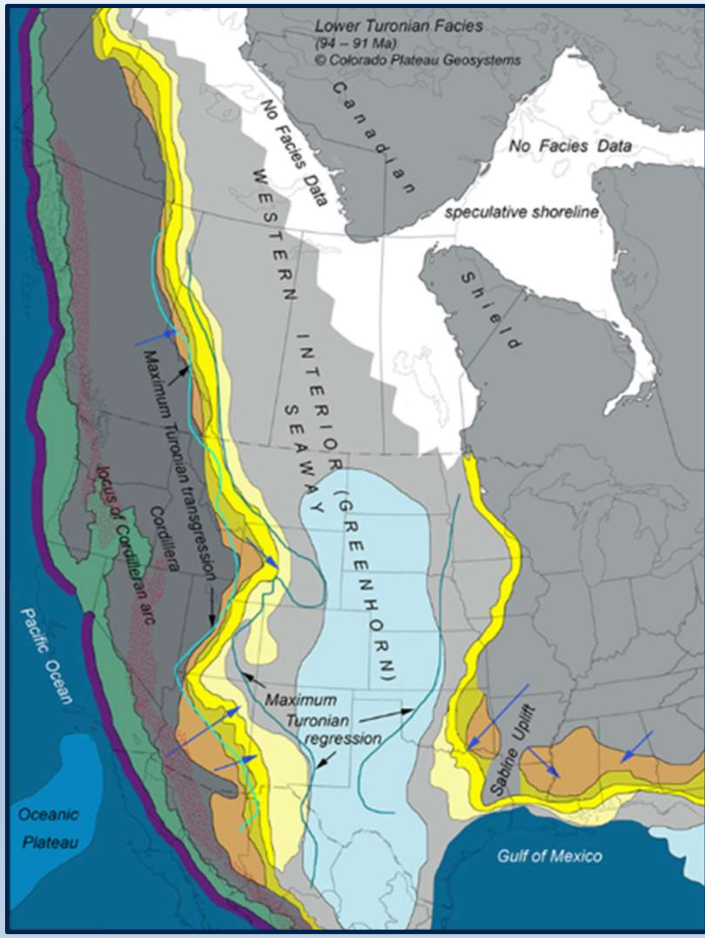
Christopher Matson, PhD Student, Spring 2023

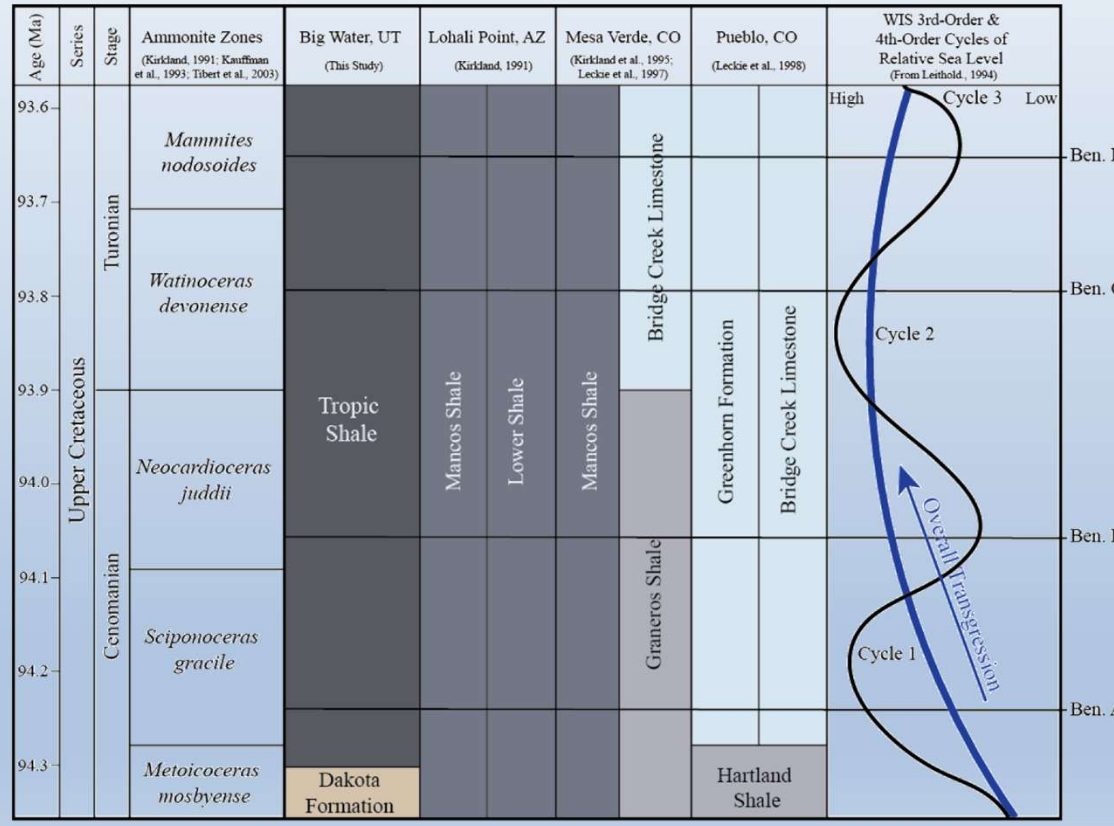
THE INFLUENCE OF SUBMARINE VOLCANISM ON WATER COLUMN ANOXIA DURING OCEAN ANOXIC EVENT 2 (OAE 2)

Outline

- Paleogeography and water mass circulation of the Greenhorn Seaway Cenomanian Turonian Boundary (CTB) and OAE 2
- OAE 2 and contemporaneous LIP volcanism during CTB
- Isotopic signatures and elemental proxies of ocean anoxia, volcanism, and water circulation during OAE 2
- Greenhorn Core Description in Denver-Julesburg Basin
- Continuing research

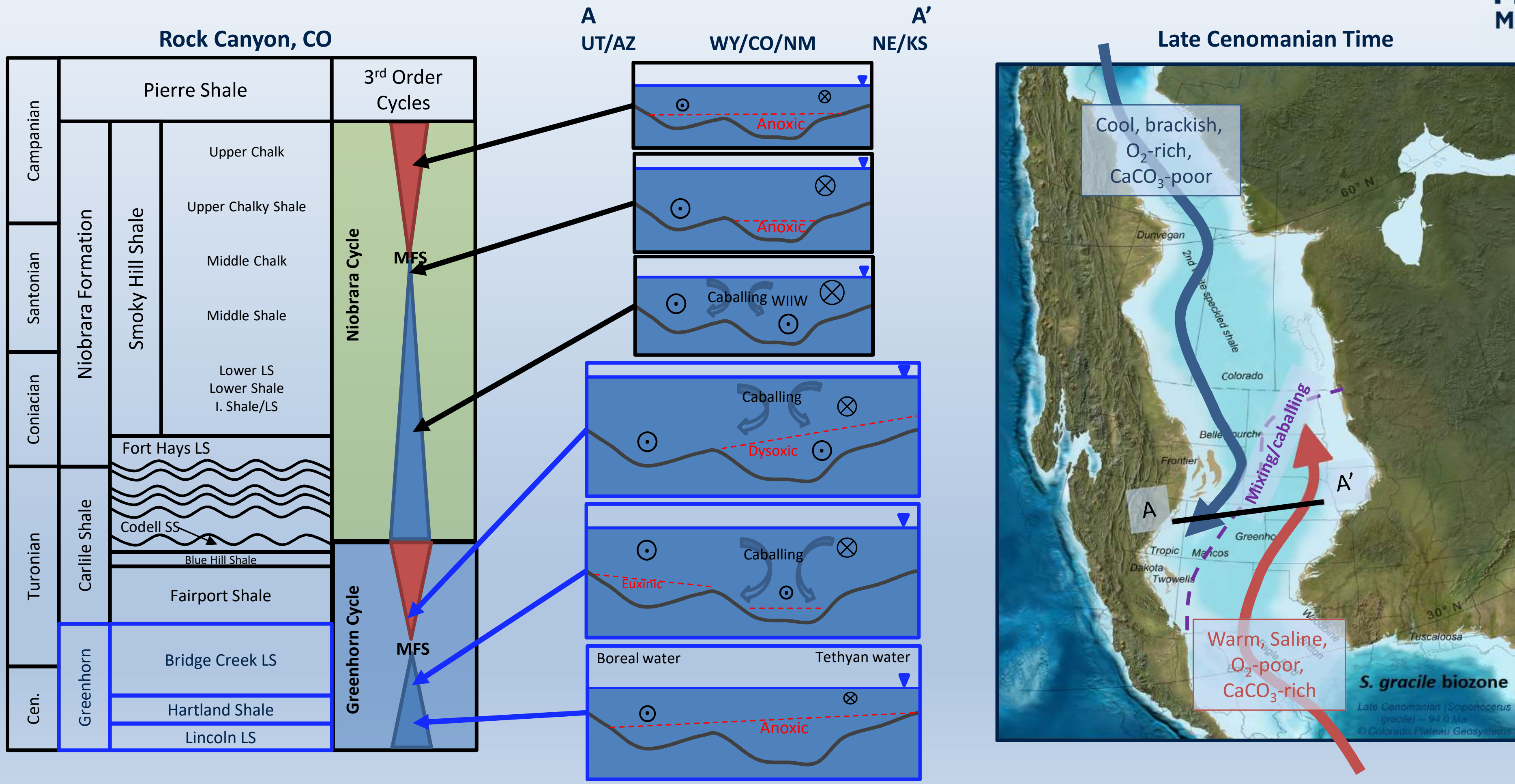
Upper Cretaceous (CTB), WIB





Parker, 2016 (MSc Thesis); Leithold, 1994, © DeepTimeMaps R. Blakey

Water Mass Circulation in WIS

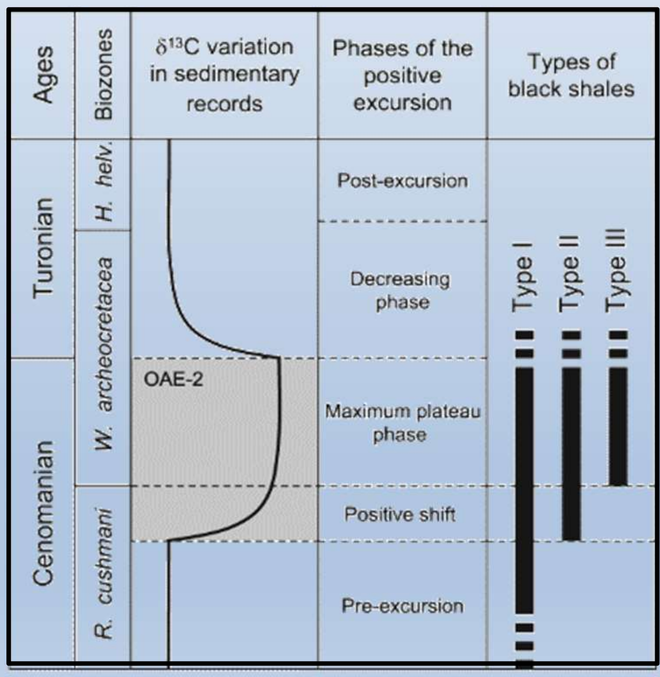


Adapted from Lowery et al., 2018, © DeepTimeMaps R. Blakey

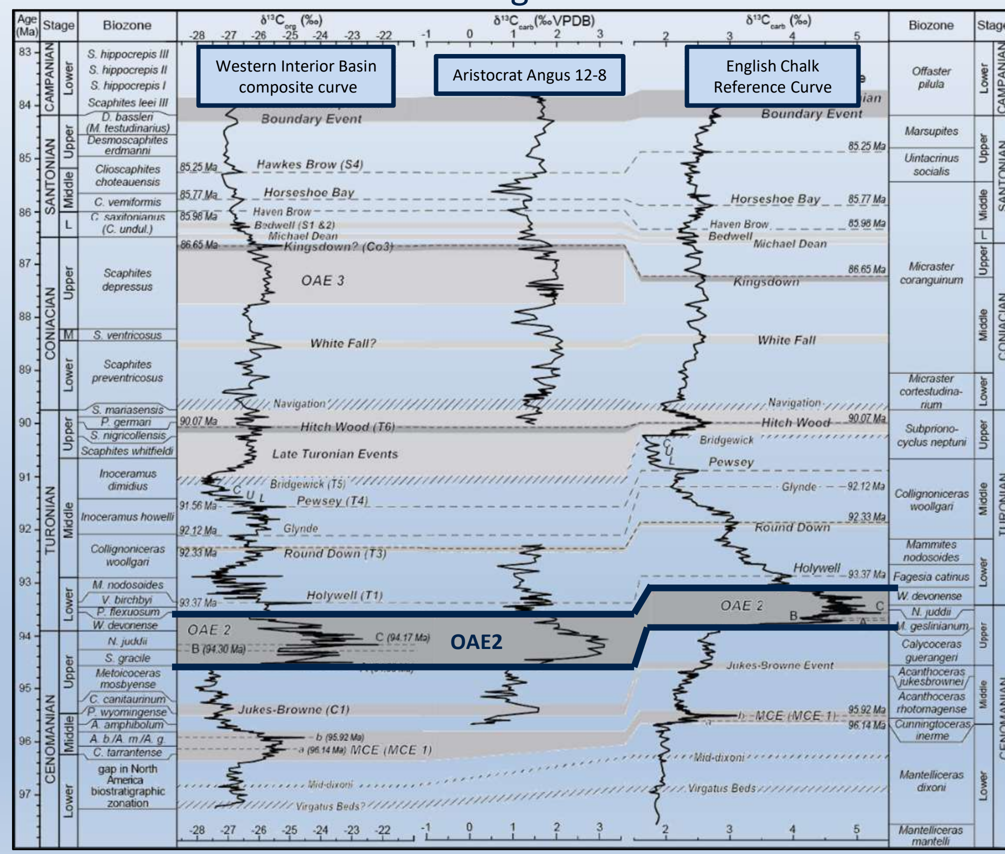
Global C Isotope Signal OAE 2

OAE 2 = 619 ± 39 kyr (UT) – 820 ± 25 kyr (Tibet)
Perturbations in C, O, N, P, Cr, Sc,
Os, Re, Li, Cu, Co, Zn, Cd…

Idealized OAE 2 $\delta^{13}C$ curve



Positive OAE 2 $\delta^{13}C$ org and carb excursion

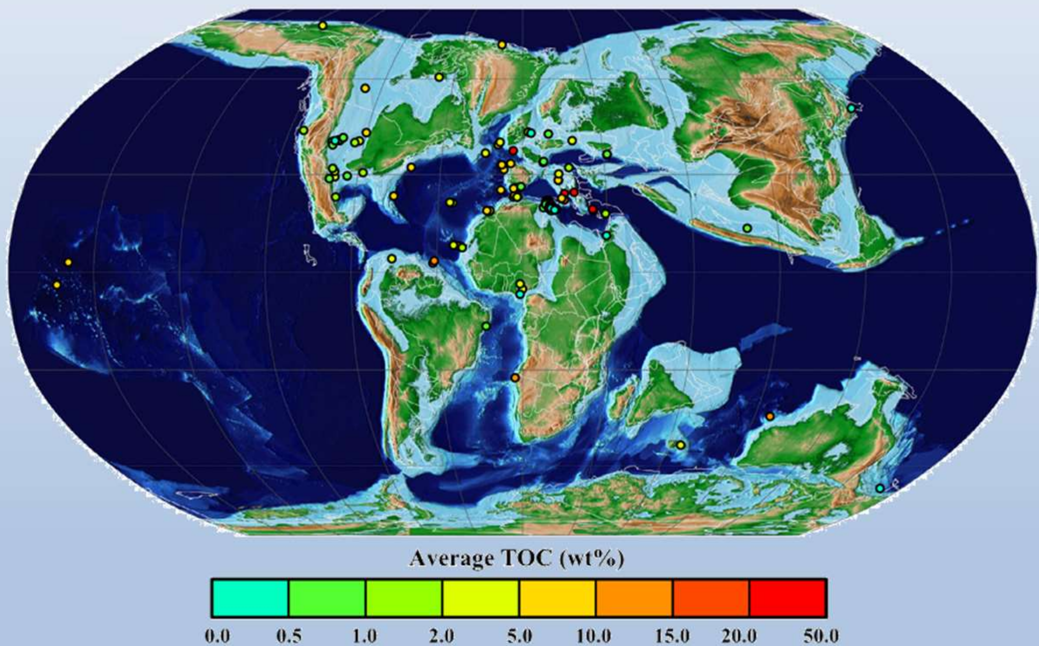


Joo and Sageman, 2014; Parker, 2016 (MSc Thesis); Keller et al., 2008; Du Vivier et al., 2015; Jones et al.,2019; Li et al., 2017

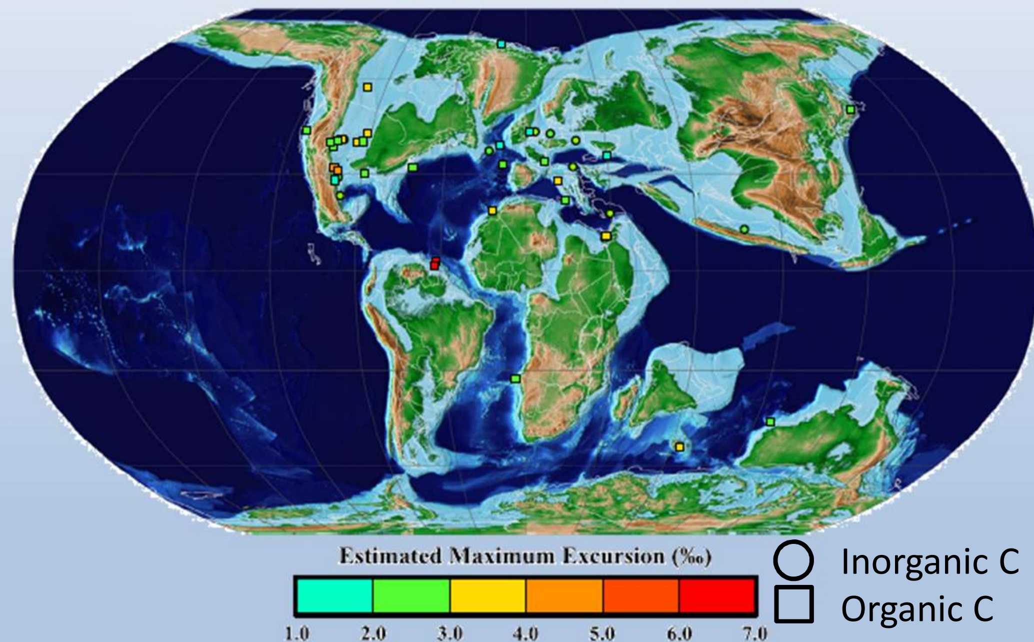
Global evidence for OAE 2

Late Cenomanian Time (~93.9 Ma)

TOC at CIE localities



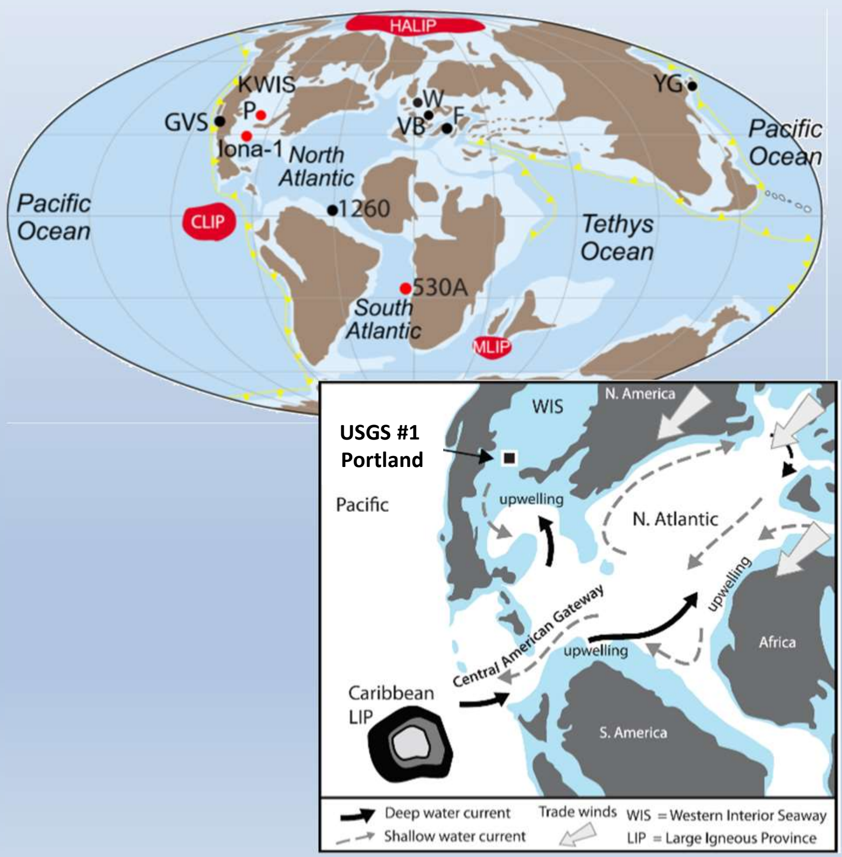
Maximum CIE ‰

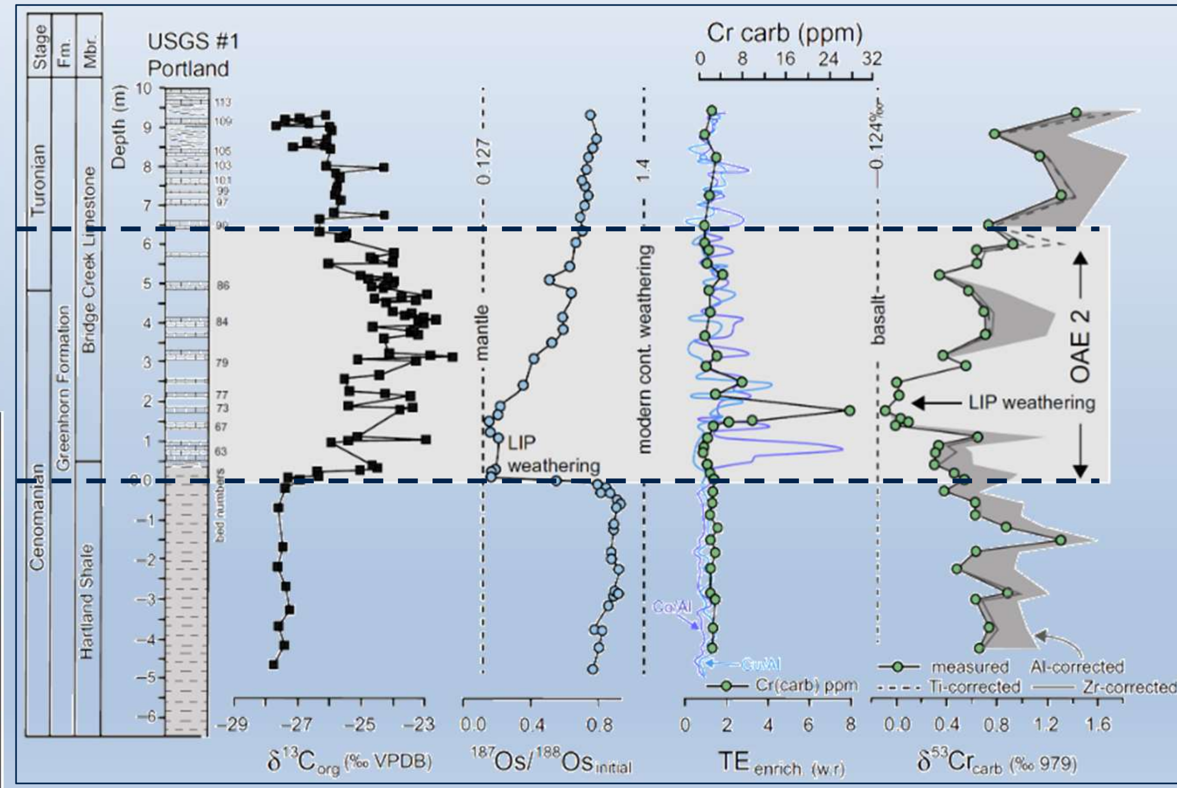


Owens et al., 2018

Influence of Large Igneous Provinces

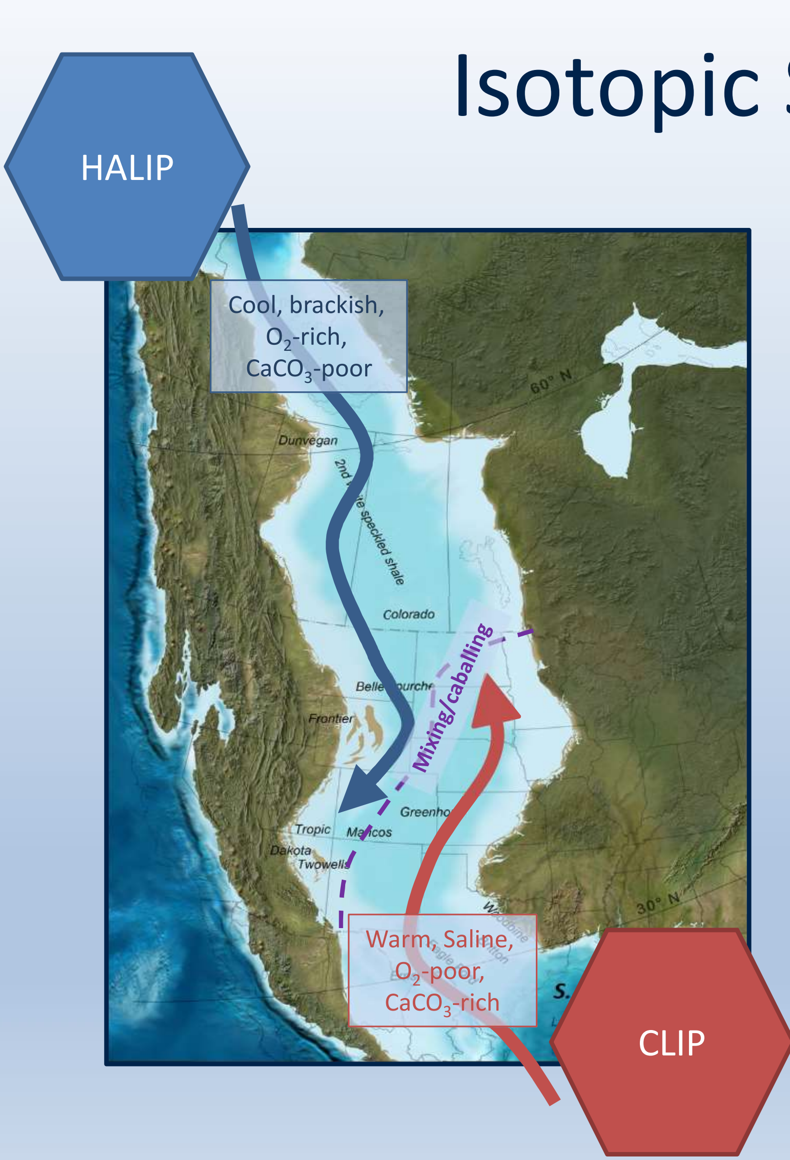
HALIP: High Artic Large Igneous Province
CLIP: Caribbean Large Igneous Province
MLIP: Madagascar Large Igneous Province





Sullivan et al., 2020; Du Vivier et al., 2015; Holmden et al., 2016

Isotopic Signatures of LIPs



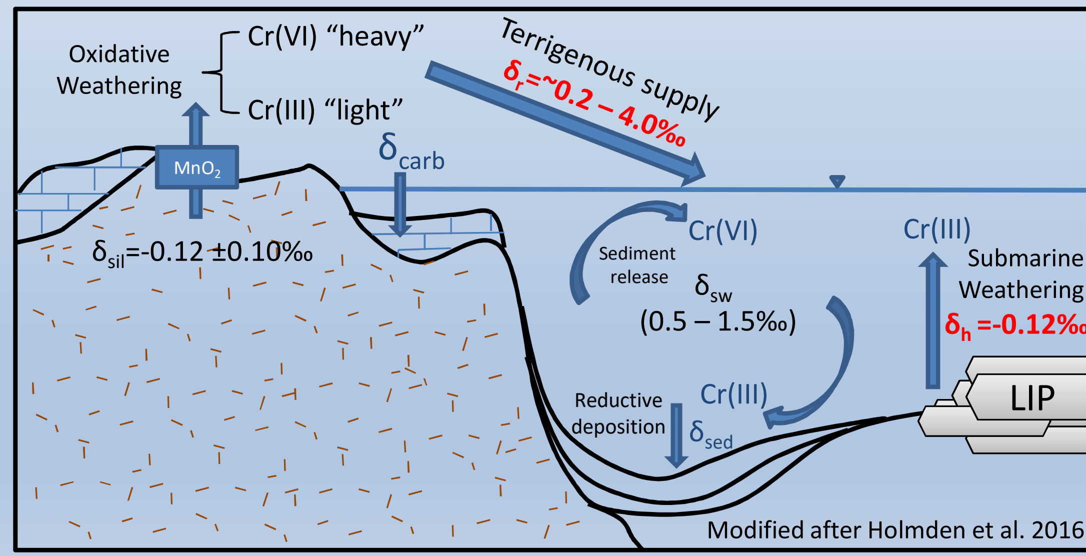
Chemically distinguishable, discrete pulses:

Caribbean LIP:

- 1st (main) 95-83 Ma
- 2nd 81-69 Ma

High Artic LIP:

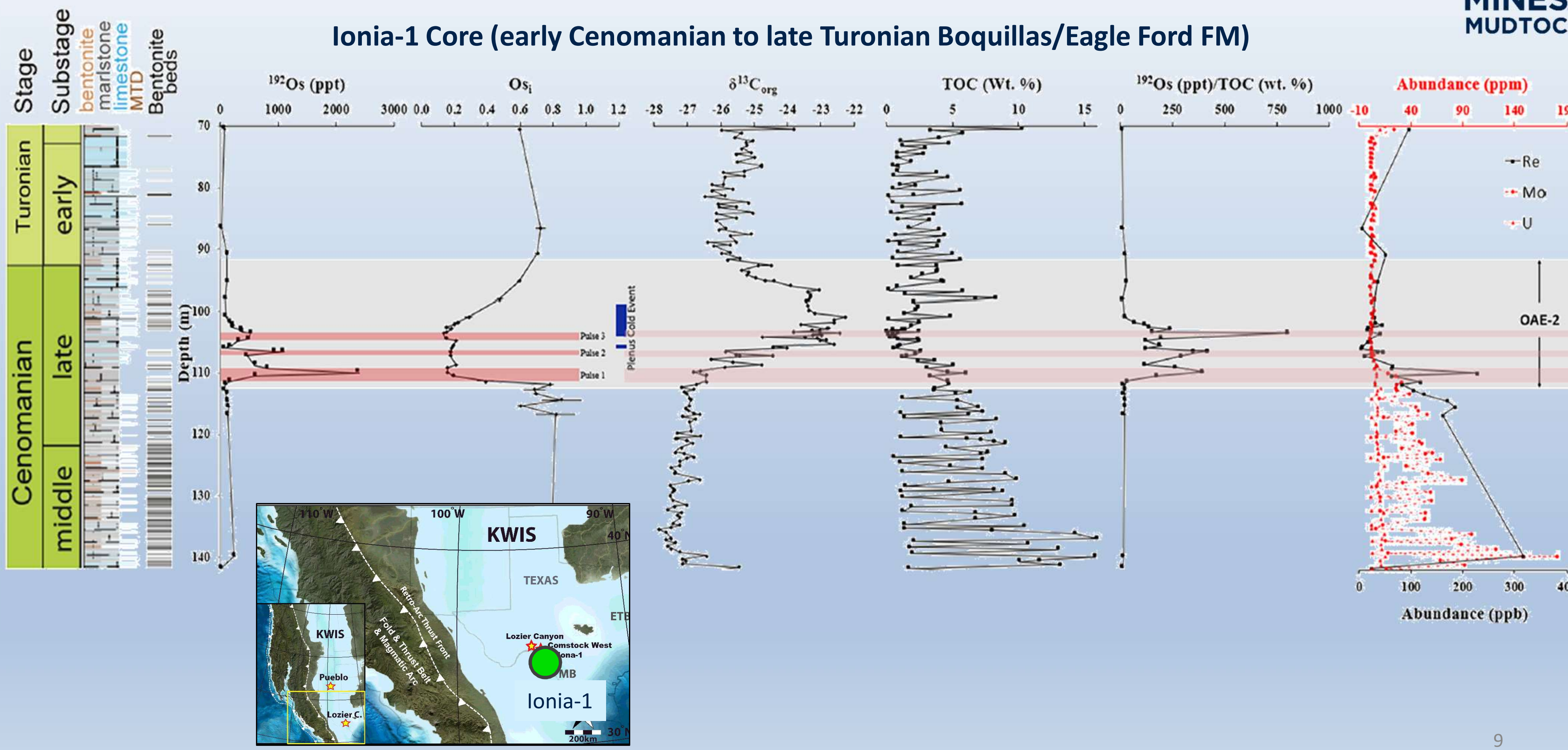
- 1st 130-83 Ma (tholeiitic)
- 2nd 93-60 Ma (calc-alkaline)



Lowery et al., 2018; Schröder-Adams et al., 2019; Dodsworth& Eldrett, 2018

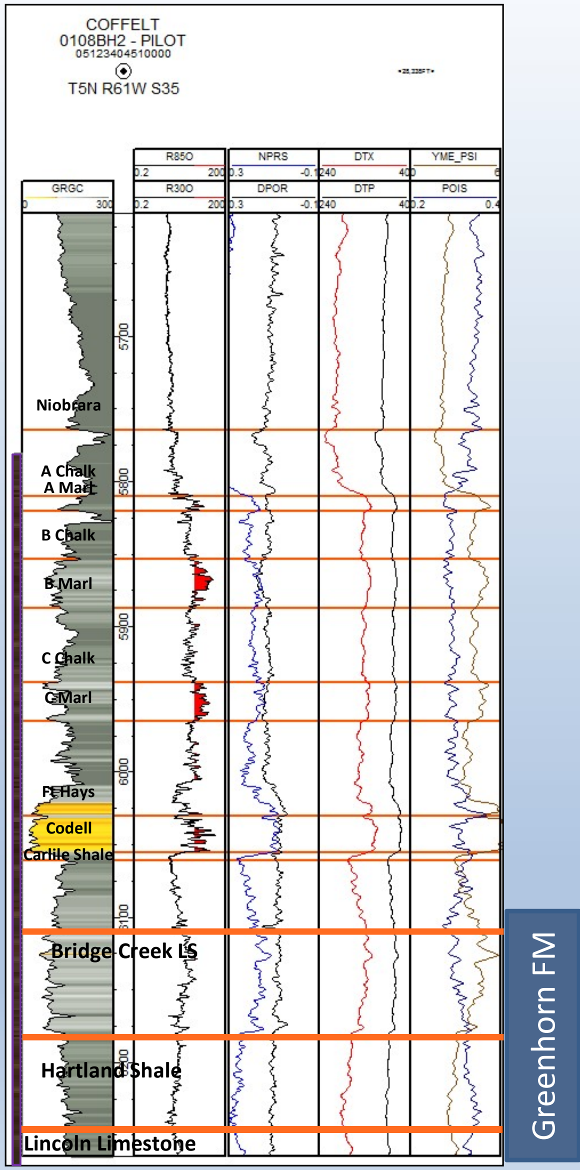
Distinguishing LIP magmatic pulses

Ionia-1 Core (early Cenomanian to late Turonian Boquillas/Eagle Ford FM)

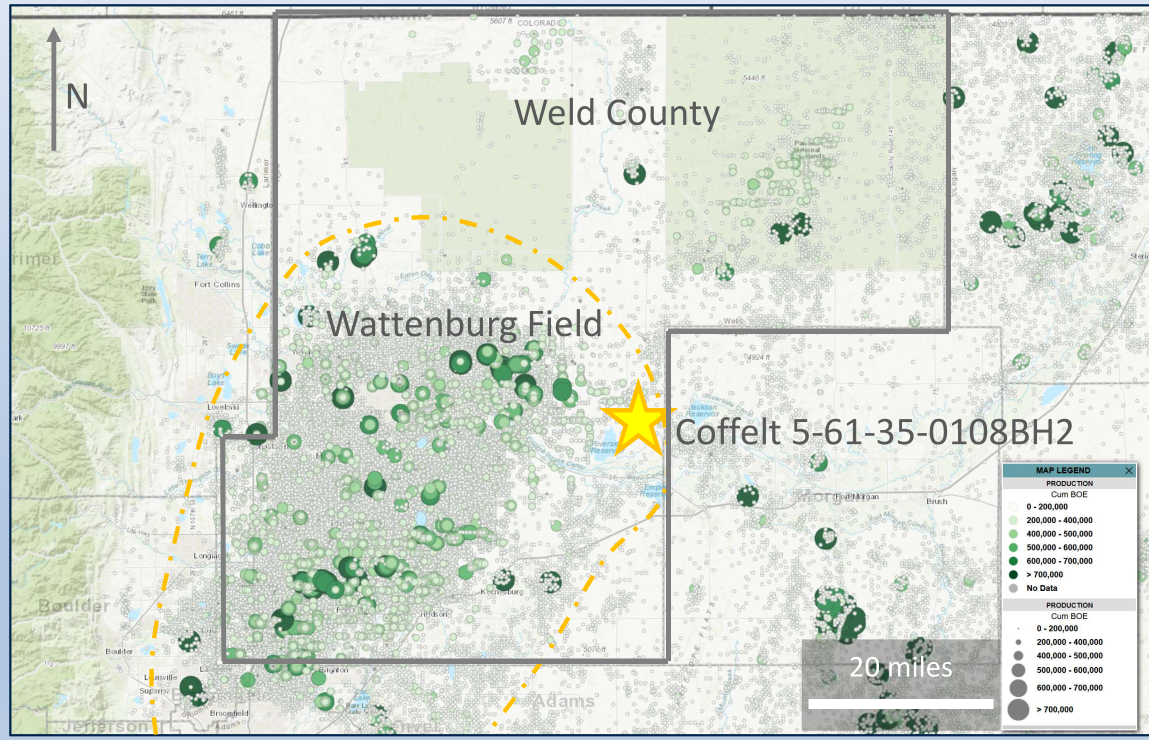


Sullivan et al., 2020; Eldrett et al., 2017; Jenkyns et al., 2017; Dodsworth, 2015

Coffelt Well
Greater Wattenberg (DJ Basin)



Production as of 1 Nov 2021

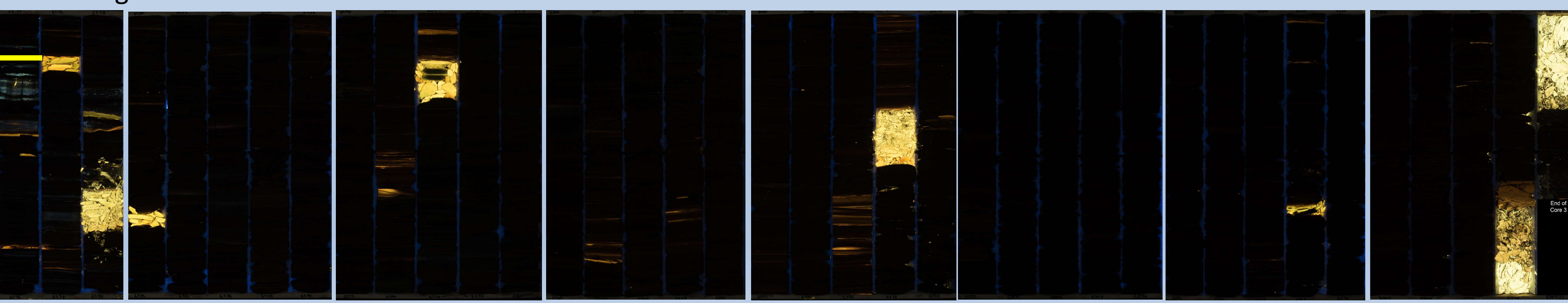


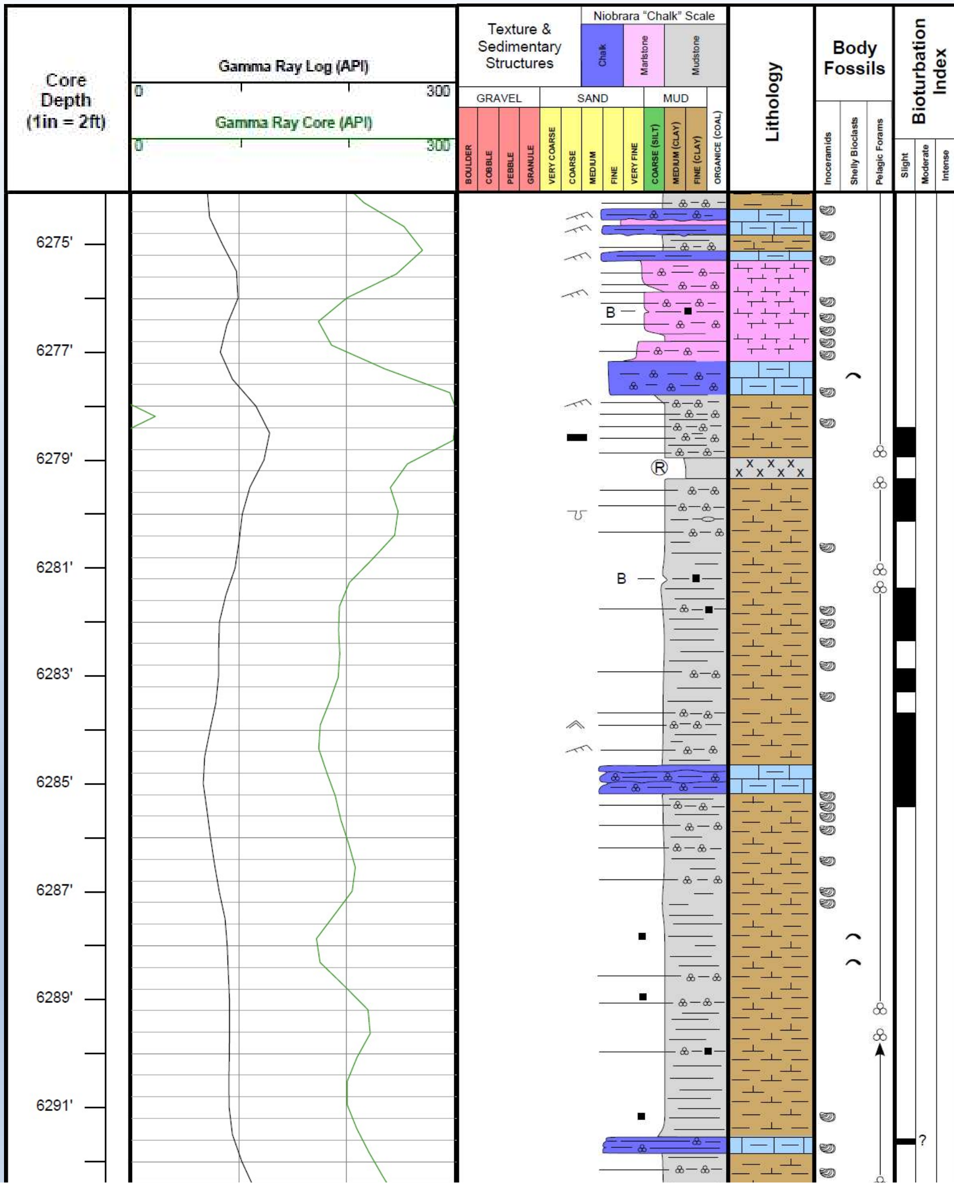
Enverus Drillinginfo, 2021

Coffelt Lincoln Limestone Member (Greenhorn FM): 72.95 ft

White Light

UV Light



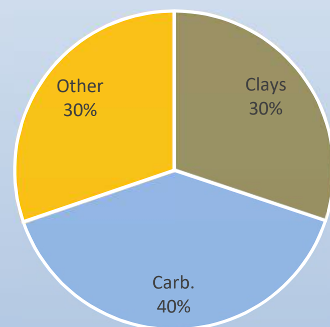


Coffelt Greenhorn

Lincoln Limestone Member: 72.95’

- Lower and Upper Members.
- Faint to distinctly laminated, calcareous mudstones (ranging to marlstones) with interstratified thinly laminated chalks.

XRD Ave wt%



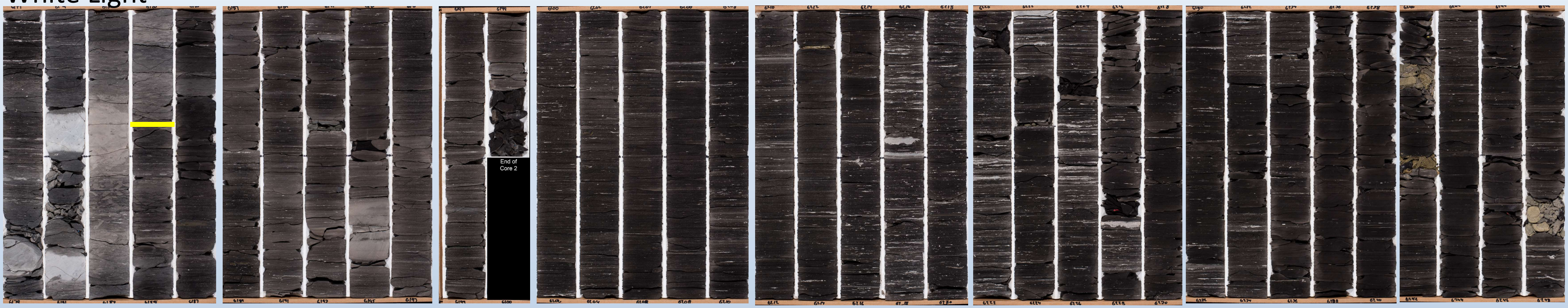
Programed pyrolysis (SRA)

Depth (feet)	TOC	S1	S2	S3	Tmax (°C)	HI	OI	S2/S3	S1/TOC *100	PI
6295.2	2.55	2.51	5.84	0.36	451	229	14	16	98	0.30
6306.2	1.86	1.96	4.30	0.32	448	231	17	13	105	0.31
6320.1	3.51	3.30	9.67	0.40	452	275	11	24	94	0.25
6341.7	3.40	3.30	9.72	0.37	451	286	11	26	97	0.25
6349.0	2.99	2.00	7.03	0.30	451	235	10	23	67	0.22

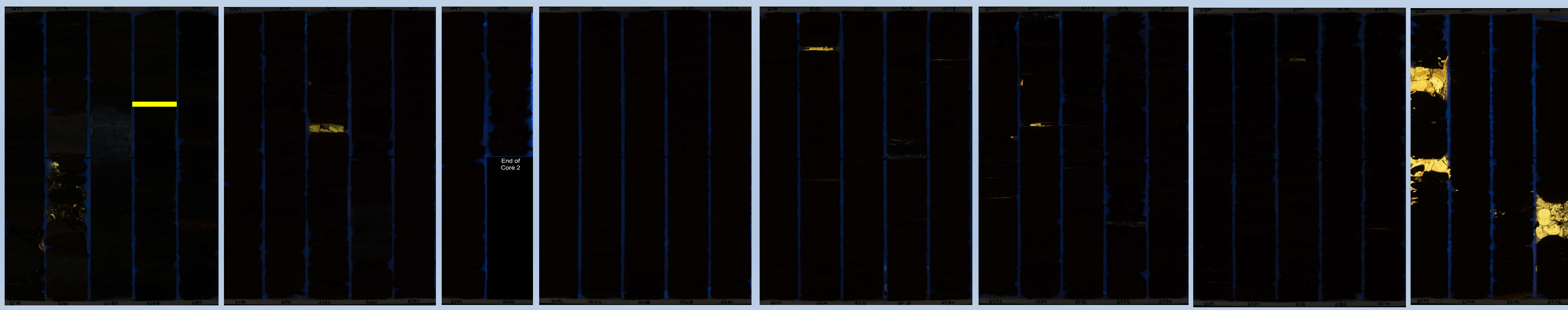
- Sharp basal contact with 0.4’ thick clay-rich X-bentonite (altered fine tuff) regional marker.
- Deposited in distal shelf environment dominated by terrigenous sediment with various episodes of pelagic input and sediment reworking by bottom currents.

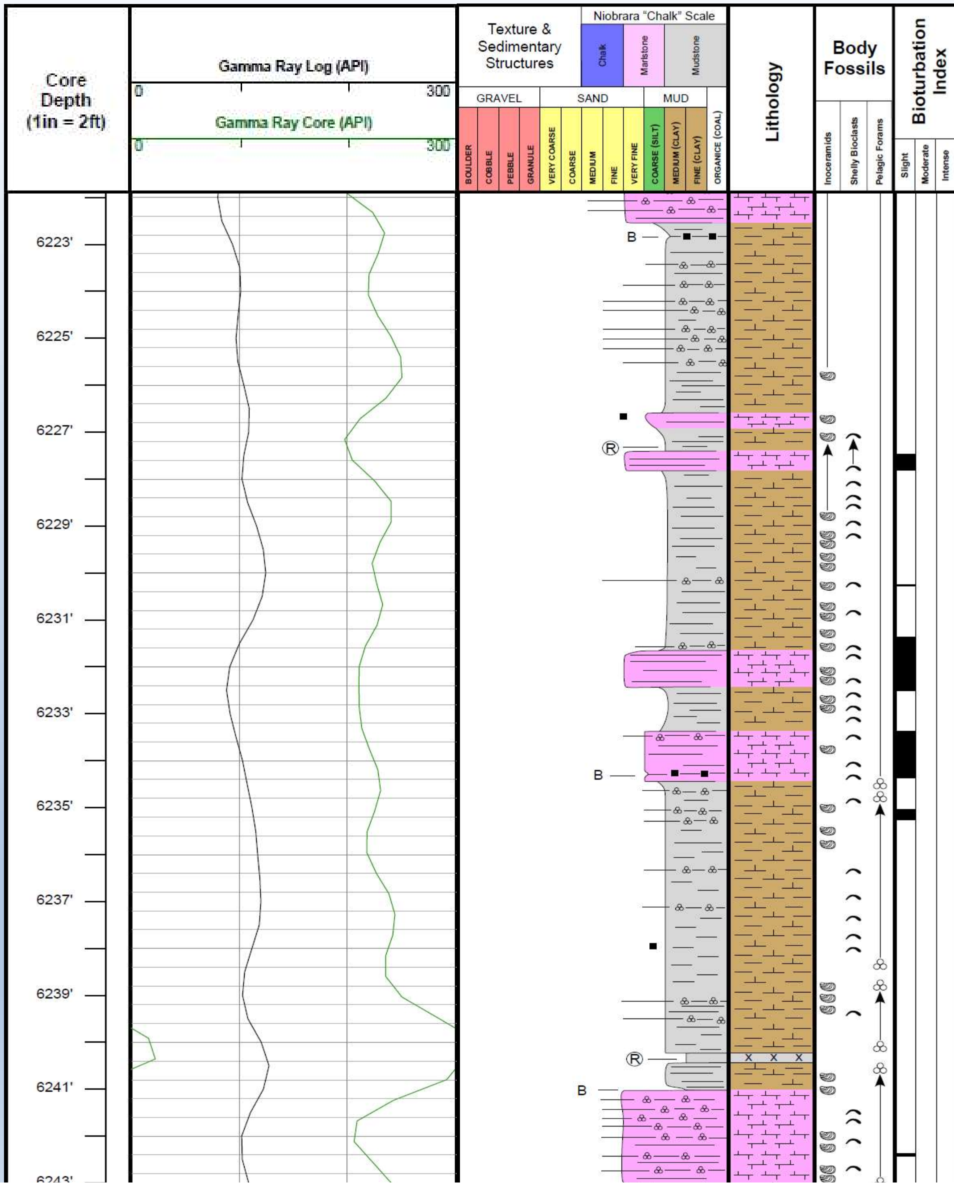
Coffelt Hartland Shale Member (Greenhorn FM): 90.30 ft

White Light



UV Light

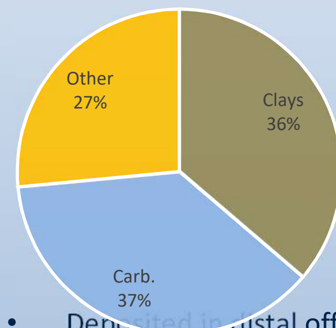




Coffelt Greenhorn

Hartland Shale Member: 90.30’

- Lower and Upper Members.
- Laminated marlstones with discrete, planer, foraminifera-rich chalk laminae. Foraminifera are ubiquitous through the interval.



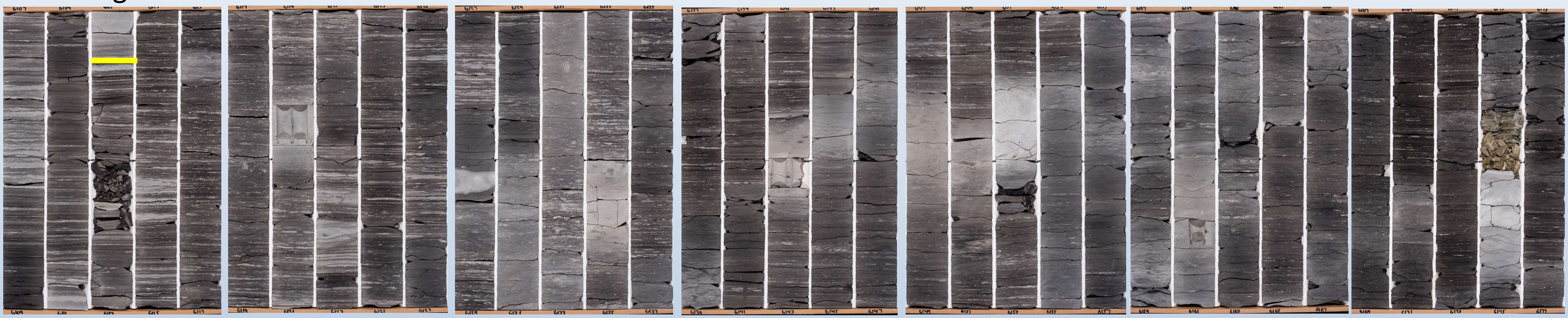
Programed pyrolysis (SRA)

Depth (feet)	TOC	S1	S2	S3	Tmax (°C)	HI	OI	S2/S3	S1/TOC *100	PI
6194.6	0.98	2.50	2.26	0.34	441	230	35	7	255	0.53
6218.2	2.33	2.75	5.39	0.38	449	231	16	14	118	0.34
6274.9	0.61	1.54	1.47	0.35	442	240	57	4	251	0.51

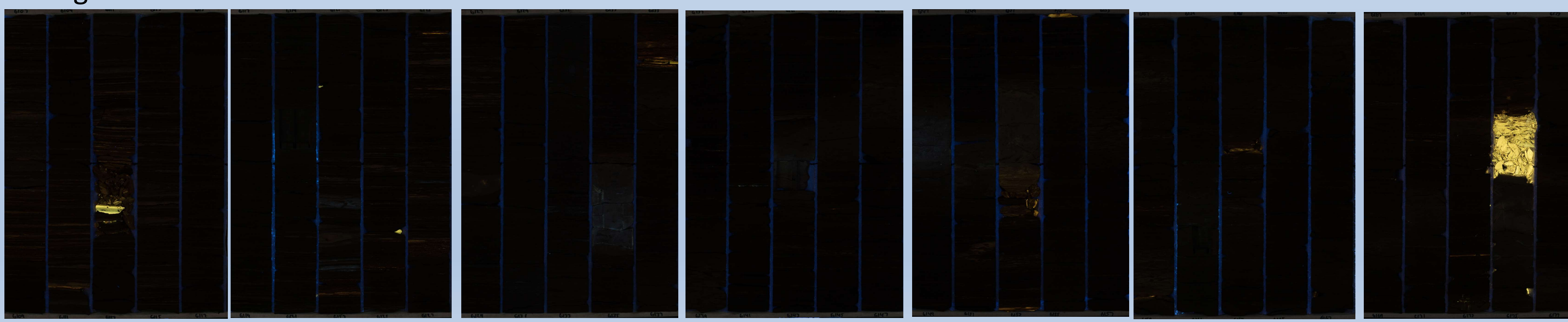
- Deposited in distal offshore (shelf) environment dominated by terrigenous sediment supply and episodes of hemipelagic input and sediment reworking by bottom currents.

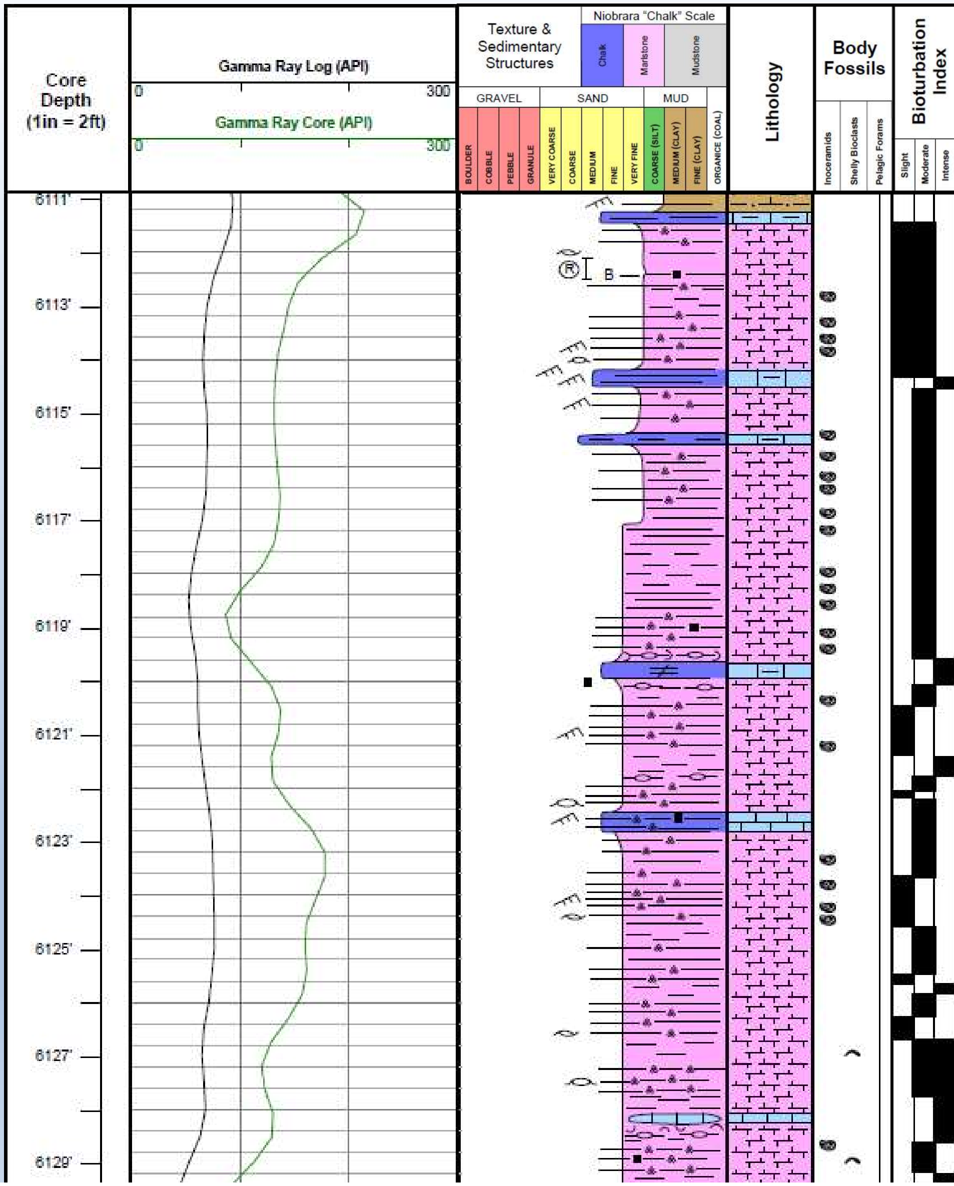
Coffelt Bridge Creek Member (Greenhorn FM): 72.75 ft

White Light



UV Light



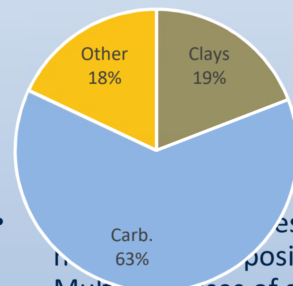


Coffelt Greenhorn

Bridge Creek Limestone Member: 72.75’

- Laminated Marlstone with interbedded impure chalks/chalky laminae.
- 1-3 ft chalking-upward cycles becoming intensely bioturbated at top. Chalk beds are pervasively calcite-cemented with nodules.

XRD Ave wt%



Programed pyrolysis (SRA)

Depth (feet)	TOC	S1	S2	S3	Tmax (°C)	HI	OI	S2/S3	S1/TOC *100	PI
6120.1	0.84	1.11	1.46	0.35	448	174	42	4	132	0.43
6134.6	1.49	1.87	3.46	0.39	447	232	26	9	126	0.35
6165.4	1.02	1.27	1.53	0.36	449	150	35	4	125	0.45

- …esents … position with minor sediment reworking by bottom currents. Multip… pulses of sedimentation occur followed by seafloor mineralization.

Continued Study

- Coffelt 5-61-35-0108BH2 (Wattenburg) and Razor 25-2514H (Redtail) [...]
  - Whole rock elemental interpretation
  - Whole oil-extract GC (biomarker)
  - Fe-speciation (Fe_{HR}/Fe_T)
  - Bentonite radiometric age dates
  - $\delta^{13}C$ and other isotopic datasets: Cr (δ^{53}), Os($\delta^{187/188}$), and possibly Eu, Re & Li
- Tie in cores to published Greenhorn OAE 2 studies
- Petrographic, SEM, mineral mapping with CL

Conclusions

- Water mass circulation and water column anoxia during the CTB in the Greenhorn Sea
- LIP volcanism as a proxy for distinguishing water mass provenance during Greenhorn Cyclothem
- Use of isotopic and elemental proxies to describe and detect anoxia, water provenance, and water mass circulation.
- Example Greenhorn Core
- Next steps

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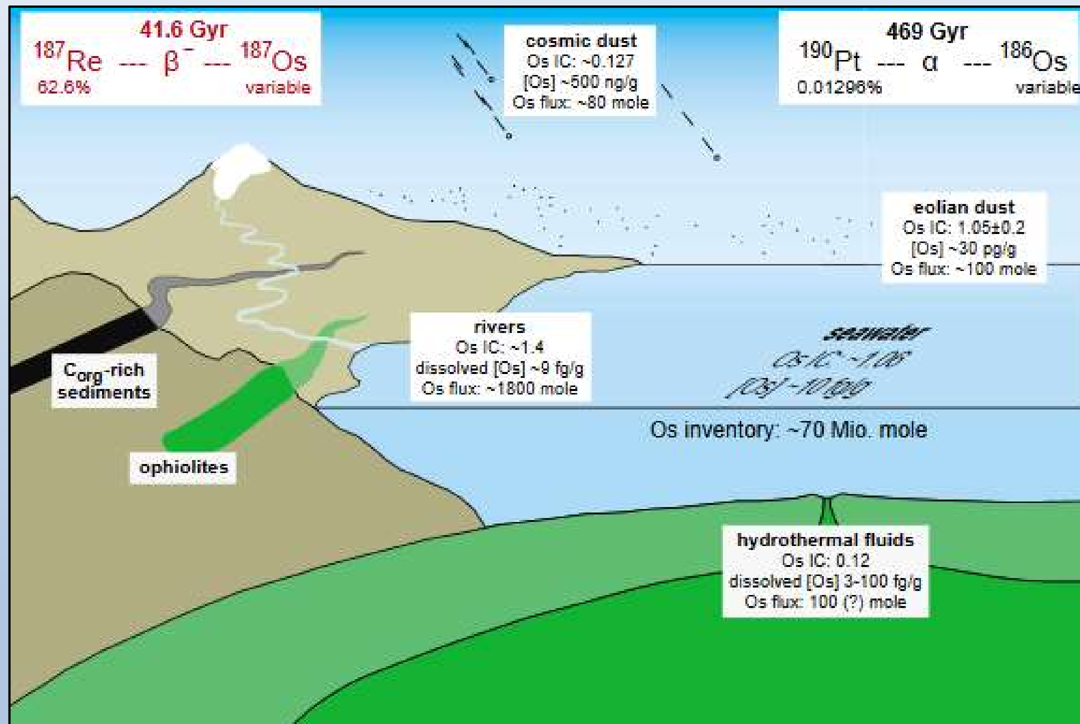
- This proposed study seeks to combine multiple geochemical and lithologic records from new and previously published core and outcrop data from the Greenhorn Formation (Cenomanian-Turonian) during the coincidence of the OAE2 and the maximum transgression of the Greenhorn Cyclothem (WIS). The nature, timing, and influence of LIP volcanism to widespread OAE2 ocean anoxia will be evaluated by adding significant resolution to the question using geochronology with geochemical proxies that have relatively short residence times in modern ocean environments (<10 k.a.) and are thus more sensitive to environmental perturbations than data used in previous studies. These include but are not limited to Fe-speciation, rare earth element anomalies (Ce, Eu), and Cr-isotopic data. Combined with more traditional lithostratigraphic and petrographic datasets, this study seeks to resolve the influence of distinct volcanic events (such as pulses of LIP submarine volcanism) with observed and assumed changes in ocean chemistry, water column anoxia, and coincident changes to continental sediment supply and submarine weathering.

Abstract

Ocean Anoxic Events (OAE's) are isotopically distinguishable, short-lived periods of global bottom water anoxia and black shale deposition. Although widespread deoxygenation is only known from a handful of geographically limited areas today, the marine and epicontinental sediment of the Cretaceous preserves one of the best records of these oceanic crises. A detailed stratigraphic, biostratigraphic, paleoclimatic, and geochemical record the Late Cretaceous Ocean Anoxic Event 2 (OAE 2) spanning the Cenomanian-Turonian Boundary (CTB; ca. ~94 Ma) is preserved during peak transgression of the Greenhorn Cyclothem within the semi-restricted North American Western Interior Basin (WIB). The prominent, rhythmically bedded lime- and marlstones of the Bridge Creek Member of the Greenhorn Formation were deposited during the maximum transgression of the Western Interior Seaway (WIS) and can be traced extensively throughout the WIB. Beginning the in Harland Shale Member and into the lithologically gradational overlying Bridge Creek Member, a positive isotopic excursion of $\delta 13C$ and $\delta 18O$ characteristic of OAE 2 is observed and is correlative to both the WIB composite curve and the English Chalk Reference Curve. Although widespread ocean anoxia is well documented from CTB sediments from around the world, the WIS record of deoxygenation during OAE 2 is significantly more nuanced. Western margin sediments proximal to the Sevier Highlands, such as the Tropic Shale of Utah, reveal evidence of photic zone euxinia (PZE) while the much more distal Bridge Creek Member records a shift from anoxic to well-oxygenated bottom waters at the very onset of OAE 2. While OAE's are thought to be the result of significant and global changes to ocean circulation, ocean-atmosphere warming, and Corg fixation by photoautotrophs (biogenic nutrient flux), the role of volcanic input to the ocean-atmosphere-geosphere system is receiving increased scrutiny. Two significant marine Large Igneous Provinces or LIPS to the north and south of the WIS were variously active during the CTB and may have acted as a primary driver of ocean water chemistry changes and nutrient supply. Using detrital, biogenic, and authigenic geochemical proxies, this study seeks to elucidate the nature and influence of LIP volcanism on water column oxygenation and organic matter preservation during the OAE 2. The applications and limitations of these proxies will be discussed including techniques for identifying volcanic signatures and will include elemental, stable isotopic, organic whole rock geochemical, and biomarker analyses.

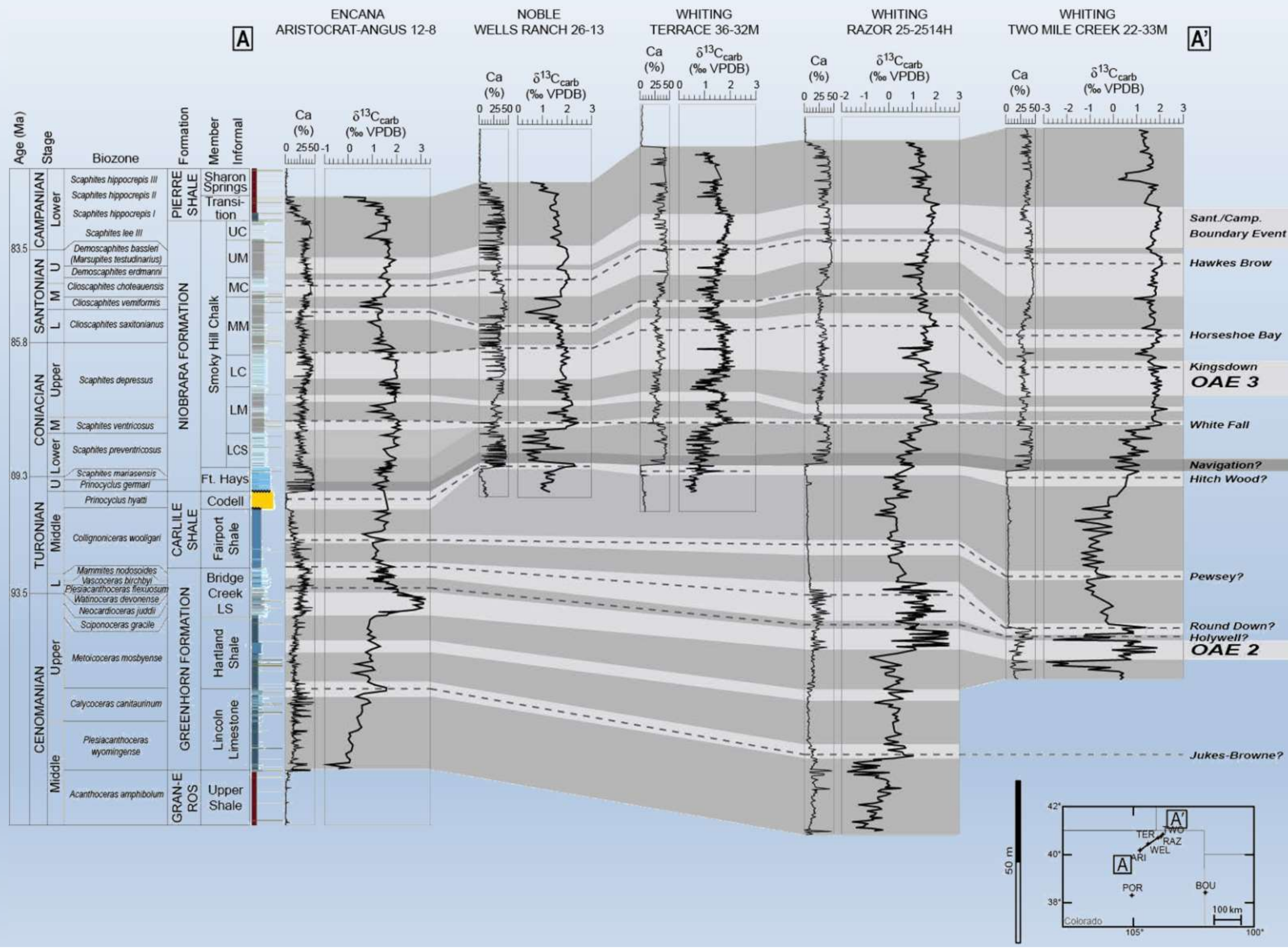
Marine Os isotope cycling



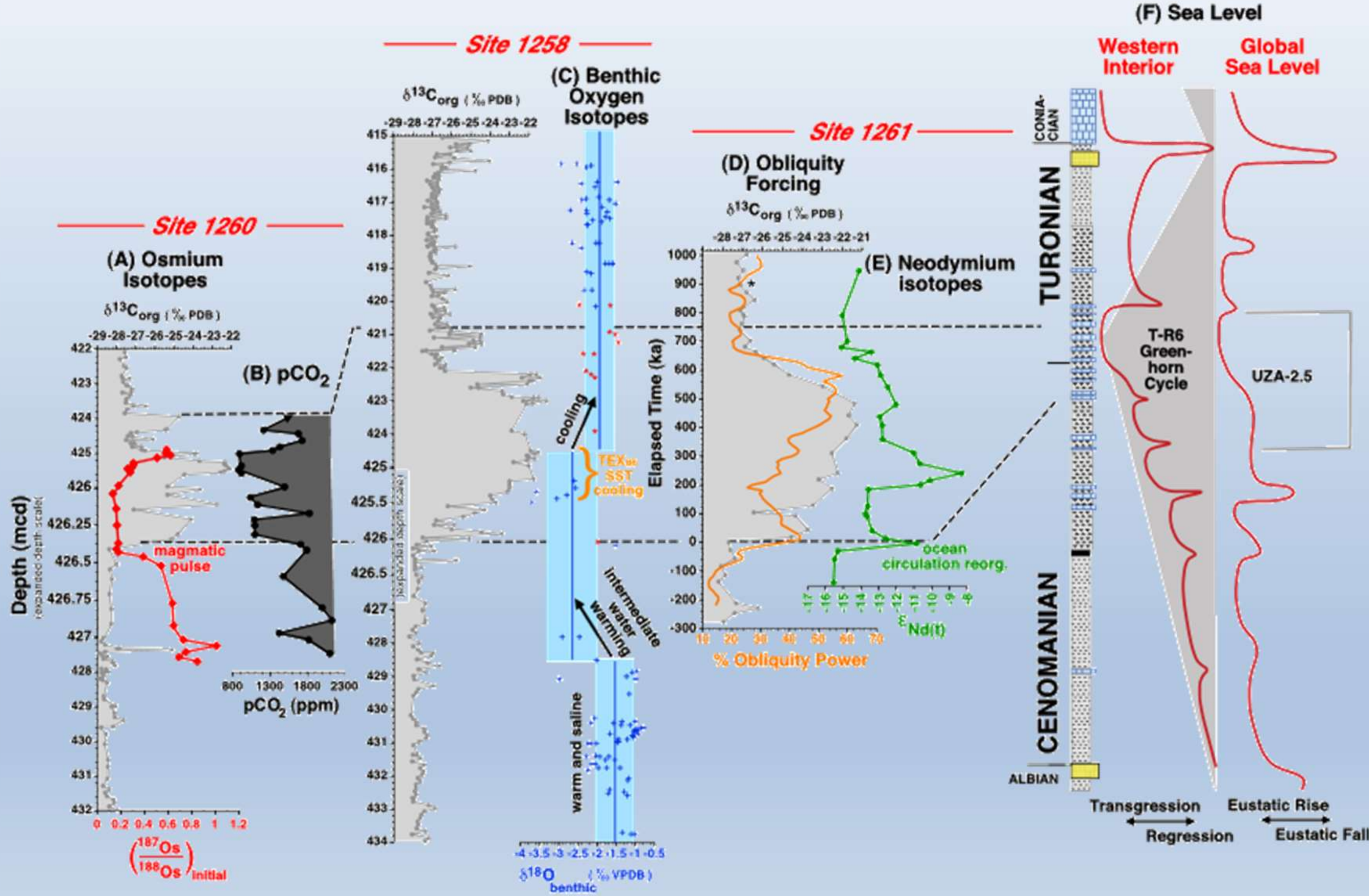
Peucker-Ehrenbrink and Ravizza, 2000

Other cores in the DJ

COLORADO SCHOOL OF MINES MUDTOC



Os and Nd


Site 1260
(A) Osmium Isotopes
(B) pCO2
Site 1258
(C) Benthic Oxygen Isotopes
Site 1261
(D) Obliquity Forcing
(E) Neodymium isotopes
(F) Sea Level
Western Interior
Global Sea Level
Depth (mcd)
magmatic pulse
pCO2 (ppm)
cooling
TEX86 SST cooling
intermediate water warming
warm and saline
Elapsed Time (ka)
% Obliquity Power
ocean circulation reorg.
CONIACIAN
TURONIAN
CENOMANIAN
ALBIAN
T-R6 Greenhorn Cycle
UZA-2.5
Transgression
Regression
Eustatic Rise
Eustatic Fall