

Stratigraphy and Source Rock Characterization of the Early Cretaceous Skull Creek Formation Denver Basin, CO



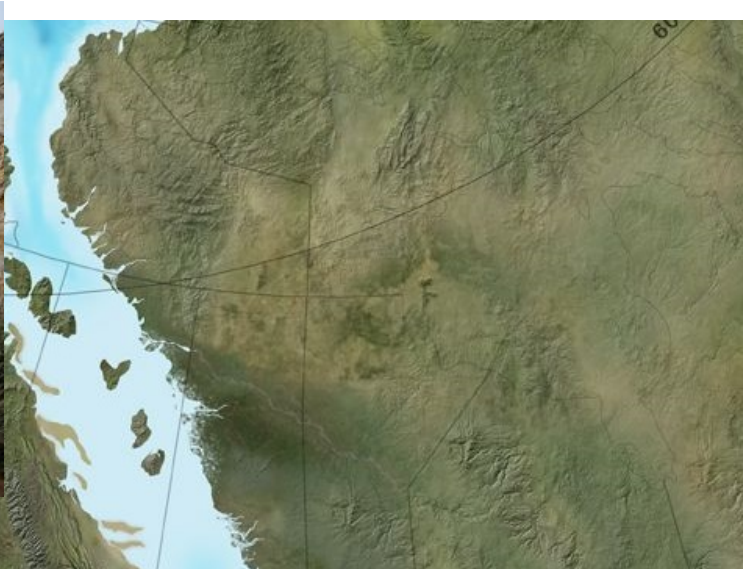
Patrick Sullivan
MS Student
Exp. Grad. Spring 2021

patrickssullivan@mymail.mines.edu



1. Introduction and Motivation
 - Why the Skull Creek Shale?
 - Background literature
2. Regional Geology and Tectonics
 - The Denver Basin
 - Western Interior Cretaceous Seaway
3. Data
 - Sedimentology: facies descriptions and interpretations
 - Well log cross sections
4. Next Steps

Introduction and Motivation



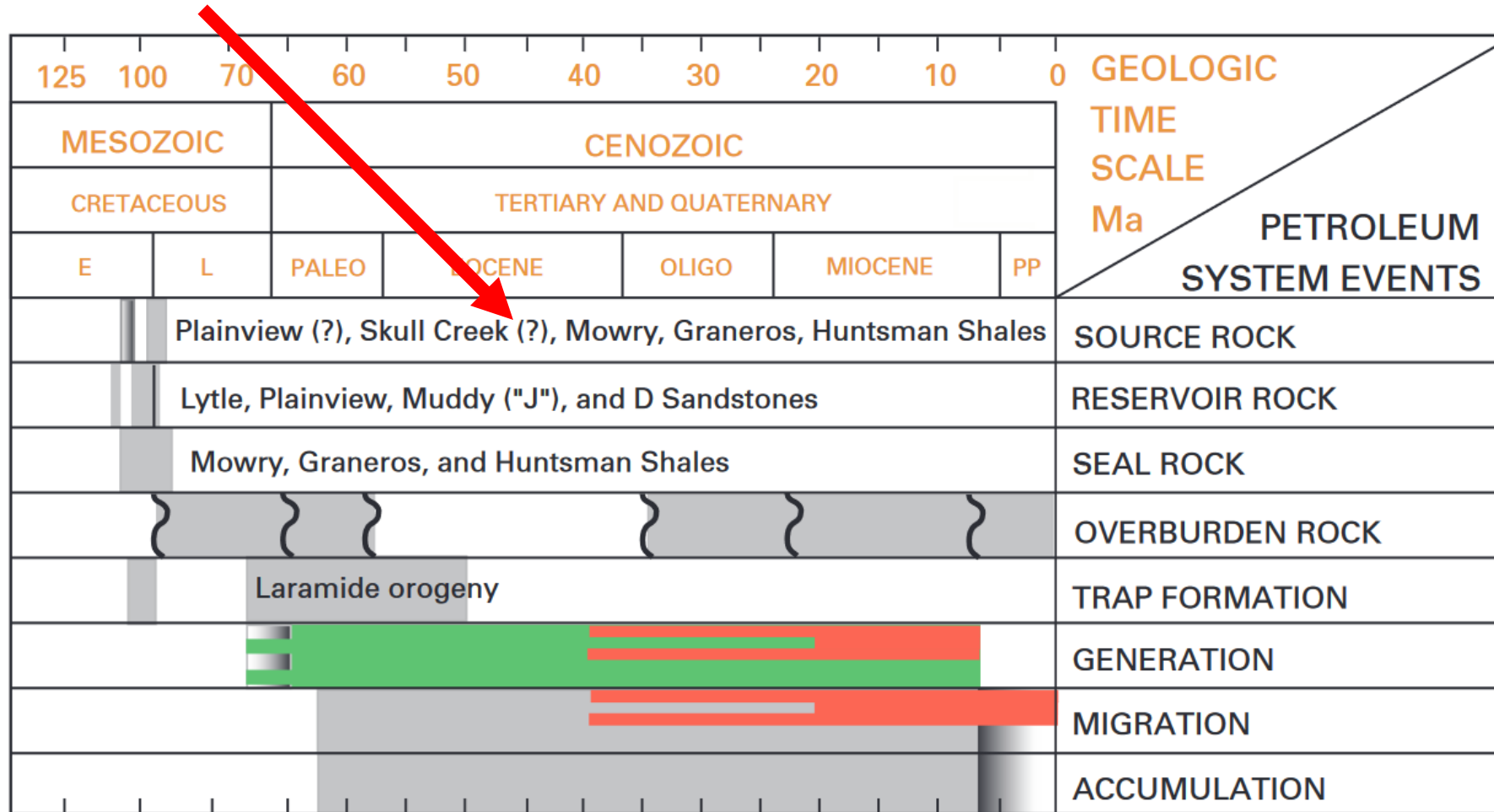
Introduction and Motivation



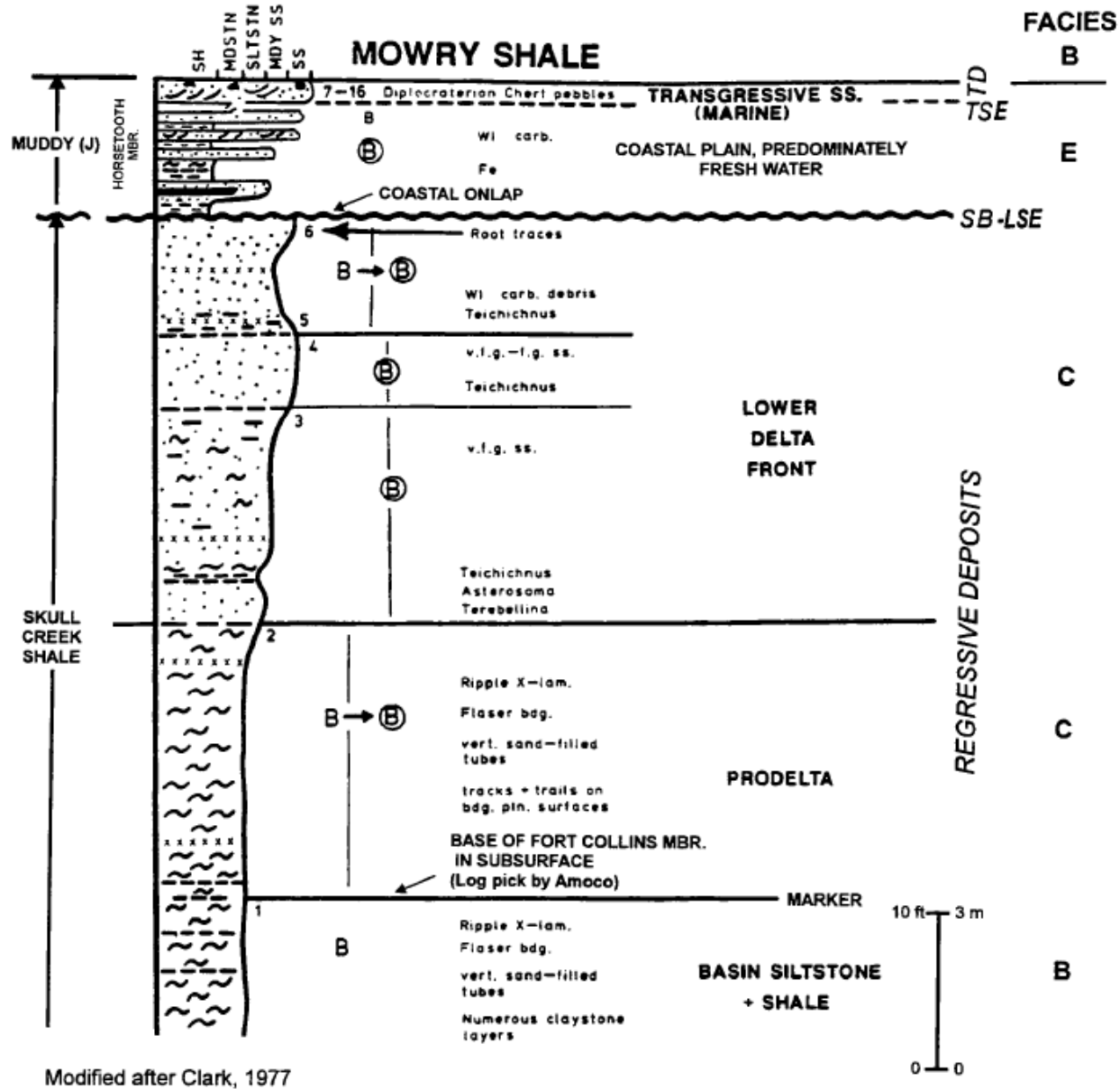
		NORTHERN FRONT RANGE, OUTCROP		ADJACENT DENVER BASIN
QUAT.		Undifferentiated alluvial deposits		Undifferentiated alluvial deposits
	TERTIARY	Undifferentiated boulder & gravel deposits		
Denver Formation		Castle Rock Conglomerate		
Arapahoe Formation		Dawson-Denver Formations		
UPPER CRETACEOUS	Pierre Shale	Laramie Formation		Laramie Formation
		Fox Hills Sandstone		Fox Hills Sandstone
		Richard Sandstone Mbr.	Pierre Shale	Terry "Sussex" Ss. Member
		Terry Sandstone Mbr.		Hygiene "Shannon" Ss. Member
		Hygiene Sandstone Mbr.		Sharon Springs Member
		Niobrara Formation	Smoky Hill Shale Mbr.	
	Fort Hays Limestone Mbr.		Fort Hays Limestone Member	
	Codell Sandstone Mbr.		Codell Sandstone Member	
	Carlile Shale		Carlile Shale	
	Greenhorn Limestone		Greenhorn Limestone	
	Graneros Shale		Graneros Shale "D" sandstone	
	LOWER CRETACEOUS	Dakota Group	Mowry Shale	
South			North	Muddy ("J") Sandstone
Upper members, South Platte Formation		Muddy ("J") Sandstone	Skull Creek Shale	
South Platte Fm.		Plainview Ss. Member	Plainview Formation	"Dakota" of drillers
JURASSIC	Lytle Formation		"Lakota" of drillers	
	Morrison Formation		Morrison Formation	
	Ralston Creek Formation		Older Jurassic rocks may be present	
	Sundance Formation			

Source: U.S. Energy Information Administration based on data from various published studies. Canada and Mexico plays from ARI. Updated: May 9, 2011

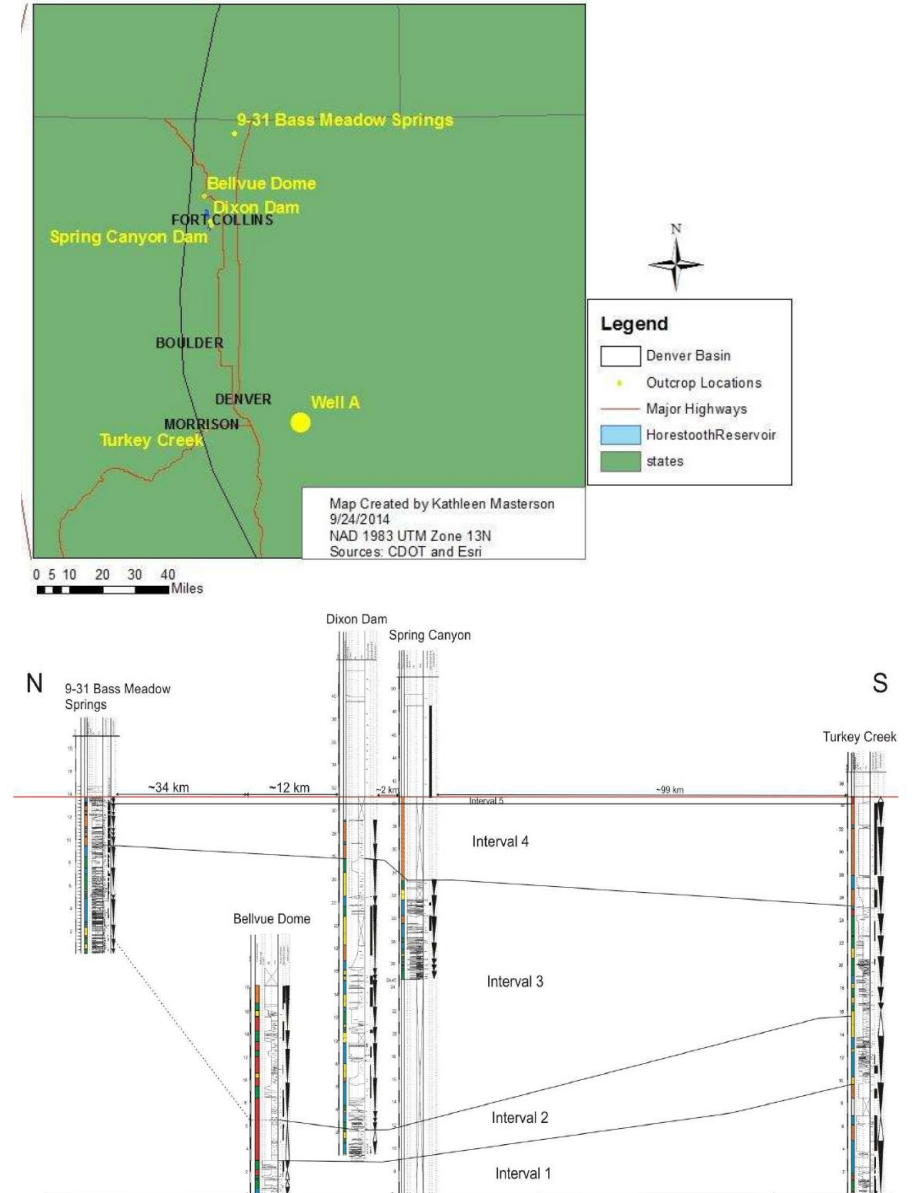
Introduction and Motivation



Previous Work



Weimer and Sonnenberg 1996

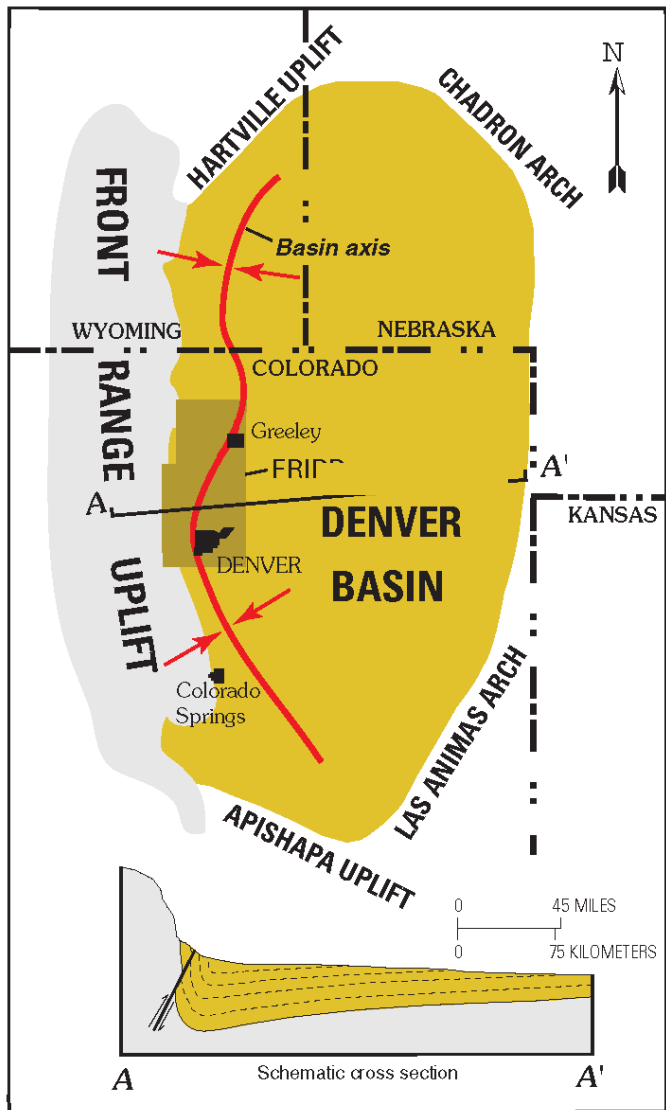


Masterson 2015

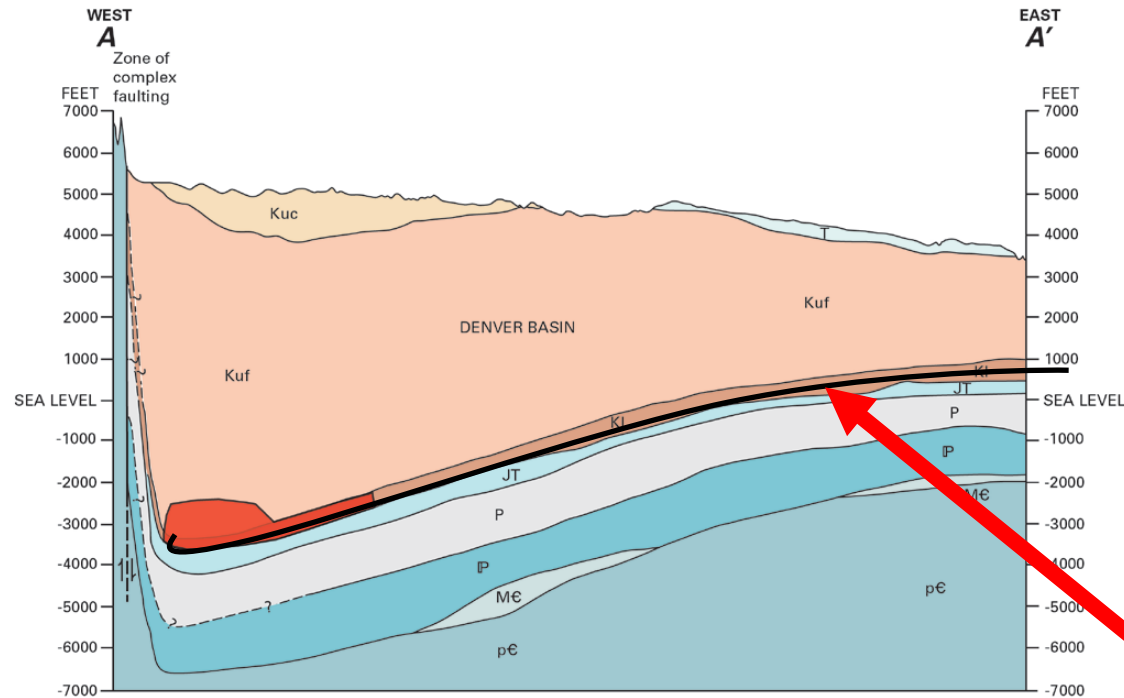


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The Denver Basin



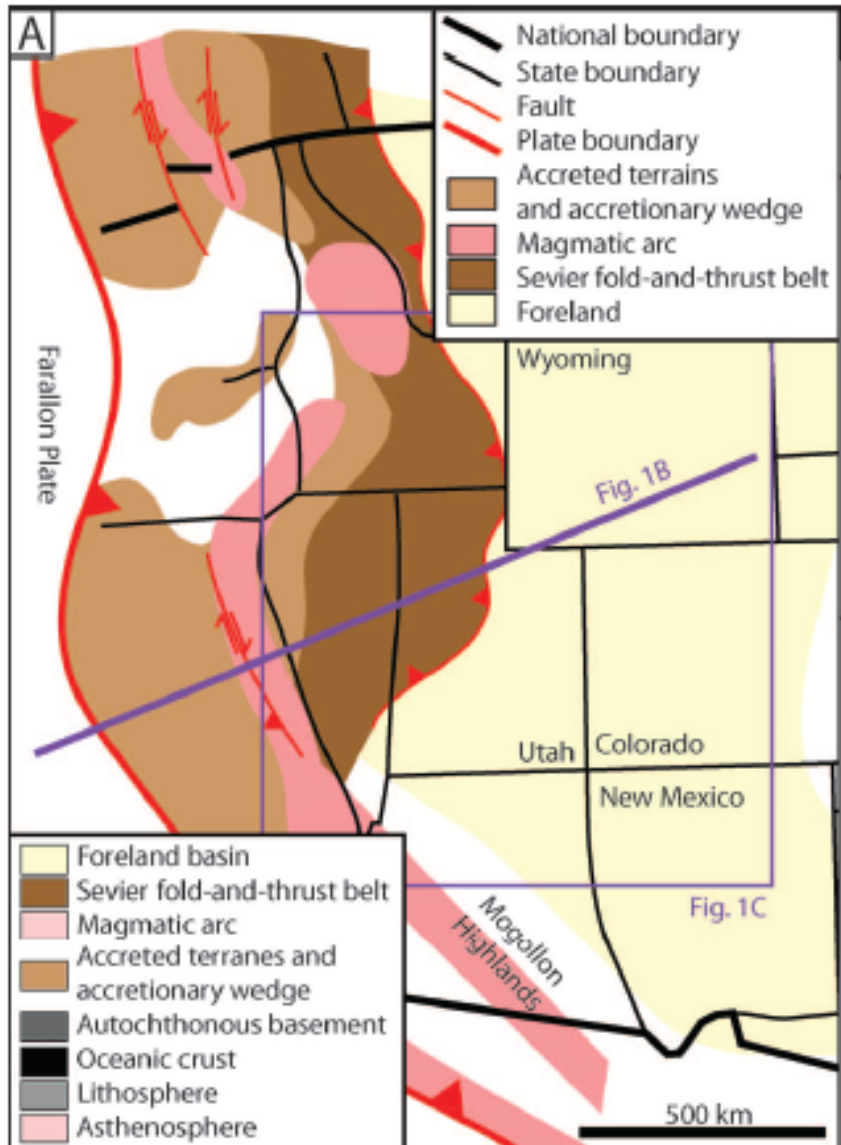
Mod. Knepper, 2002



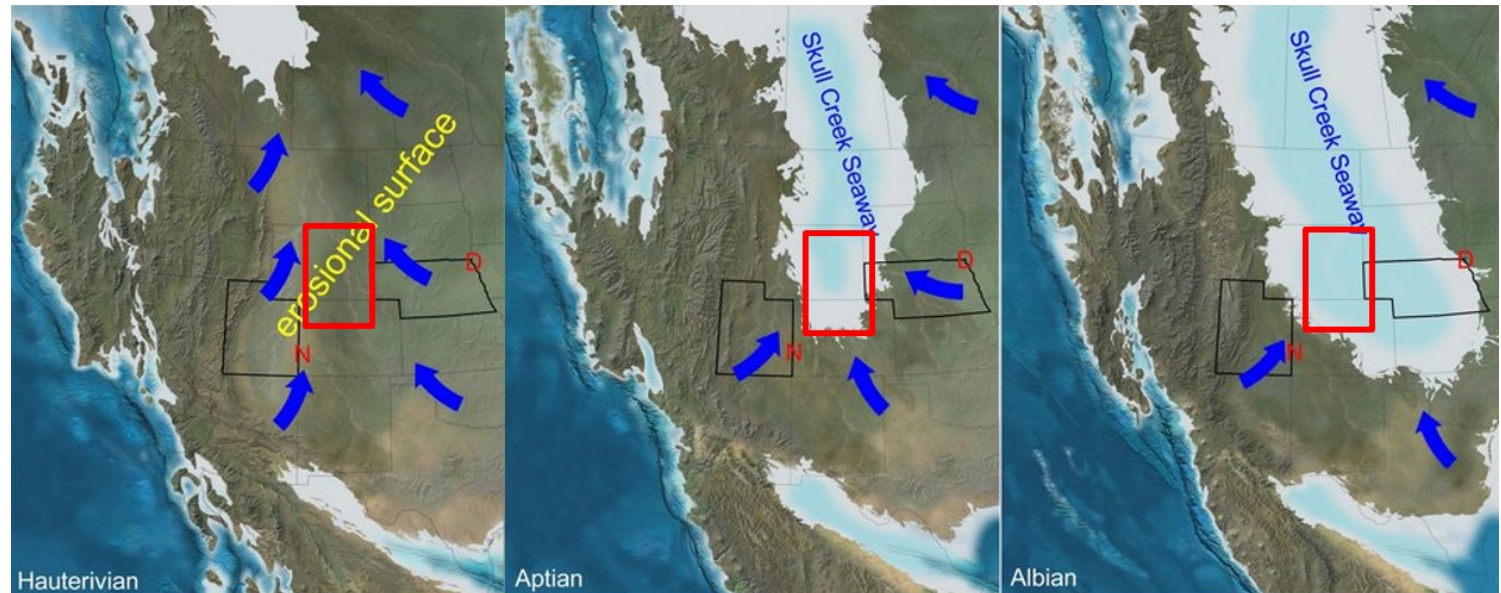
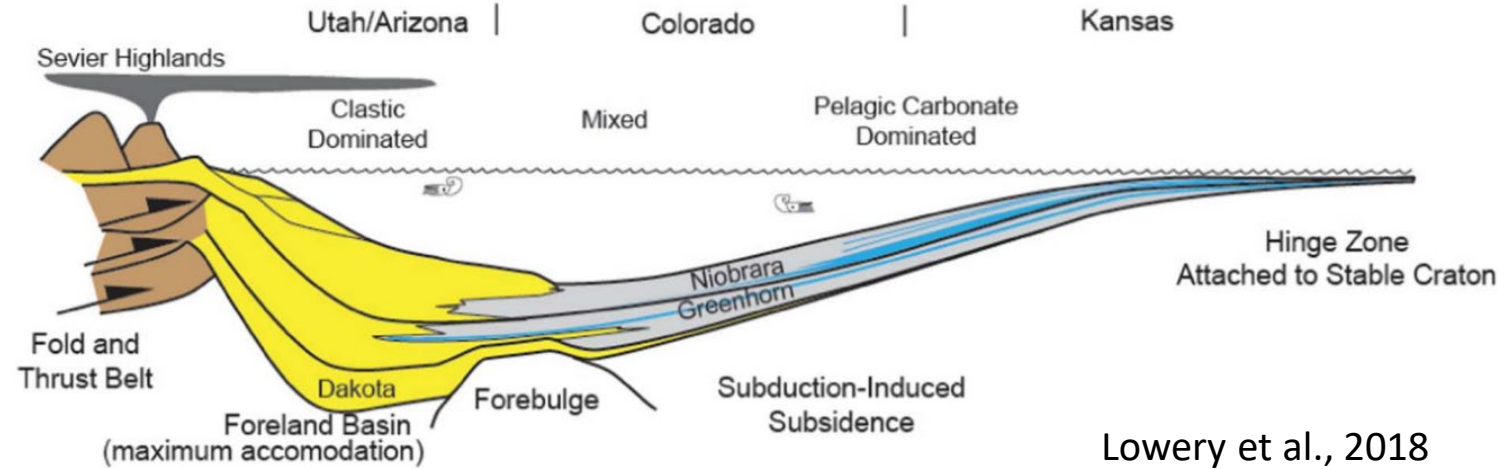
Mod. Nelson and Santus, 2011

		Denver Basin	
		Source rocks	Production
			Mainly oil Mainly gas Oil and gas
UPPER CRETACEOUS	Laramie Formation		
	Niobrara Formation		
LOWER CRETACEOUS	Dakota Group		
	JURASSIC		

Pierson, 2017



Van Capelle et al., 2018

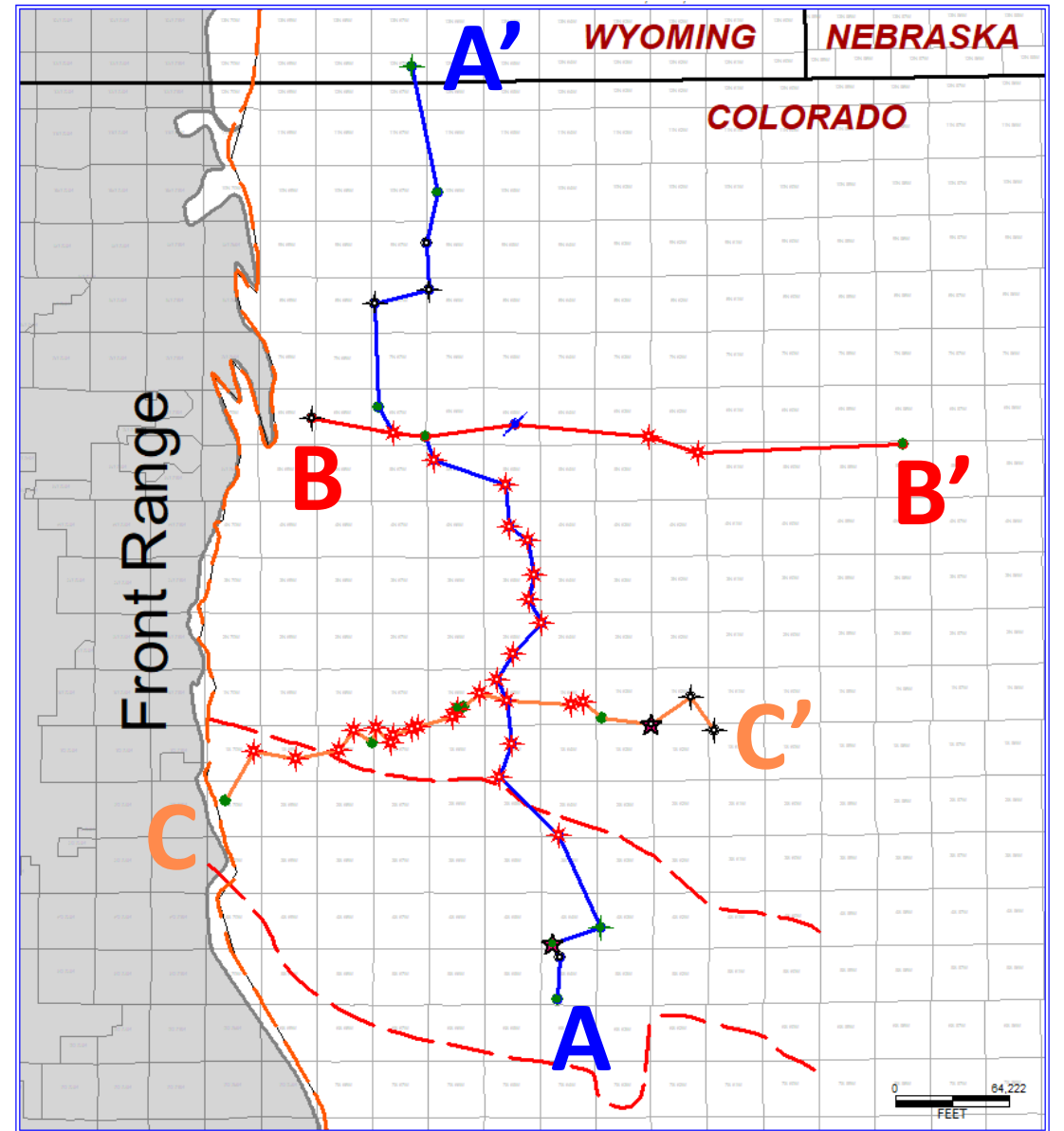
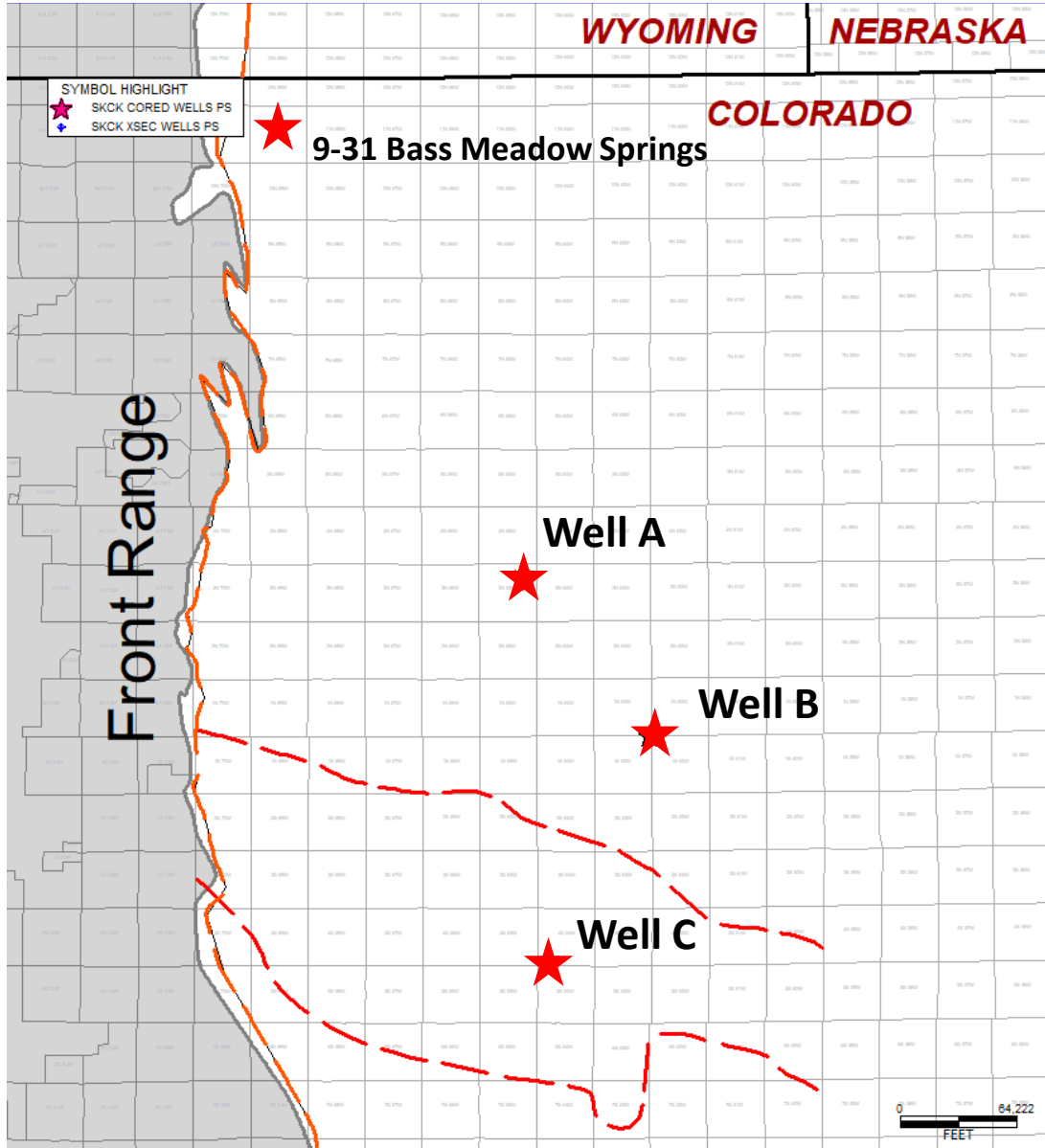


Mod. Blakey, 2014

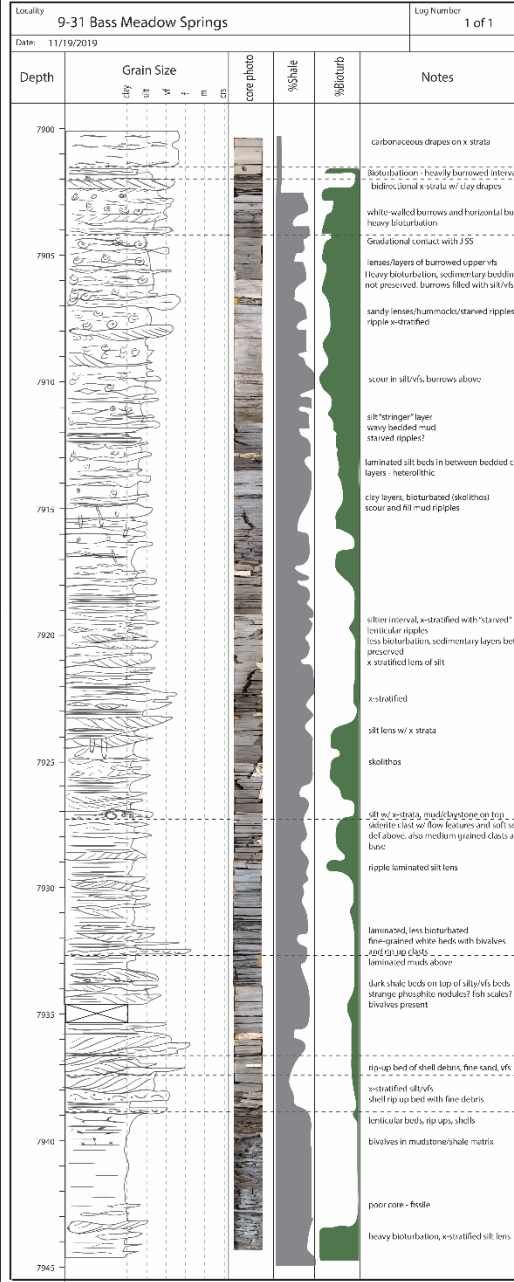
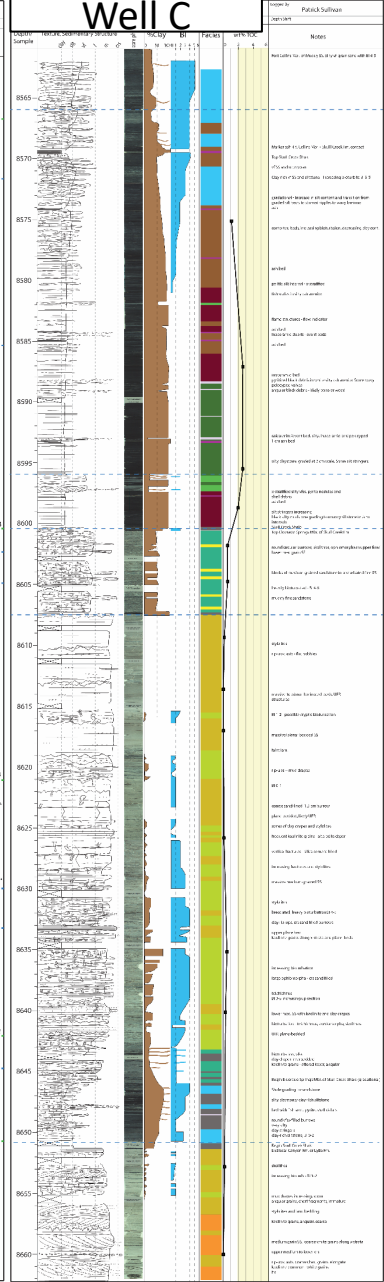
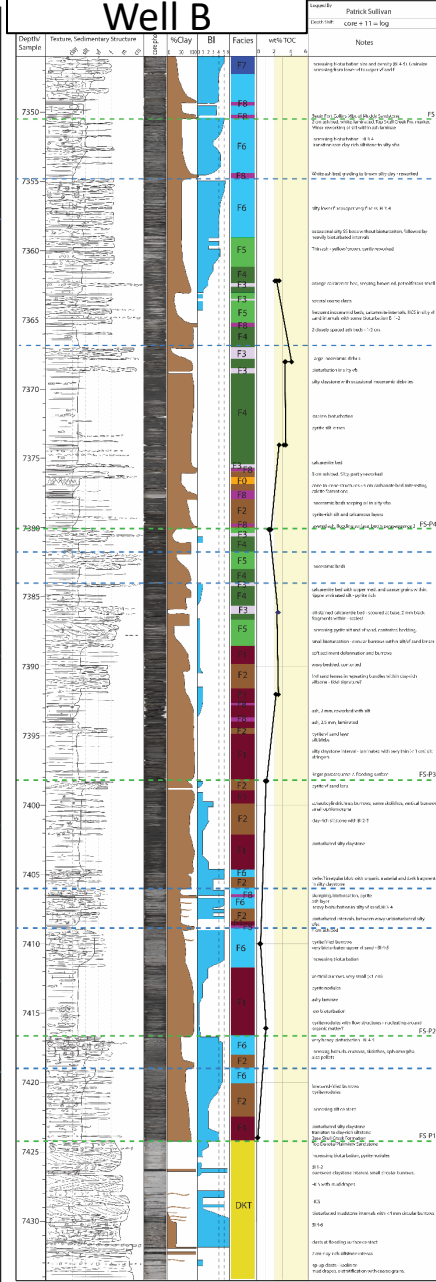
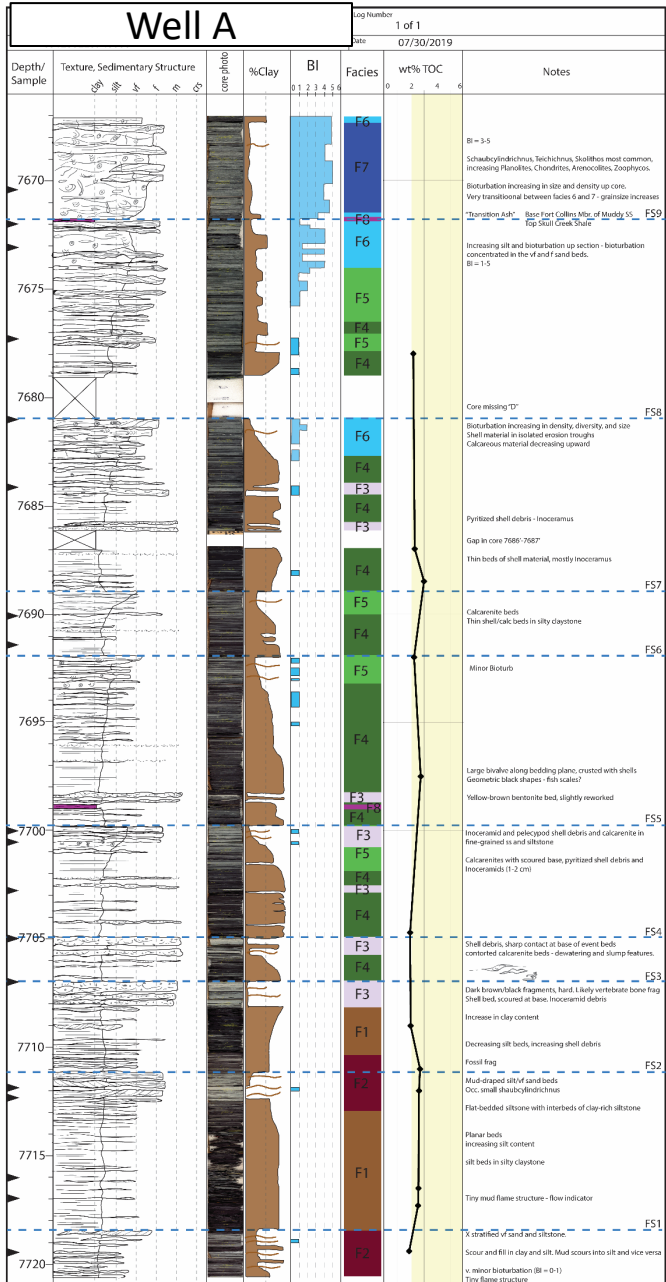


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4 Cores and 41 Well Logs



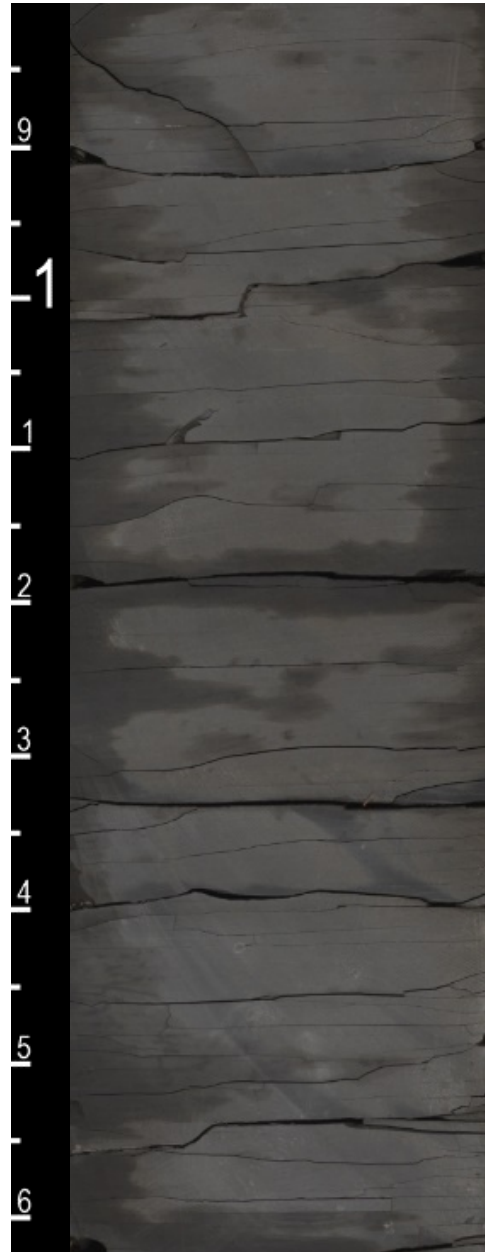
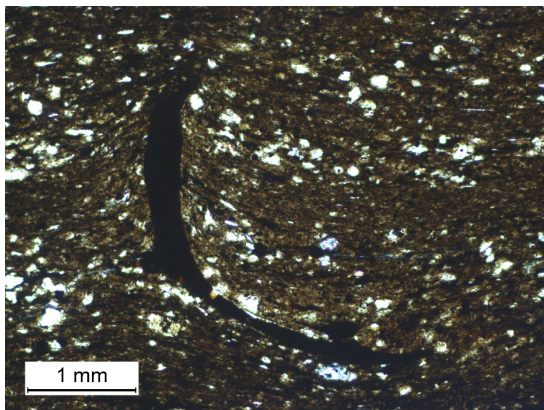
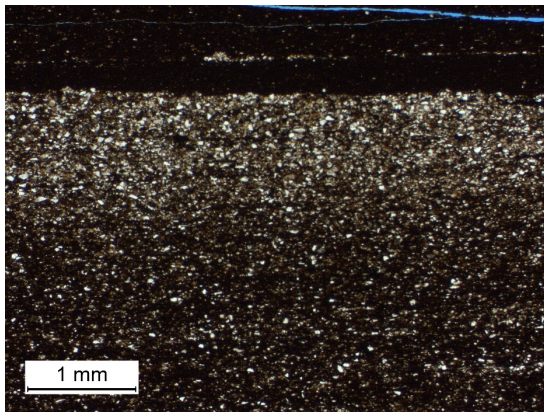
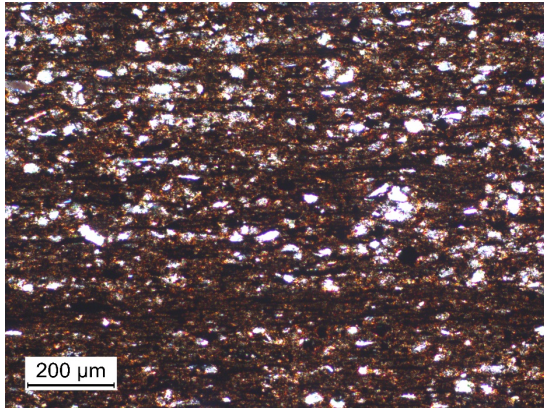
Core Descriptions



Facies Descriptions



Facies	Bed Thickness	Description	Composition	Process/Interpretation
Massively bedded carbonate with cone-in-cone structures (F0)	2 cm	Calcium carbonate bed with cone-in-cone structures. Likely diagenetic.	Calcium Carbonate	Early diagenesis
Graded silty claystone and clay-rich siltstone (F1)	2 mm - 10 cm	~5mm inversely graded intervals from black silty claystone to ~1-2 mm light gray clay-rich siltstone. Occasional flow indicator - 1 mm thick flame structure in silt. Rare bioturbation (BI 0-1) consisting of vfs-filled circular burrows	Clays, Quartz, Kspar, Organic Material	Bottom currents, periods of slow deposition followed by turbidity. Organic-rich.
Ripple laminated coarse siltstone and very fine sandstone (F2)	3 cm - 20 cm	Coarse siltstone and occasional very fine sandstone beds with wavy laminae commonly draped with <1mm clay drape. Rare bioturbation (BI 0-1) consisting of <2 mm <i>Schaubcylindrichnus</i> and other small round burrows (cruziana, etc.). No fossil material.	Clays, Quartz, Kspar, Organic Material	Tidal energy and bottom currents, Cyclicity observed
Bivalve-rich disorganized calcarenite (F3)	2 mm - 7 cm	Upper-fine to lower med-grained white calcarenite bed with angular black debris (fish scales, bones, mudstone rip-ups), inoceramid shells, and common pyrite replacement of vertebrate skeletal fragments. Contact tends to be erosional at the base and sharp at the top	Calcite, wood, bone	Turbidity currents
Fossiliferous silty claystone with HCS (F4)	2 mm - 5 cm	Silty claystone with frequent < 1cm beds of upper fine-lower med-grained calcarenite and/or inoceramid debris and erosional/wavy bedding. HCS calcareous silt beds common in massively bedded mudstone	Quartz, Calcite, Clays, Organic Material	Mixed bottom current, hemipelagic, and storm wave
Calcareous ripple-laminated muddy siltstone with bivalves (F5)	2 cm - 10 cm	Ripple-laminated calcareous siltstone and very fine sandstone with a high abundance of white upper fine-lower medium calcareous grains and common bivalves (<i>Inoceramus</i> and pelecypods), fossil fragments, and pyrite. Mud drapes exhibit flame structures, slumping, and rare bioturbation (BI 0-1).	Quartz, Calcite, Organic Material, Bone, Wood	Turbidity currents followed by tidal energy and storm waves
Bioturbated Clay-rich lower very fine sandstone (F6)	5 cm - 20 cm	Medium-bioturbated (BI 2-4) clay-rich siltstone and very fine sandstone Bedding is sometimes disrupted by bioturbation Frequent SSD, contorted beds and collapse features in dark mudstone. Silt-filled traces of <i>Schaubcylindrichnus</i> , <i>Zoophycus</i> , <i>Teichichnus</i>	Quartz, clays, Kspar	Tidal energy
Heavily Bioturbated Silty Upper Very Fine Sandstone (F7)	5 cm - 50 cm	Highly bioturbated (BI: 4-5) very fine - fine sandstone with high silt content and wavy beds of clay-rich siltstone. Very few preserved sedimentary features. Includes dense <i>Schaubcylindrichnus</i> , <i>Skolithos</i> , <i>Teichichnus</i> and less frequent <i>Zoophycos</i> , <i>Asterosoma</i> , and <i>Arenacolithes</i>	Quartz, clays, Kspar	Tidal energy
Ash Bed (F8)	5 mm - 3 cm	Bentonite deposit, usually slightly reworked and grading into clay-rich siltstone.	ash (altered to clay)	Pelagic, reworking by bottom currents
Mud-draped bioturbated upper fine grained sandstone (F9)	2 cm - 20 cm	Muddy lower upper fine and lower-medium grained sand with BI 2-4 in zones and scoured blocks of F12. Texturally immature, occasional coarse black chert fragments. <i>Skolithos</i> , <i>ophiomorpha</i> ,	Kaolinite, quartz,	Fluvial/tidal energy
Plane-bedded medium grained kaolinite sandstone (F10)	2 cm - 20 cm	White, clean L-U medium sandstone. Massive or faint planar beds of coarse grains every ~3-5 cm. Bedding is planar to massive. BI 0-1, some cryptic bioturbation possible	Kaolinite, quartz,	Upper flow regime - fluvial/tidal
Bioturbated silty claystone (F11)	1 - 8 cm	Laminated silty claystone (F1) with densely packed circular silt/vf sand-filled burrows 1mm - 1cm. BI 2-4	kaolinite, quartz	tide-dominated reworking
Coarse-grained massive lithic sandstone (F12)	1-10 cm	Gray upper medium-coarse grained sandstone. Massive to faintly laminated. Contains interspersed coarse black angular grains along bedding planes - likely chert. Sharp basal contact. BI 0-1	kaolinite, quartz, chert	lower flow regime, high discharge
Medium-grained x-stratified kaolinite sandstone (F13)	1-20 cm	Cross-stratified upper medium-grained sandstone with coarse white grains (kaolinite - altered feldspars) along x-strata. Low mud content, BI 0	kaolinite, quartz	fluvial, lower flow regime
Heavily Bioturbated Medium-grained sandstone (F14)	5-50 cm	Lower upper fine and lower-medium grained sand with BI 1-3 in zones. Interbedded with F10. Texturally immature, occasional coarse black chert fragments. Large coarse grain-lined <i>ophiomorpha</i> , <i>teichichnus</i>	Kaolinite, quartz, chert	fluvial/tidal

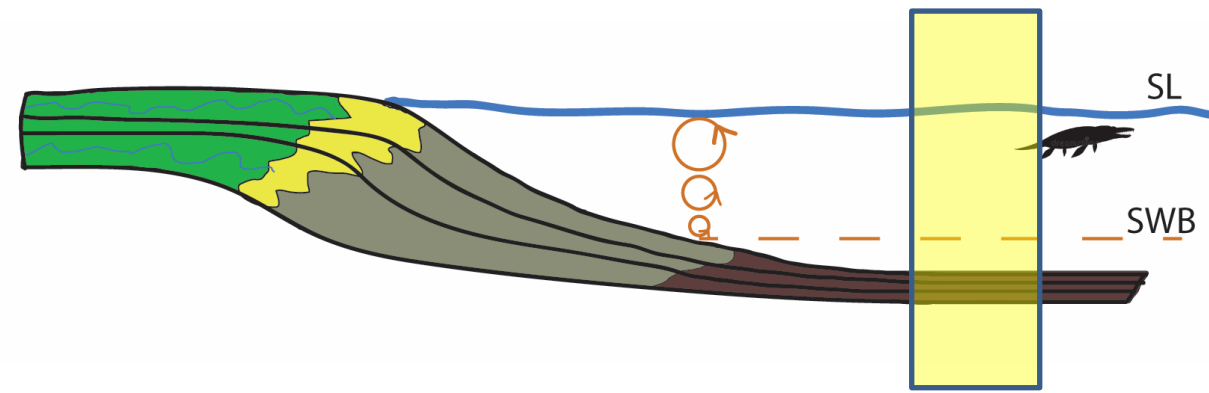


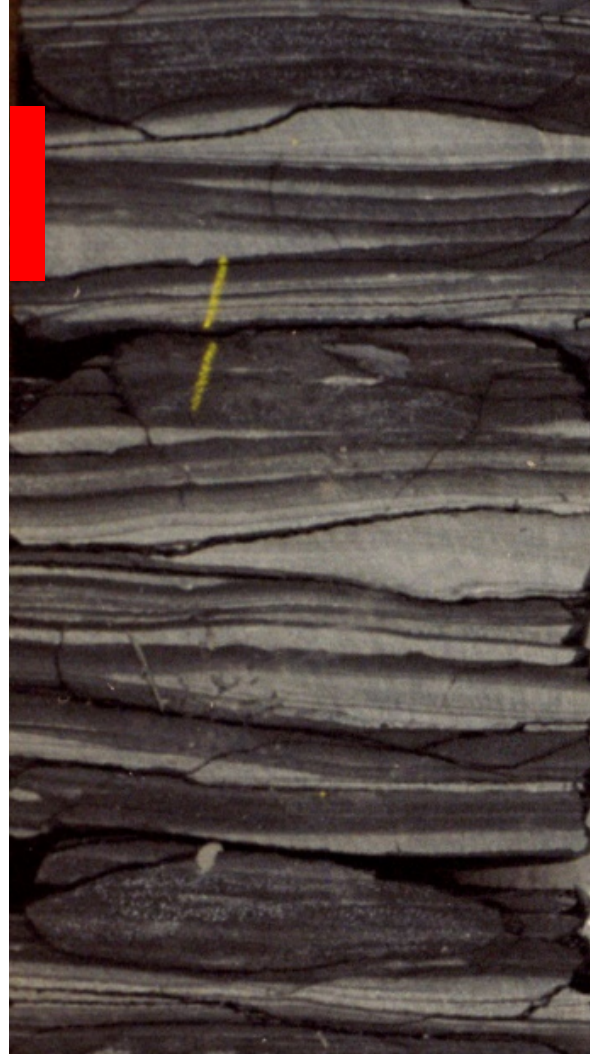
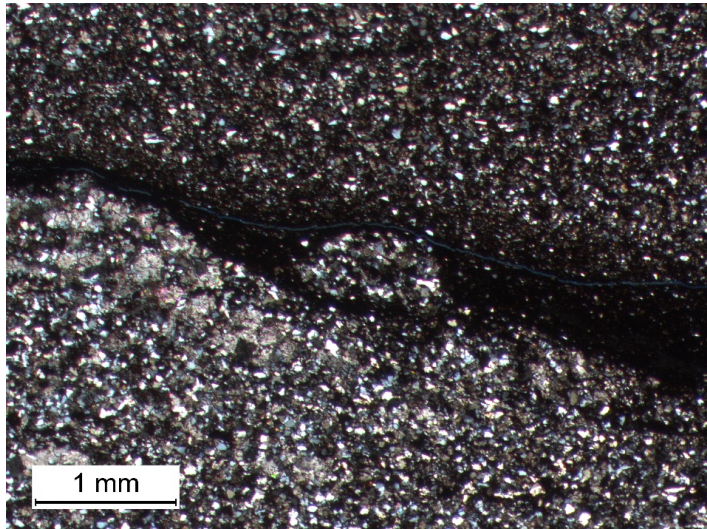
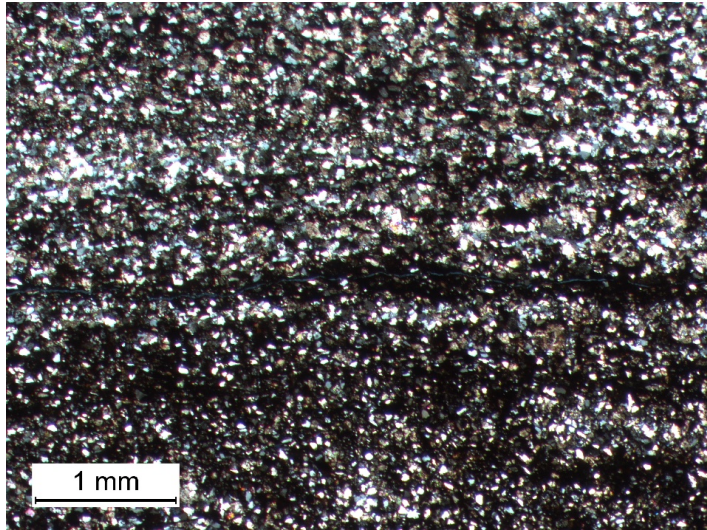
Facies Name: Graded to massive silty claystone and clay-rich siltstone (F1)

Description: ~5mm inversely graded intervals from black silty claystone to ~1-2 mm light gray clay-rich siltstone. Occasional flow indicator - 1 mm thick flame structure in silt. Rare bioturbation (BI 0-1) consisting of silt-filled circular burrows (*Planolites*)

Composition: Clays, Quartz, Kspar, Organic Material

Process: Hemipelagic deposition and bottom currents, periods of slow deposition followed by turbidity. Organic-rich.





Facies Name: Starved HCS laminated coarse siltstone and very fine sandstone (F2)

Description: Coarse siltstone and occasional very fine sandstone beds with wavy laminae commonly draped with <1mm clay drape. Rare bioturbation (BI 0-1) consisting of <2 mm *Schaubcylichnus* and occasional *Ophiomorpha* and *Teichichnus*

Composition: Clays, Quartz, Kspar, Organic Material, occasional calcite

Process: Storm waves and bottom currents

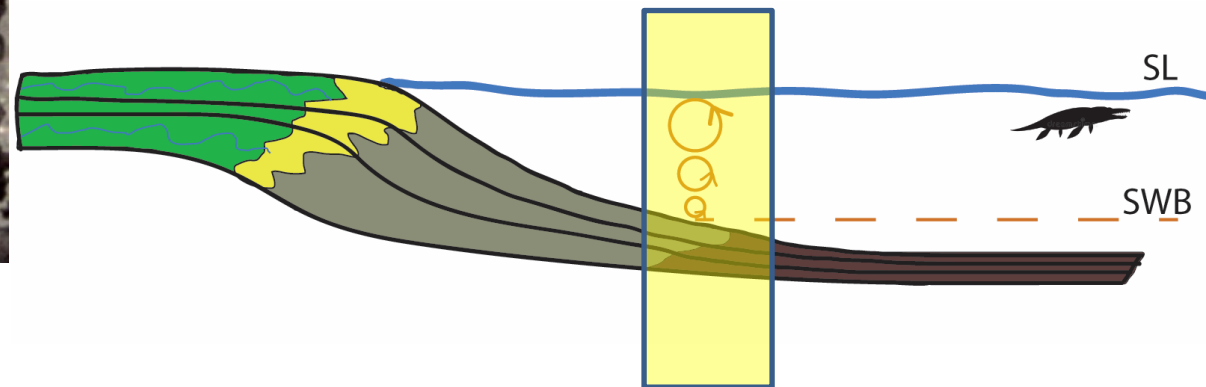




Figure 9. Gutter cast at Soldier Canyon Dam with basal markings of *Asterosoma*. Black, mechanical pencil beneath cast for scale.



Mod. Blakey, 2014

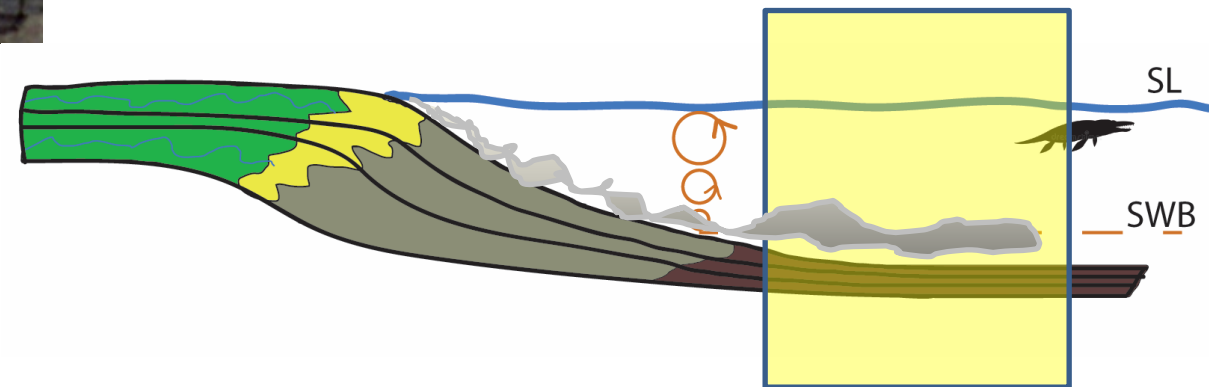


Facies Name: Bivalve-rich disorganized calcarenite (F3)

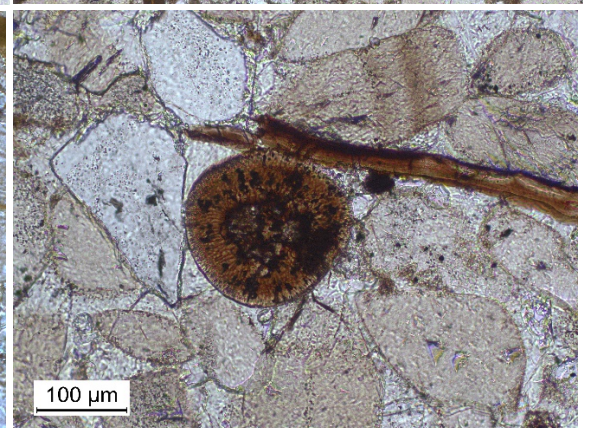
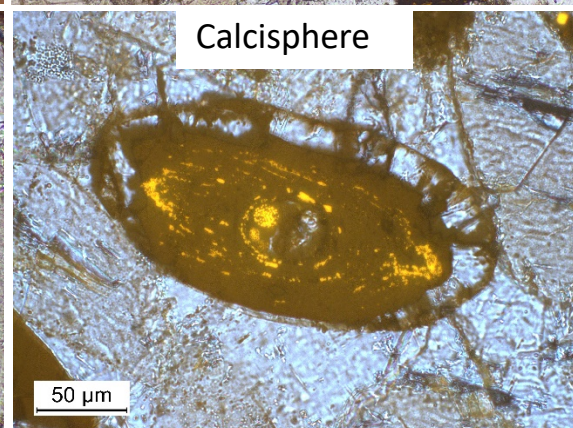
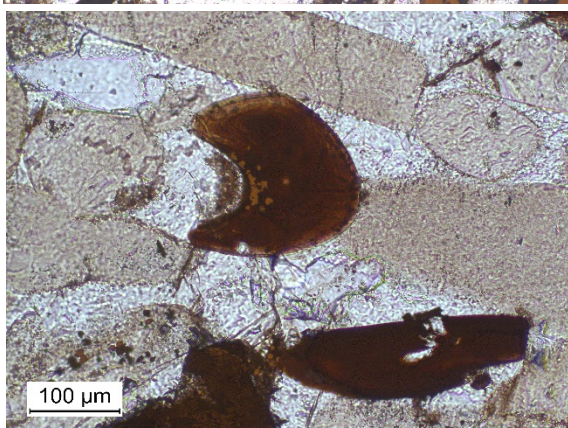
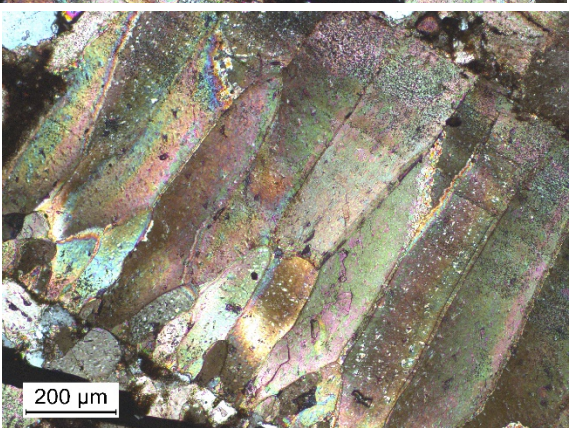
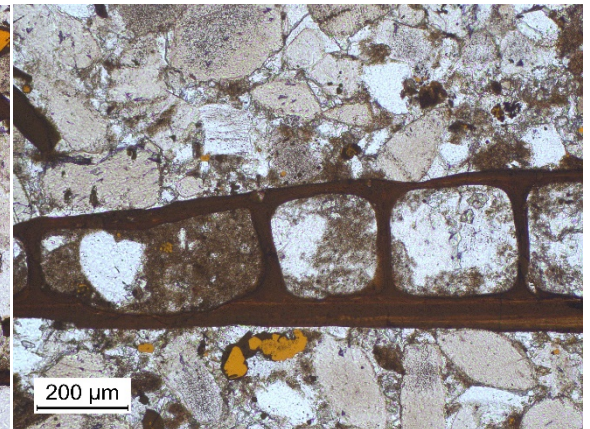
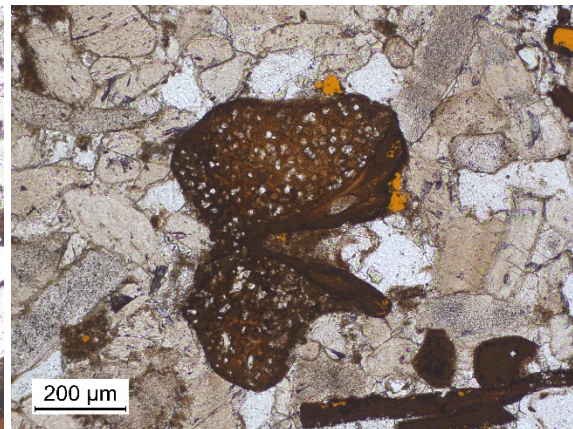
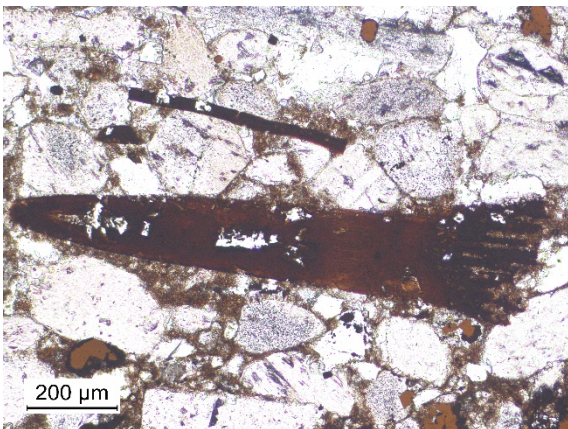
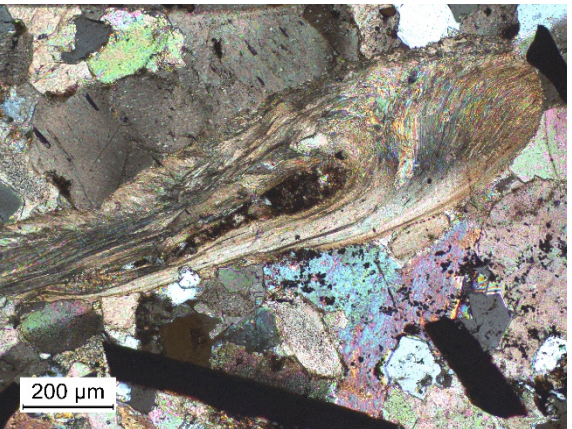
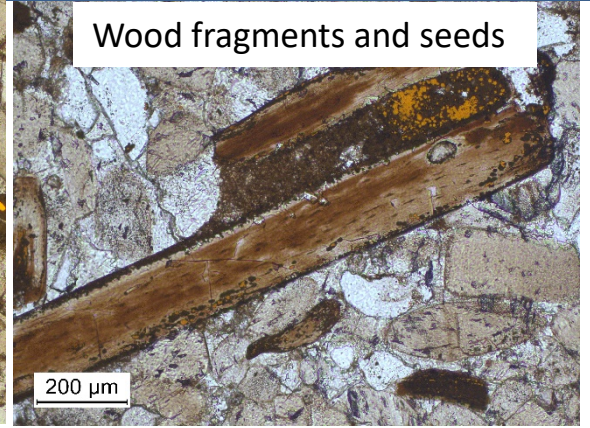
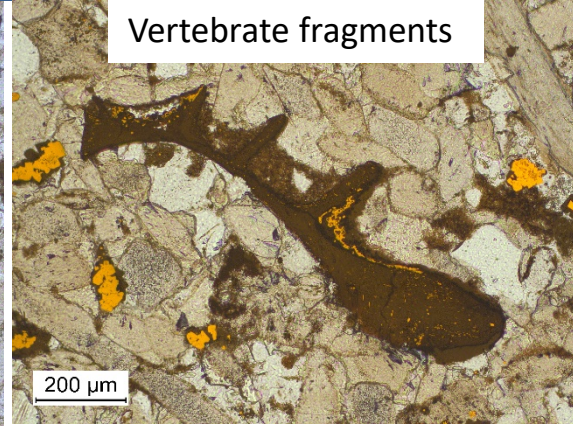
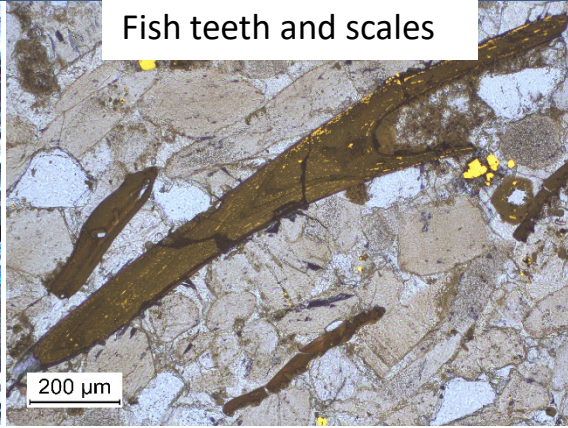
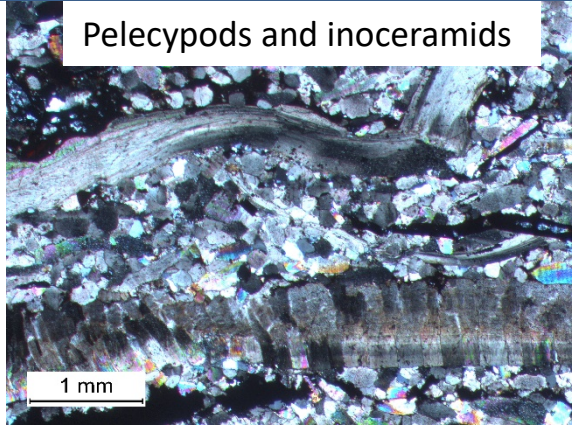
Description: Upper-fine to lower med-grained white calcarenite bed with angular black debris (fish scales, bones, wood fragments), inoceramid shells, and common pyrite replacement of vertebrate skeletal fragments. Contact tends to be sharp and erosional at the base and gradational at the top

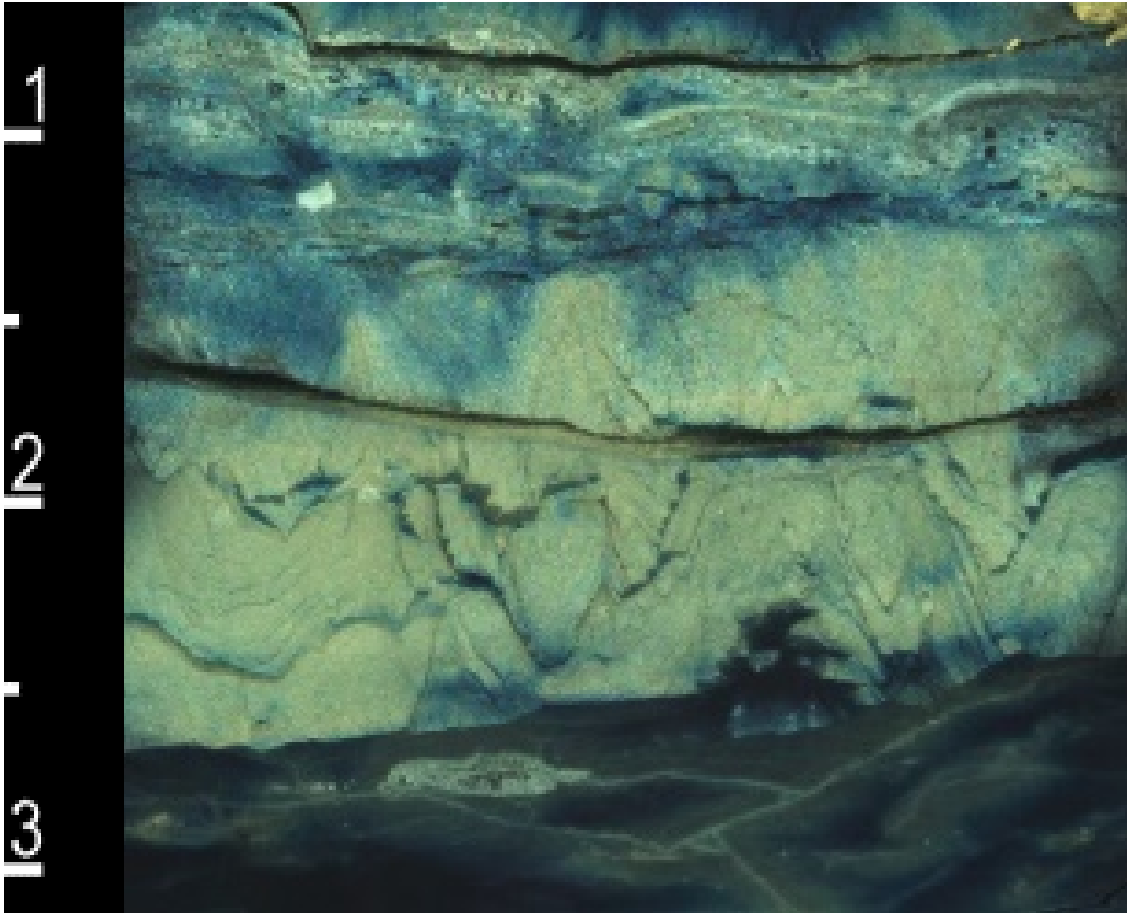
Composition: Calcite, clay, wood, bone

Process: Turbidity currents



Facies 3



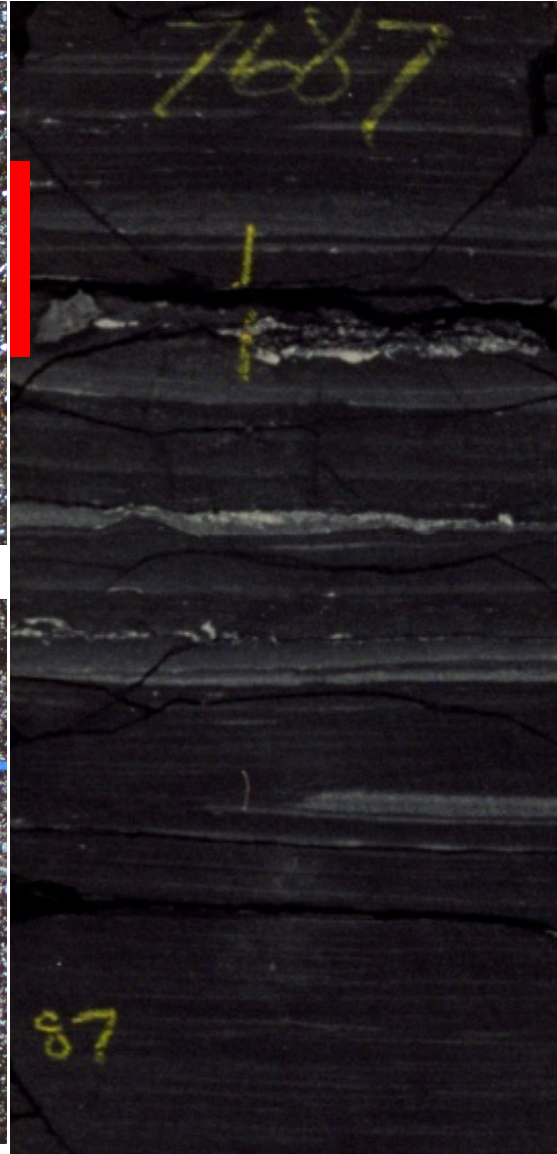
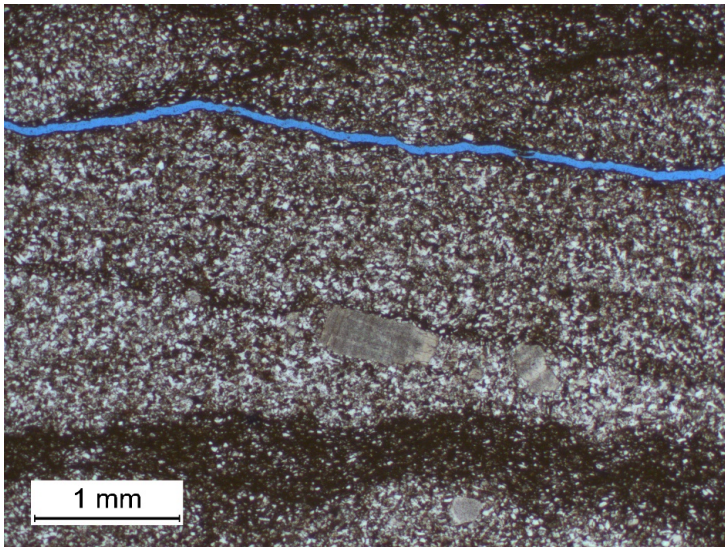
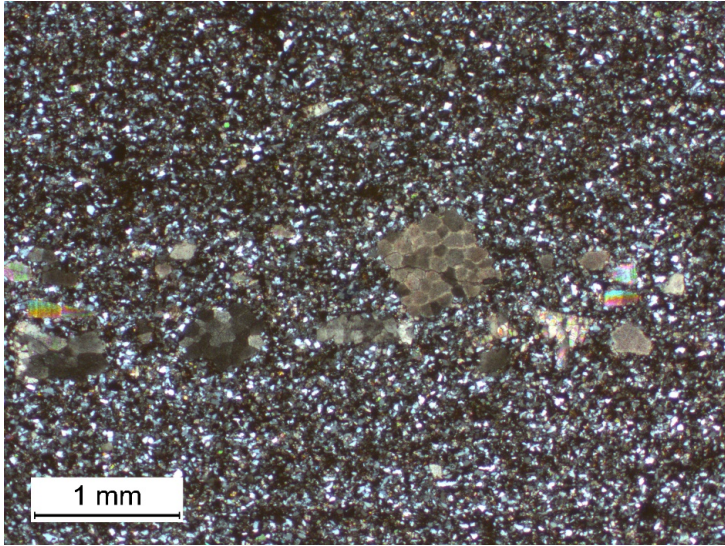


Facies Name: Massively bedded carbonate with cone-in-cone structures (F0)

Description: Calcium carbonate bed with cone-in-cone structures. Likely a result of early diagenesis. Associated with F3

Composition: Calcite

Process: Early diagenesis – likely related to aragonite alteration to calcite and/or shallow compaction

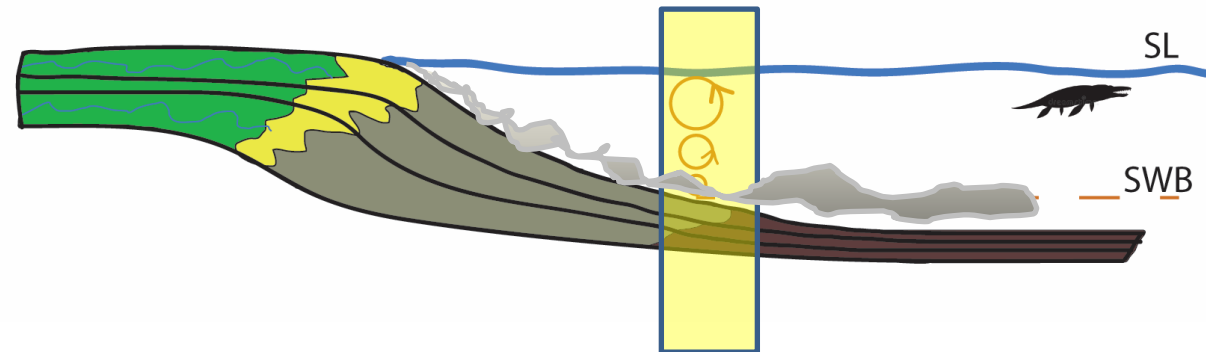


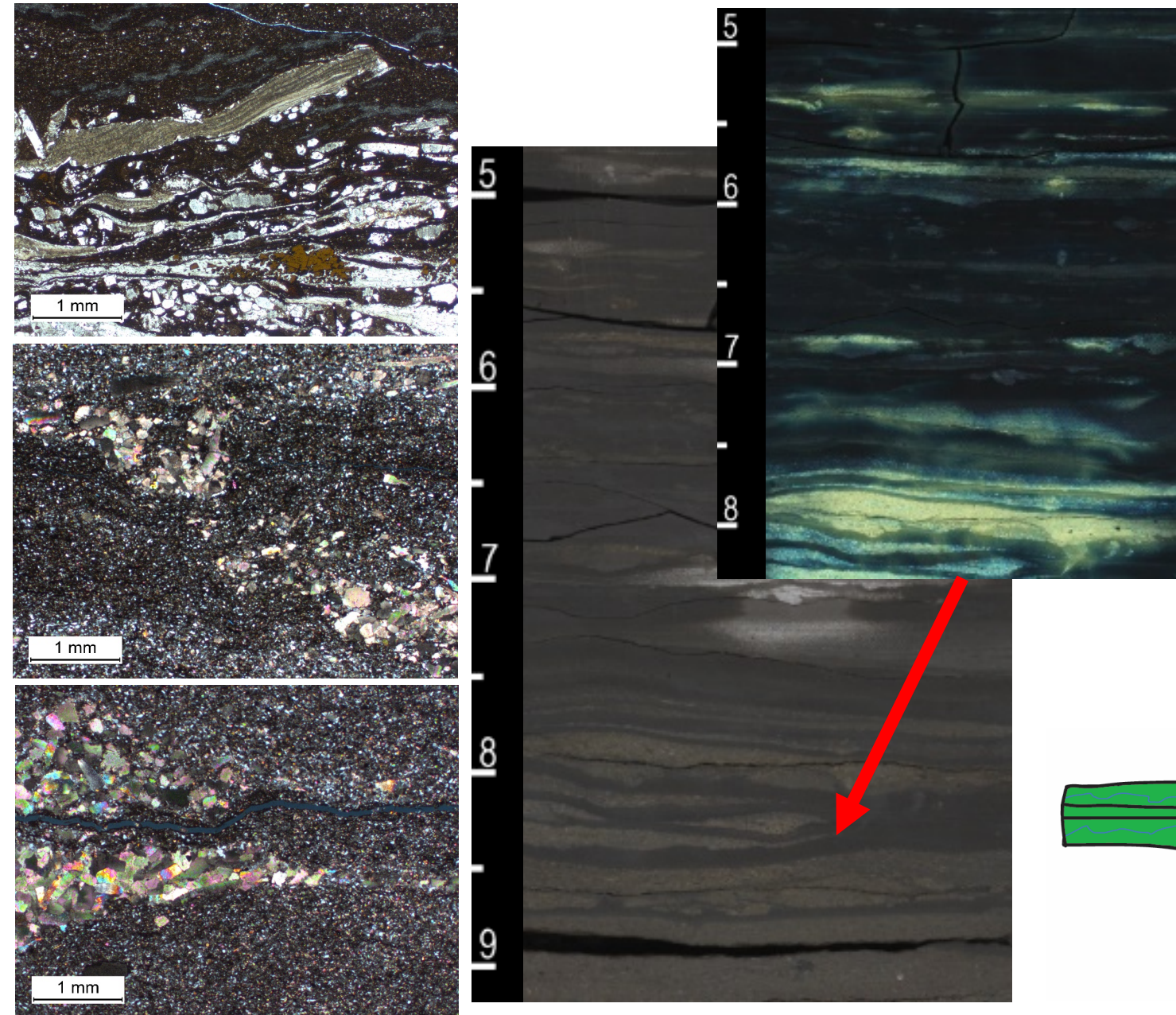
Facies Name: Fossiliferous silty claystone with starved HCS (F4)

Description: Silty claystone with frequent < 1cm beds of upper fine-lower med-grained calcarenite and/or inoceramid debris and erosional/wavy bedding. Discontinuous (starved) HCS calcaerous silt beds common in massively bedded mudstone

Composition: Quartz, Calcite, Clays, Organic Material

Process: Storm waves, turbidity currents.



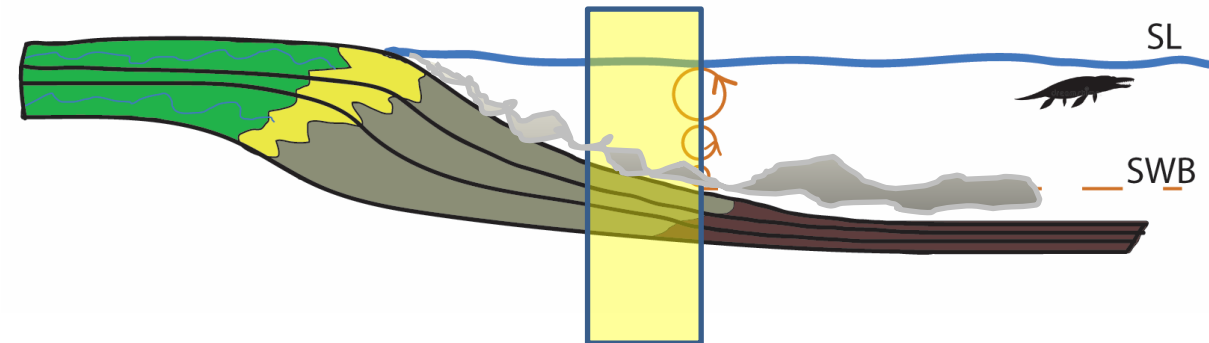


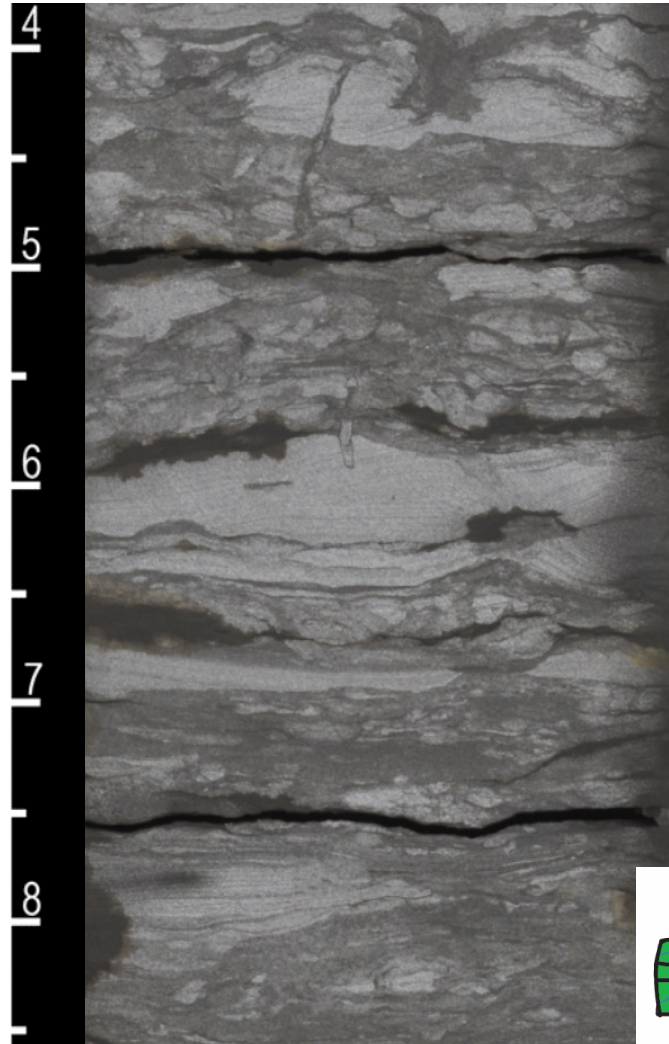
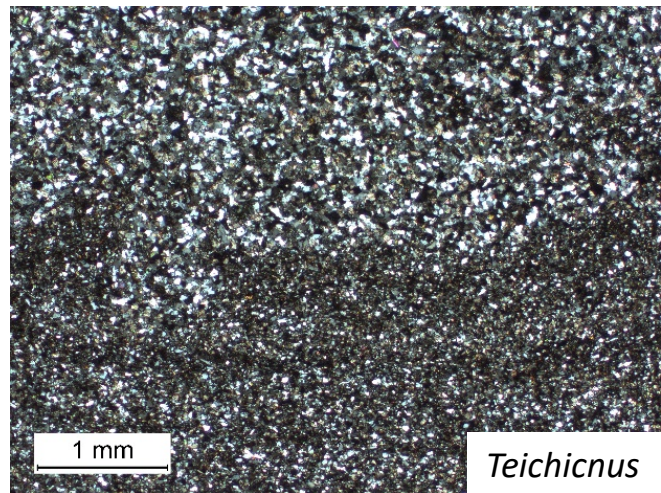
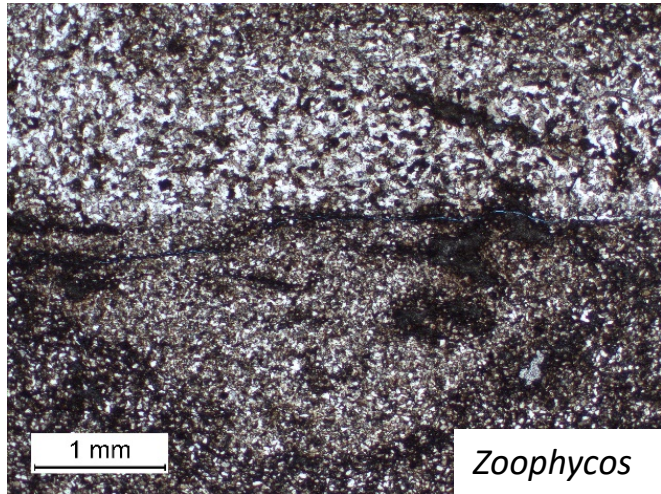
Facies Name: Calcareous ripple-laminated fossiliferous muddy siltstone (F5)

Description: Ripple-laminated calcareous siltstone and very fine sandstone with a high abundance of white upper fine-lower medium calcareous grains and common bivalves (Inoceramids and pelecypods), fossil fragments, and pyrite. Mud drapes exhibit flame structures, slumping, and rare bioturbation (BI 0-1).

Composition: Quartz, Calcite, Organic Material, Bone, Wood

Process: Turbidity currents followed by tidal energy and storm waves



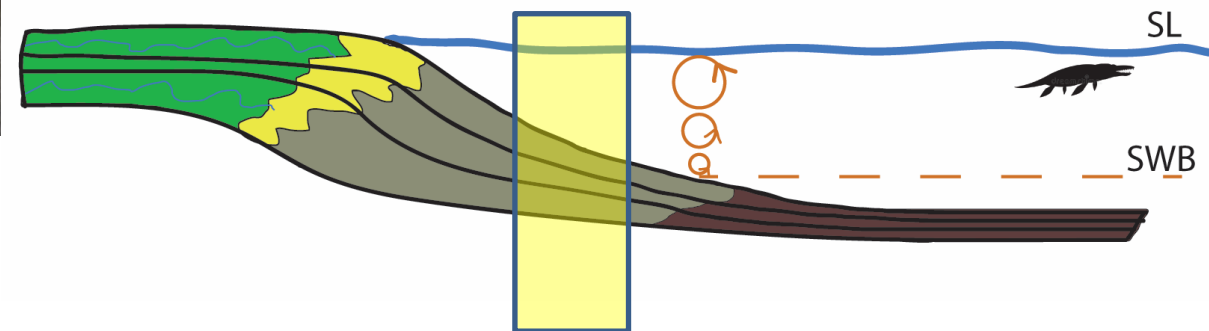


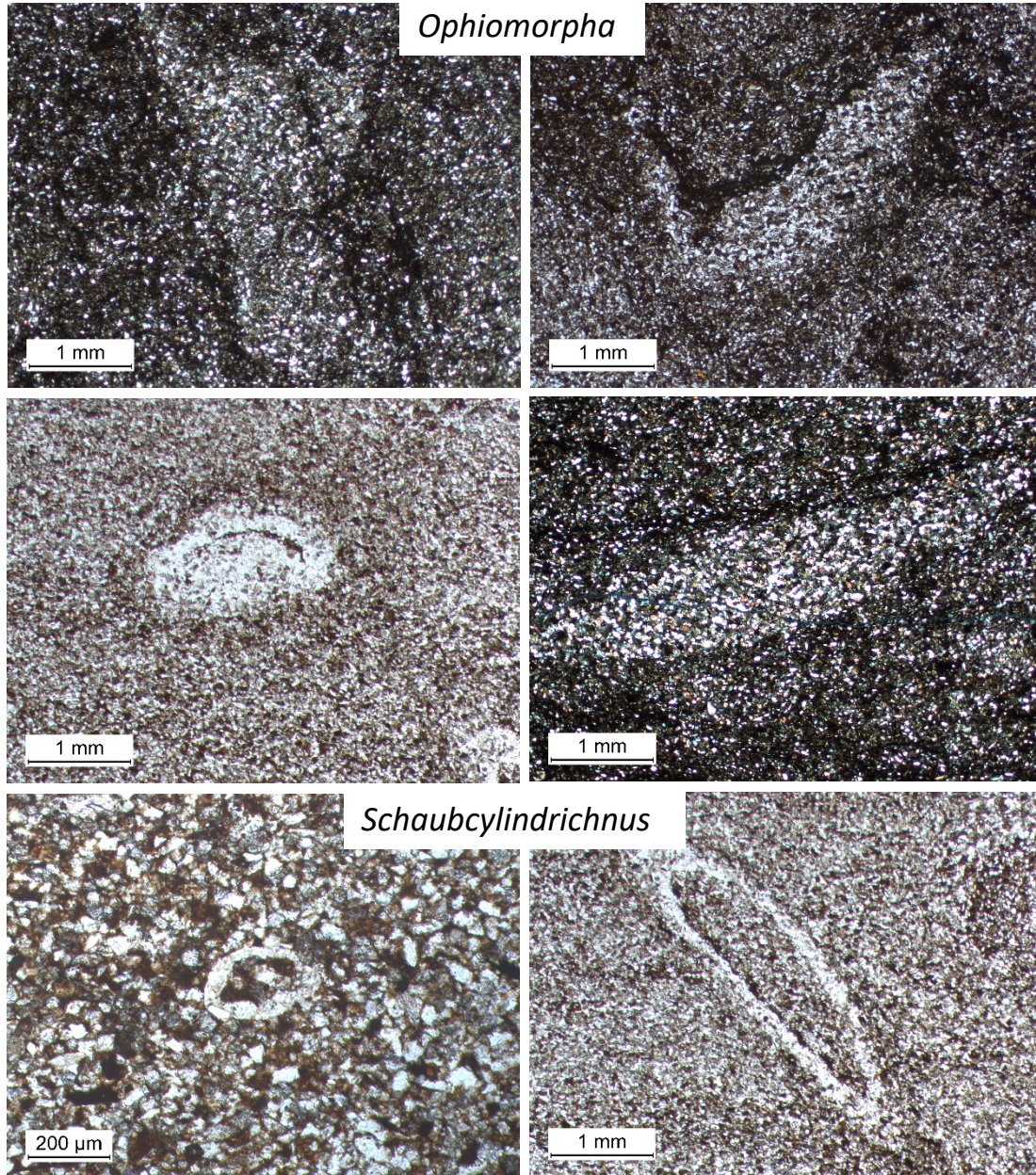
Facies Name: Bioturbated clay-rich very fine sandstone (F6)

Description: Bioturbated (BI 2-4) clay-rich siltstone and very fine sandstone. Bedding is sometimes disrupted by bioturbation. Frequent soft-sediment deformation and planar to hummocky cross-stratification in vf sand intervals. Contorted beds and collapse features in dark mudstone. Silt-filled traces of *Schaubcylindrichnus*, *Zoophycos*, *Skolithos*, *Teichichnus*.

Composition: Quartz, clays, Kspar, organic material.

Process: Storm waves, tidal energy

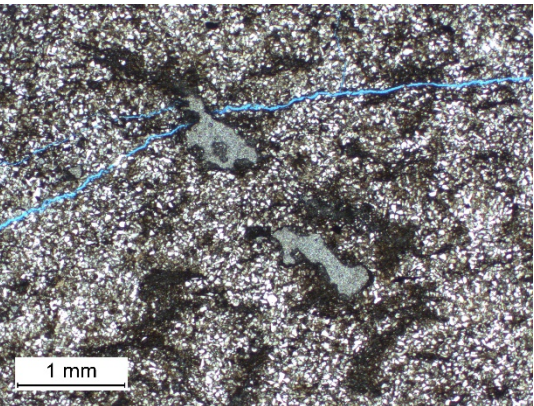
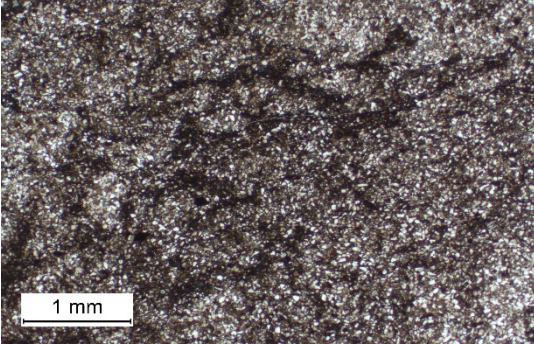




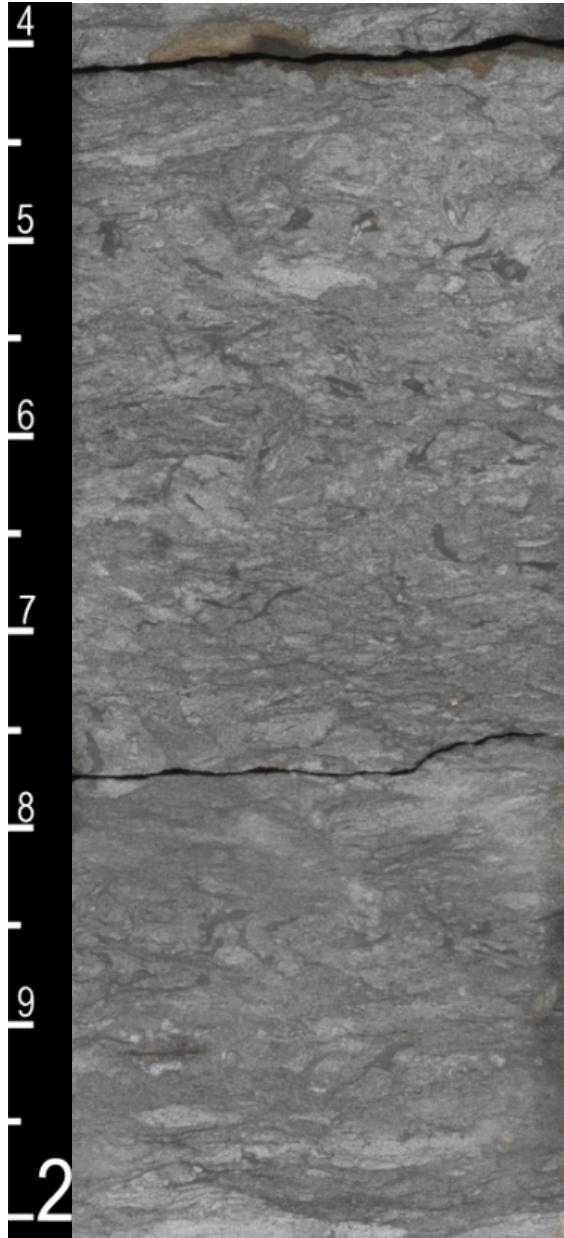
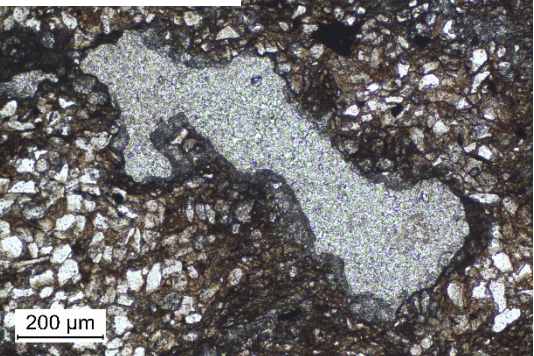
KEY TO BIOTURBATION INTENSITY			
BI	Characteristics	Mudstone Facies	Sandstone Facies
0	Bioturbation absent		
1	Sparse bioturbation, bedding distinct, few discrete traces		
2	Uncommon bioturbation, bedding distinct, low trace density		
3	Moderate bioturbation, bedding boundaries sharp, traces discrete, overlap rare		
4	Common bioturbation, bedding boundaries indistinct, high trace density with overlap common		
5	Abundant bioturbation, bedding completely disturbed (just visible)		
6	Complete bioturbation, total biogenic homogenization of sediment		



Psycosiphon



Ophiomorpha

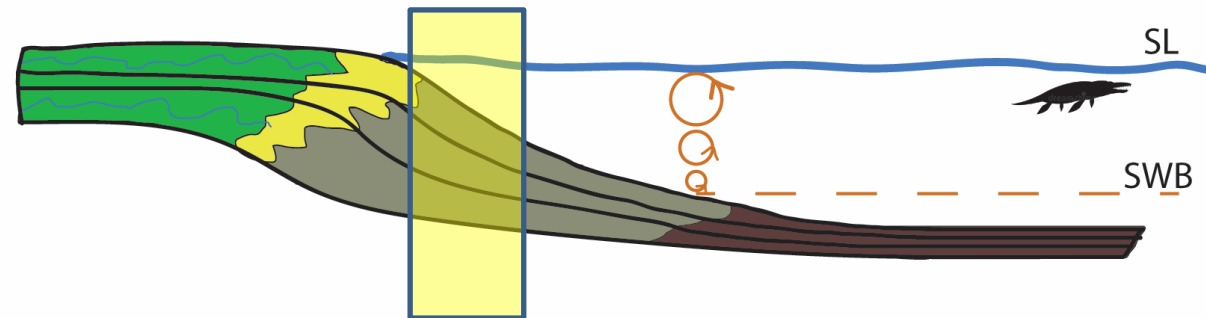


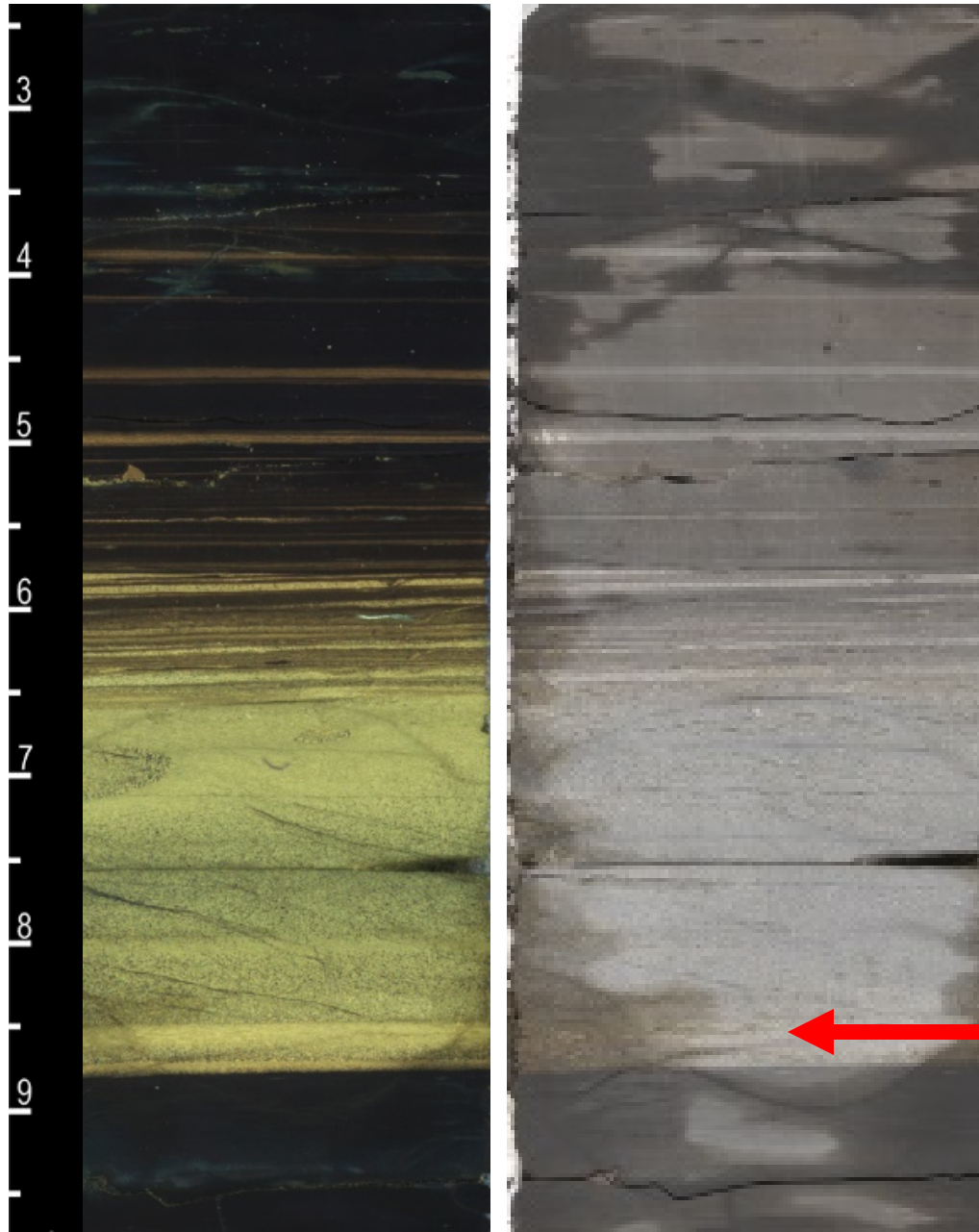
Facies Name: Heavily Bioturbated Silty Upper Very Fine Sandstone (F7)

Description: Heavily bioturbated (BI: 4-6) very fine - fine sandstone with high silt content and wavy beds of clay-rich siltstone. Very few preserved sedimentary structures. Includes dense *Schaubcylindrichnus*, *Phycosiphon*, *Skolithos*, *Teichichnus* and less frequent *Zoophycos*, *Asterosoma*, and *Arenicolites*

Composition: Quartz, clays, Kspar, rare calcite

Process: Tidal energy, storm waves





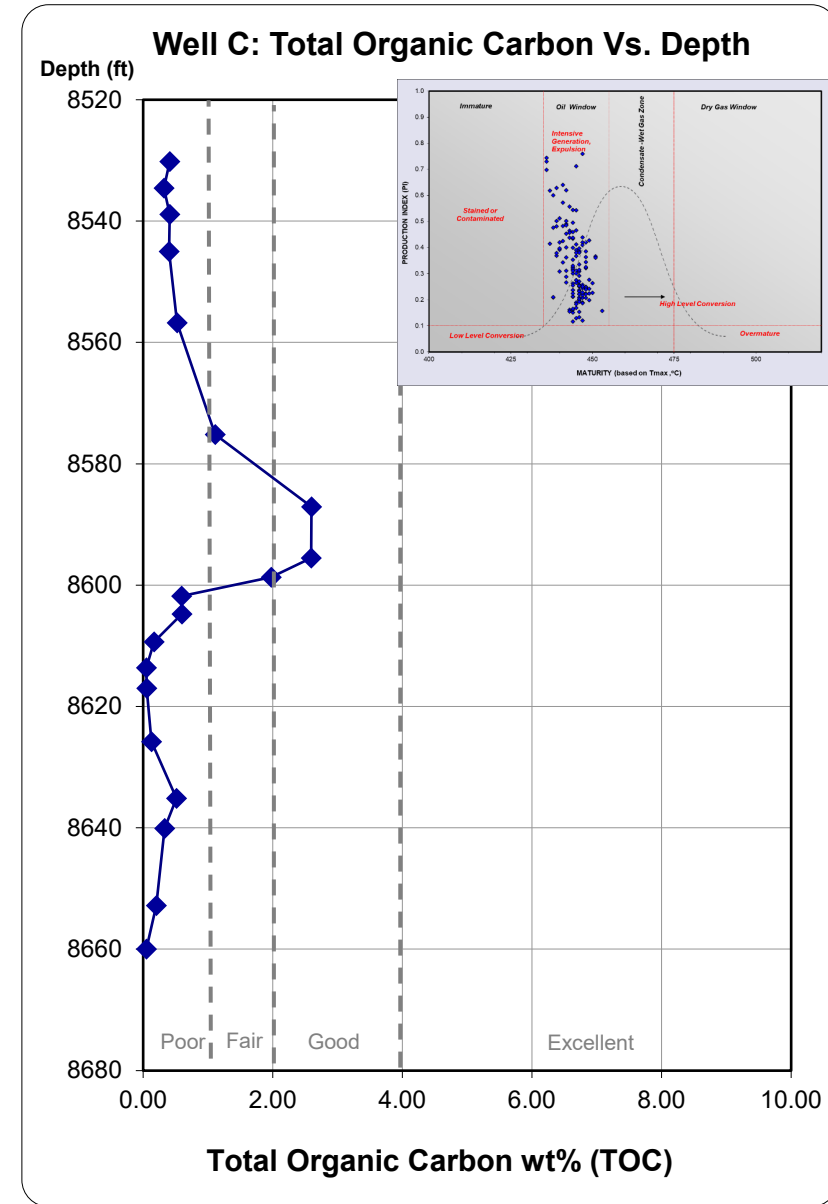
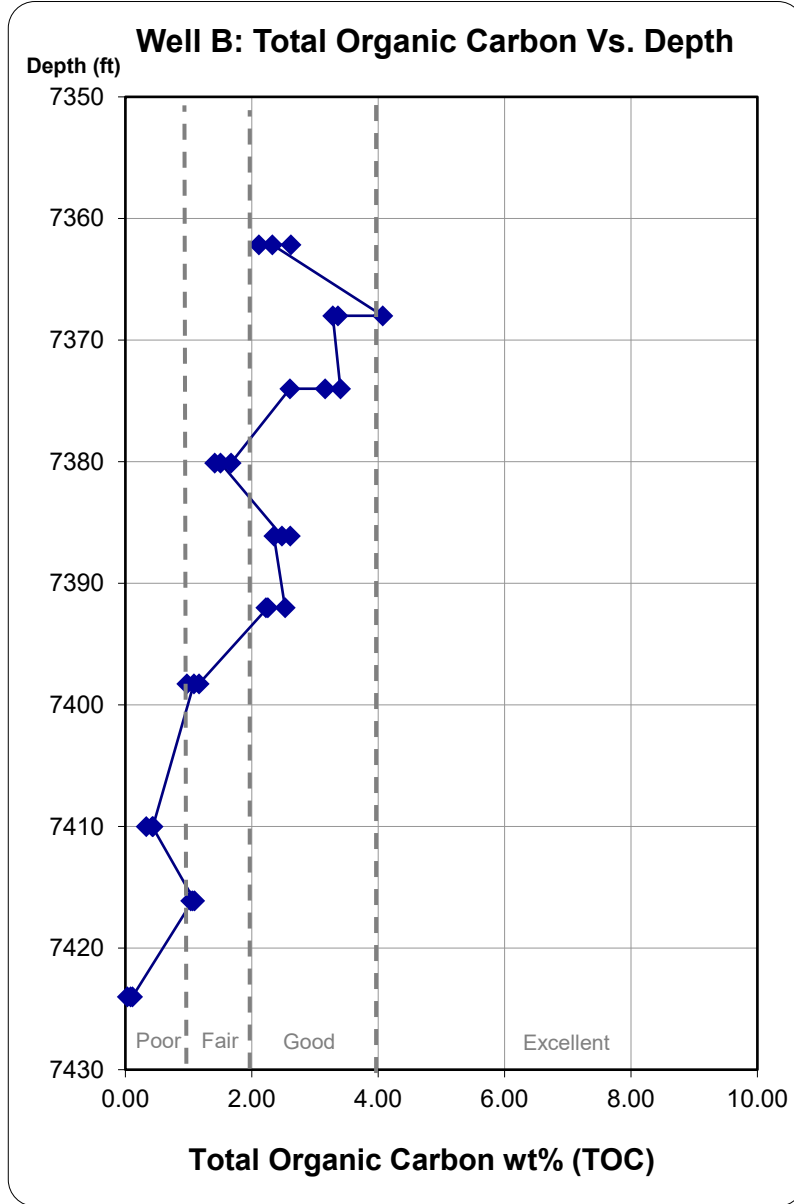
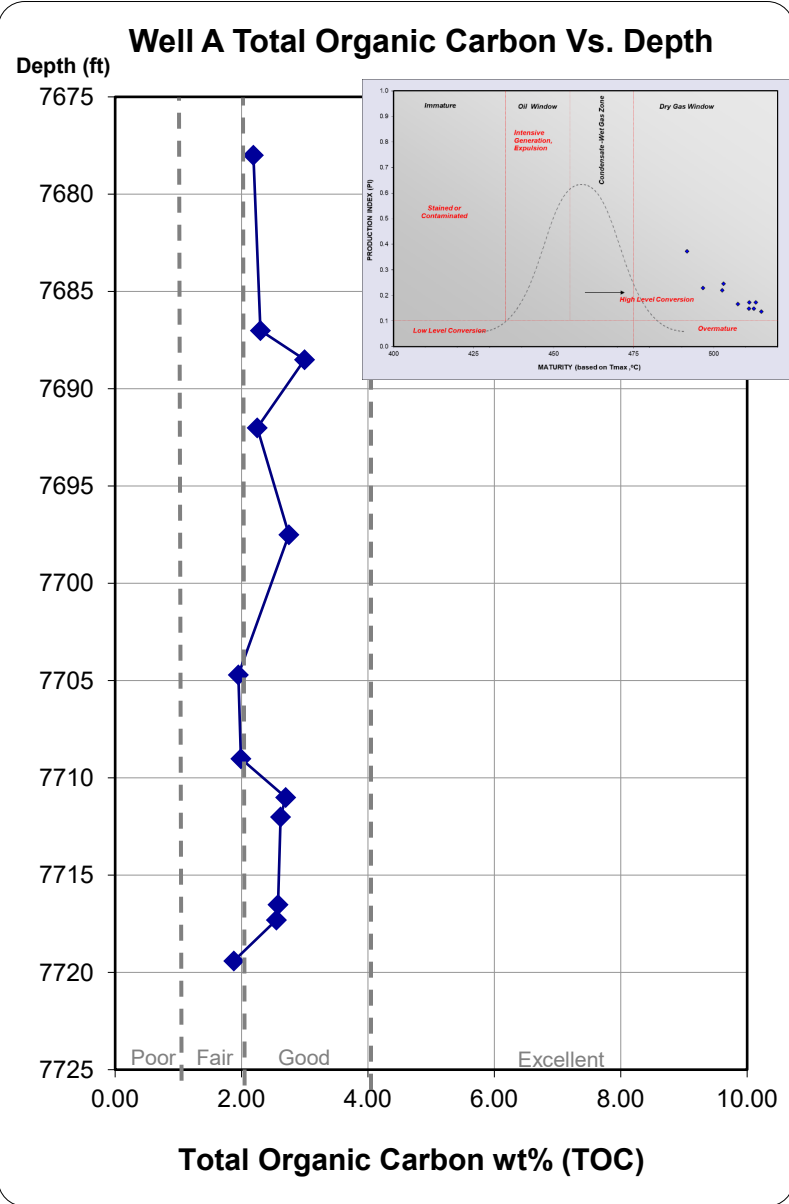
Facies Name: Ash Bed (F8)

Description: Bentonite deposit, usually slightly reworked and grading into clay-rich siltstone.

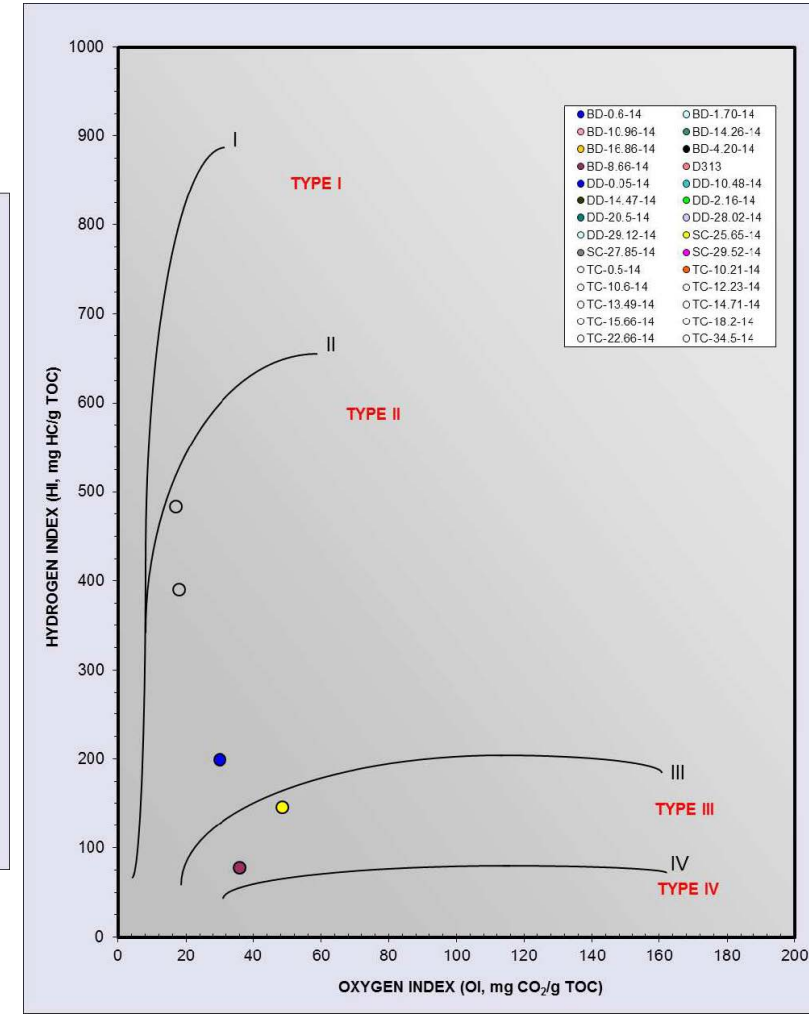
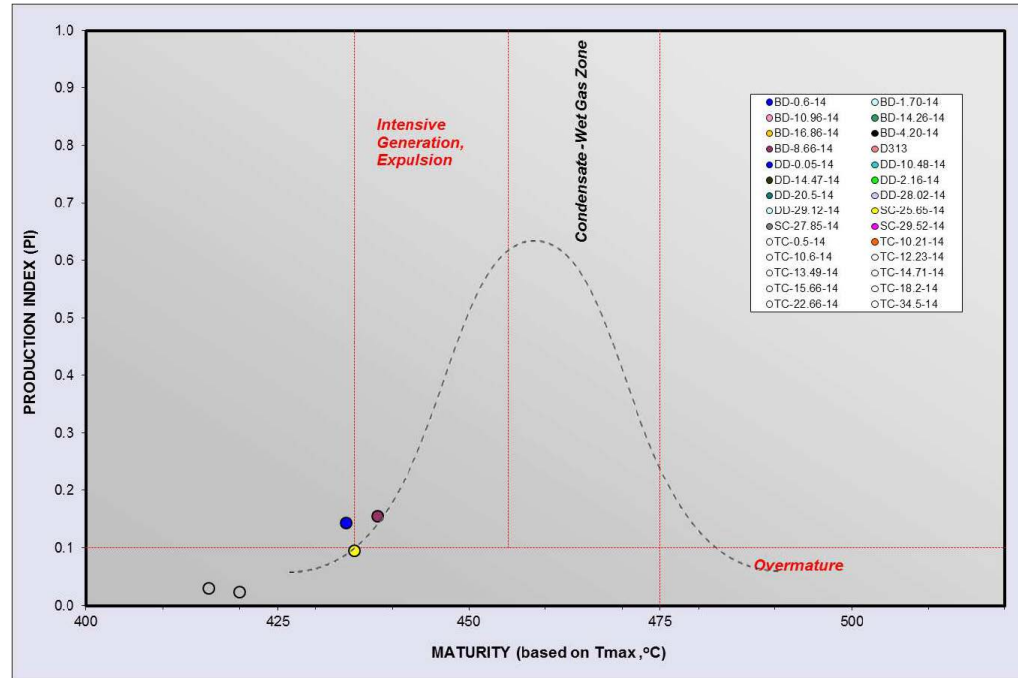
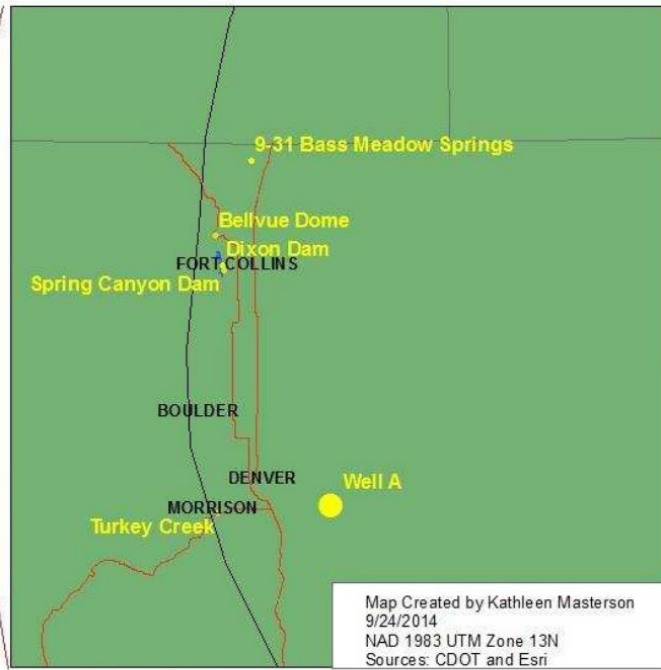
Composition: Bentonite clay

Process: N/A

Source Rock Analysis: wt% TOC



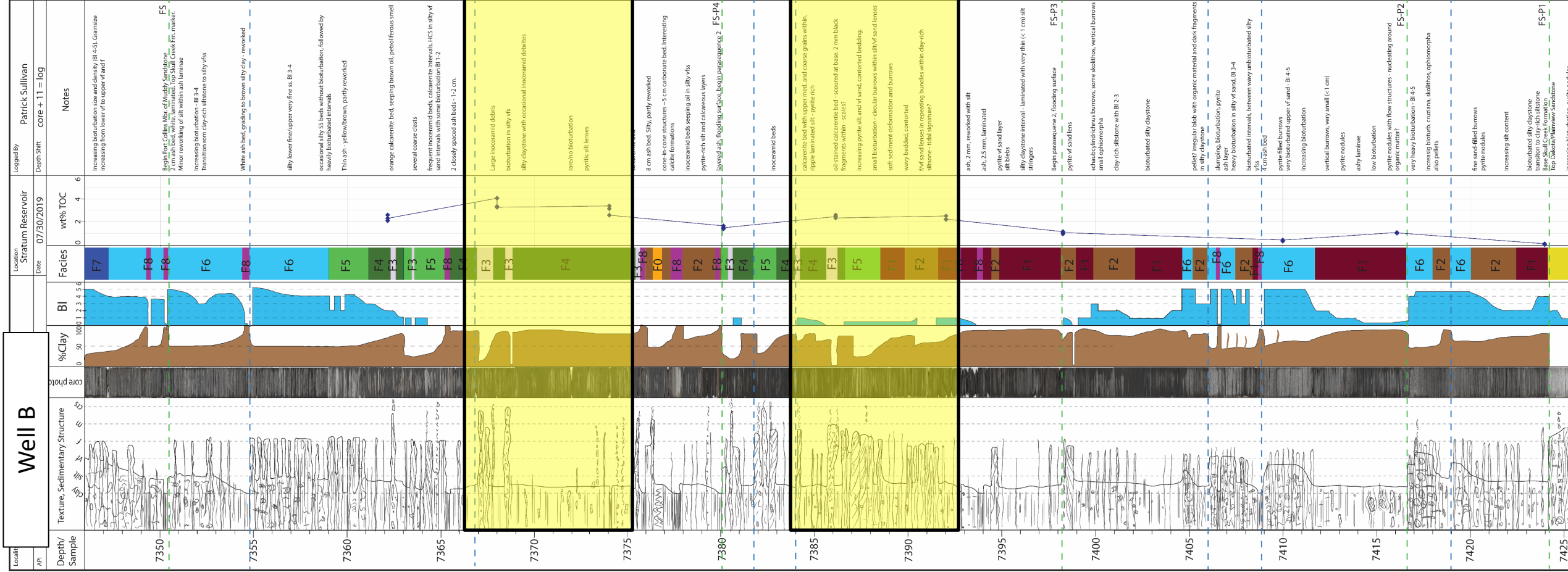
Source Rock Analysis: Outcrops





1. Introduction and Motivation
 - Why the Skull Creek Shale?
 - Background literature
2. Regional Geology and Tectonics
 - The Denver Basin
 - Western Interior Cretaceous Seaway
3. Data
 - Sedimentology: facies descriptions and interpretations
 - Well log cross sections
4. Next Steps

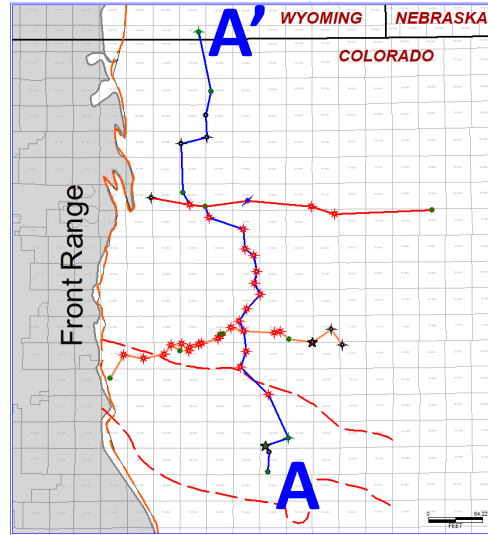
Link Facies to wt% TOC



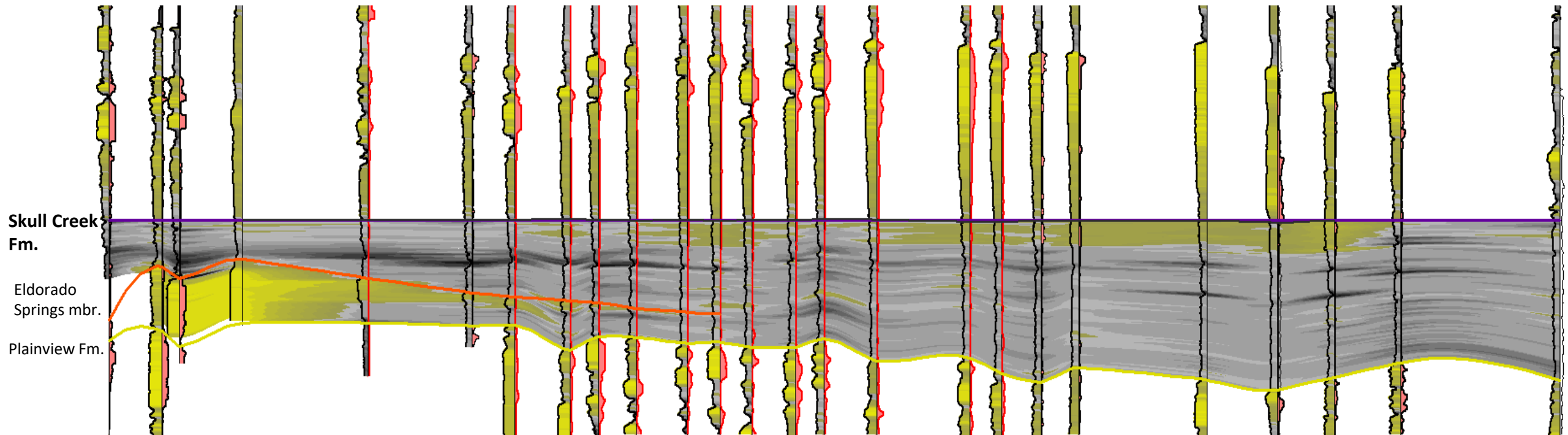
Stratigraphic Correlations: A – A'



A



A'

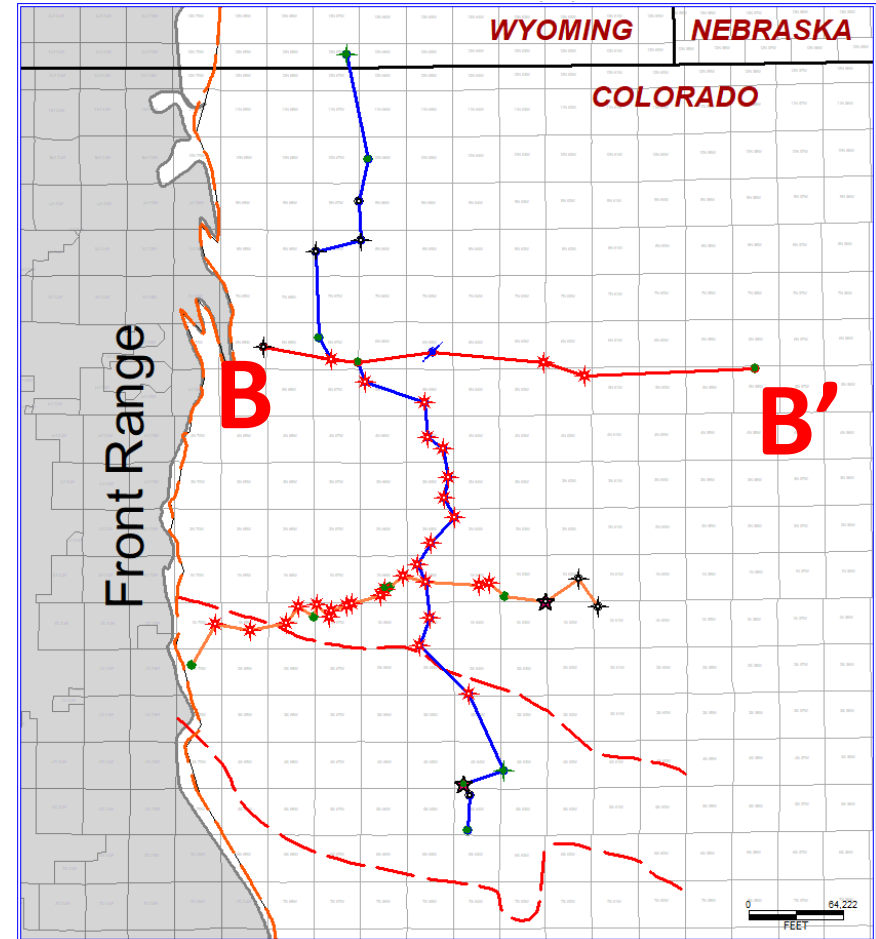
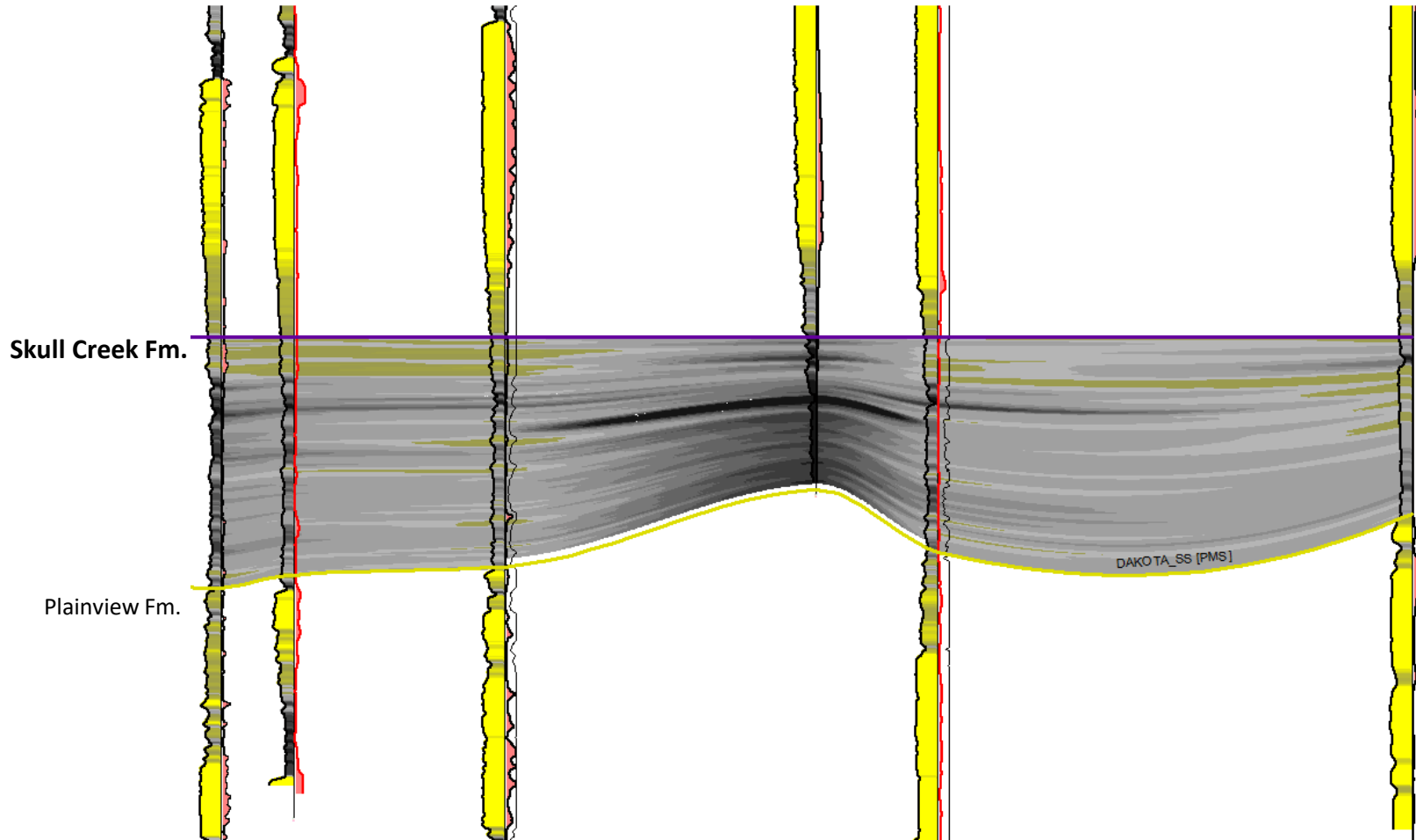


Stratigraphic Correlations: B – B'

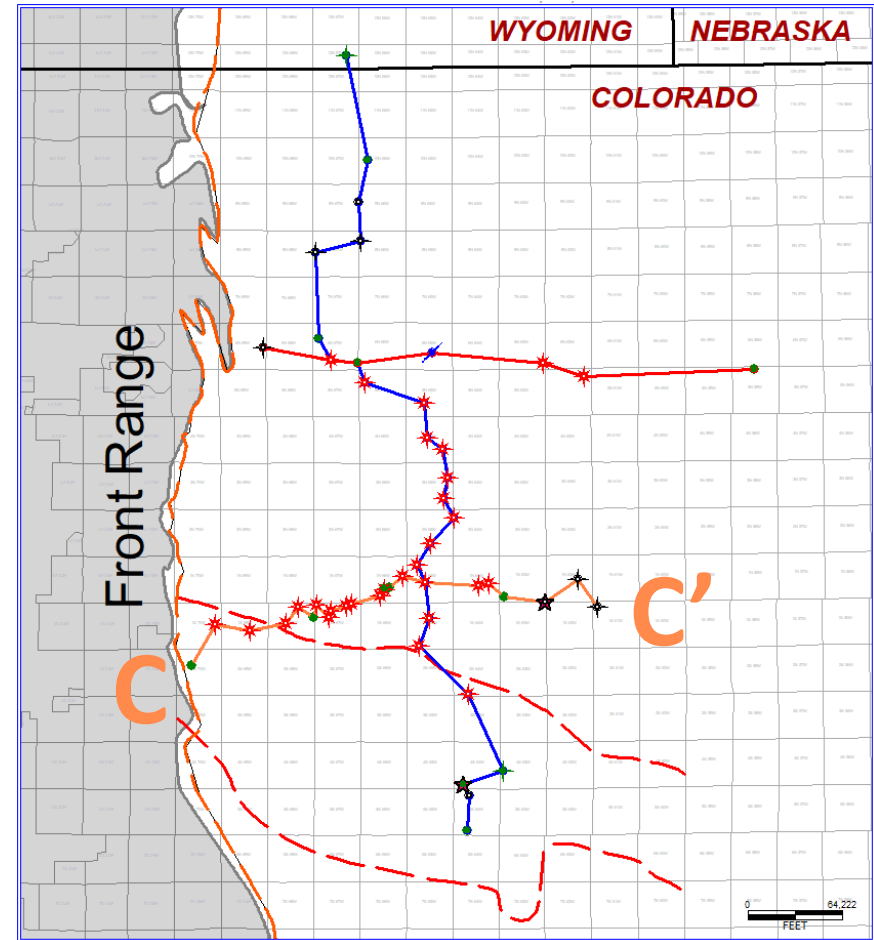
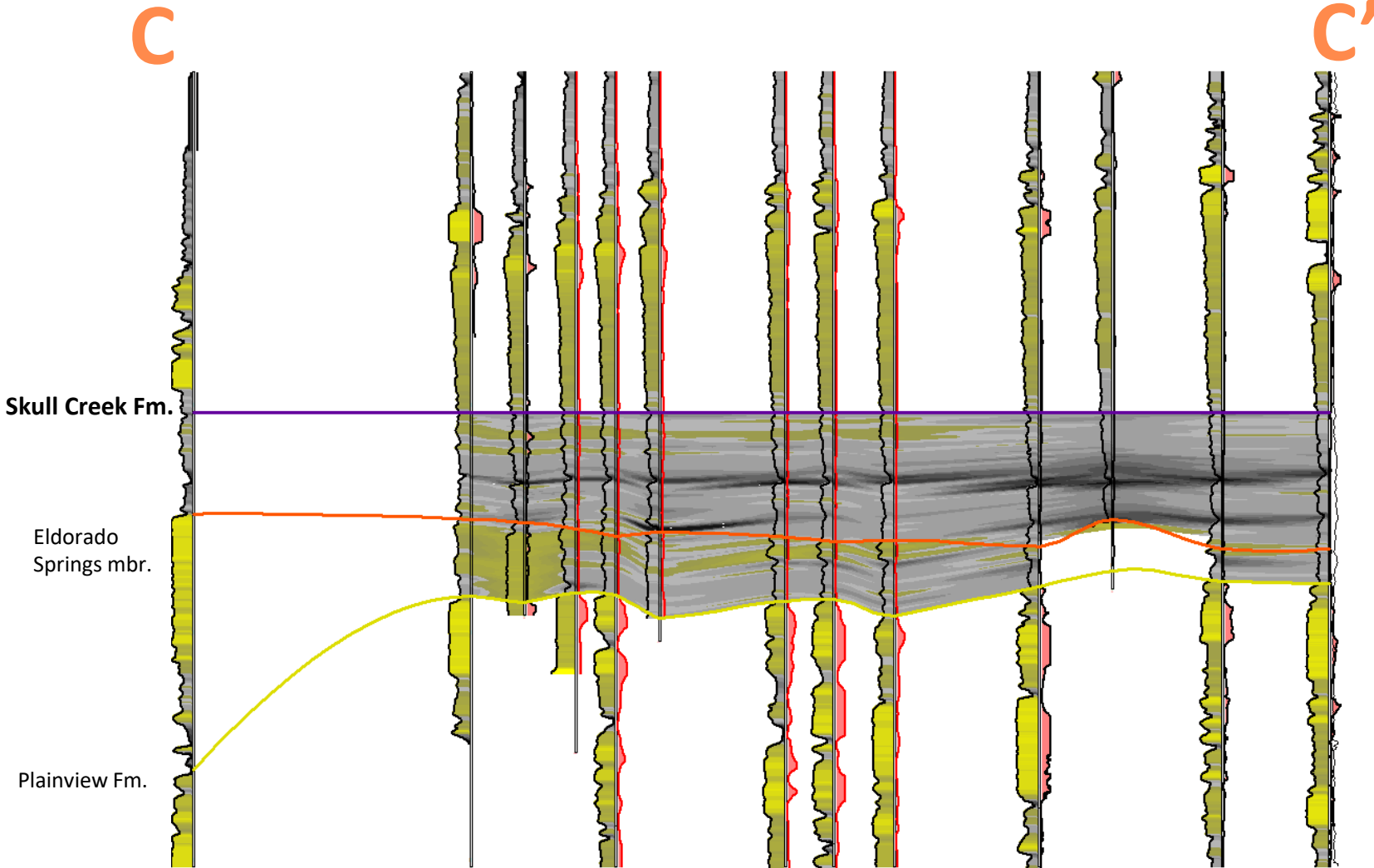


B

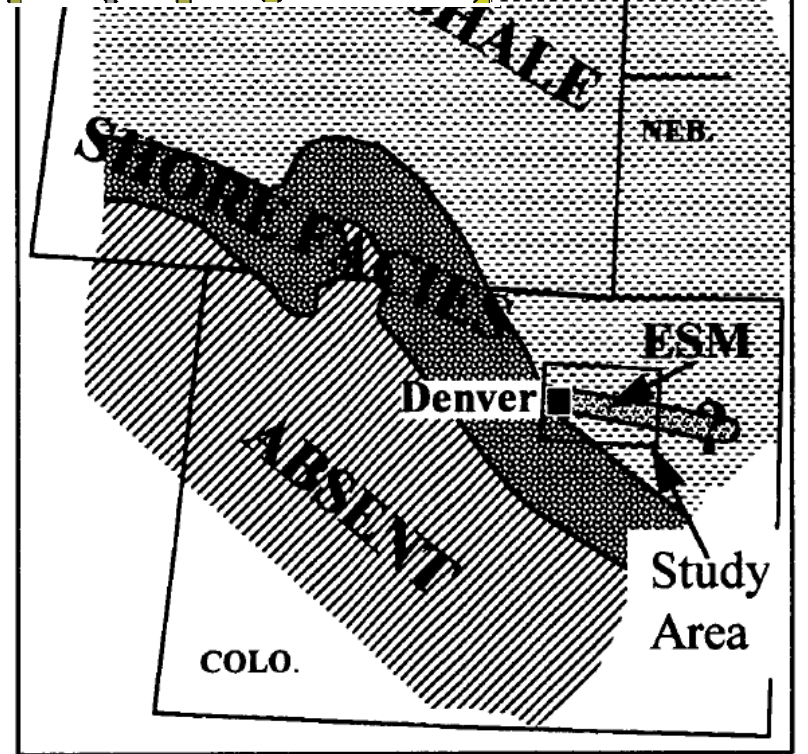
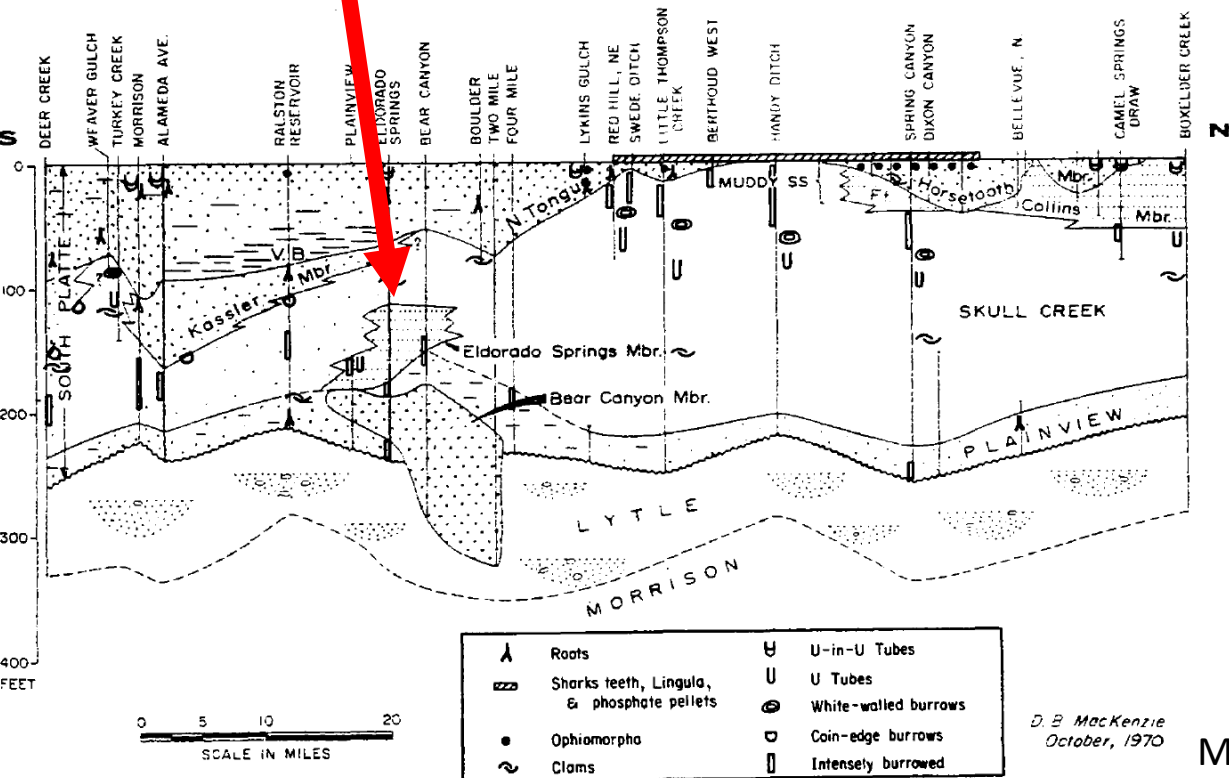
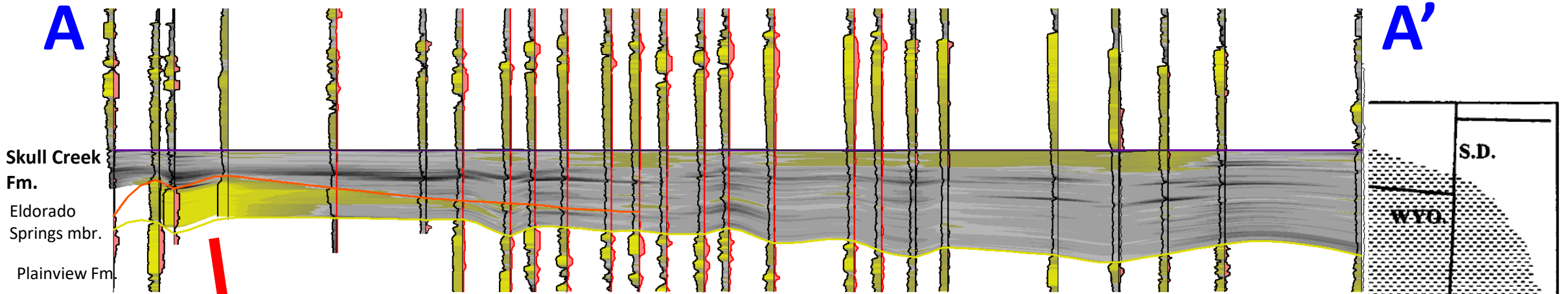
B'

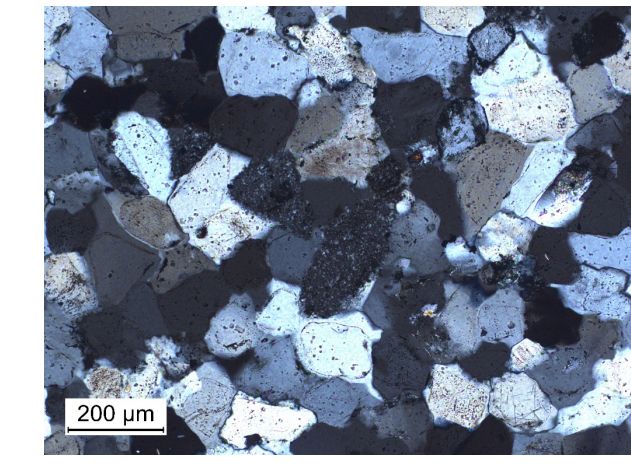
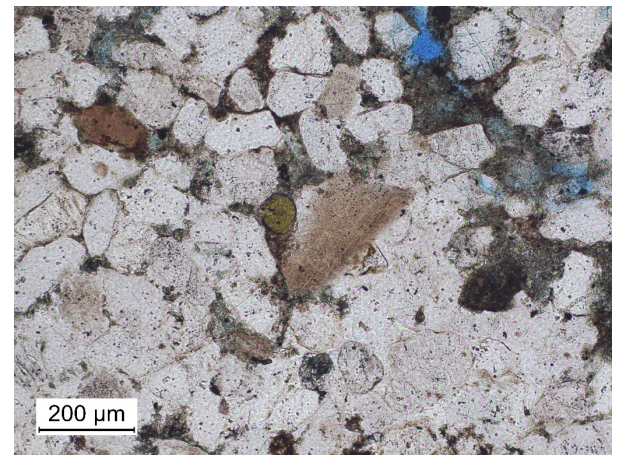
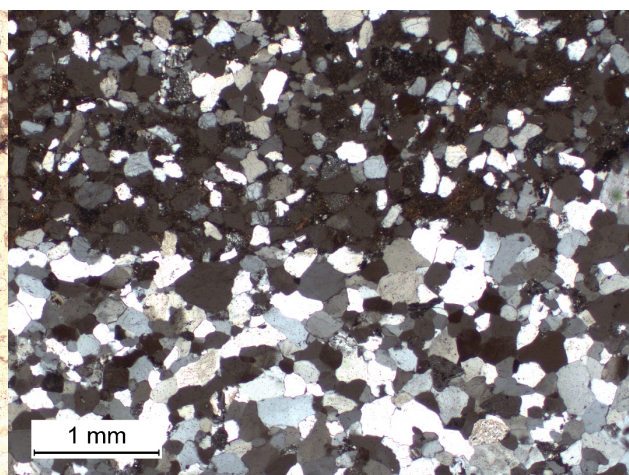
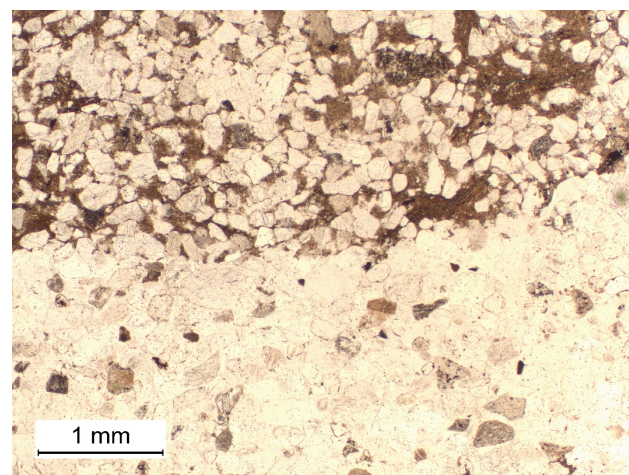
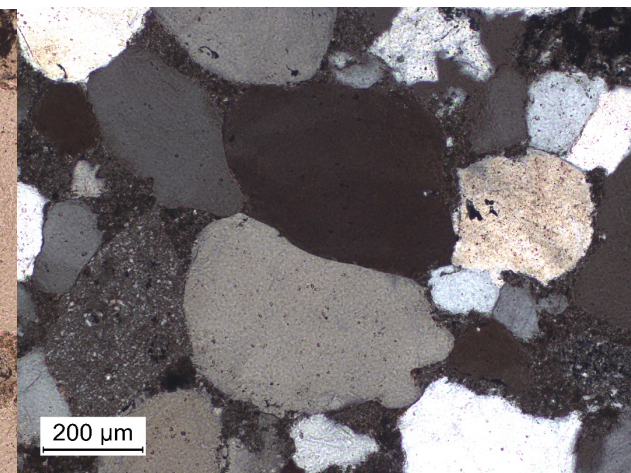
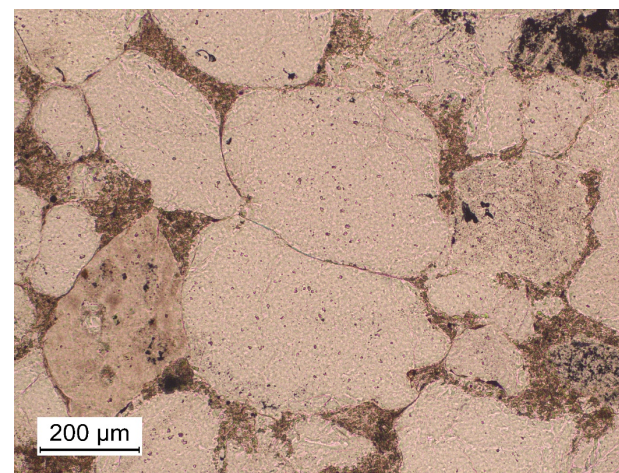
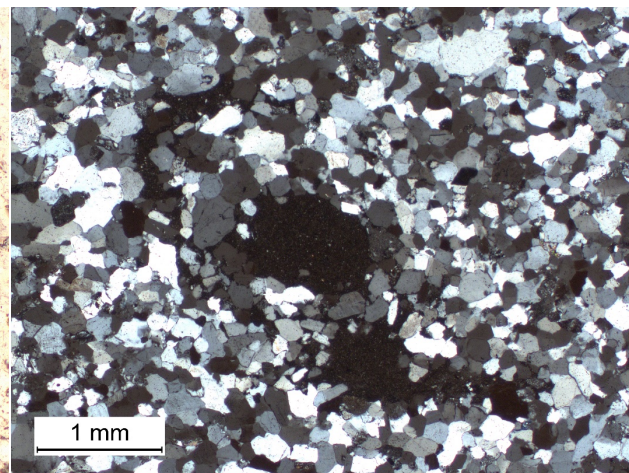
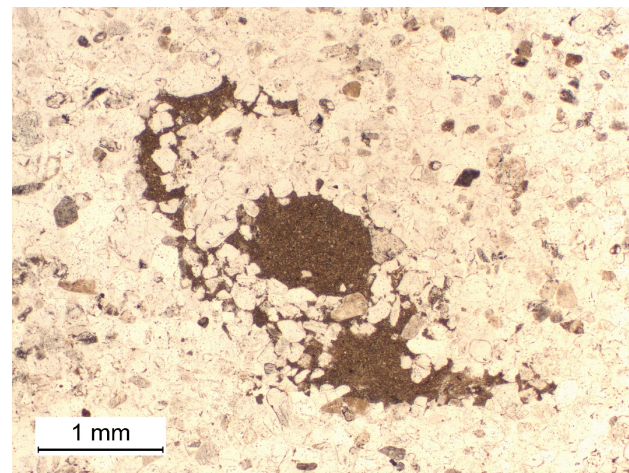


Stratigraphic Correlations: C – C'



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