Chemostratigraphy of the Greenhorn Formation in the Greater Wattenberg Area, Denver Basin, Colorado.

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MUDTOC

Christopher Matson
Fall 2023

Outline

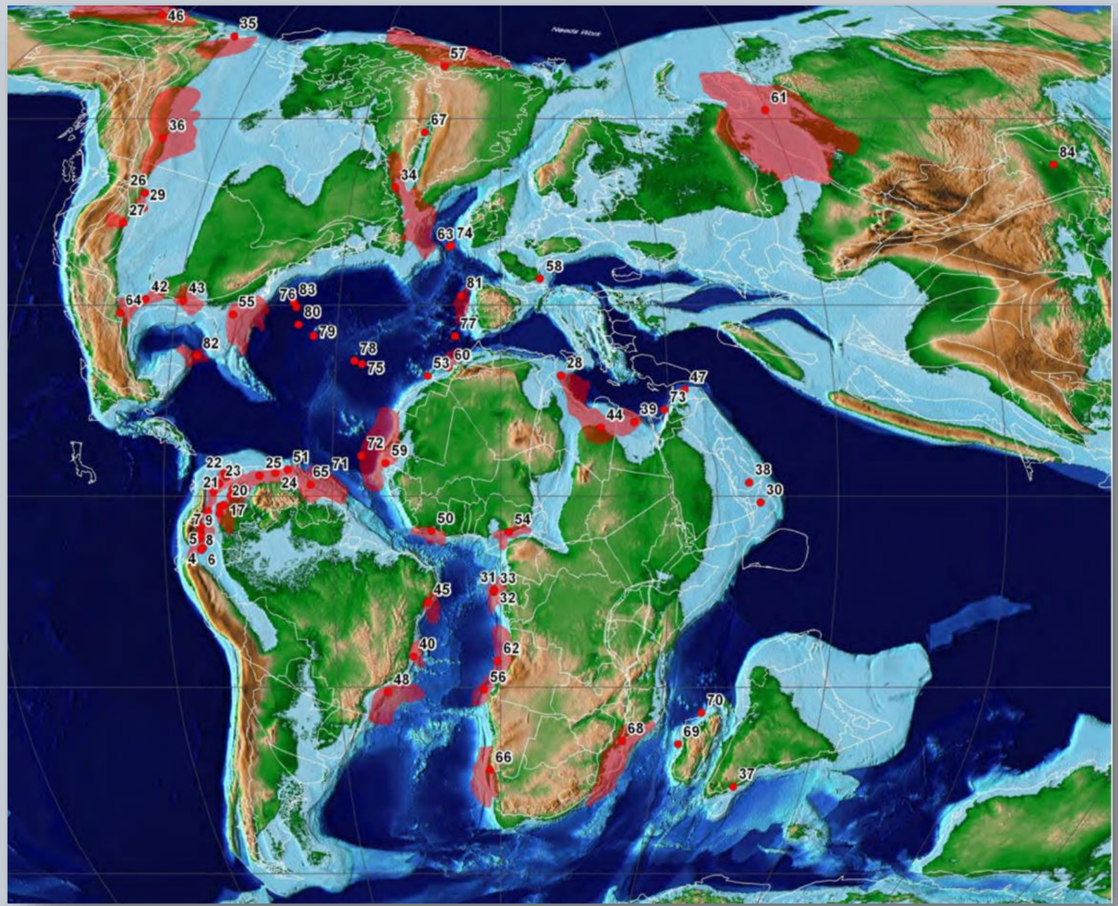
- Geological background
- OAE 2 and LIP Signals in Western Interior Sea
- Greenhorn Formation in the Denver Basin
  - Coffelt and Razor cores
  - Facies and depositional history
  - Elemental framework
  - Chemostratigraphy
  - Element-Mineral and Element-TOC relationships
- Conclusions

Late Cretaceous paleogeography

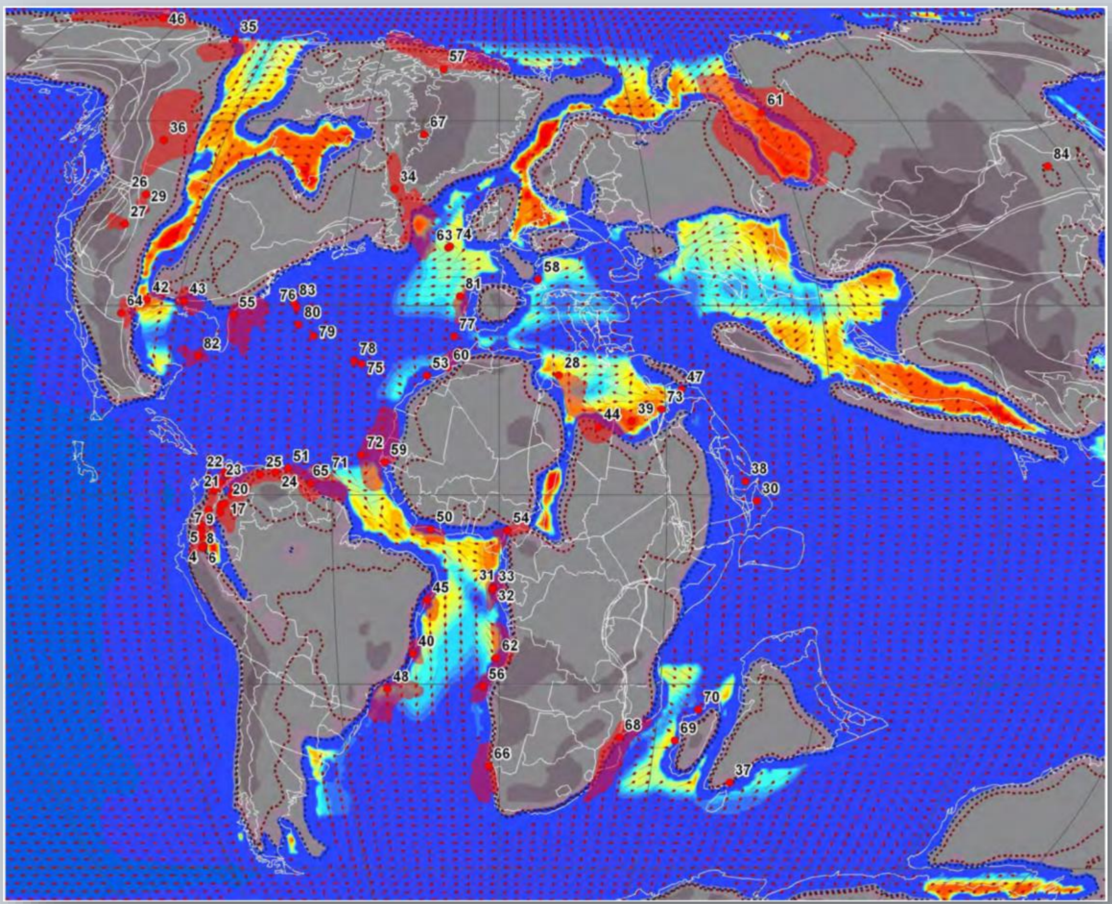
Cenomanian-Turonian Boundary

~93.9 ± 0.15 Ma

Paleogeography

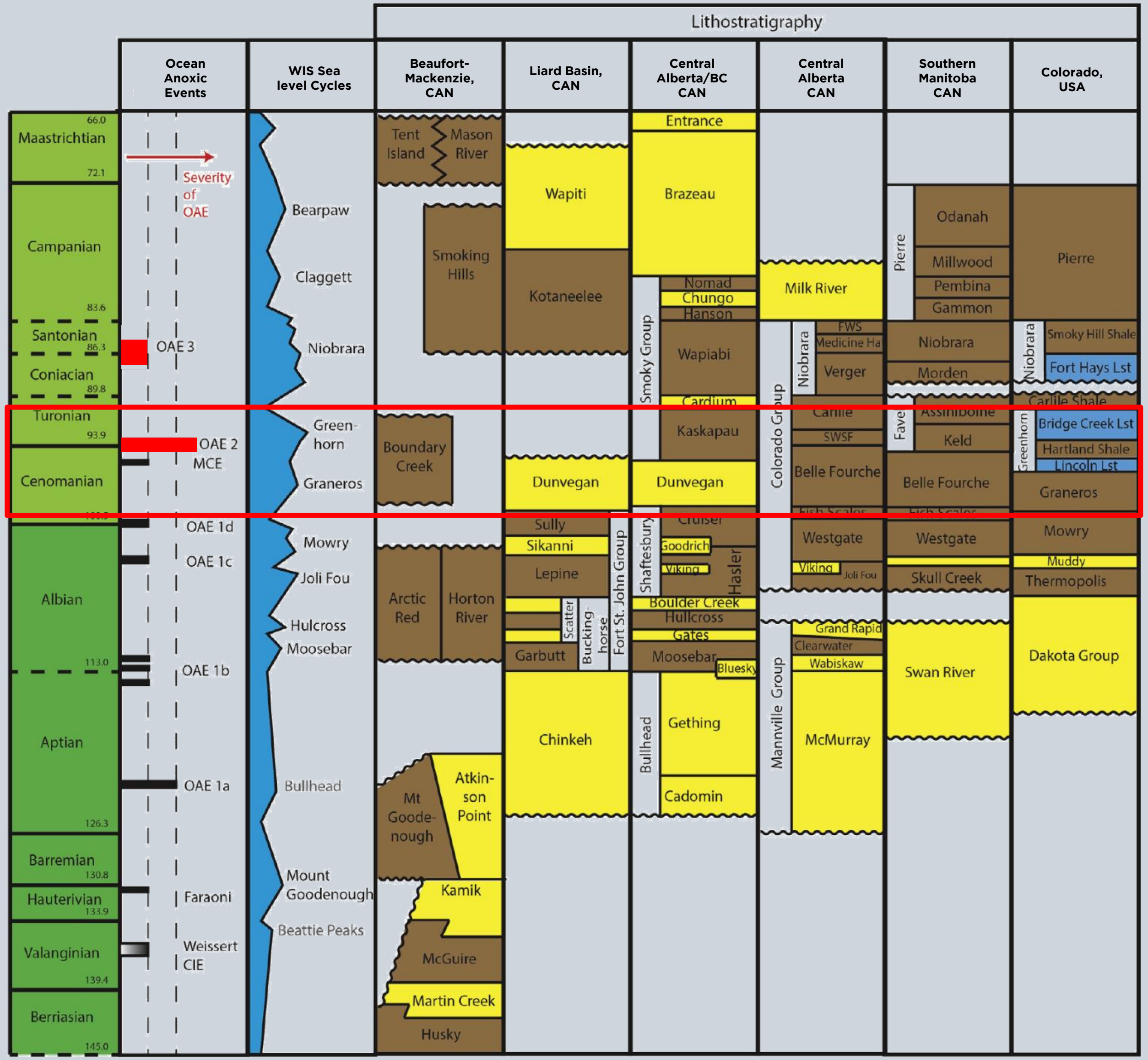


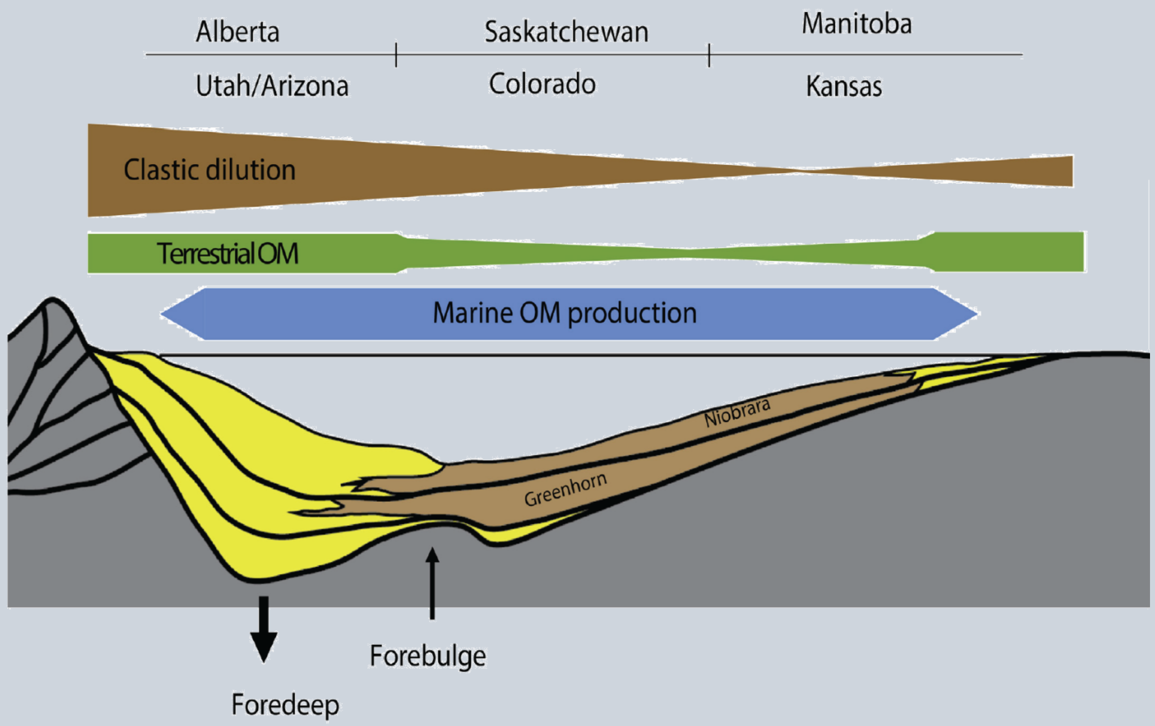
Ocean Restriction



Scotese et al., 2007: The GANDOLPH Project

Western Interior Basin and eustacy

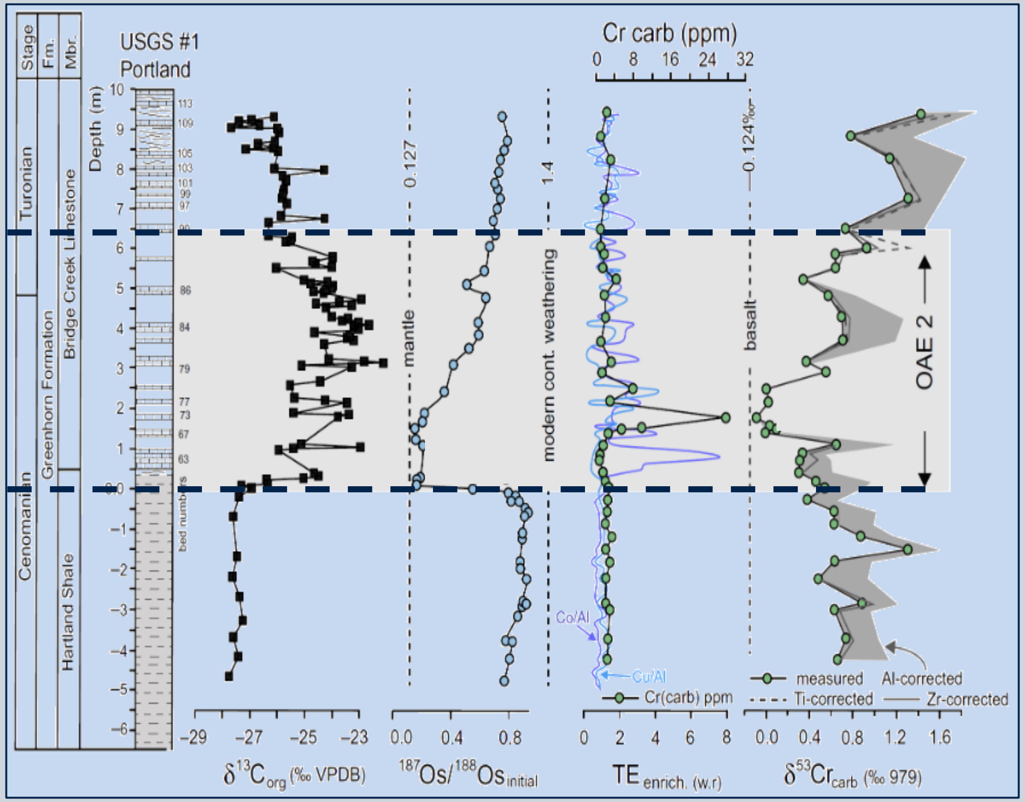




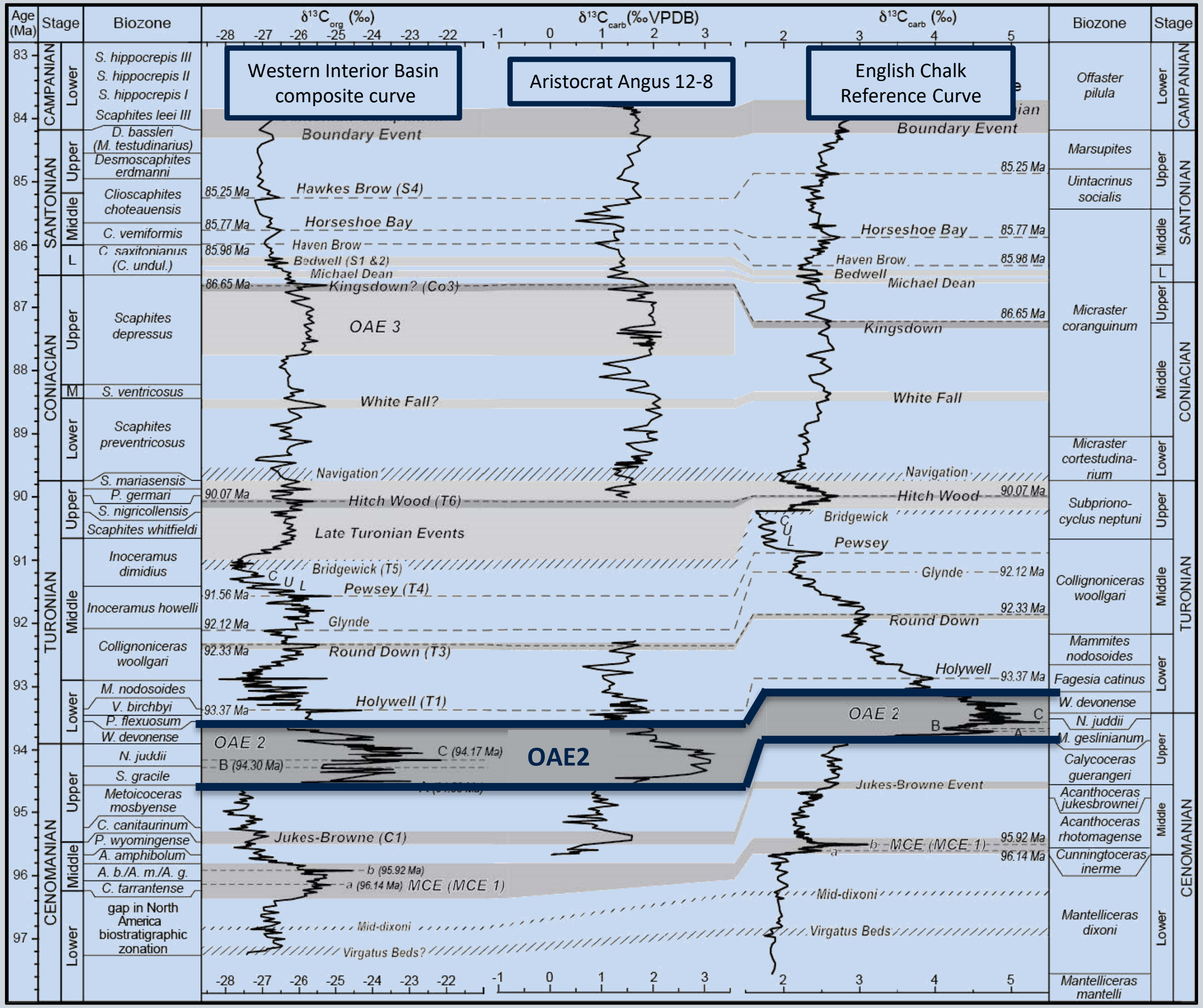
Modified from Lowery et al., 2018; Kauffman, 1984; Kauffman et al., 1993; Kauffman and Caldwell, 1993; Arthur and Sageman, 2005; Schroder-Adams, 2014; Stott, 1982; Leckie et al., 1991; Watkins, 1993

CTB: OAE 2 global isotope signals

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



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



Transient reversals and timing

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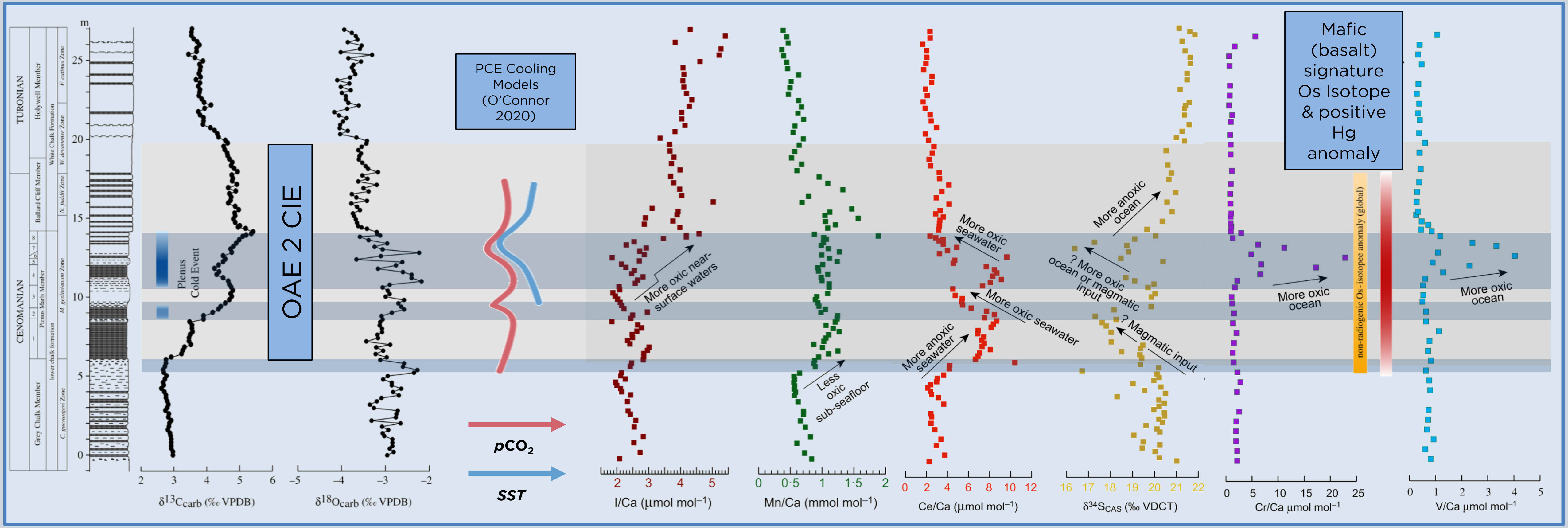
Pre-OAE 2 and Plenus Cold Event (PCE)

English Chalk: Eastbourne, Sussex, UK



Modified from Jenkyns et al., 2017a, Jenkyns, 2018; Tsikos et al., 2004; O'Connor 2020

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Bulk mineralogy

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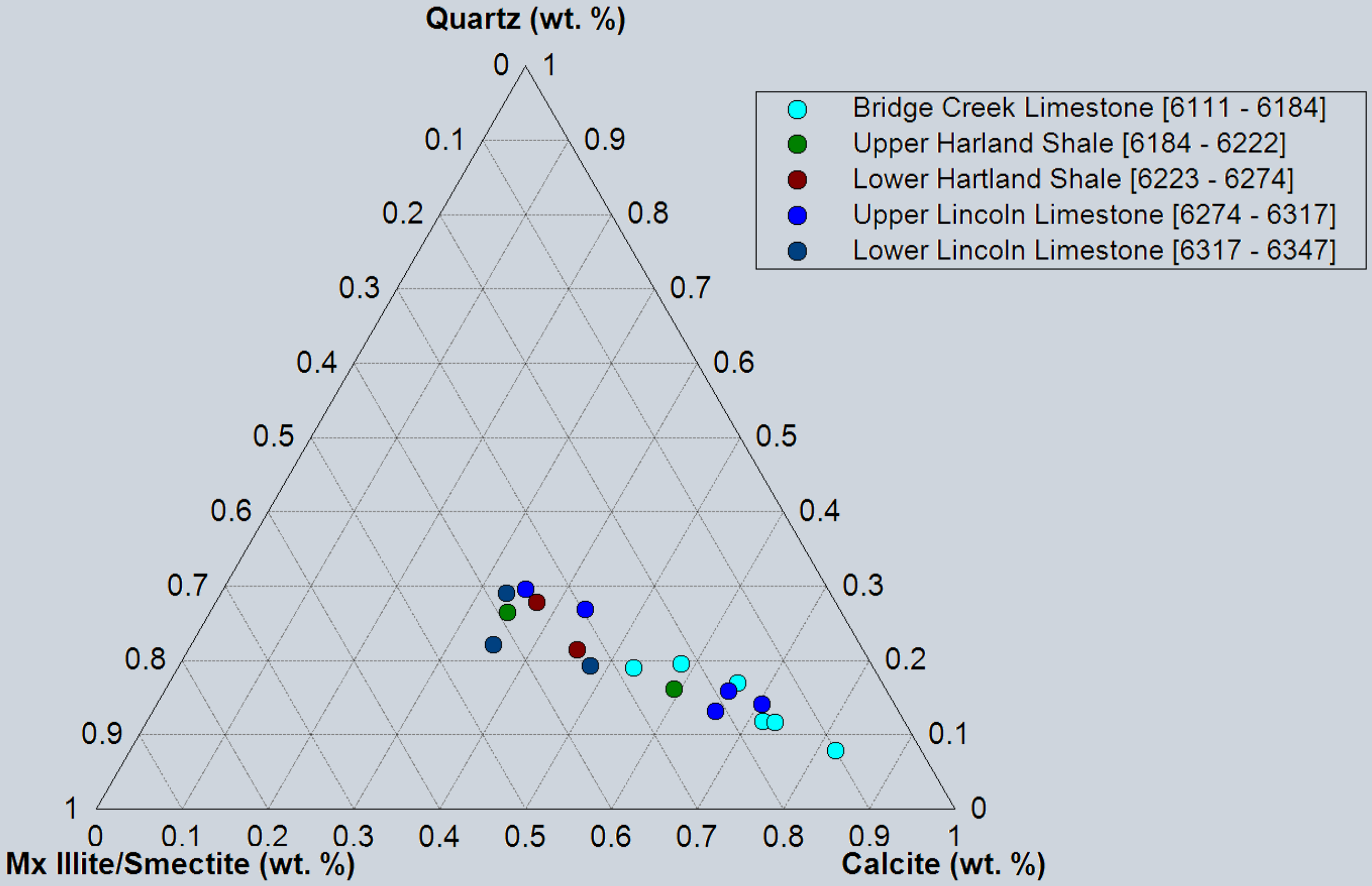

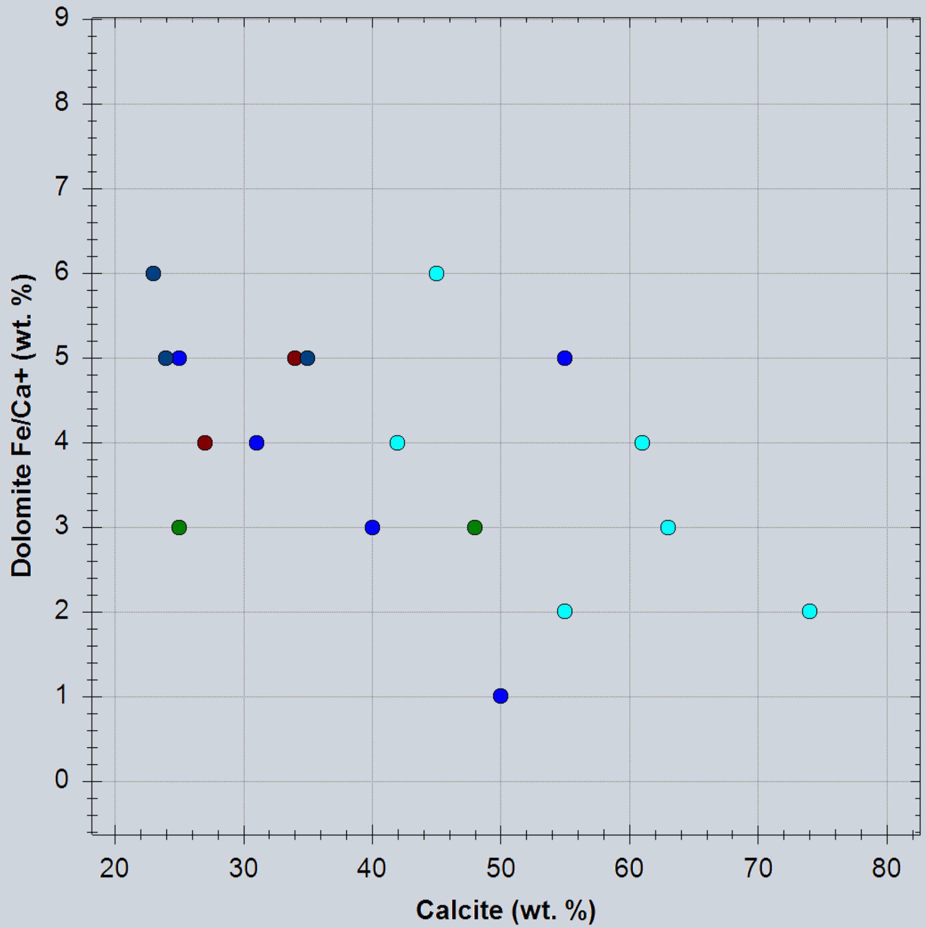

Major elements

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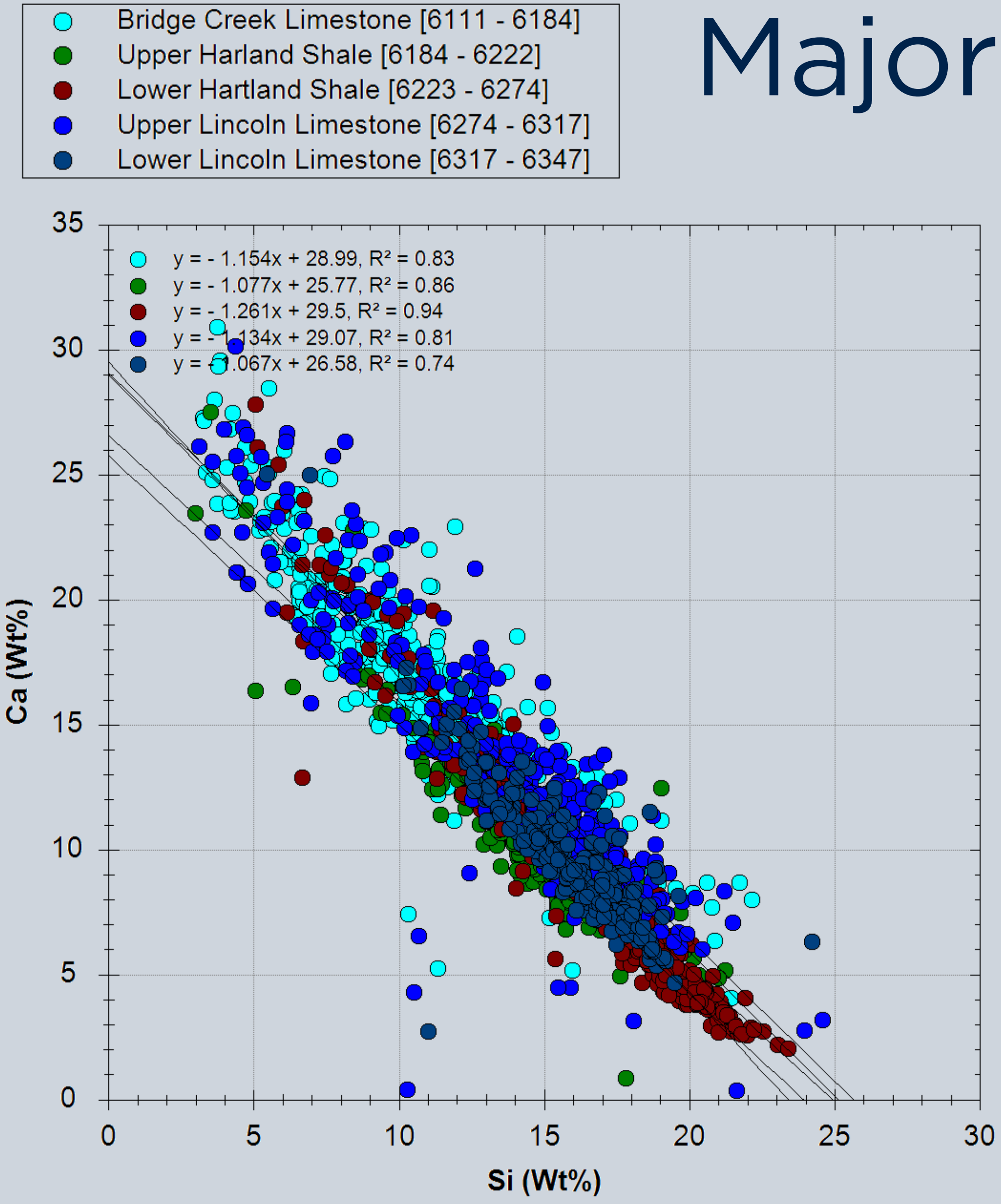
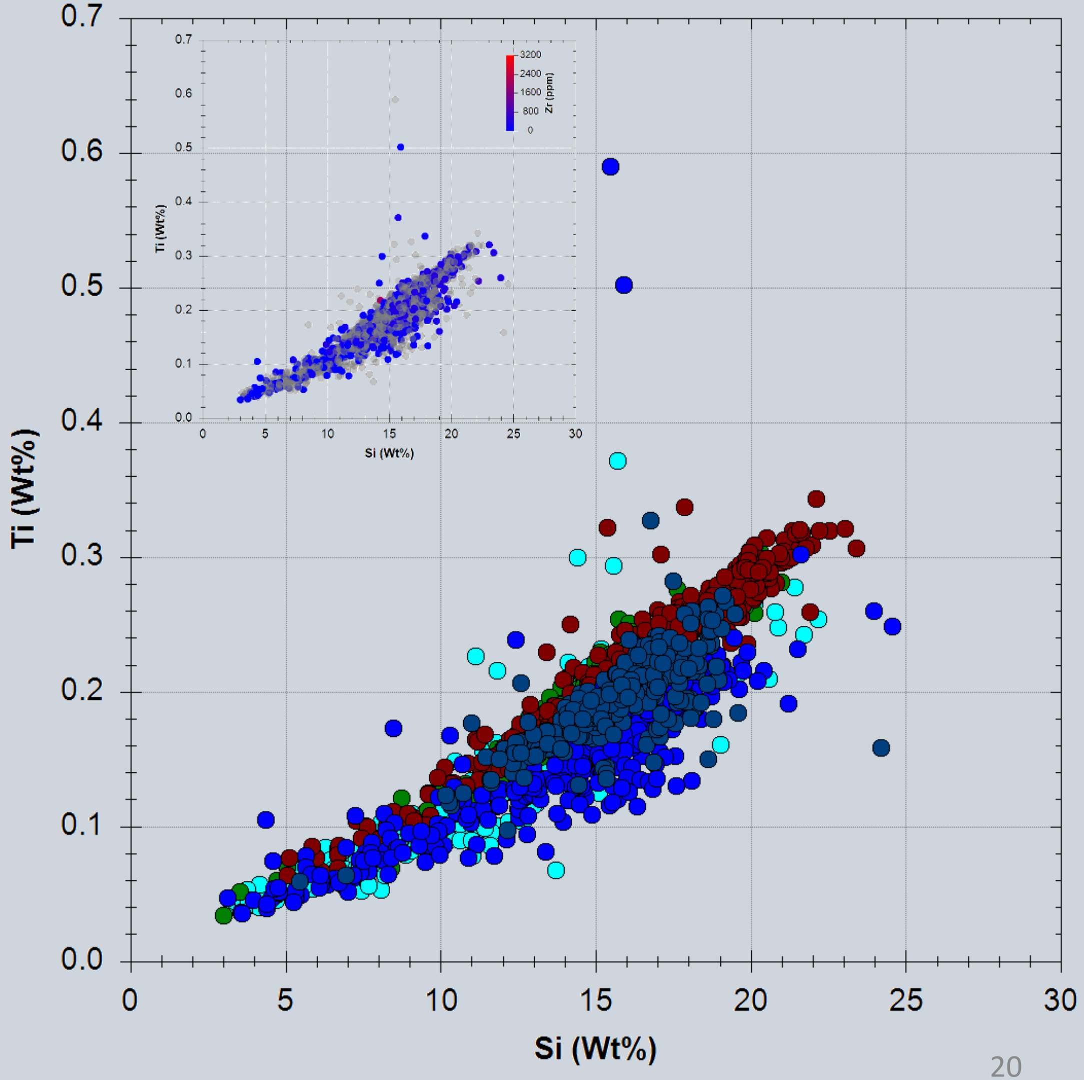
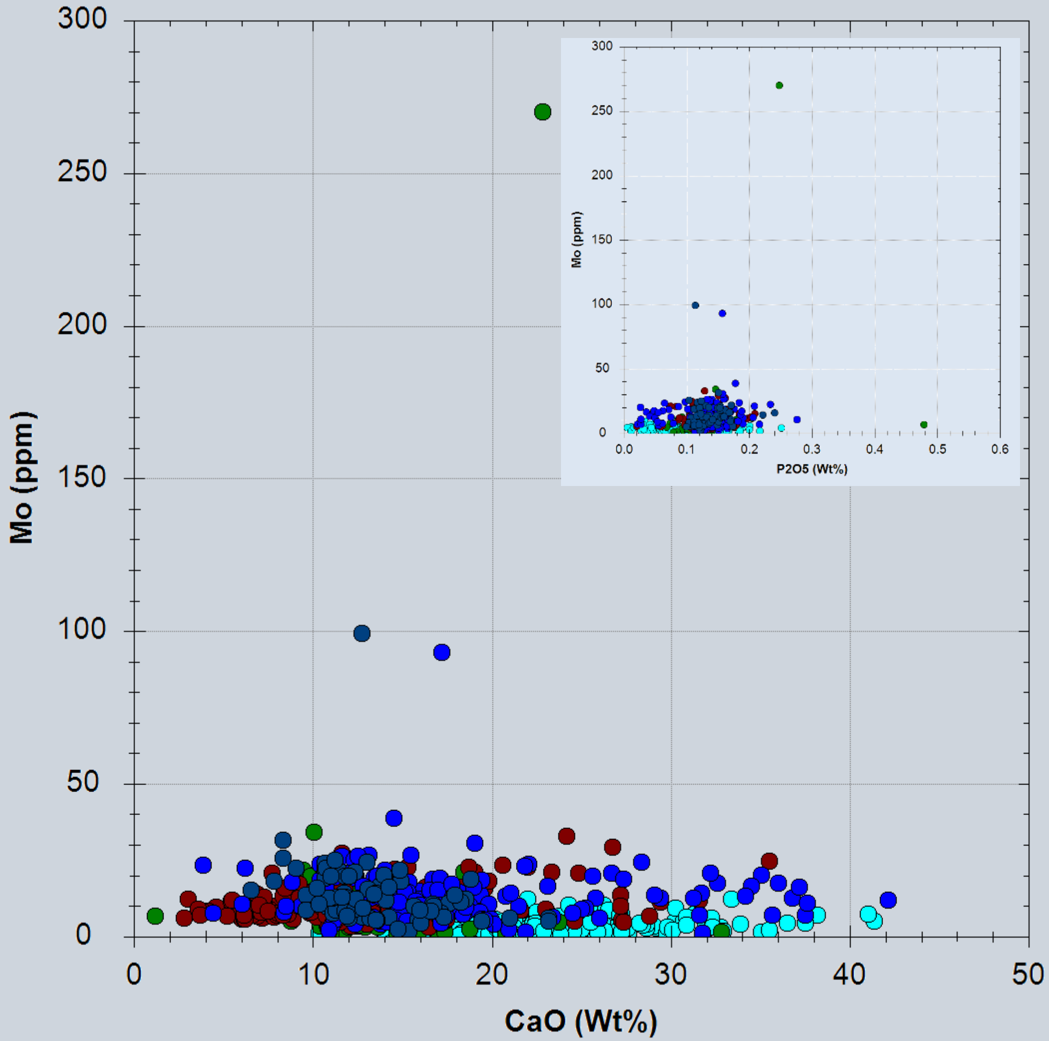
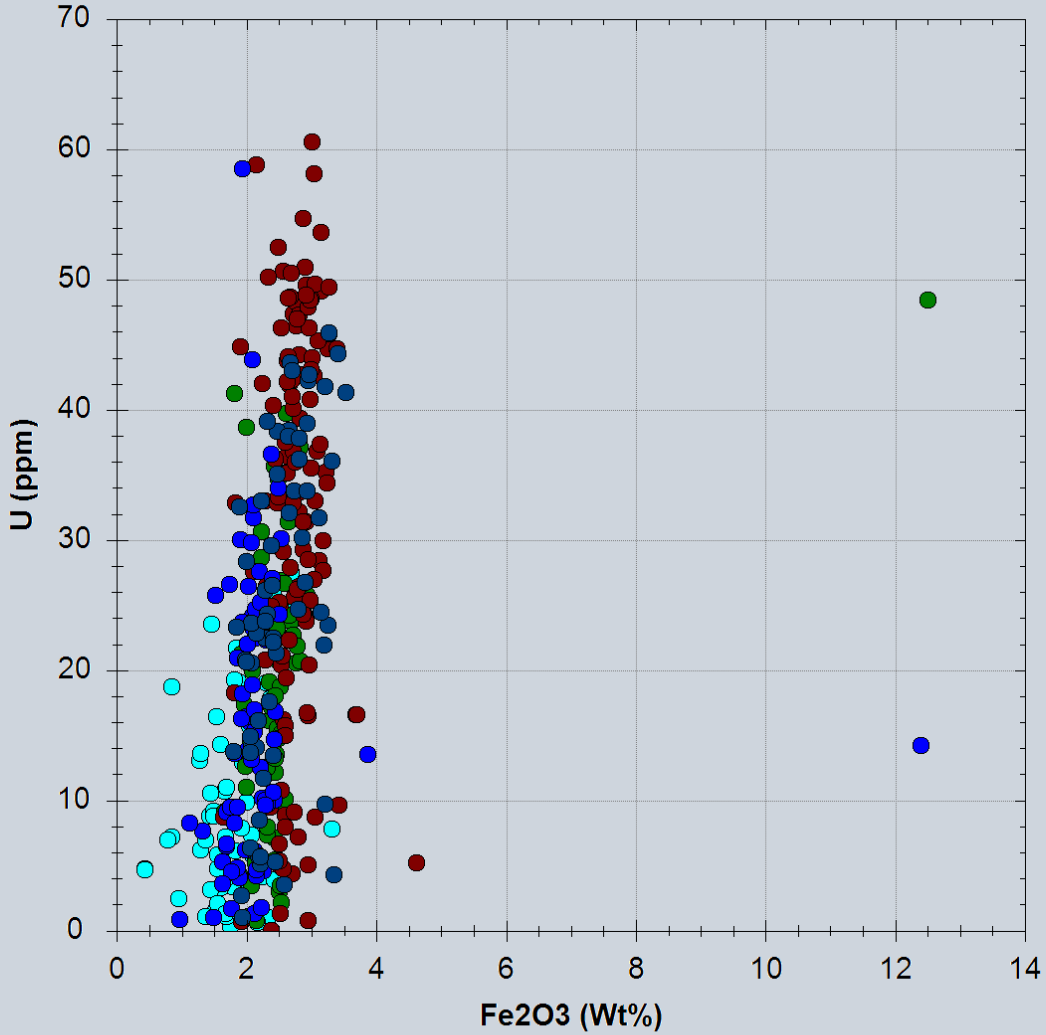




Trace elements

- Bridge Creek Limestone [6111 - 6184]
- Upper Harland Shale [6184 - 6222]
- Lower Hartland Shale [6223 - 6274]
- Upper Lincoln Limestone [6274 - 6317]
- Lower Lincoln Limestone [6317 - 6347]





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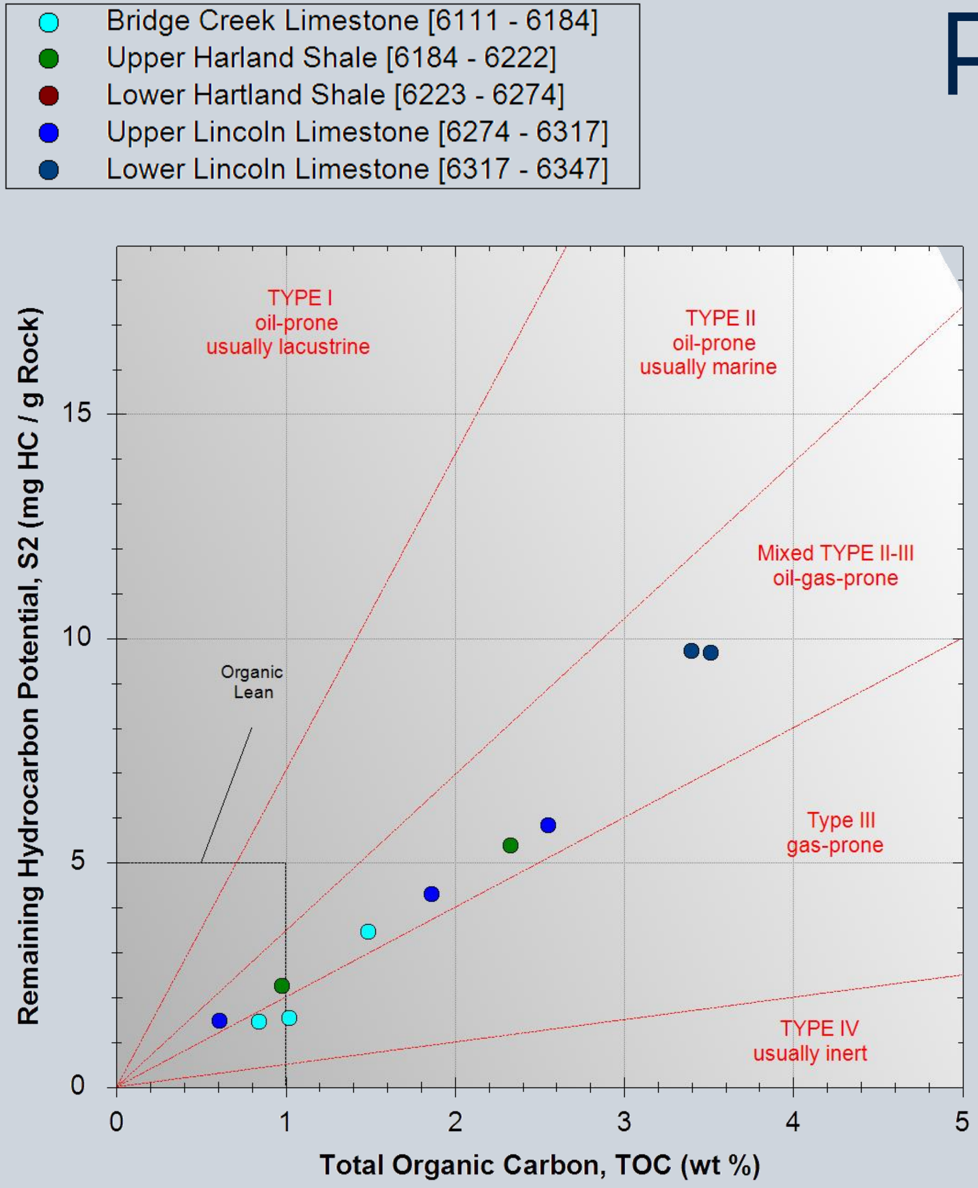
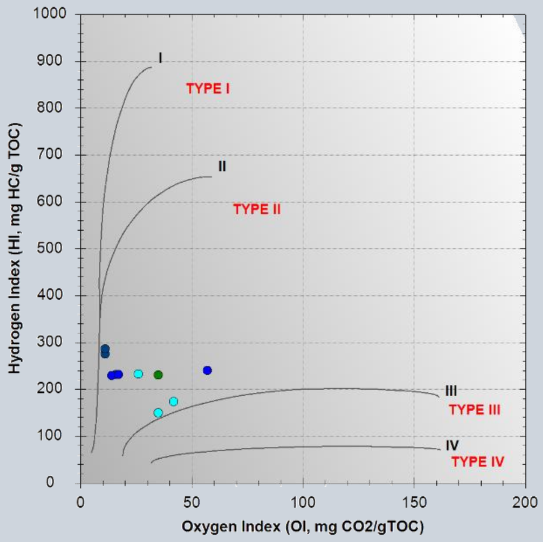
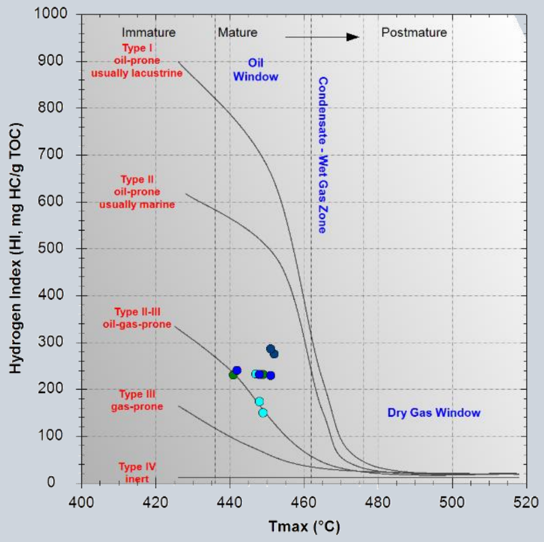
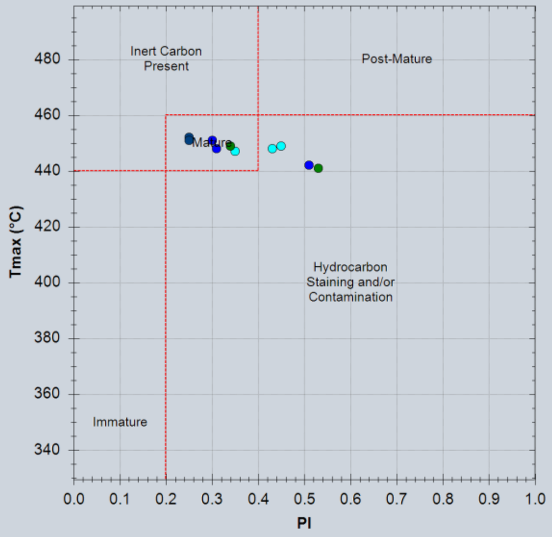
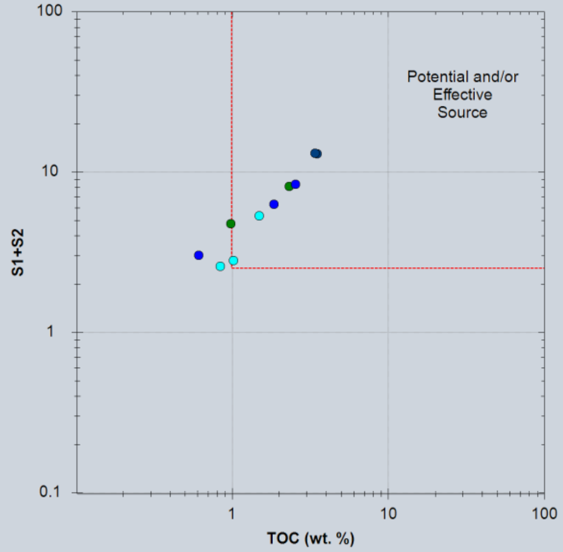
Pyrolysis


Bridge Creek Limestone [6111 - 6184]
Upper Harland Shale [6184 - 6222]
Lower Hartland Shale [6223 - 6274]
Upper Lincoln Limestone [6274 - 6317]
Lower Lincoln Limestone [6317 - 6347]
TYPE I
oil-prone
usually lacustrine
TYPE II
oil-prone
usually marine
Mixed TYPE II-III
oil-gas-prone
Type III
gas-prone
TYPE IV
usually inert
Organic
Lean
Remaining Hydrocarbon Potential, S2 (mg HC / g Rock)
Total Organic Carbon, TOC (wt %)

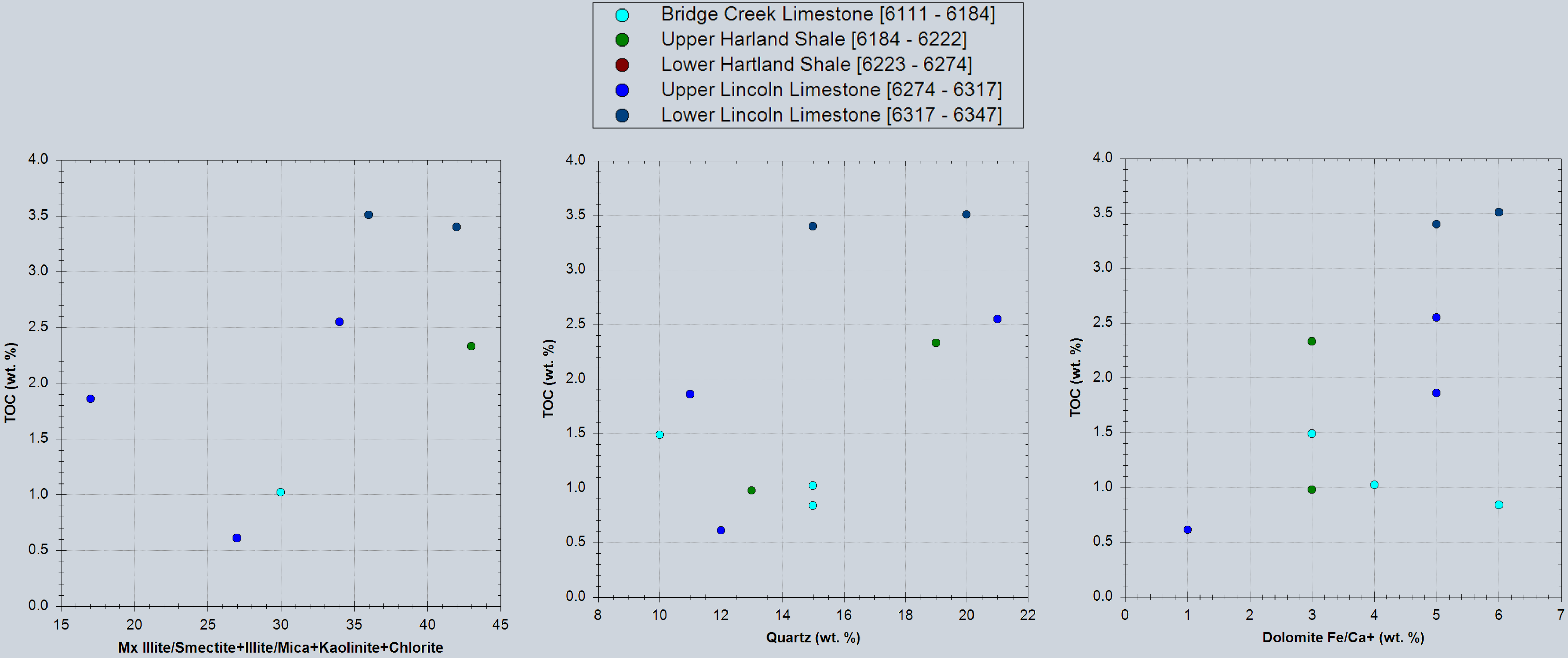

TYPE I
TYPE II
TYPE III
TYPE IV
Hydrogen Index (HI, mg HC/g TOC)
Oxygen Index (OI, mg CO2/gTOC)


Immature
Mature
Postmature
Type I
oil-prone
usually lacustrine
Oil
Window
Condensate - Wet Gas Zone
Type II
oil-prone
usually marine
Type II-III
oil-gas-prone
Type III
gas-prone
Type IV
inert
Dry Gas Window
Hydrogen Index (HI, mg HC/g TOC)
Tmax (°C)

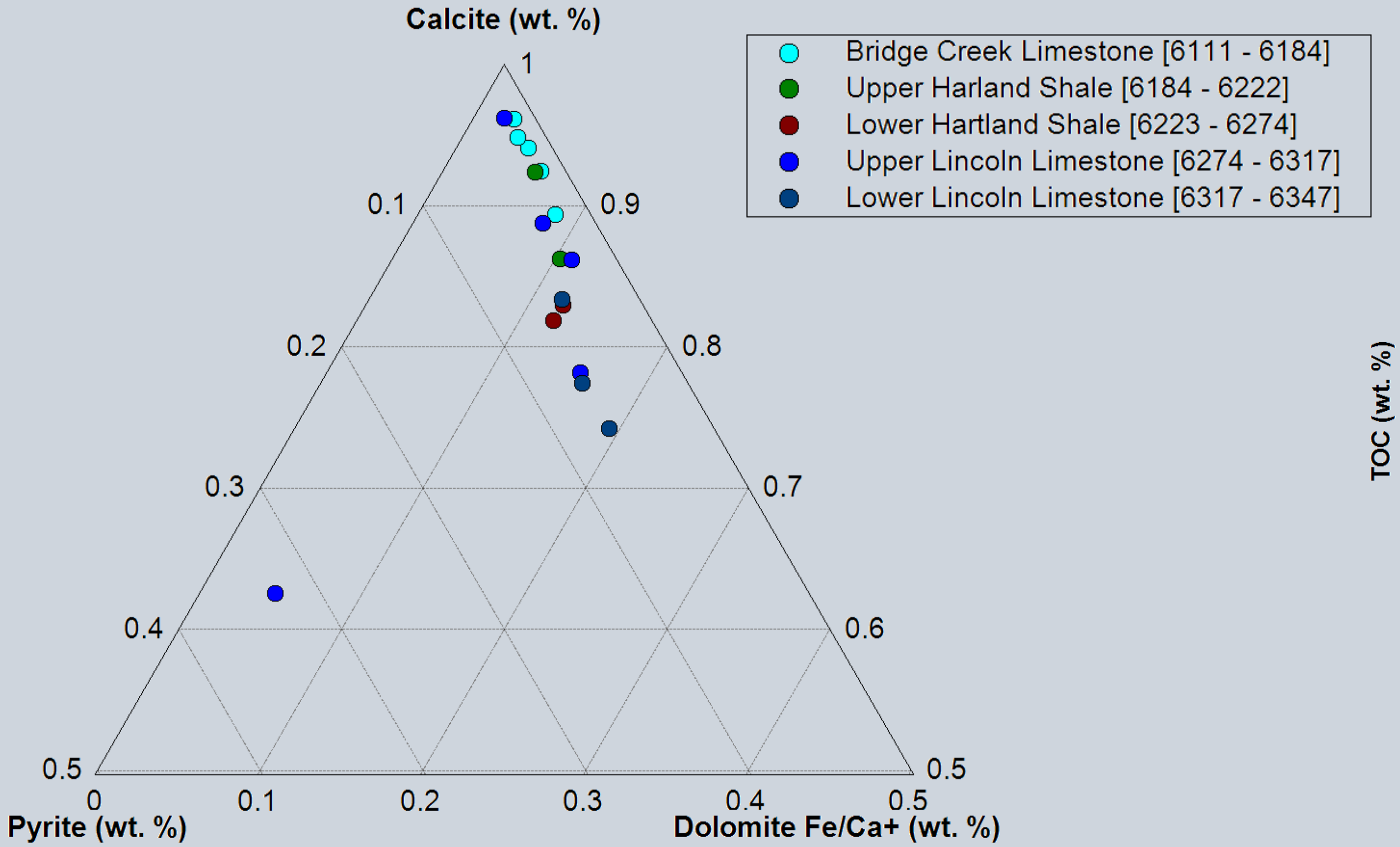

Inert Carbon
Present
Post-Mature
Mature
Hydrocarbon
Staining and/or
Contamination
Immature
Tmax (°C)
PI

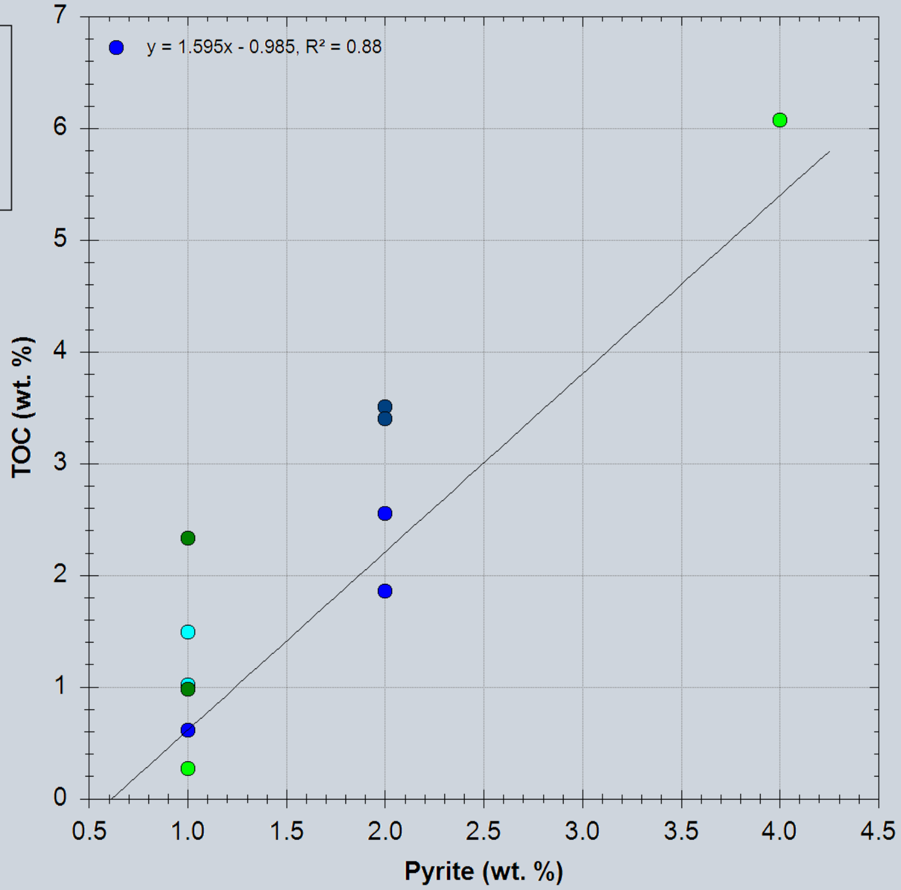

Potential and/or
Effective
Source
S1+S2
TOC (wt. %)

Bulk mineralogy and TOC



TOC affinity





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.
- Resolution
  - More complete sedimentary record, particularly within early "build" OAE 2 and Plenus Cold Event (Angus core e.g. Jones et al., 2021) allowing for more detailed event sequencing.
- Timing
  - Proxy signals of volcanic input will increase immediately prior to or contemporaneous with the initial carbon isotope excursion of OAE 2. Same for Plenus Cold Event.
  - Volcanic signals will be short lived, diminishing before other proxies return to pre-OAE 2 conditions.
- Mechanism
  - Link between intensified weathering, eutrophication, anoxia, and volcanism
  - Application to other times of pronounced carbon cycle perturbations such as PETM and the Triassic-Jurassic transition.

References

Du Vivier, A. D. C., A. D. Jacobson, G. O. Lehn, D. Selby, M. T. Hurtgen, and B. B. Sageman, 2015, Ca isotope stratigraphy across the Cenomanian-Turonian OAE 2: Links between volcanism, seawater geochemistry, and the carbonate fractionation factor: Earth and Planetary Science Letters, v. 416, p. 121-131.

Ernst, R. E., and N. Youbi, 2017, How Large Igneous Provinces affect global climate, sometimes cause mass extinctions, and represent natural markers in the geological record: Palaeogeography, Palaeoclimatology, Palaeoecology, v. 478, p. 30-52.

Jenkyns, H. C., 2018, Transient cooling episodes during Cretaceous Oceanic Anoxic Events with special reference to OAE 1a (Early Aptian): Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences, v. 376, p. 20170073.

Jenkyns, H. C., A. J. Dickson, M. Ruhl, and S. H. J. M. van den Boorn, 2017, Basalt-seawater interaction, the Plenus Cold Event, enhanced weathering and geochemical change: deconstructing Oceanic Anoxic Event 2 (Cenomanian–Turonian, Late Cretaceous): Sedimentology, v. 64, p. 16-43.

Jones, M. M., B. B. Sageman, D. Selby, B. R. Jicha, B. S. Singer, and A. L. Titus, 2021, Regional chronostratigraphic synthesis of the Cenomanian-Turonian Oceanic Anoxic Event 2 (OAE2) interval, Western Interior Basin (USA): New Re-Os chemostratigraphy and Ar-40/Ar-39 geochronology: Geological Society of America Bulletin, v. 133, p. 1090-1104.

Joo, Y. J., and B. B. Sageman, 2014, Cenomanian to Campanian carbon isotope chemostratigraphy from the Western Interior Basin, USA: Journal of Sedimentary Research, v. 84, p. 529-542.

Keller, G., T. Adatte, Z. Berner, E. Chellai, and D. Stueben, 2008, Oceanic events and biotic effects of the Cenomanian-Turonian anoxic event, Tarfaya Basin, Morocco: Cretaceous Research, v. 29, p. 976-994.

Kerr, A. C., 1998, Oceanic plateau formation: a cause of mass extinction and black shale deposition around the Cenomania-Turonian boundary?: Journal of the Geological Society, v. 155, p. 619 - 626.

Li, Y.-X., I. P. Montañez, Z. Liu, and L. Ma, 2017, Astronomical constraints on global carbon-cycle perturbation during Oceanic Anoxic Event 2 (OAE2): Earth and Planetary Science Letters, v. 462, p. 35-46.

Lowery, C. M., R. M. Leckie, R. Bryant, K. Elderbak, A. Parker, D. E. Polyak, M. Schmidt, O. Snoeyenbos-West, and E. Sterzinar, 2018, The Late Cretaceous Western Interior Seaway as a model for oxygenation change in epicontinental restricted basins: Earth-Science Reviews, v. 177, p. 545-564.

O'Brien, C. L., S. A. Robinson, R. D. Pancost, J. S. Sinninghe Damsté, S. Schouten, D. J. Lunt, H. Alsenz, A. Bornemann, C. Bottini, S. C. Brassell, A. Farnsworth, A. Forster, B. T. Huber, G. N. Inglis, H. C. Jenkyns, C. Linnert, K. Littler, P. Markwick, A. McAnena, J. Mutterlose, B. D. A. Naafs, W. Püttmann, A. Sluijs, N. A. G. M. van Helmond, J. Vellekoop, T. Wagner, and N. E. Wrobel, 2017, Cretaceous sea-surface temperature evolution: Constraints from TEX86 and planktonic foraminiferal oxygen isotopes: Earth-Science Reviews, v. 172, p. 224-247.

O'Connor, L. K., H. C. Jenkyns, S. A. Robinson, S. R. C. Remmelzwaal, S. J. Batenburg, I. J. Parkinson, and A. S. Gale, 2020, A Re-evaluation of the Plenus Cold Event, and the Links Between CO2, Temperature, and Seawater Chemistry During OAE 2: Paleoceanography and Paleoclimatology, v. 35.

Owens, J. D., T. W. Lyons, X. N. Li, K. G. Macleod, G. Gordon, M. M. M. Kuypers, A. Anbar, W. Kuhnt, and S. Severmann, 2012, Iron isotope and trace metal records of iron cycling in the proto-North Atlantic during the Cenomanian-Turonian oceanic anoxic event (OAE-2): Paleoceanography, v. 27.

Parker, A. L., 2016, Oceanic Anoxia Event 2 (~ 94 Ma) in the US Western Interior Sea: High resolution foraminiferal record of the development of anoxia in a shallow epicontinental sea.

Schröder-Adams, C., J. Herrle, D. Selby, A. Quesnel, and G. Froude, 2019, Influence of the High Arctic Igneous Province on the Cenomanian/Turonian boundary interval, Sverdrup Basin, High Canadian Arctic: Earth and Planetary Science Letters, v. 511, p. 76-88.

Scotese, C., H. Ilich, J. Zumberge, and S. Brown, 2007, The GANDOLPH Project: Year One Report: Paleogeographic and Paleoclimatic Controls on Hydrocarbon Source Rock Deposition, A Report on the Methods Employed, the Results of the Paleoclimate Simulations (FOAM), and Oils/Source Rock Compilation, Conclusions at the End of Year One, February, 2007.

Tsikos, H., H. Jenkyns, B. Walsworth-Bell, M. Petrizzo, A. Forster, S. Kolonic, E. Erba, I. P. Silva, M. Baas, and T. Wagner, 2004, Carbon-isotope stratigraphy recorded by the Cenomanian–Turonian Oceanic Anoxic Event: correlation and implications based on three key localities: Journal of the Geological Society, v. 161, p. 711-719.

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