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

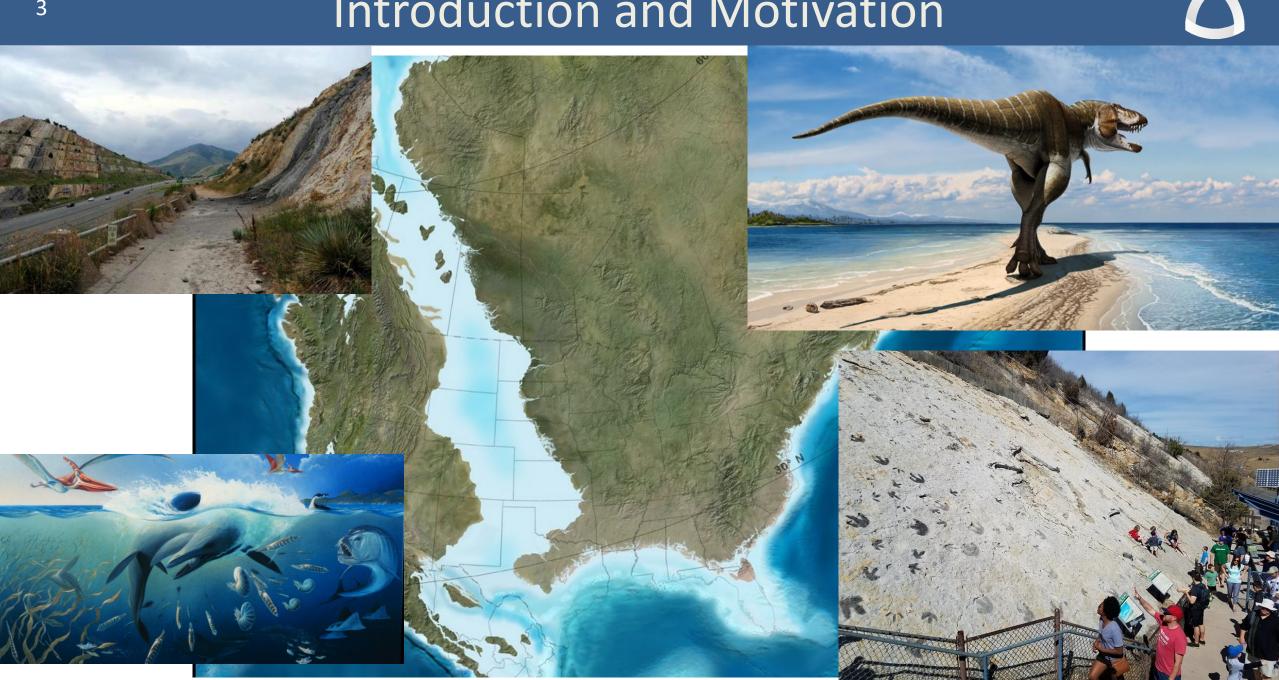
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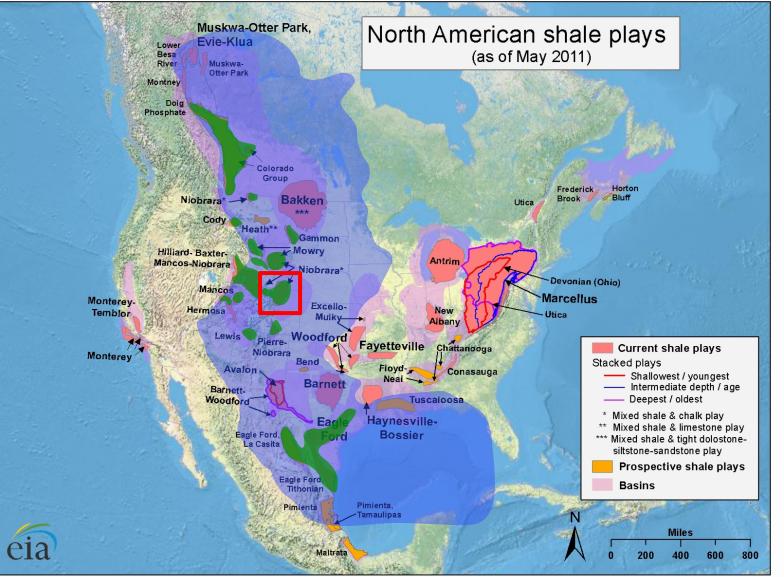
- 1. Introduction and Motivation
  - Why the Skull Creek Shale?
  - Background literature
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  - Sedimentology: facies descriptions and interpretations
  - Well log cross sections
- 4. Next Steps

# Introduction and Motivation



# Introduction and Motivation

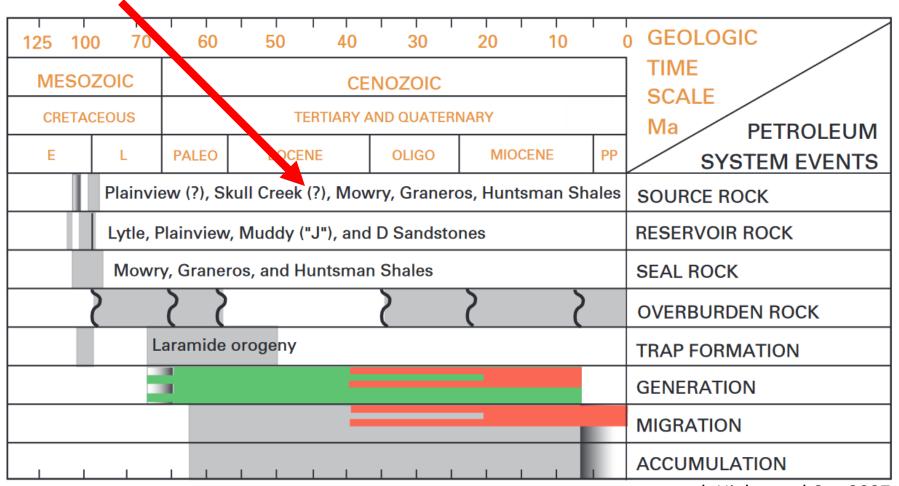




Source: U.S. Energy Information Administration based on data from various published studies. Canada and Mexico plays from ARI. Updated: May 9, 2011

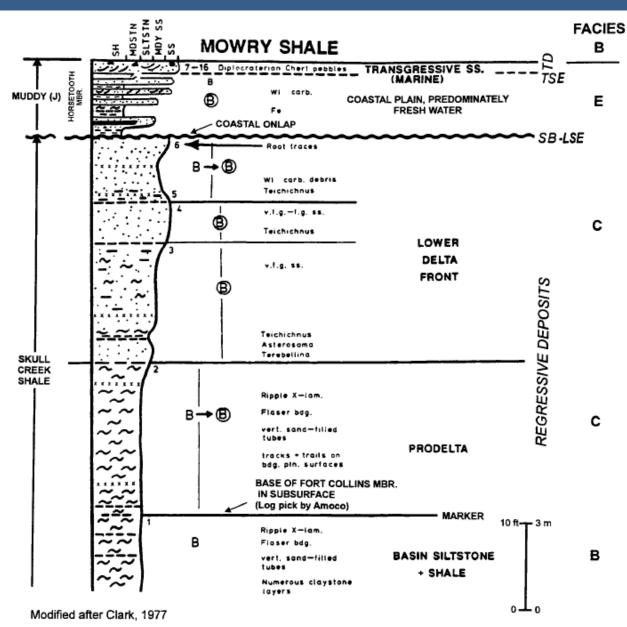
	NORTHERN FRONT RANGE, OUTCROP					ADJACENT DENVER BASIN			
QUAT.	Undifferentiated alluvial deposits			lluvial deposits	Undifferentiated alluvial deposits				
ιRY									
TERTIARY	Undifferentiated boulder & gravel deposits								
臣					Castle Rock Conglomerate				
	<u> </u>		Denver Fo		Dawson-Denver Formations				
	Arapahoe Formation					Arapahoe Formation			
	Laramie Formation					Laramie Formation			
	Fox Hills Sandstone					Fox Hills Sandstone			
Ś	Pierre		Richard Sandstone Mbr.		Pierre Shale				
ñ		ale				Terry "Sussex" Ss. Member			
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ETA		<sup>o</sup> < Hygiene Sandstone Mbr.				Sharon Springs Member			
UPPER CRETACEOUS	rara	Smoky Hill Shale Mbr.			Smoky Hill Shale Member				
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			Codell Sar	ndstone Mbr.	Codell Sandstone Member				
			Carlile S	Shale	Carlile Shale				
			Greenhorn L	imestone	Greenhorn Limestone				
			Graneros	Shale	Graneros Shale D" sandstone				
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S	iroup	÷	South	North					
CRETACEOUS		latte Fm.	Upper members,	Muddy ("J") Sandstone		Muddy ("J") Sandstone			
	ota (	uth F		Skull Creek Shale		Skull Creek Shale			
LOWER	Dak	ŝ	Plainview Ss. Member	Plainview Formation	"Dakota" of drillers				
2	Lytle Formation			mation	"Lakota" of drillers				
U	Morrison Formation				Morrison Formation				
S	Ralston Creek Formation					Older Jurassic			
JURASSIC			Raiston Creek	Formation		Older Jurassic			

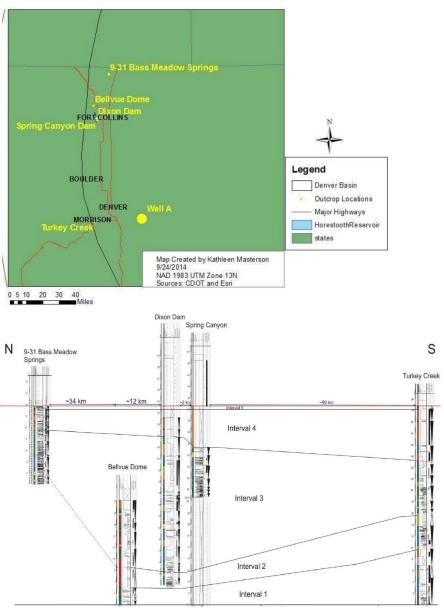
#### mod. Higley and Cox 2007



mod. Higley and Cox 2007

#### Previous Work





Weimer and Sonnenberg 1996

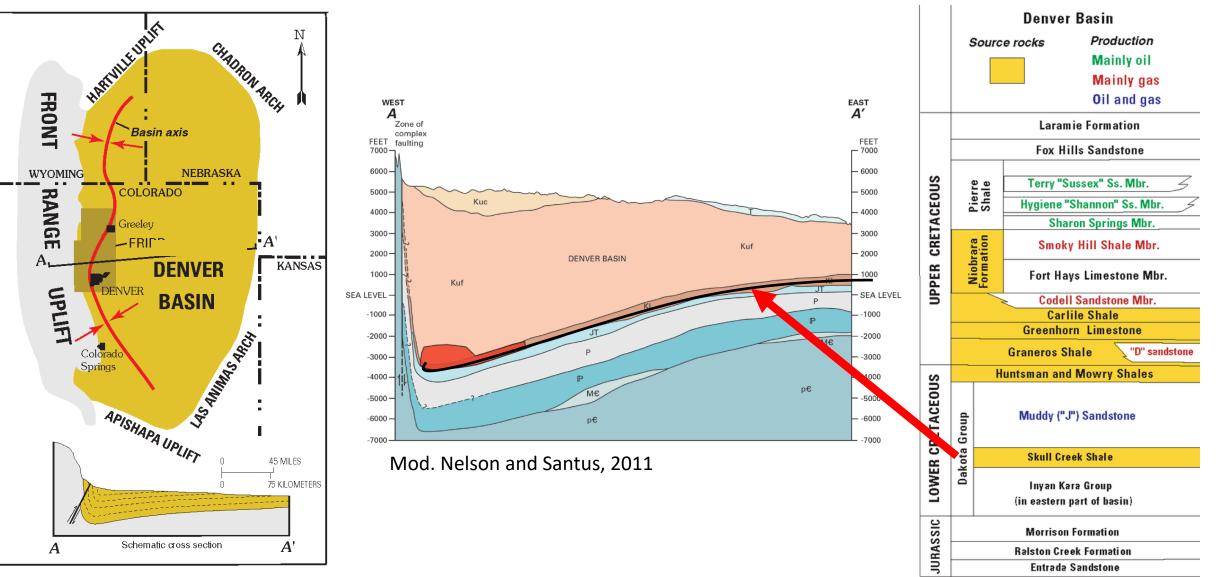
Masterson 2015



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## The Denver Basin

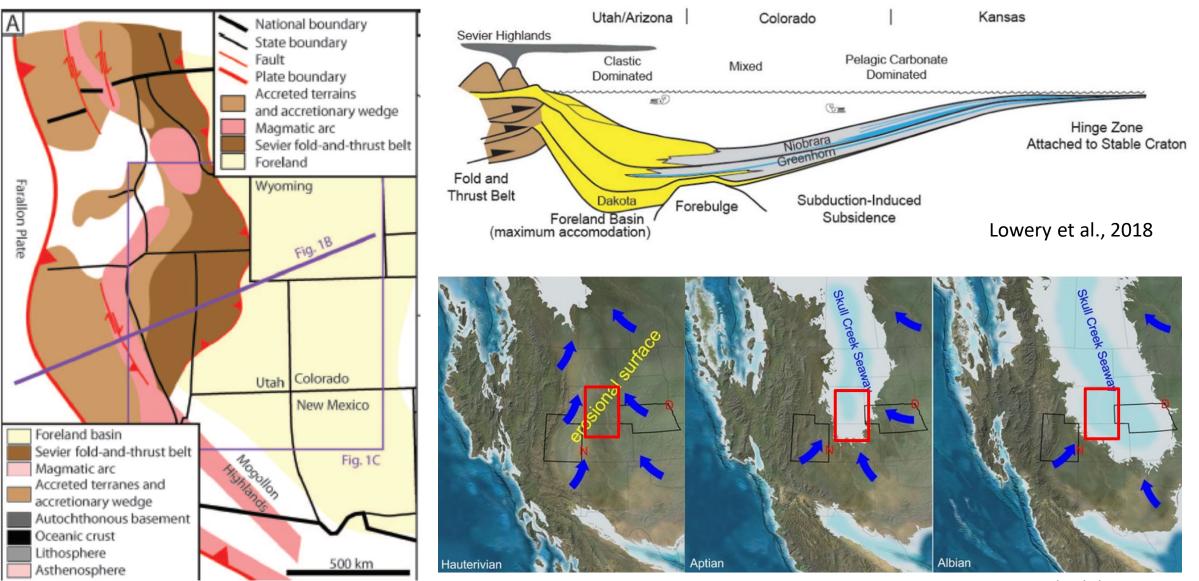




Mod. Knepper, 2002

Pierson, 2017

# **Regional Geology and Tectonics**



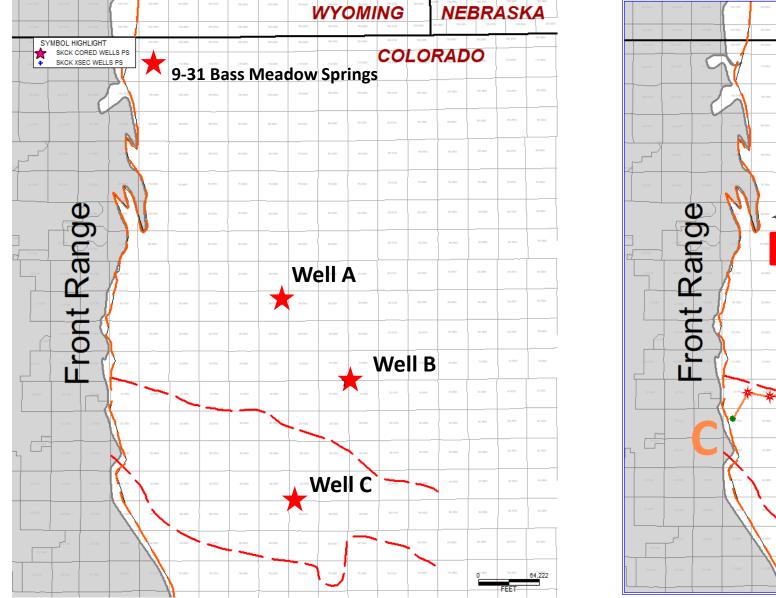
Van Capelle et al., 2018

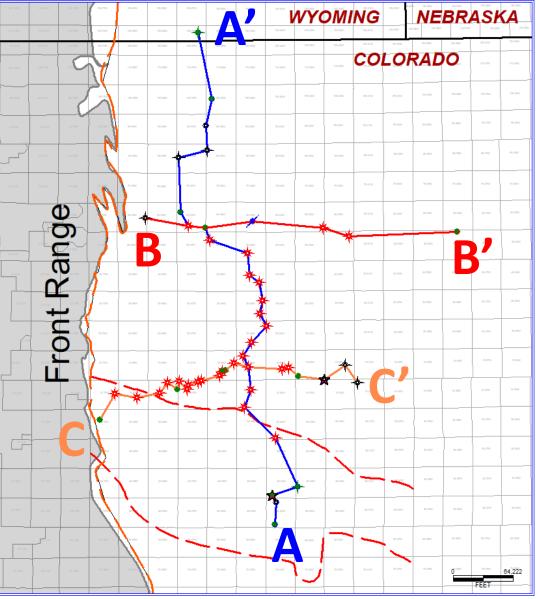
Mod. Blakey, 2014



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# 4 Cores and 41 Well Logs





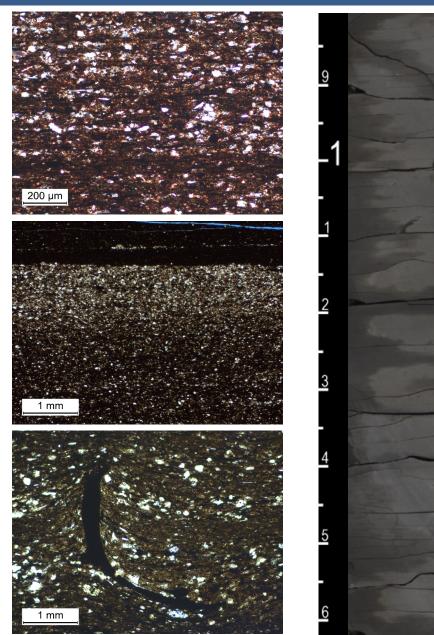
# Core Descriptions

Well A	Log Number 1 of 1	Well B	Patrick Sullvan Destribit core + 11 = log	Well C	Patrick Sullivan	9-31 Bass Meadow Springs	Log Number 1 of 1	Facies	Bed Thickness	Description
	Date 07/30/2019	Depth/ Texture, Sedimentary Structure 2 % %Clay BI Faciles we%TOC Sample % % > e % % L z pop12143 8 2 4 6	Deputy Tentarcised	exemplifiary services at Social Bill Packes attention また、ので見つれのの計算に行き さくく	Notes	Date: 11/19/2019		Massively bedded carbonate with		Calcium carbonate bed with cone-in-cone structures. Likely
Depth/ Sample ぷ 多 な く ぐ ど の1 2 3 4 5 6	acies wt% TOC Notes	F7	executing fields between of serving 39 + 1 ( Calming     evening from bose-of seagers Vandf     evening from bose-of seagers Vandf     evening		Net Latter Tax, in Mercy St. II yet gen since with Ref 3	Depth Grain Size Oto Herse Quantum Grain Size	Notes	cone-in-cone structures (F0)	2 cm	diagenetic.
	F6 B=35 F7 Including funders, Chordets, Americality, Spelliters most common, Including funders, Chordets, Americality, Spellity of Statements, Spelli	7330	standard conclusion of a site of a s		Makanah Kulufan Versikali kasenat Badikal Den dina		anaceous drapes on x strata	graded silty claystone and clay rich siltstone (F1)	2 mm - 10 cm	"Smm invessely graded intervals from black silly claystone to 1 2 mm light gray clay rish sillstone. Occasional flow indicator - 1 mm black fams structure in sill. Vary rare blautabation (bl 5-1) consisting of vis-filled clacular burrows
7670-	Boturbation increasing in site and density up core.     Very transitional between fades 6 and 7- gainable increases     Tangtion Adv: Bisper for Callus More of Markoy S.S. ES9.     Increasing all and bioturbation up sector- boturbation	735 - Total Control Co	atty benefit wangerweyf in on it 14 attacted any 50 laior - that iteration (shows by wey) beat attacted any 50 laior - that iteration (shows by wey) beat attacted and (shows by attacted any 50 laior - that iteration (shows by attacted attacted		Our new ensistent and an and a series on a bala in a set set and an and a series and a series on a bala in a set set and an and a series and a series of a set of a se		ballicion - heavily burrowed interval cc lamal x strata w/ clay drapts -walled burrows biorat contact with 755	mud-draped coarse slistone and very fine sandstone (T2)	3 cm - 20 cm	Coarse sillstome and occasional very line sandstone beds with wavy laminac commonly draped with < treer clay drape. Very are biostrabation (810-1) consisting of <2 mm Schoubythinkines and other small round barrows (crusiano, etc.). No facuit material.
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	F6 Core mixing 0" _ <u>F58</u> Built instead of the second of t		gelie sille men		nalascella Sinor Hard, al Sus, Instala an la una gen regioned I e cara blad al al digitazione grobell et 2 civicales Symo init de regiones	wavy staw	ringen <sup>4</sup> fayer badded mud d ripples? ted allt beda in between bedded clay -heterolithic	Ripple-Jamina ted fine-grained muddy sitisatone with bins less (55)	2 am - 10 cm	Sipple la minated calcareous siltstone and very fine sendstone with a high abundance of white upper fine-lower median calcareous grain and common the less (howerows and prinsepport), rosal fragments, and price. Nud draps exhibit: fame structures, slunging, and rare botturbation (810 1).
7685	F3 Pyrtlazed dhell debris - Inocestamus Gap in core 7666 7667	F8 F2	Autorith faid Thomas 1995 The faith and the second		e manhee stryche syste seature on der Hone ander Die Veranne wegener Erste dass Die Unterenz (Programme der Schwarter an SekUDANDE (Programme der Schwarter an wecklicher erste sent dass eine von verweicheren geer fan- ter anset dass eine anderen son verweicheren geer fan-	3 G cirvia	yers, bioturbased (skolithos) and fill mud ripiples	Bioturbated muddy very line sandston: (FG)	5 cm - 20 cm	Nedium-bioturbated (BI 2-1) clay-rich sitistone and very fine sandstone Bedding is sometimes disrupted by bio tarbation Prequent SSD, contented beds and collapse features in dark mudstone. Sit-Billed traces of Schauboylindrichnus, Zoophysas, Techchros
►7690	F4 This beds of shall material, mostly incoceramus F5 Calcereite beds Tain shellcak: beds in sity daystone		solumente bel vitt upper verl, and upper précor dat.		Nakad necho yaked andine for contain d'ar 15 hely blass and 5 KB meter for and 600		interval, x-stratified with "starved" uter ripples	Heavily Bioturbated Silty Fine Sandstone (F7)	5 cm 50 cm	Highly bioturbated (Bi: <-5) fine sandstone with high slit content and wavy bets of clay-rich slitstone, Very few preserved sudimentary features, includes dona Schubeyholichtung, Skolitikos, Leichekoss and less frequent Zoophysio, Astersone, and Arenozoliter
	F5 Minor Booutb		and bases also a short which such as the site of the second secon		njulini rporosekolo velites nevice kolena belsazel astylijit attolica	virus x sta	iotarbation, sedimentary layers better vxd tified lens of silt	Ash Bed (F8)	āmm - 3 cm	Bentorite deposit, usually slightly rewarked and grading into clav-rich silstore.
7695	F4	7395	nythori and lave all blick By daystave hereoni - instructes with swythin (< 1 cm) sit:		III 1 position agent Balanceiron westign interes boccest (b) Mintores Tap-art – mint Balance error	7923	ns w/ x strata	Mud-draped bioturbated upper fine grained sandstone (F9)	2 cm - 20 cm	Muddy lower upper line and lower-median grained sand with 82 - 4 in zones and stoured blocks of F12. Testually linmature, octational coarse block chert fragments. Skolitos, ophiomorpho,
	Hallow brown benchmit bed, slightly resorted     F5     F3     F5     F5		characterization and a service and a famore and a planetary		an annes an de Hort II Jan surver Jahn Andre Jührfelm Moscore auf Andrea Andrea Moscore surves anne Alta Anton Moscore surves anne Alta Anton Milla Barazo, Villainen i Mod	dia dia dia bos	2 sstrata, mud/claystone on top te clast w/ flow features and soft sed. ovec also medium grained clasis at	Plane-bedded medium grained kaolinite sandstone (F10)	2 cm - 20 cm	White, close I. U modium sandstone. Massive or faist planar beds of coarse grans every "3-5 cm. Bedding to planar to massive. BI 0-1, some cryptic biosubation possible
7705	F3 F4 F4 F4 F54		Aurgent setting attention to constrained at the set of		In many balances openeds means webergrand St option Innovati beng start based on t and to get a start based on t option options with the part of the start of the total	7930	ared, less bioturbated	Sioturbated silky claystone (F11)	1-8cm	laminated sity claystone matrix with clensely packed circular sity/of sand-filed burrows 2mm - 2cm
	F3 F4 F3 F3 F3 F3 F3 F3	7410 F6	any disculate upon of service 1963 Second service serv		lie moorg taa advatuur 1920 Saldo voo pra- oo 12 soldikoor 1929 Saldo voo pra- oo 12 soldikoor 1929 February sala voo kaal 1929 - New York Saldo Voo Pra- Beerenges	733 - Free Contract of Contrac	prained white heds with bivalves Jup Class ared muds above shale becks on top of silly/vfs beds pe phosphice indules? Fish scales? res present	Coarse-grained massive lithic sandstone (F12)	1-10 cm	Gray upper medium-coarse grained sandstone. Massive to faintly laminates: Contain in Intergenesed coarse black angular grains along bedding planms. Hely dythets. Sharp basal contact. BI 0-1
	F1 Decreasing sit beds, increasing shell debris Fost fing F2 U U U U U U U U U U U U U U U U U U U		Instructional Technologies (Constraint)		Manutu in sin kina uma uma ungla dalina. Wi Jeroberted Manutu in Jaka daplano na Jak daplano na Jak Magnatu azaka Kapita sasara (kang dalaka) Kapita sasara (kang dalaka) Yalapada uma kana	X-stra	bed of shell debris, fine cand, of s Lifed struks, in ou bed with fine debris	Medium-grained x-stratified kaofinite sandstone (F13)	5-20 cm	Cross-strattled upper medium-grained sandstone with coarse while guilars (Jaulinite – altered feldgars) along a- strata. Low muid content, bi ()
7715-	Flat-bedded sittoare with interbeds of clay rich sittoare Planar beds increasing sit content Sit beds in sitty claystore	743	seturation of ally displaces transfer to displace of the set state of the set of the set of the set of the set of the set of the set of the set of the set the set of the set of the set of the set the set of the set of the set of the set of th		An Anterior New York Week State		grup dea wan nie deans olar beds, rip opsishells ves in mudstone/shale matrix	Heavily Dia Labated Medium- grained sandstone (F14)	5-50 cm	Lower upper fine and lower-medium grained and with B1-3 in zone, letertholded with F30, Textually immutur, occasional masse black chrim forgeners. Large caase grain lined ophonospha, teickbehau
	Try mud filme structure - flow indicator     Try mud filme structure - flow indicator     try filme film of sand and alternative     Try filme the structure - flow indicator     Try filme the structure - flow indicator     Try filme the structure - flow		13 Sinubard malitane internal eine chronolisale kentoon		na Anach barlag son , analy son , analy so , and		care - fixule r bioturbation, x-stratified silt; lens			

# Facies Descriptions

	De ditta i	Record allow	Come th		
Facies	Bed Thickness	Description	Composition	Process/Interpretation	
Massively bedded carbonate with cone-in-cone structures (FO)	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 silstone 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 Schaubcylindrichnus 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 currernts	
Fossiliferous silty claystone with HCS (F4)	2 mm - 5 cm		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).		Turbidity currernts followed by tidal energy and storm waves	
Bioturbated Clay-rich lower very fine sandstone (F6)	very 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, Zoophycus, 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 Schaubcylindrichnus, Skolithos, Teichichnus and less frequent Zoophycos, Asterosoma, and Arenocolites	Quartz, clays, Kspar	Tidal energy	
Ash Bed (F8)	5 mm - 3 cm	- 3 cm Bentonite deposit, usually slightly reworked and grading into clay-rich silstone.		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. Skolithos, ophiomorpha,	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)			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 ophiomorpha, teichichnus	Kaolinite, quartz, chert	fluvial/tidal	



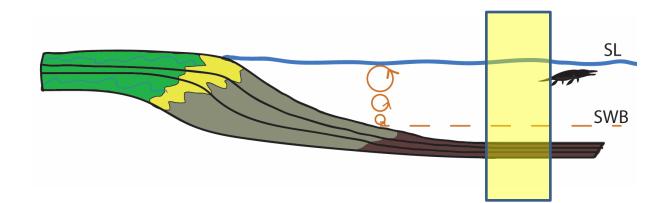


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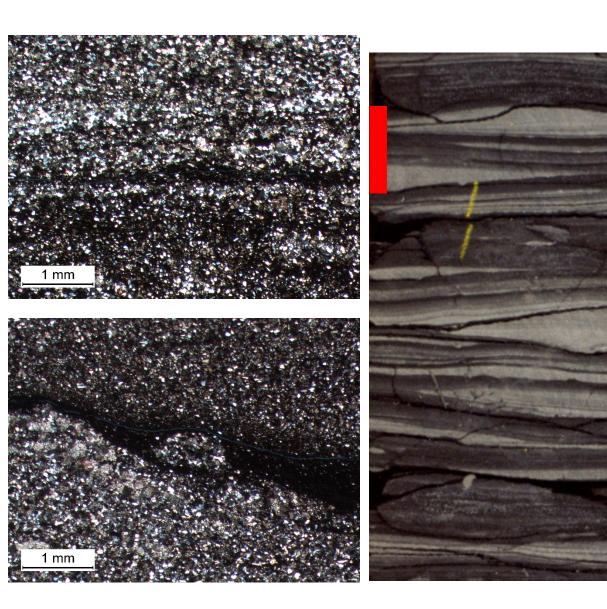
**Facies Name:** Graded to massive silty claystone and clayrich siltstone (F1)

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 *Schaubcylindrichnus* and occasional *Ophiomorpha* and *Teichichnus* 

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

**Process:** Storm waves and bottom currents

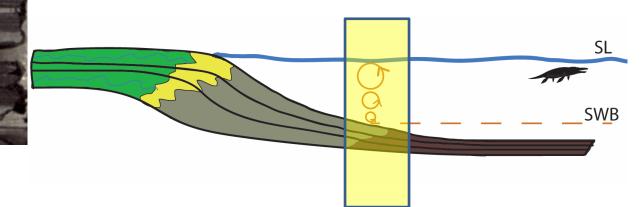
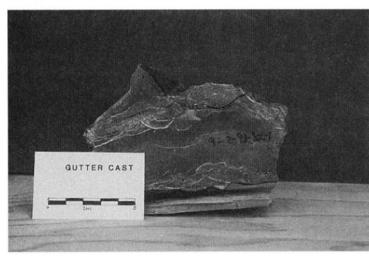
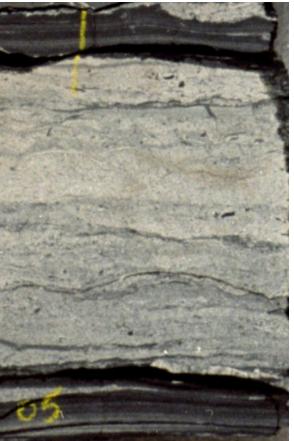




Figure 9. Gutter cast at Soldier Canyon Dam with basal markings of *Asterosoma*. Black, mechanical pencil beneath cast for scale.



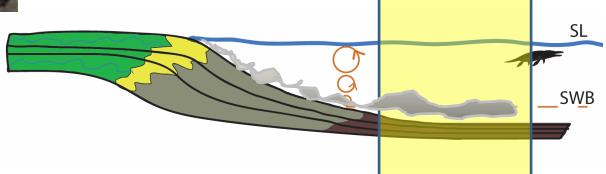


#### Facies Name: Bivalve-rich disorganized calcarenite (F3)

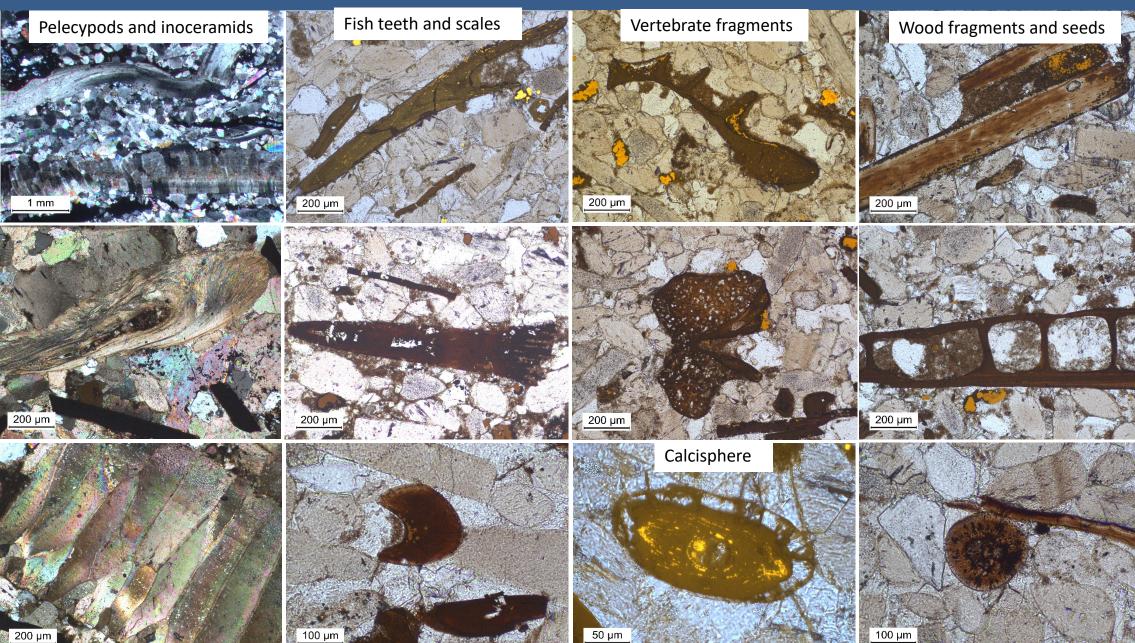
**Description:** Upper-fine to lower med-grained white calcarenite bed with angular black debris (fish scales, bones, wood fragments), inoceramid shells, and common pyrite replacement of vertebrate skeletal fragments. Contact tends to be sharp and erosional at the base and gradational at the top

Composition: Calcite, clay, wood, bone

**Process:** Turbidity currents

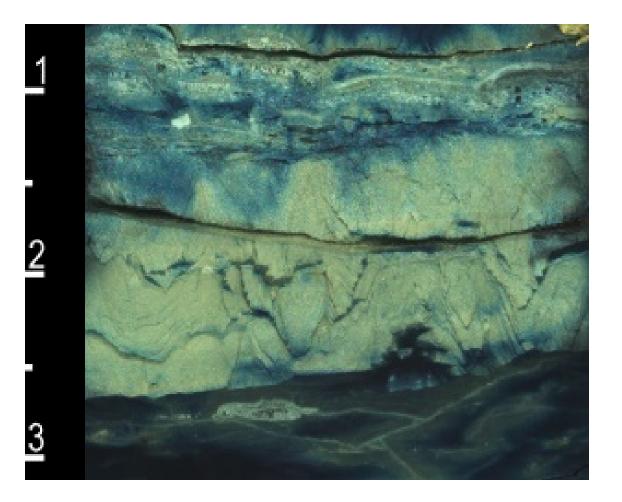


Mod. Blakey, 2014



#### Facies 3A



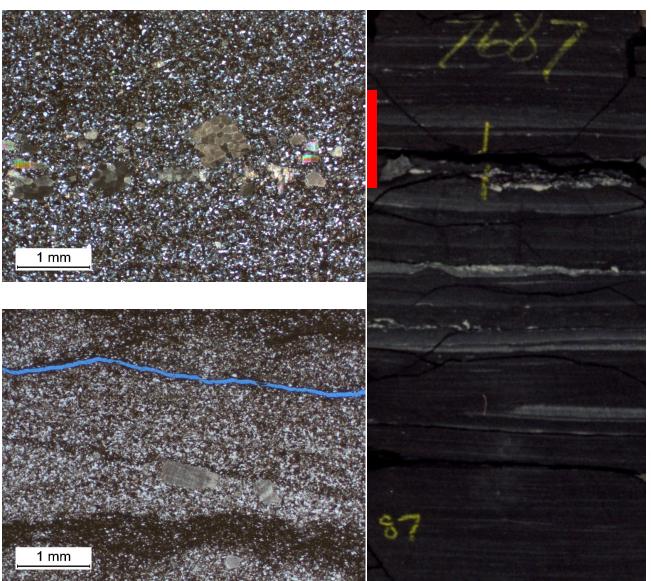


**Facies Name:** Massively bedded carbonate with cone-in-cone structures (F0)

**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

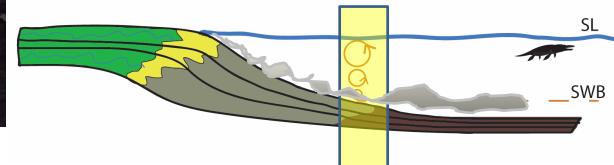


**Facies Name:** Fossiliferous silty claystone with starved HCS (F4)

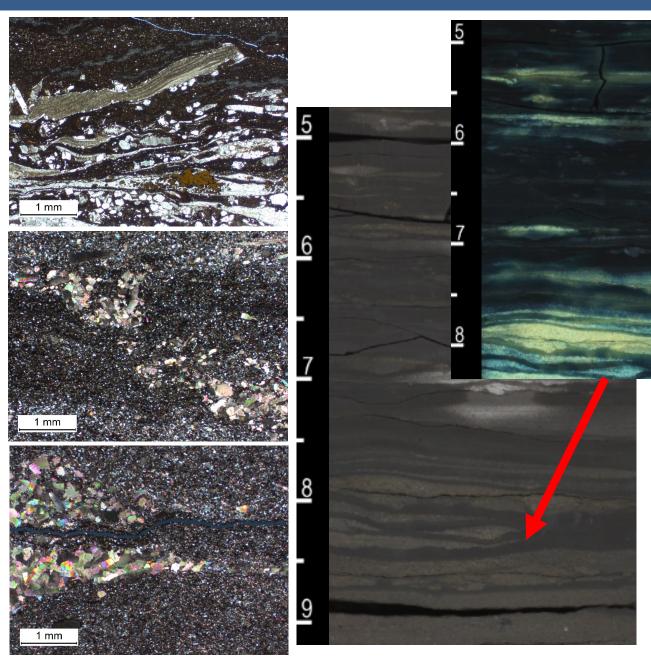
**Description:** Silty claystone with frequent < 1cm beds of upper fine-lower med-grained calcarenite and/or inoceramid debris and erosional/wavy bedding. Discontinuous (starved) HCS calcaerous silt beds common in massively bedded mudstone

**Composition**: Quartz, Calcite, Clays, Organic Material

Process: Storm waves, turbidity currents.







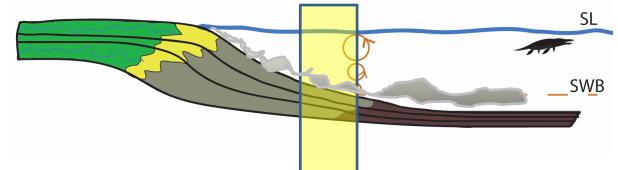
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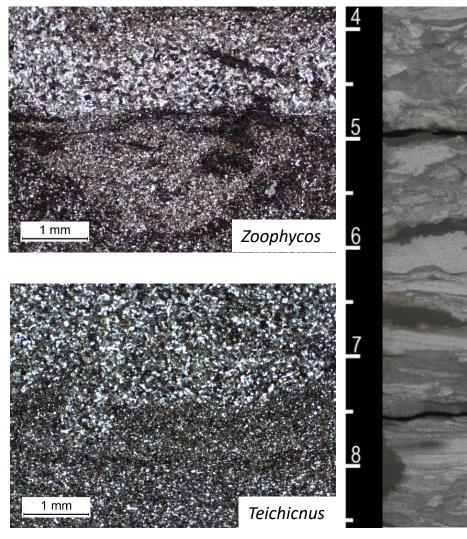
**Facies Name:** Calcareous ripple-laminated fossiliferous muddy siltstone (F5)

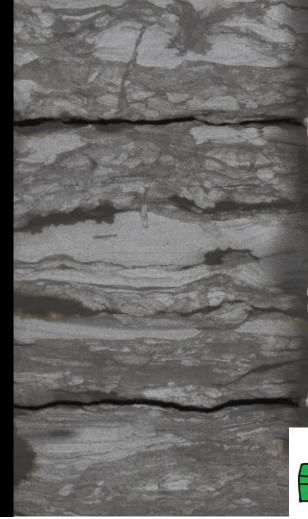
**Description:** Ripple-laminated calcareous siltstone and very fine sandstone with a high abundance of white upper fine-lower medium calcareous grains and common bivalves (Inoceramids and pelecypods), fossil fragments, and pyrite. Mud drapes exhibit flame structures, slumping, and rare bioturbation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

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

**Process:** Turbidity currents followed by tidal energy and storm waves





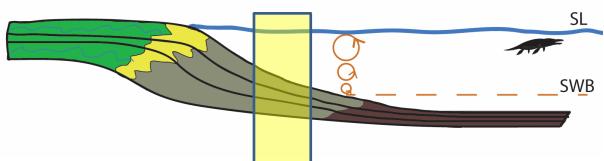


**Facies Name:** Bioturbated clay-rich very fine sandstone (F6)

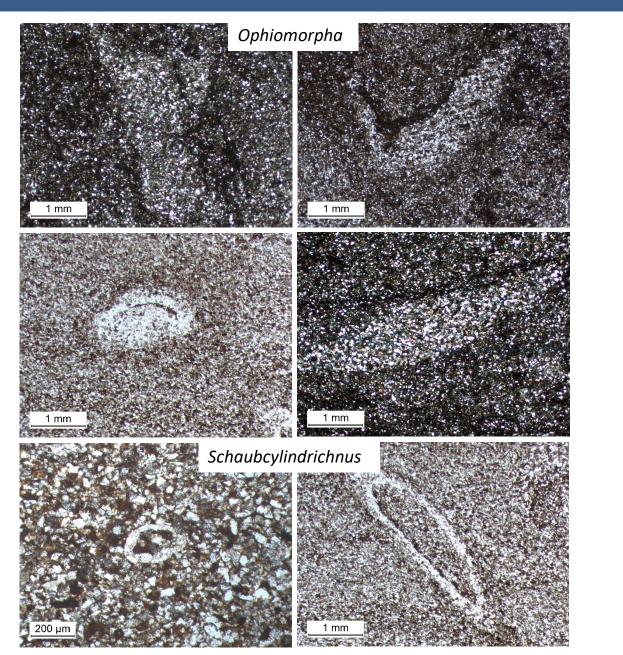
**Description:** Bioturbated (BI 2-4) clay-rich siltstone and very fine sandstone Bedding is sometimes disrupted by bioturbation Frequent soft-sediment deformation and planar to Hummocky cross-stratification in vf sand intervals. Contorted beds and collapse features in dark mudstone. Silt-filled traces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

**Composition**: Quartz, clays, Kspar, organic material.

Process: Storm waves, tidal energy



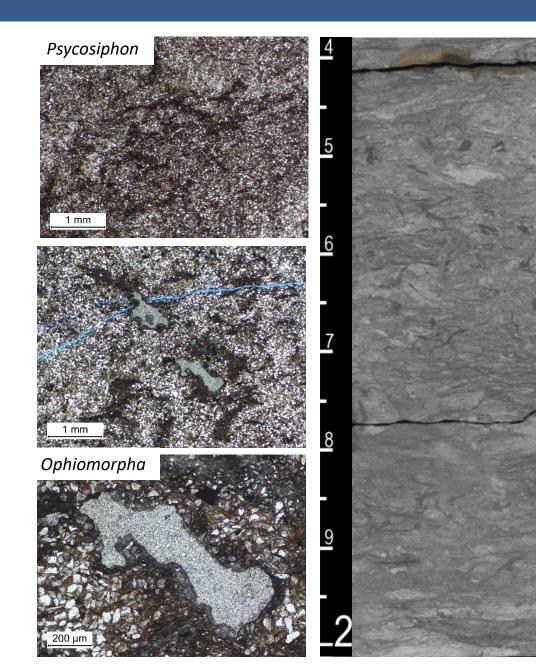




		KEY TO BIOTURBATION INTENSITY	(
ы	Characteristics	Mudstone Facies	Sandstone Facies
0	Bioturbation absent		
1	Sparse bioturbation, bedding distinct, few discrete traces	5 2 2 5	
2	Uncommon bioturbation, bedding distinct, low trace density	······································	
3	Moderate bioturbation, 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		

Van Capelle et al., 2018



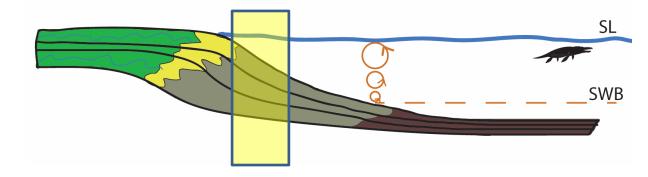


**Facies Name:** Heavily Bioturbated Silty Upper Very Fine Sandstone (F7)

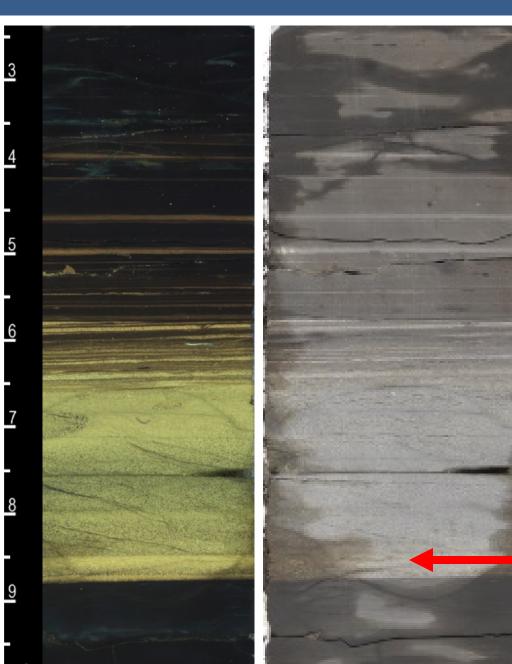
**Description:** Heavily bioturbated (BI: 4-6) very fine - fine sandstone with high silt content and wavy beds of clay-rich siltstone. Very few preserved sedimentary structures. Includes dense *Schaubcylindrichnus, Phycosiphon, Skolithos, Teichichnus* and less frequent *Zoophycos, Asterosoma,* and *Arenicolites* 

**Composition**: Quartz, clays, Kspar, rare calcite

Process: Tidal energy, storm waves







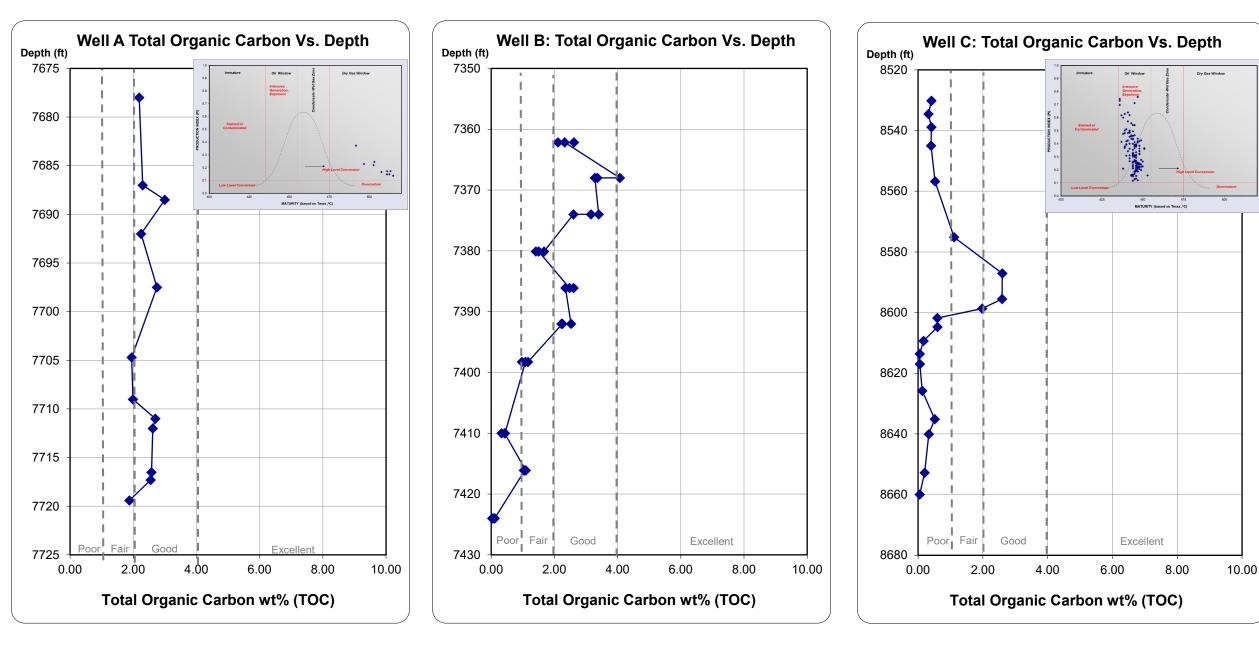
Facies Name: Ash Bed (F8)

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

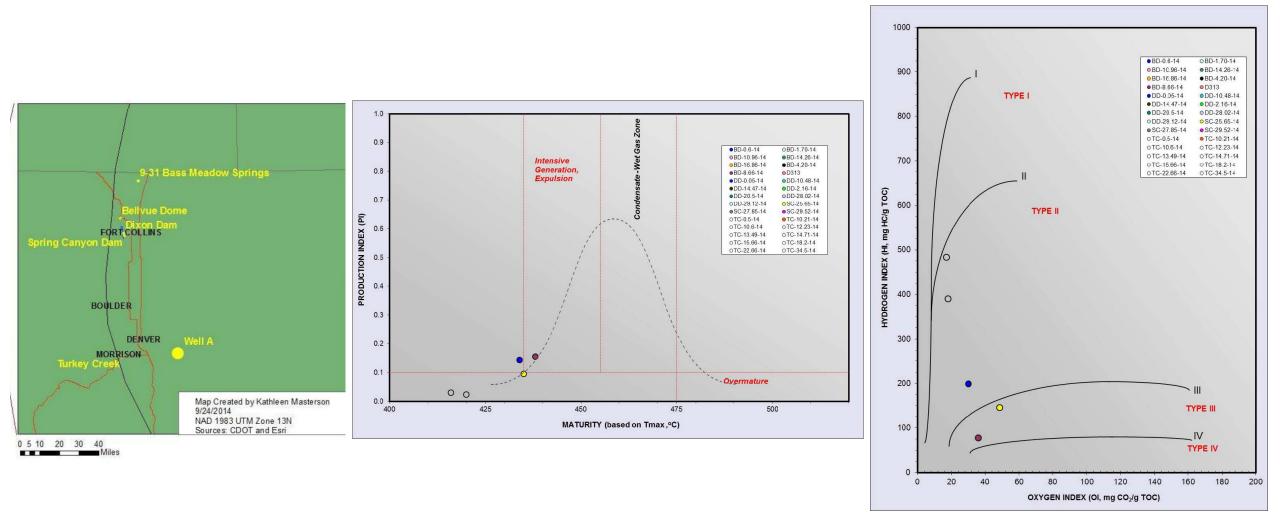
**Composition**: Bentonite clay

Process: N/A

## Source Rock Analysis: wt% TOC



## Source Rock Analysis: Outcrops

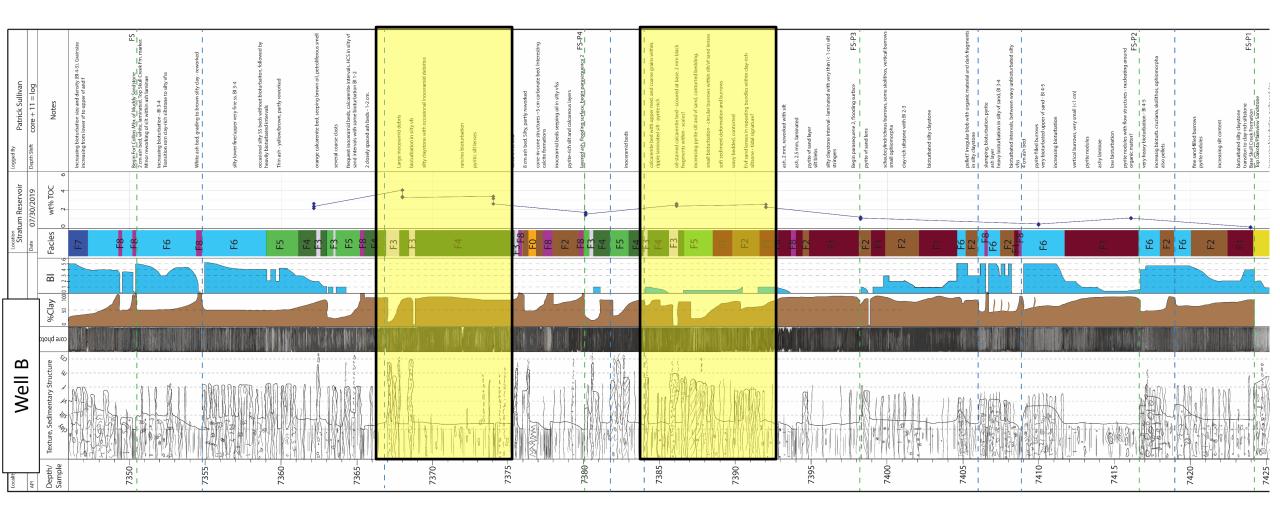


Masterson, 2015

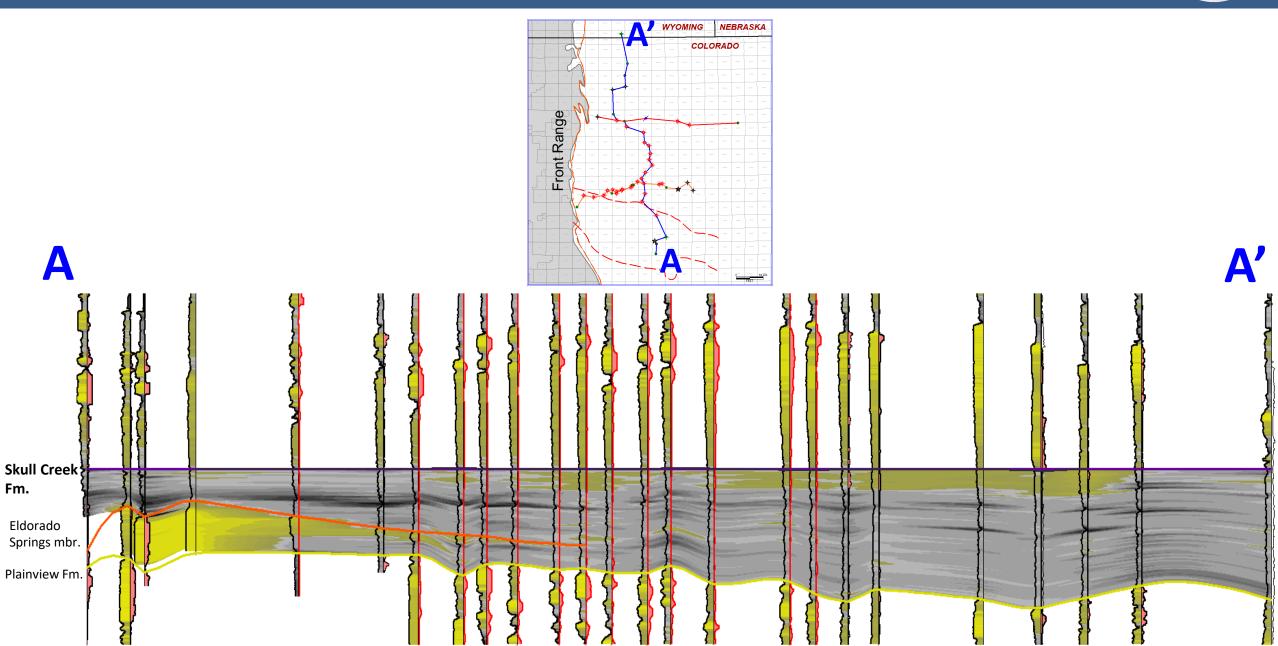


- 1. Introduction and Motivation
  - Why the Skull Creek Shale?
  - Background literature
- 2. Regional Geology and Tectonics
  - The Denver Basin
  - Western Interior Cretaceous Seaway
- 3. Data
  - Sedimentology: facies descriptions and interpretations
  - Well log cross sections
- 4. Next Steps

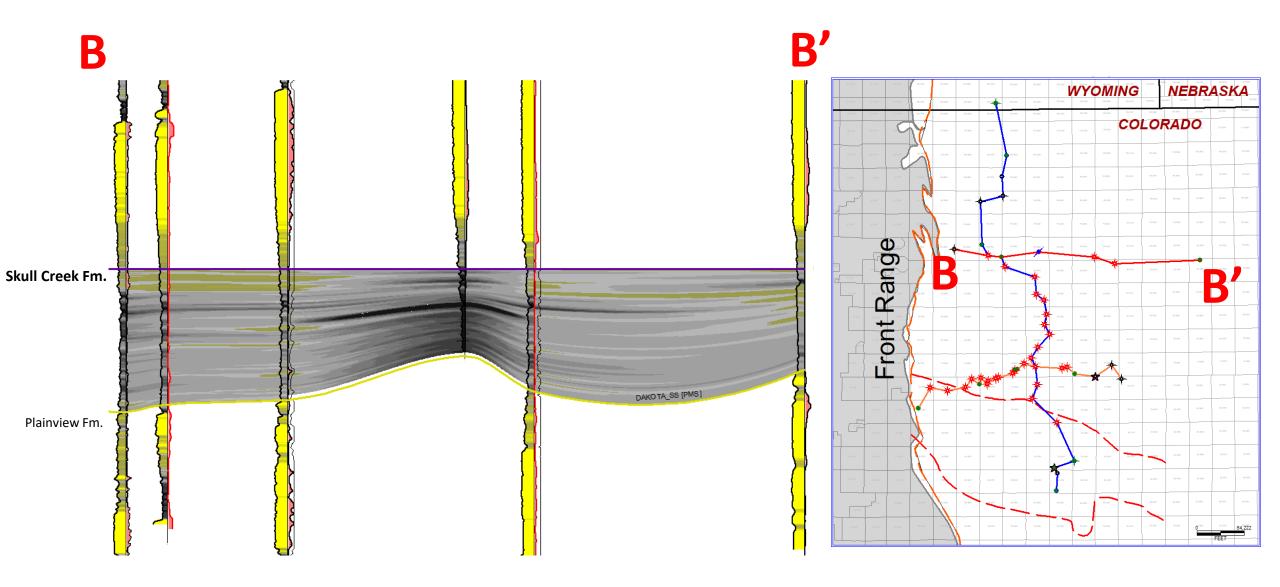




## Stratigraphic Correlations: A – A'

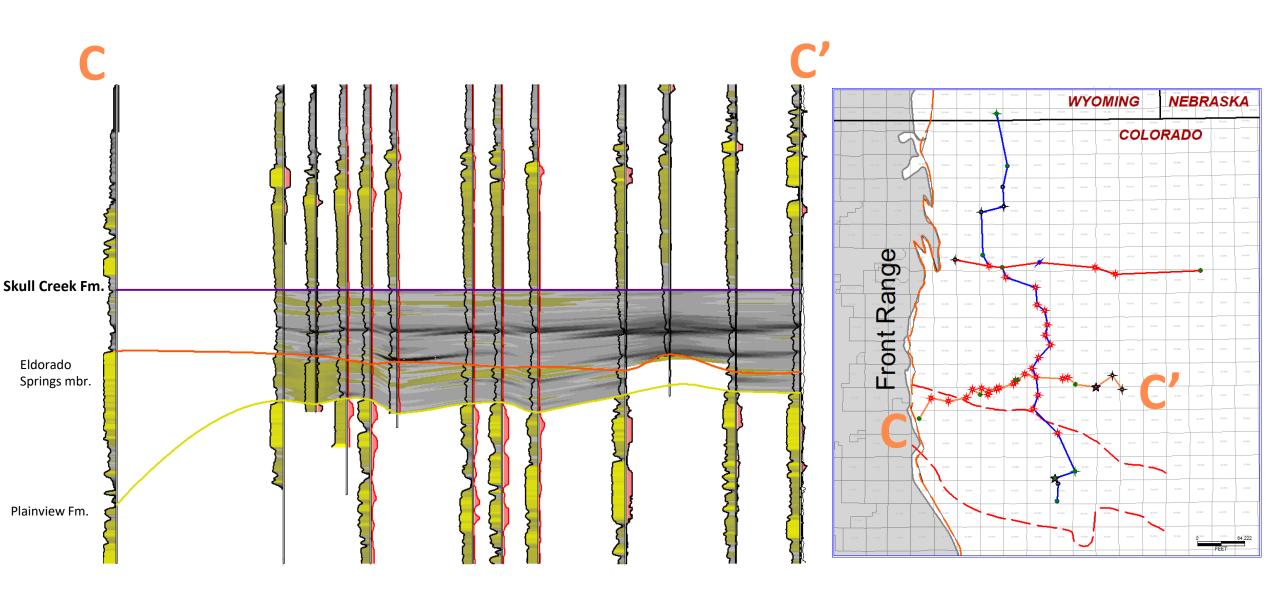


# Stratigraphic Correlations: B – B'

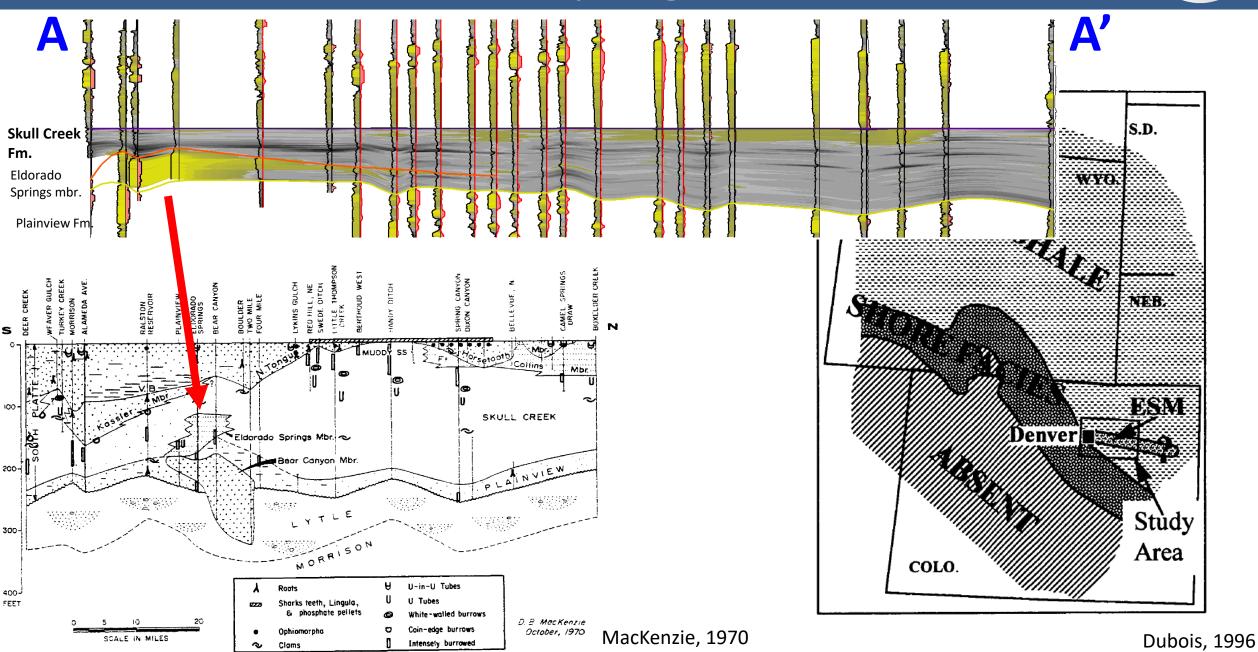


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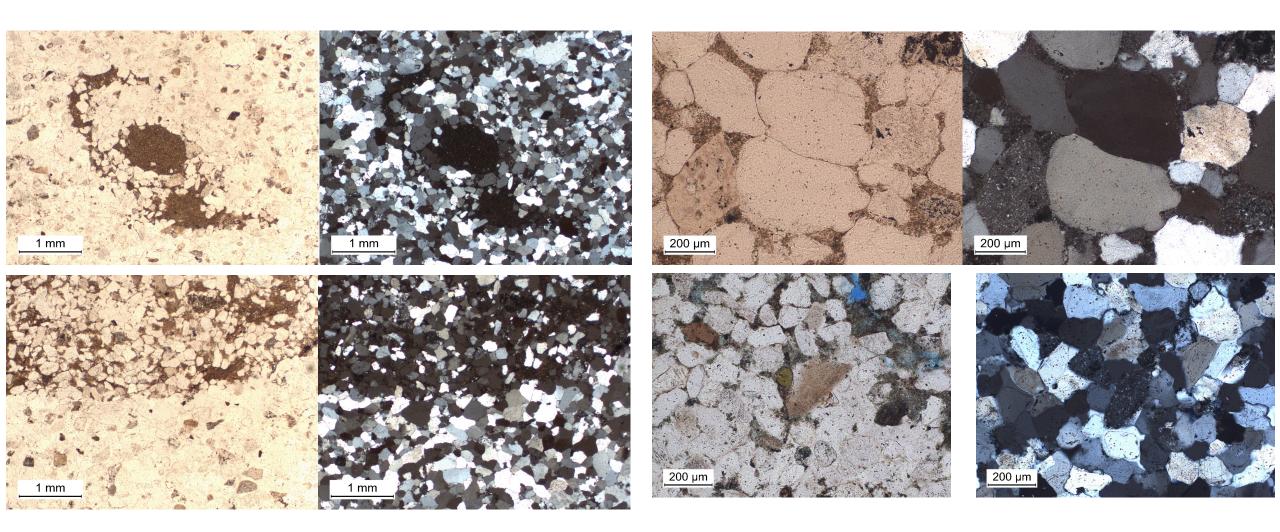
# Stratigraphic Correlations: C – C'



# Eldorado Springs Member



# Eldorado Springs Member



# Thank you, sponsors!

