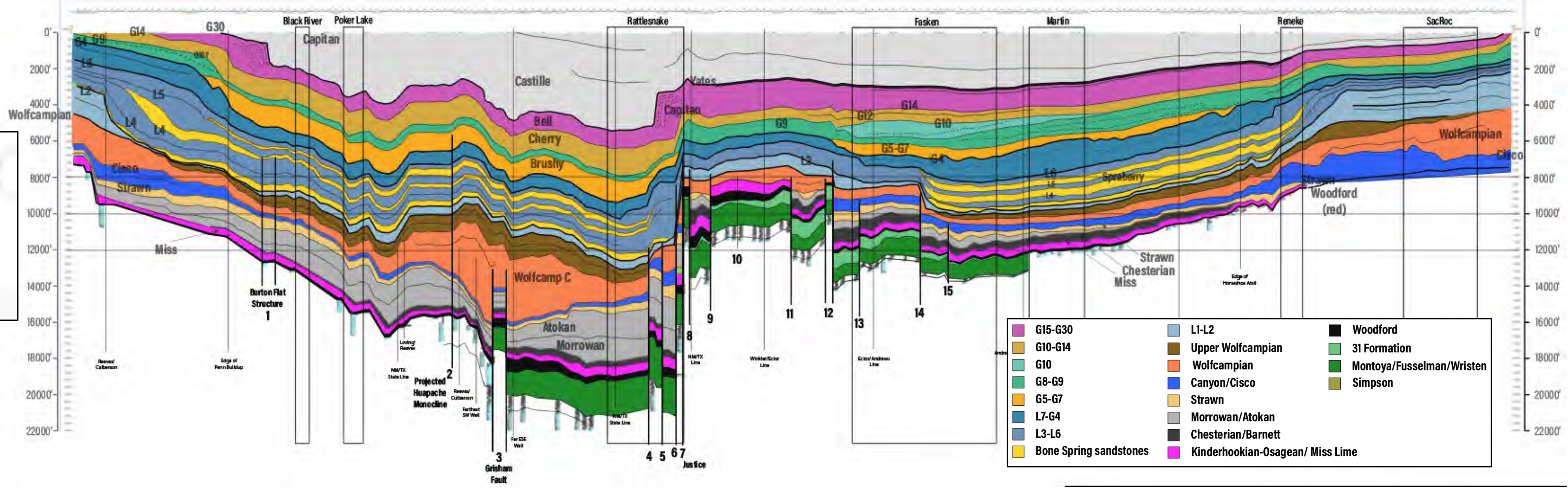
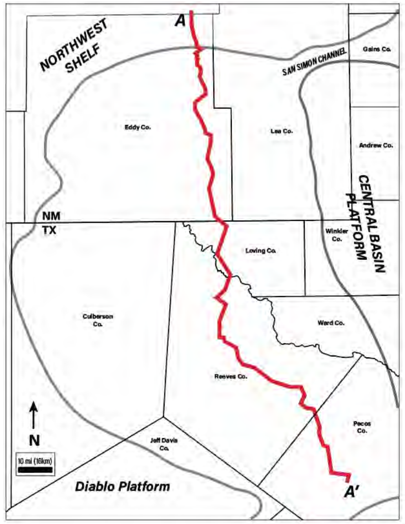
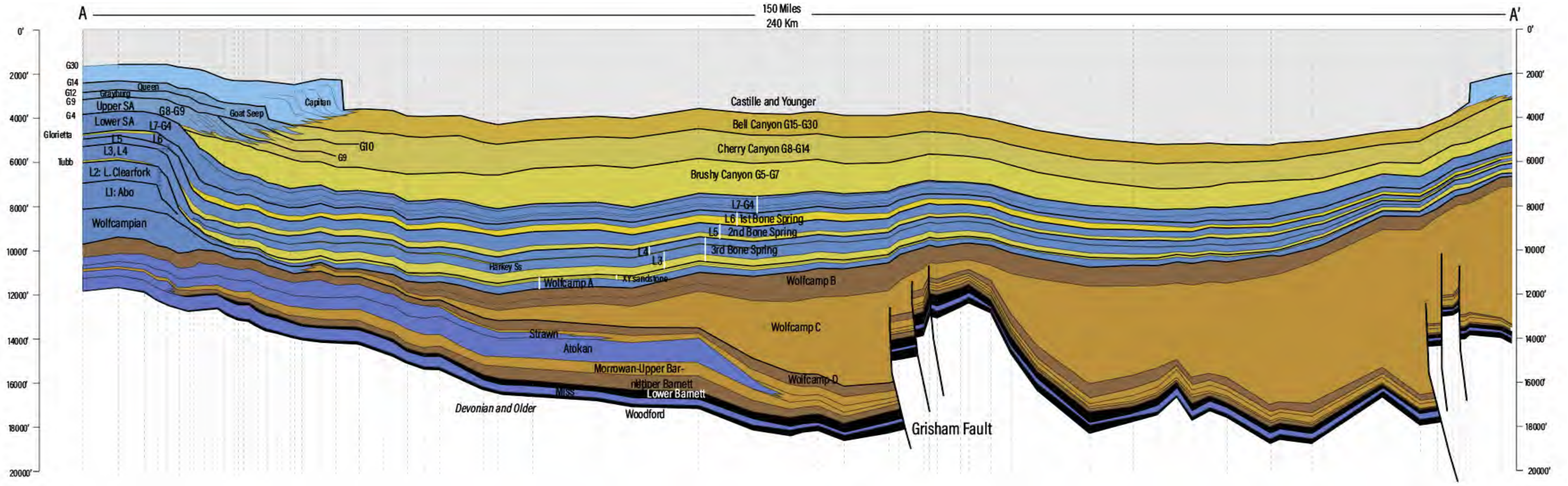
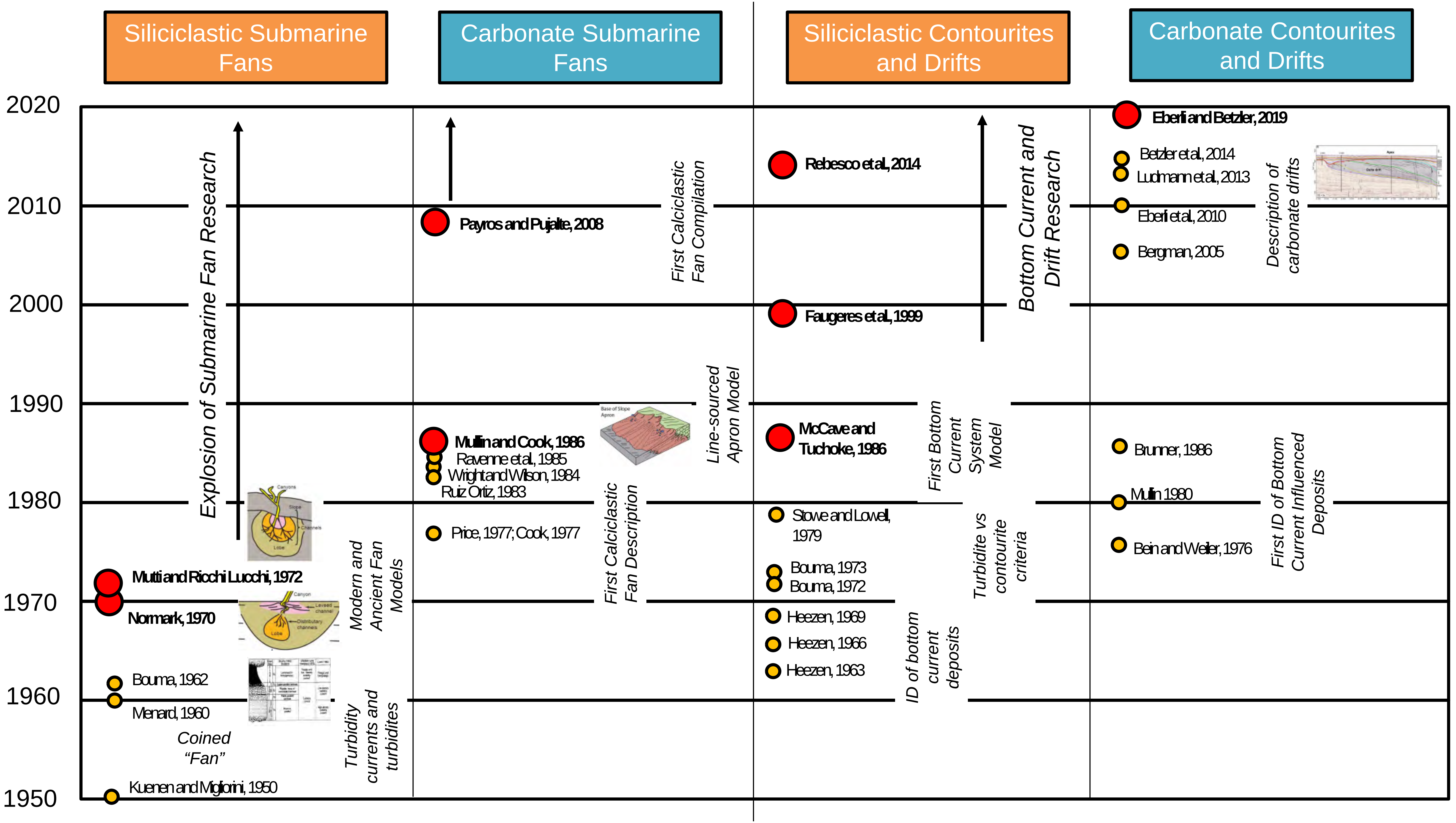




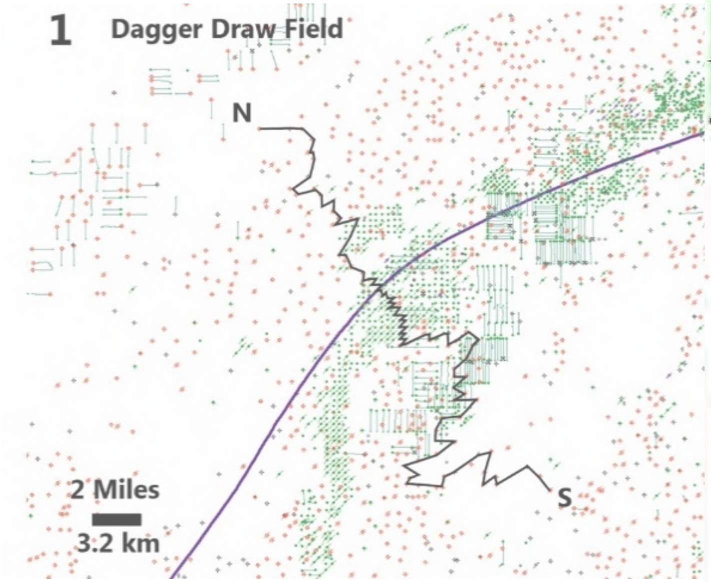
Reservoir Characterization Research Laboratory

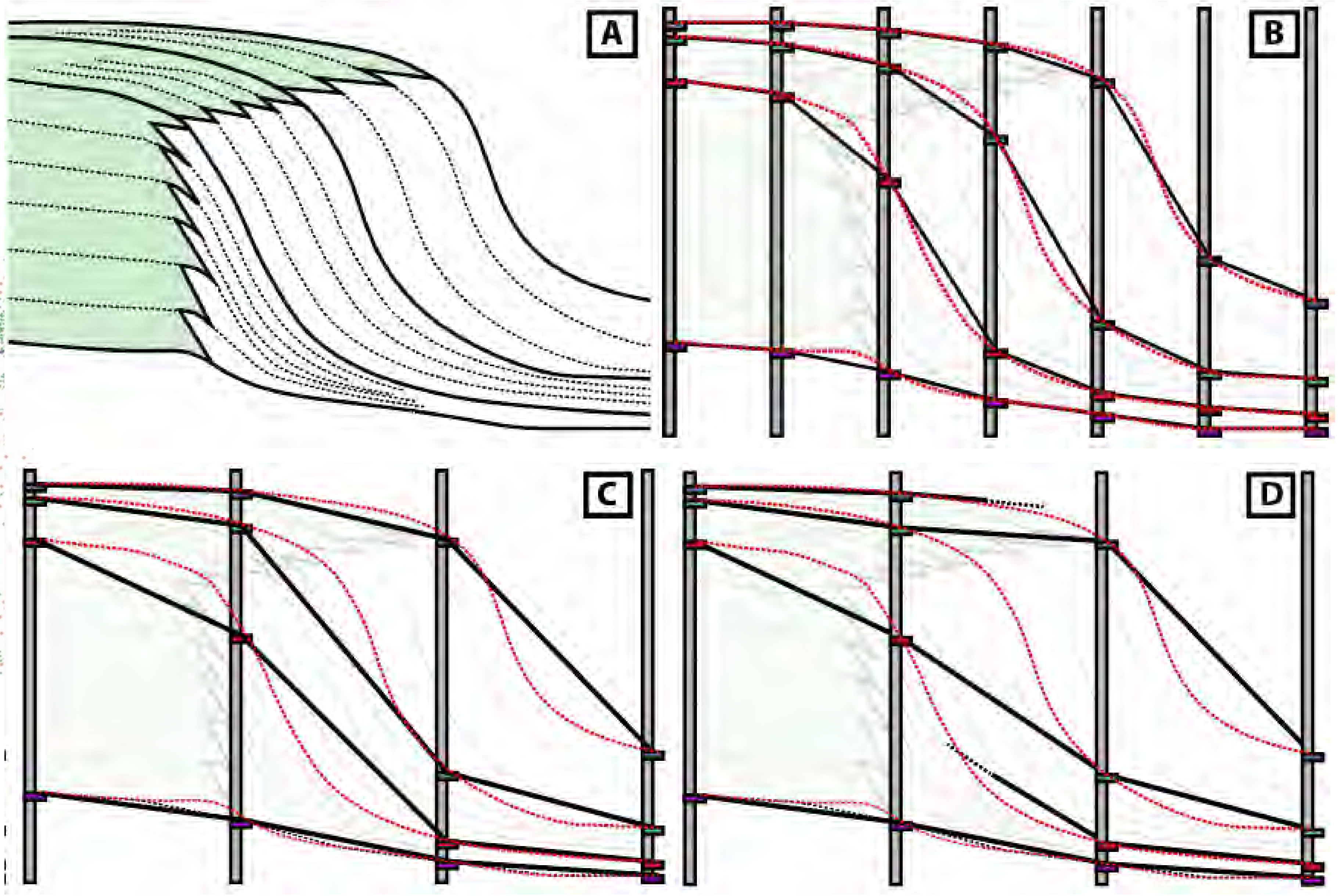


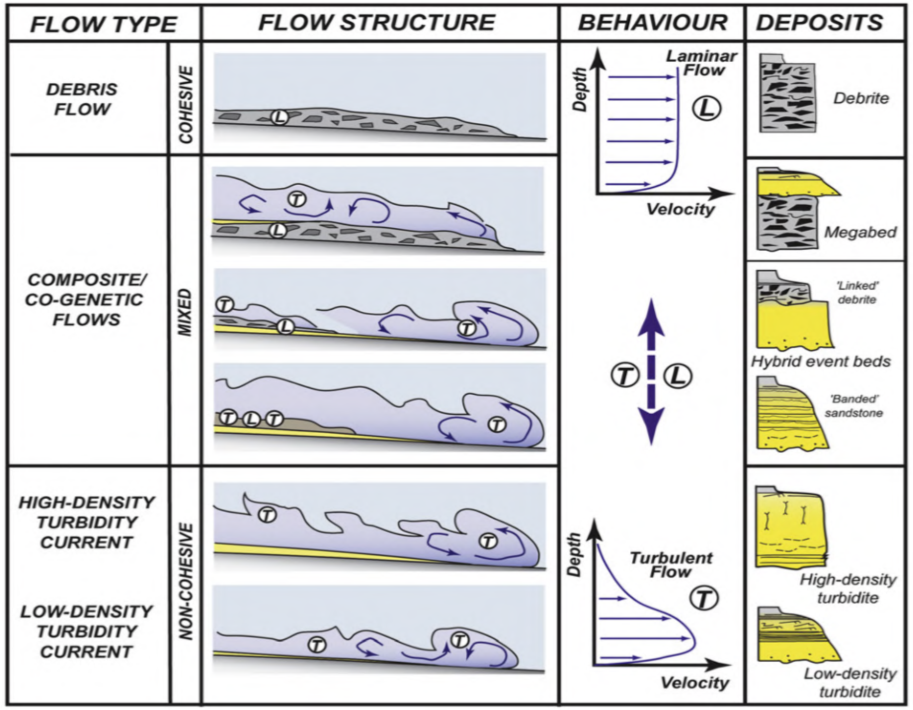

Siliciclastic Submarine Fans
Carbonate Submarine Fans
Siliciclastic Contourites and Drifts
Carbonate Contourites and Drifts
2020
2010
2000
1990
1980
1970
1960
1950
Explosion of Submarine Fan Research
Mutti and Ricchi Lucchi, 1972
Normark, 1970
Bouma, 1962
Menard, 1960
Coined "Fan"
Kuenen and Migliorini, 1950
Modern and Ancient Fan Models
Turbidity currents and turbidites
Payros and Pujalte, 2008
Mullin and Cook, 1986
Ravenne et al., 1985
Wright and Wilson, 1984
Ruiz Ortiz, 1983
Price, 1977; Cook, 1977
First Calciclastic Fan Compilation
Line-sourced Apron Model
First Calciclastic Fan Description
Rebesco et al., 2014
Faugeres et al., 1999
McCave and Tucholke, 1986
Stowe and Lowell, 1979
Bouma, 1973
Bouma, 1972
Heezen, 1969
Heezen, 1966
Heezen, 1963
Bottom Current and Drift Research
First Bottom Current System Model
Turbidite vs contourite criteria
ID of bottom current deposits
Eberli and Betzler, 2019
Betzler et al., 2014
Ludmann et al., 2013
Eberli et al., 2010
Bergman, 2005
Brunner, 1986
Mullin 1980
Bein and Weiler, 1976
Description of carbonate drifts
First ID of Bottom Current Influenced Deposits

Correlation Issues

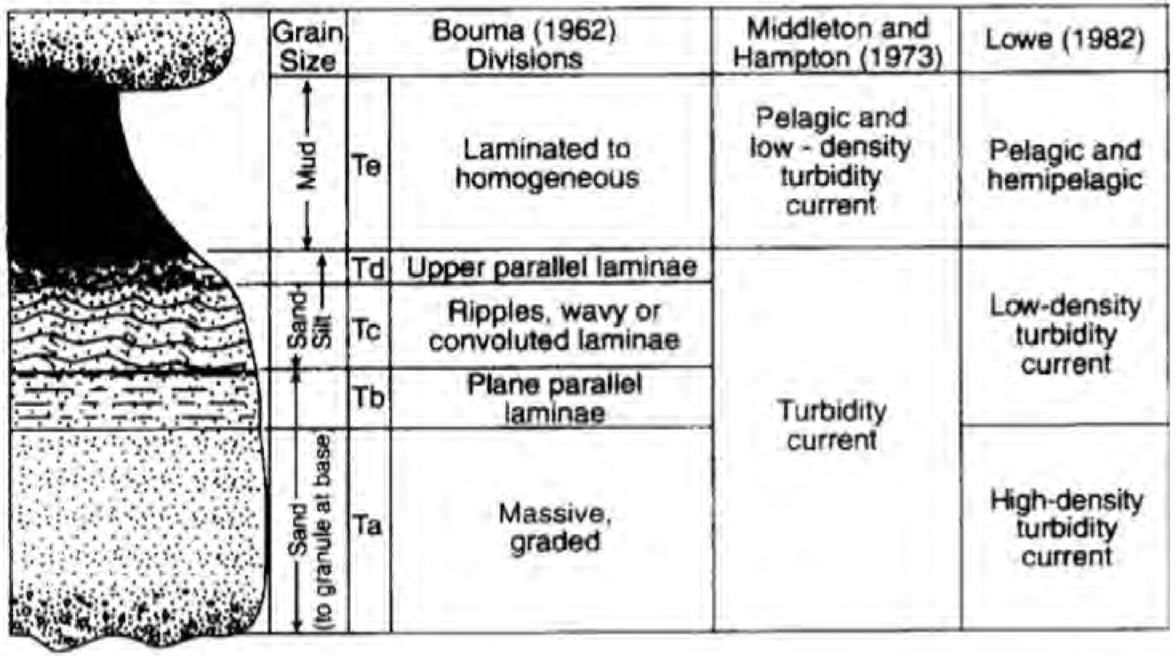
Northwestern Portion of the Delaware Basin

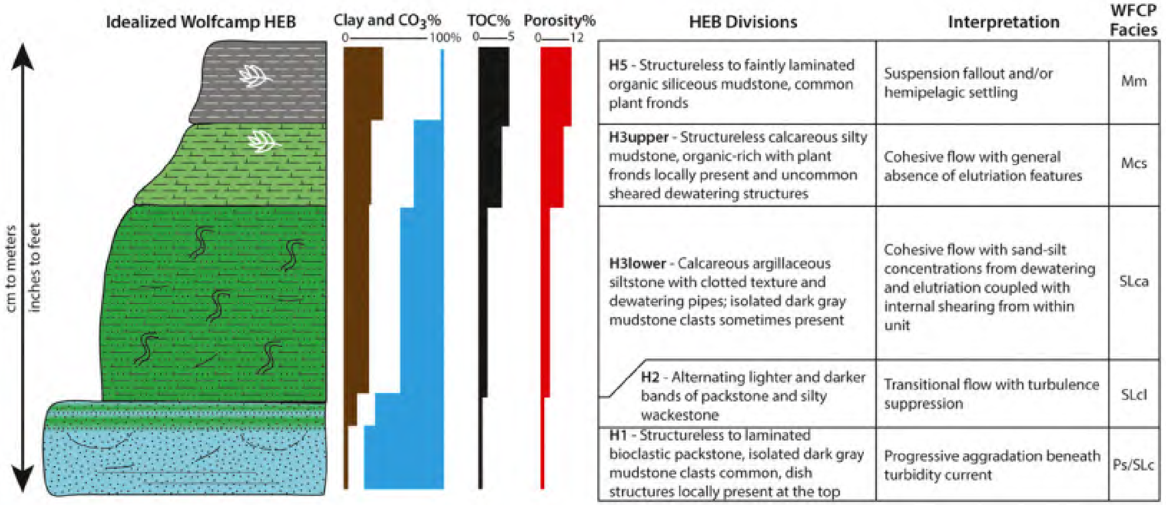




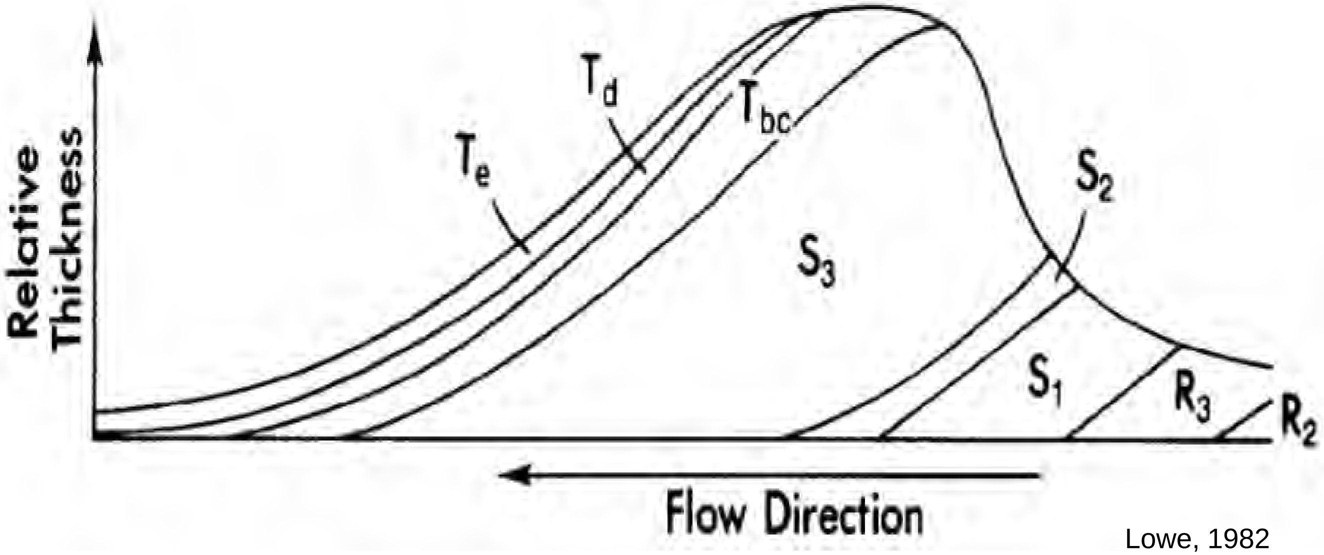


Haughton et al., 2009





Kvale et al., 2020



Lowe, 1982