Unbioturbated Carbonaceous Shales in the Cretaceous Western Interior Seaway Record Oxic Bottom–Water Conditions*

Shahin E. Dashtgard[1] and James MacEachern[2]

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[1]Earth Sciences, Simon Fraser University, Burnaby, British Columbia, Canada (sdashtgard@gmail.com)
[2]Earth Sciences, Simon Fraser University, Burnaby, British Columbia, Canada

Abstract

Dark gray to black shales are prevalent in the Cretaceous Western Interior Seaway (WIS). Many of these shales are unburrowed suggesting that macrofauna were unable to survive in the paleo-environment, and this has led to interpretations that deeper parts of the WIS may have varied from suboxic (0.2 – 2.0 mg l-1) to anoxic (< 0.2 mg l-1). A comparison of micropaleontological, geochemical, and ichnological datasets from the Joli Fou, Viking, and Westgate formations, Alberta, Canada (Albian to Cenomanian) is undertaken to determine the oxygenation of bottom waters at the time of shale deposition. These shales occur in environments interpreted as upper offshore through to shelf, and the shales are sedimentologically and ichnologically similar to carbonaceous shales preserved throughout the WIS from the Late Albian to the Santonian. Geochemical proxies (e.g., Fe/Al and Mo/Al ratios, Re concentration) and foraminiferal data indicate that the under- and unbioturbated, carbonaceous shales tested in this study were actually deposited under oxic bottom water conditions. Based on this and the results of recent work from the Gulf of Mexico, we conclude that the paucity of burrowing is a manifestation of reduced oxygenation (low oxic: 2.0 < DO < 5.0 mg l-1), which was sufficient to support diverse benthic foraminiferal communities but not burrowing macrofauna. From these data, we propose a hierarchy of datasets for recognizing decreasing oxygen saturation. 1) Highly burrowed sediments (BI ≥ 3) indicate the presence of macrofauna on the seafloor and dissolved oxygen (DO) contents likely exceeding 80% saturation (> 5.0 mg l-1). 2) Under- and unbioturbated carbonaceous shales (BI 0-2) with diverse foraminiferal contents suggest low-oxic conditions (< 80% saturation, but > 2 mg l-1 DO). 3) Sub-oxic and anoxic conditions can be determined from geochemical proxies (e.g., Fe/Al > 0.5, Mo/Al > 0.001). These sediments will show low diversities of foraminifera and be unbioturbated (BI 0). 4) Euxinic bottom water (H_2S present) is best determined from Mo (> 15 ppb) and Re (> 15 ppb) enrichment, coupled with a complete lack of benthic foraminifera and no bioturbation (BI 0).

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UNBIOTURBATED CARBONACEOUS SHALES IN THE CRETACEOUS WESTERN INTERIOR SEAWAY RECORD OXIC BOTTOM–WATER CONDITIONS

ARISE Applied Research in Ichnology and Sedimentology

SFU

Shahin Dashtgard*
James MacEachern

Objective

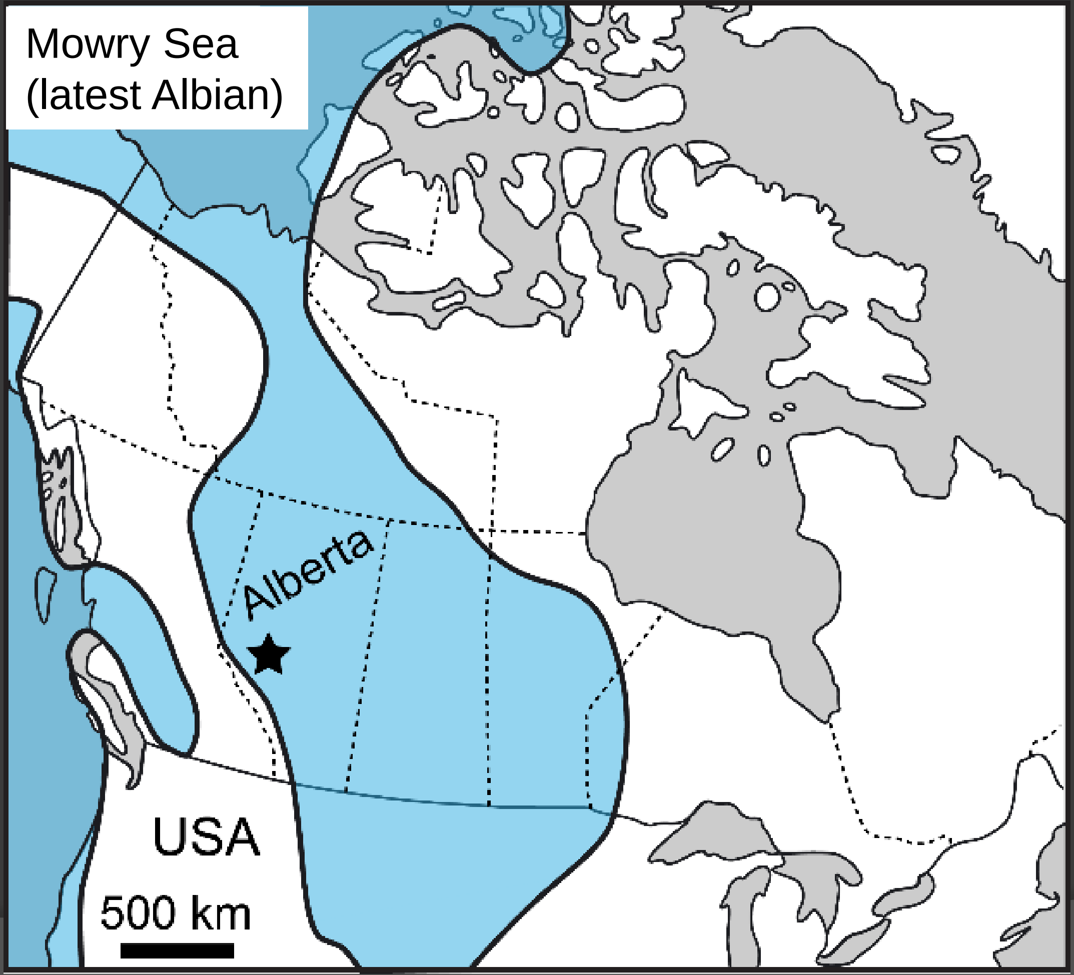
Is a paucity of bioturbation in marine mudstones indicative of anoxia?

If not, what does a paucity of burrowing represent?

Compare ichnological, foraminiferal, and geochemical datasets from the Western Interior Seaway

Study Area & Interval

Lower Cretaceous: Joli Fou – Viking – Westgate Formations, Alberta



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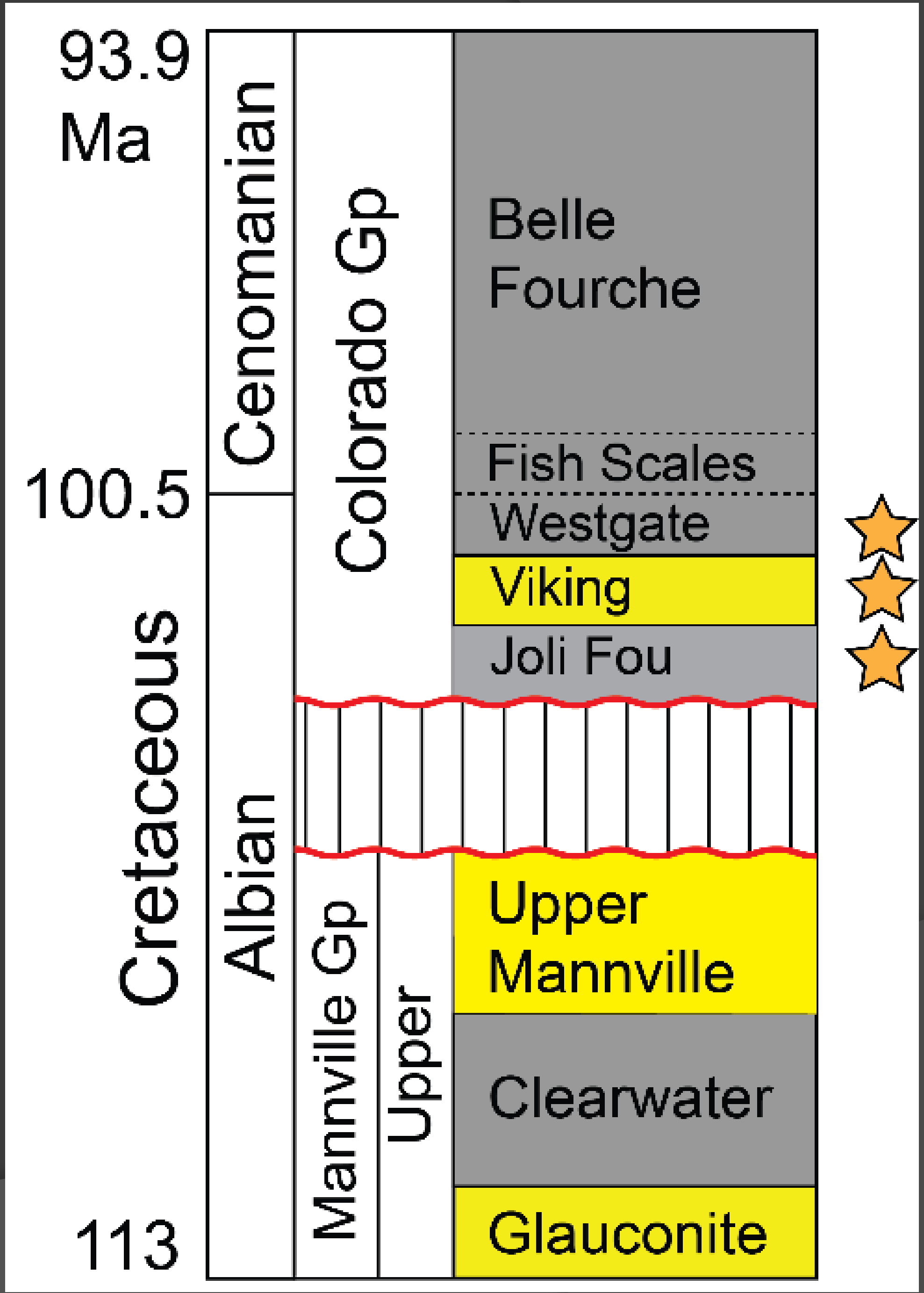


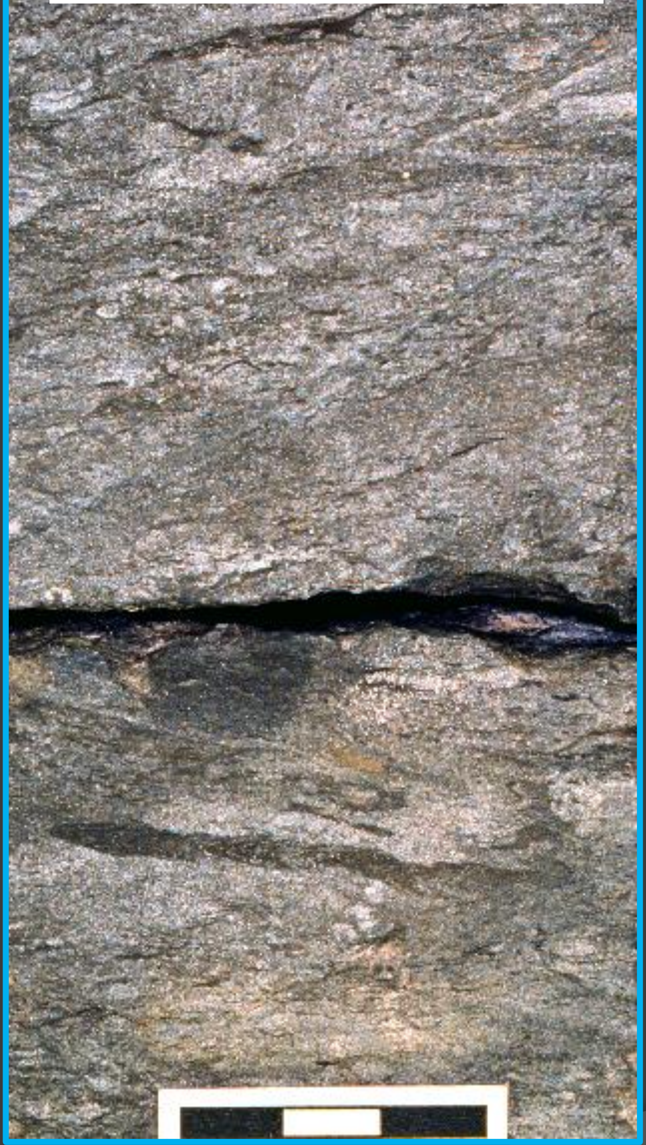
Mudstone Facies

36 mudstone / shale samples

Characterize ichnological, foraminiferal, and geochemical signatures by facies:

- **Highly bioturbated mudstone [Upper & Lower Offshore]**

Upper offshore sandy mdst



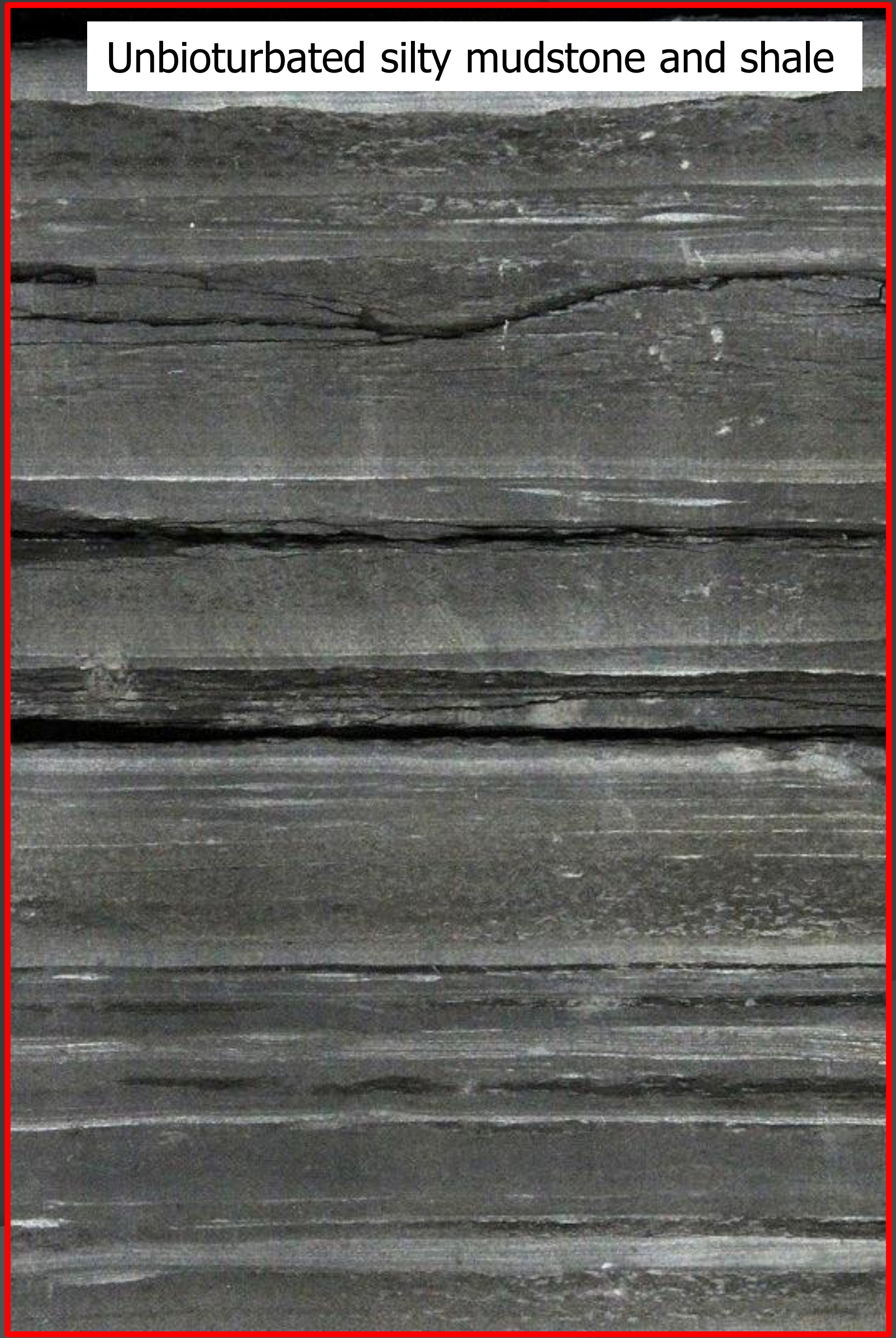
Lower offshore silty mudstone

Mudstone Facies

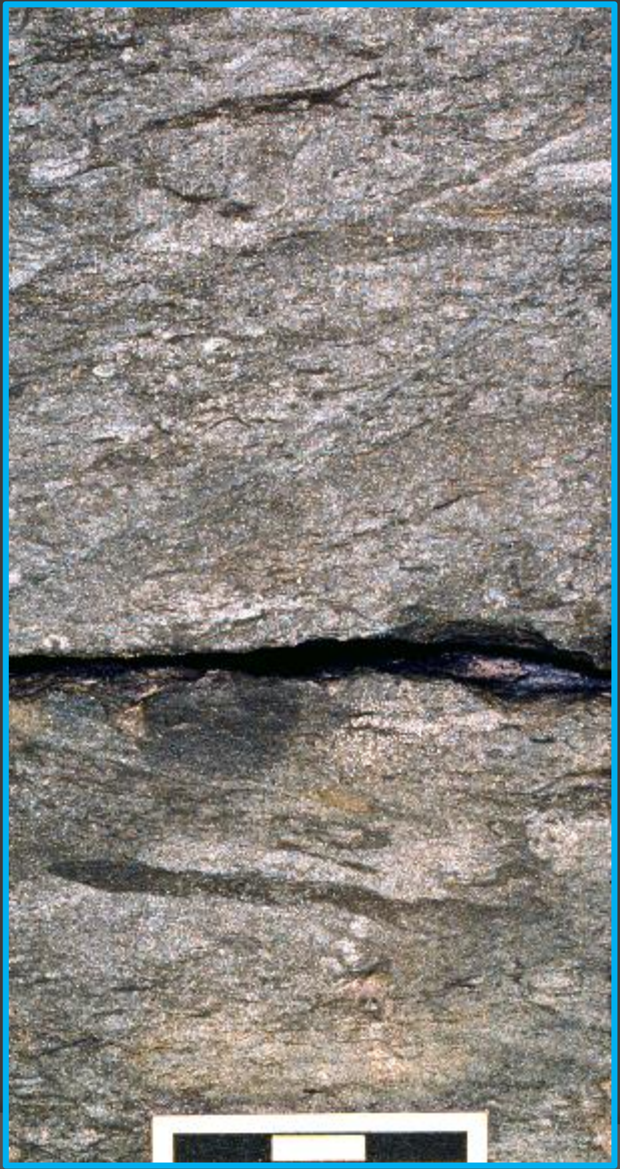
36 mudstone / shale samples

Characterize ichnological, foraminiferal, and geochemical signatures by facies:

- **Unbioturbated dark mudstones & shale [Fully Marine / Shelf]**



Ichnological Characteristics

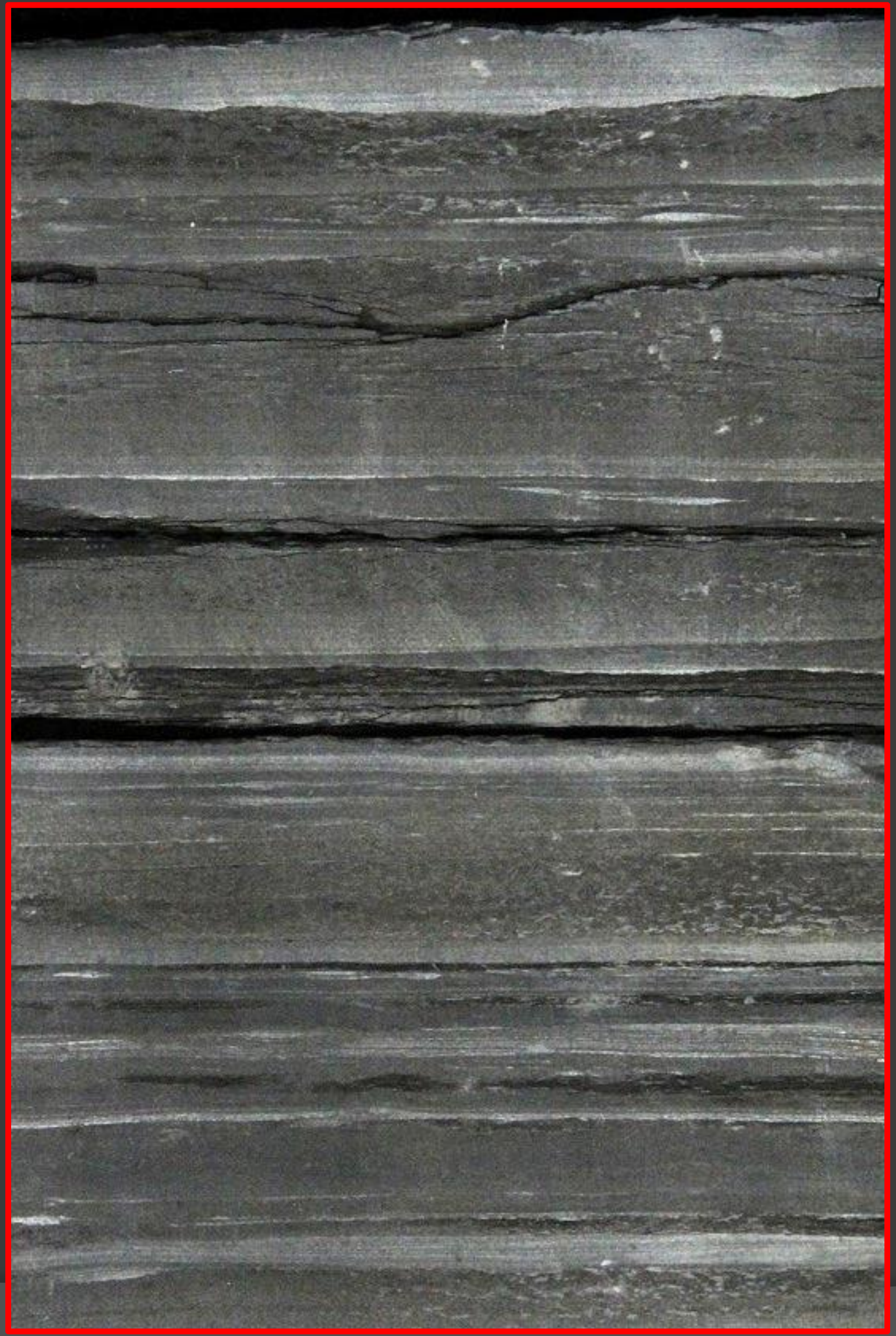


Highly bioturbated mudstone

Abundant oxygen in water column = support burrowing infauna

Healthy ecosystem

Indicative of high oxic conditions



Ichnological Characteristics

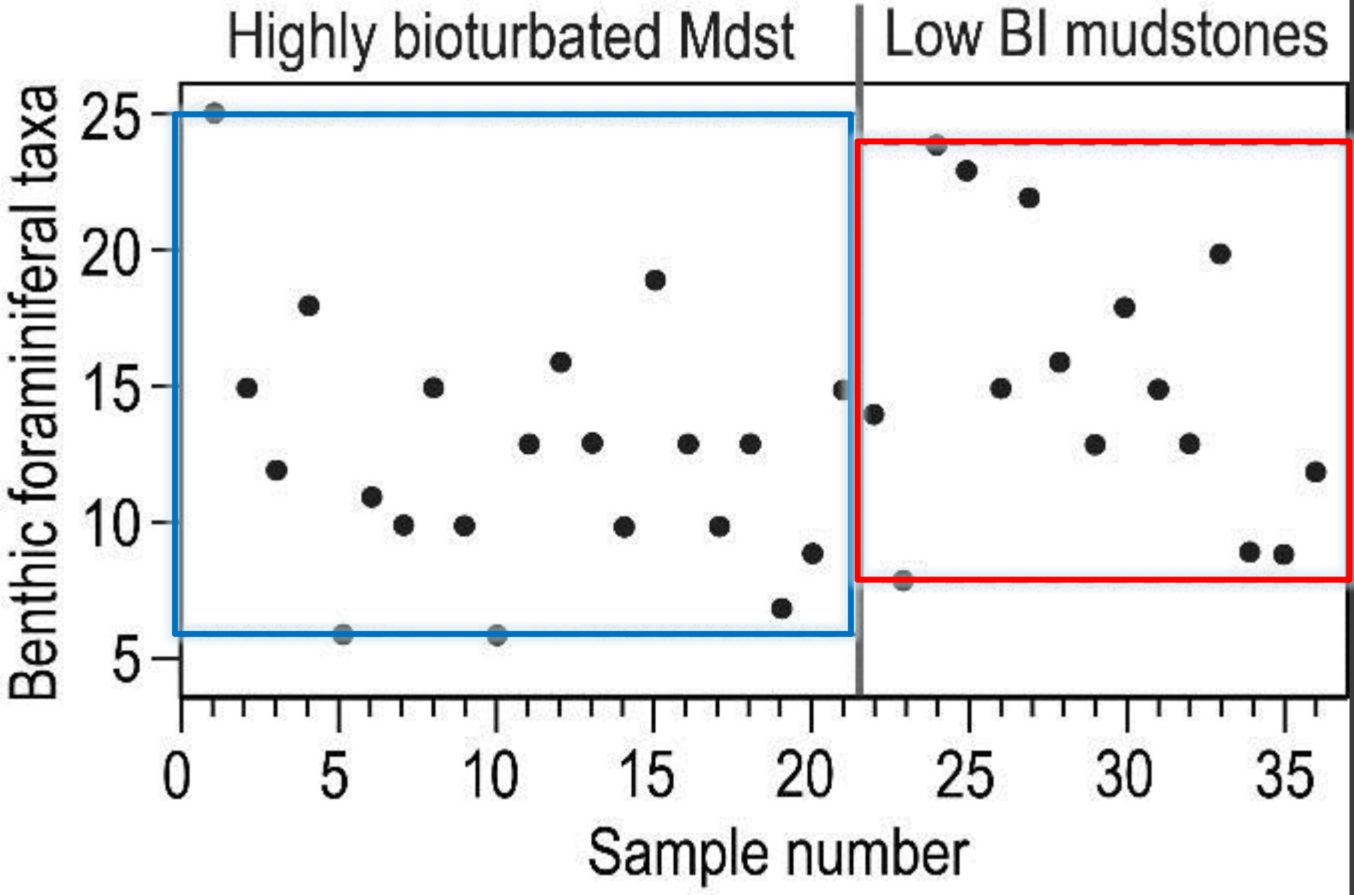
Low BI and Unburrowed mudstone

Burrowing infauna rarely present and, if so, are small.

Apparent lack of bioturbation attributed to unhealthy environment

Suboxia? Anoxia?

Micropaleontological Characteristics

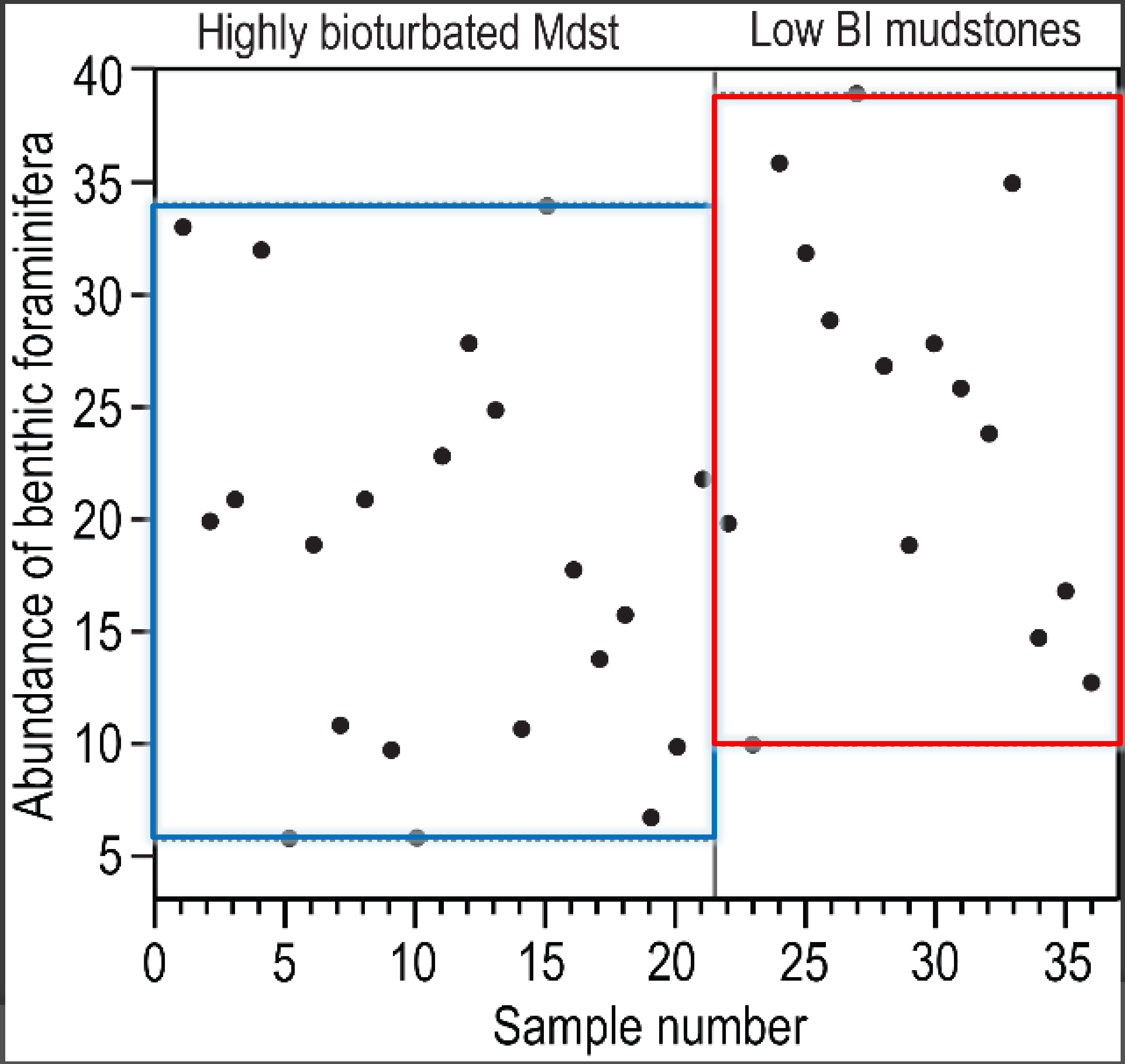


From Dashtgard and MacEachern, 2016

No difference in foram diversity between highly bioturbated and low BI mudstones

"…foraminifera are potential proxies for the lower limits [of O_2] but once levels rise to values of perhaps >1 to 2 ml l^{-1} (1.3 or 2.7 mg l^{-1}), there is no longer a relationship between oxygen levels and abundance." – Murray (2001) and Kaiho, 1994)

Micropaleontological Characteristics

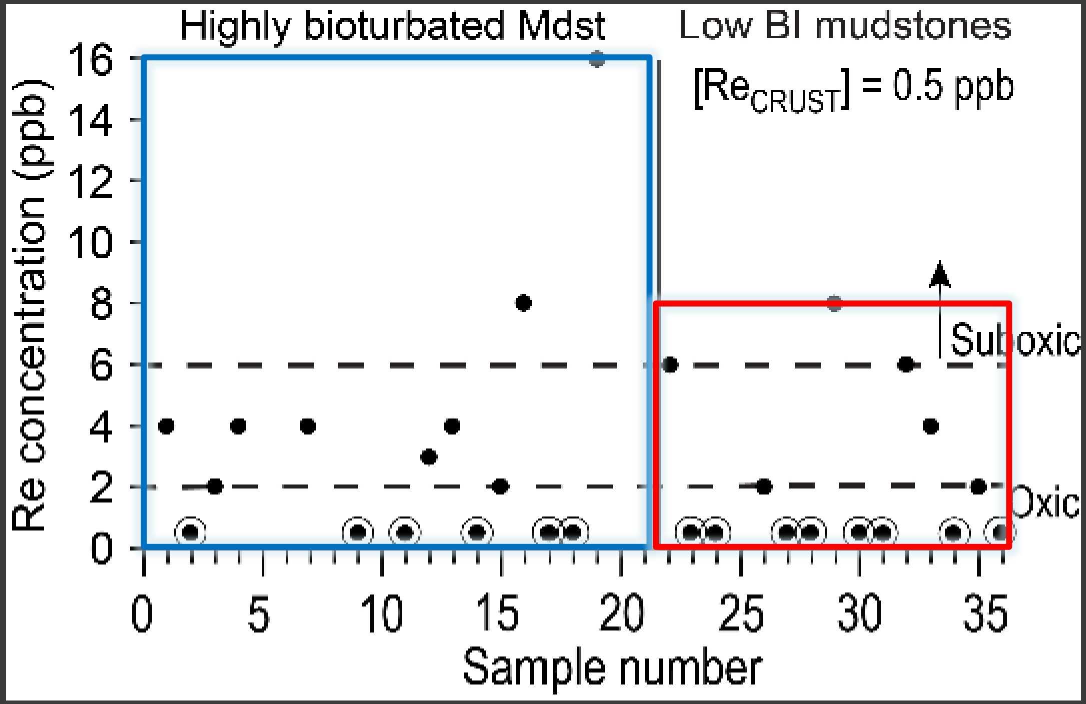


In fact, foraminifera are more abundant in low BI mudstones *vs* their highly bioturbated counterparts!

From Dashtgard and MacEachern, 2016

Geochemical Characteristics

Lack of Rhenium (Re) and Molybdenum (Mo) enrichment reflects oxygenated seafloor



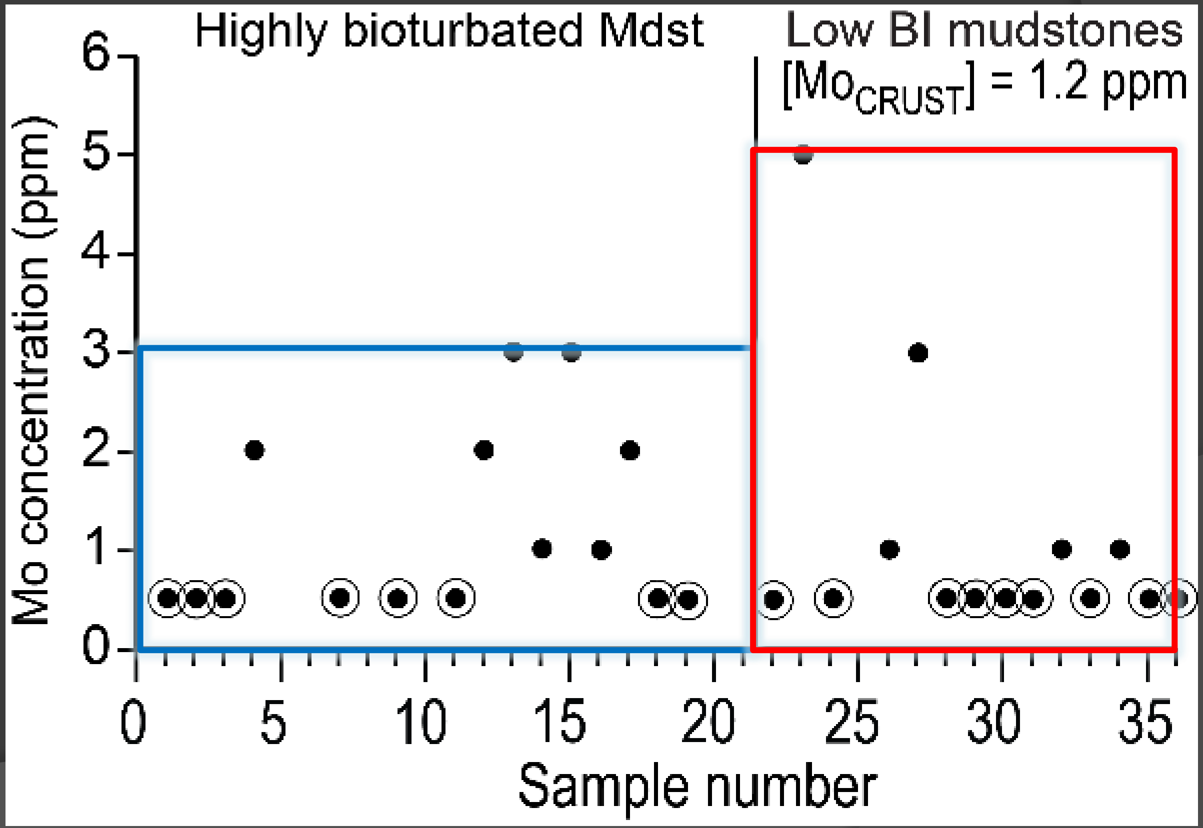
Dashtgard and MacEachern, 2016

[Rhenium]

> 6 ppb recognized in suboxic settings (Crusius et al., 1996)

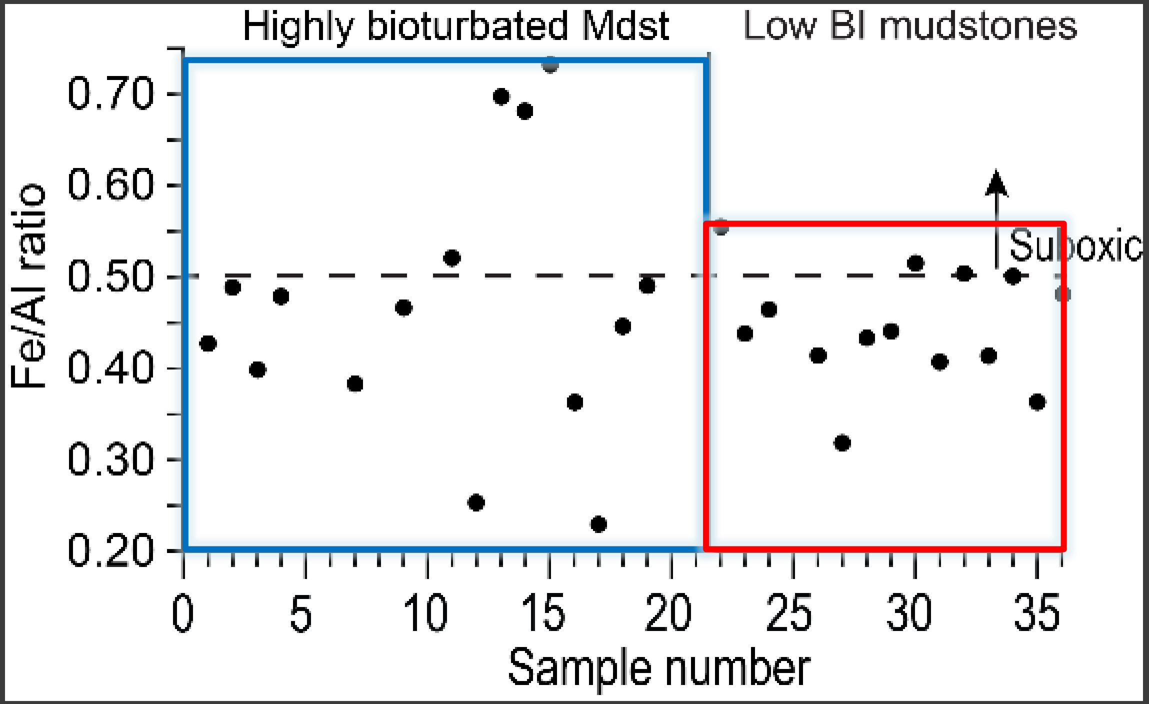
[Molybdenum]

>20 ppm recognized in euxinic sediments (Crusius et al., 1996)



Geochemical Characteristics

Iron/Aluminum (Fe/Al) and Molybdenum/Aluminum (Mo/Al) ratios also indicate an oxygenated seafloor



Dashtgard and MacEachern, 2016

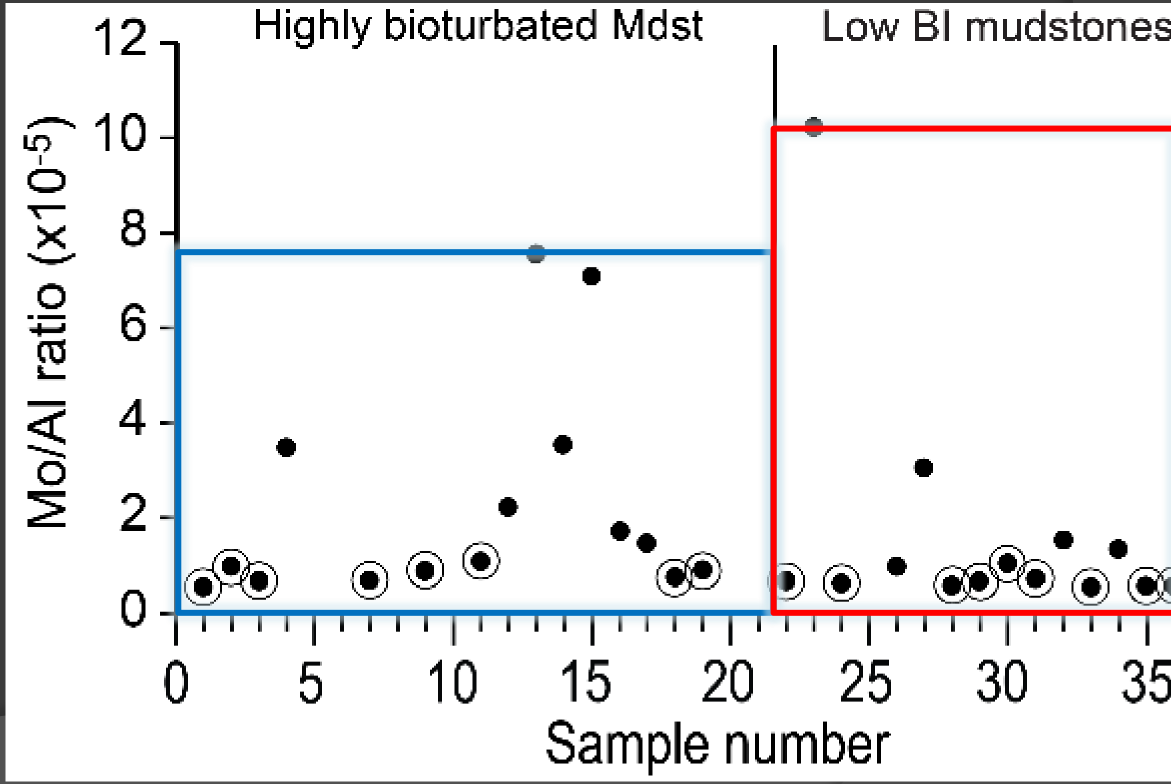
Fe/Al Ratio

Ratio > 0.50 recognized as low O_2

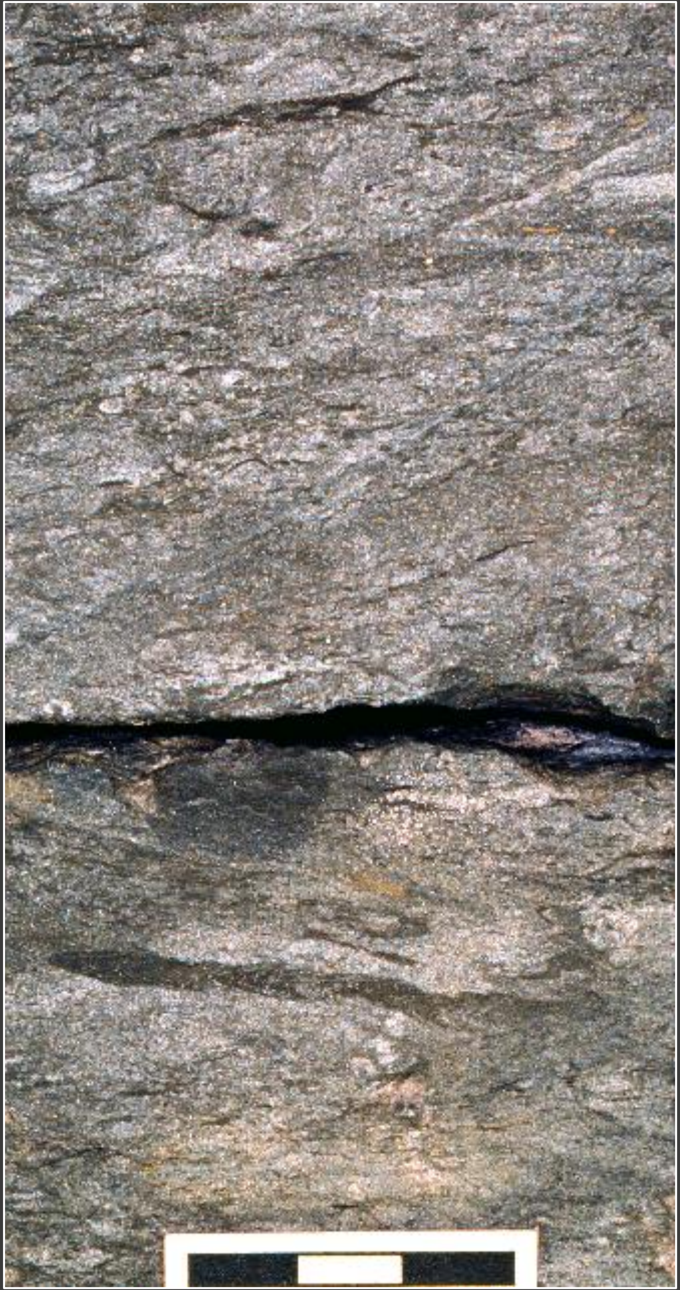
Crustal concentration (Gordon et al. 2009)

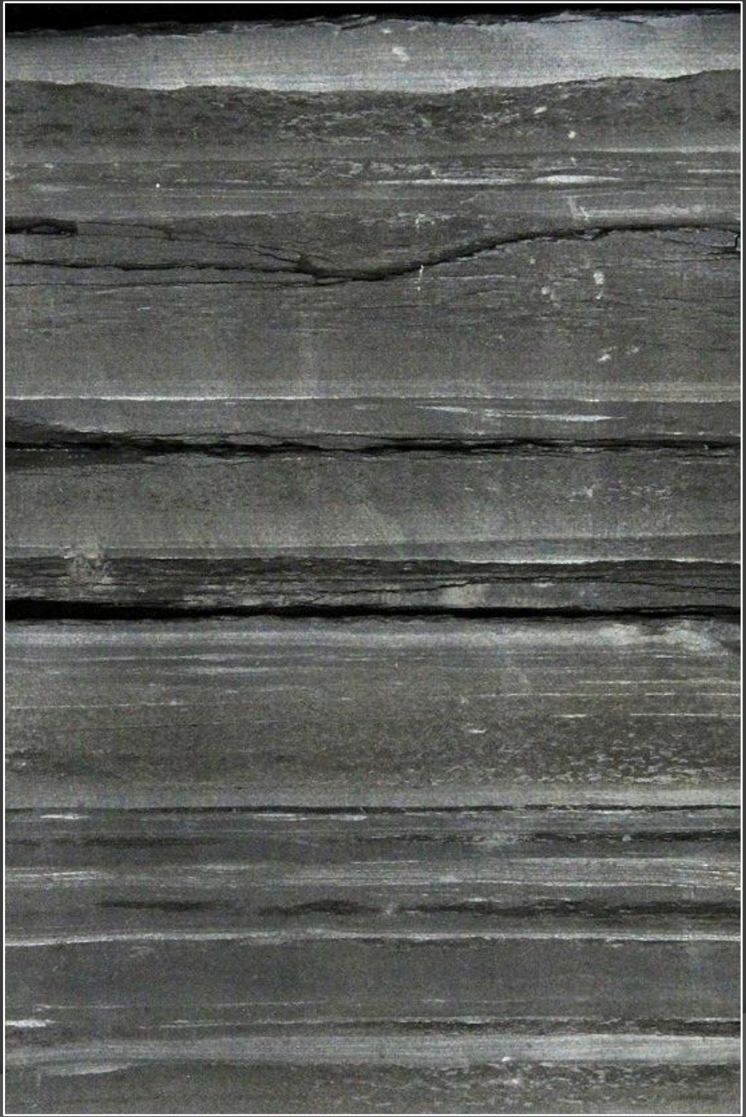
Mo/Al ratio

Ratio > 1 x 10^{-3} recognized as low O_2 (Gordon et al. 2009)



Summary of Results





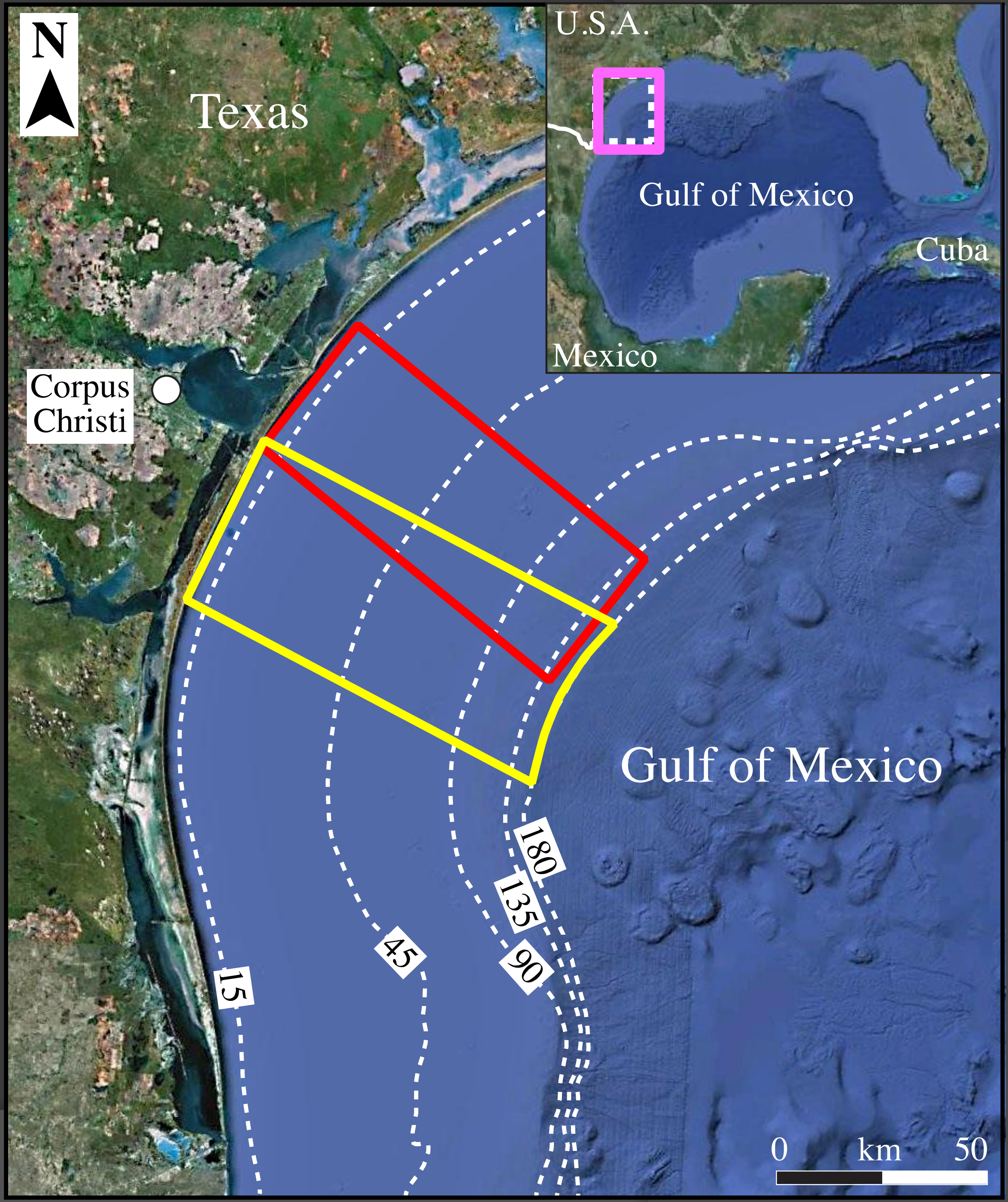
Both burrowed and unburrowed samples deposited below oxic bottom waters

Why the major difference in bioturbation then?

Gulf of Mexico

30 Box Cores: 12 to **50 cm** high, 12 to 140 m WD

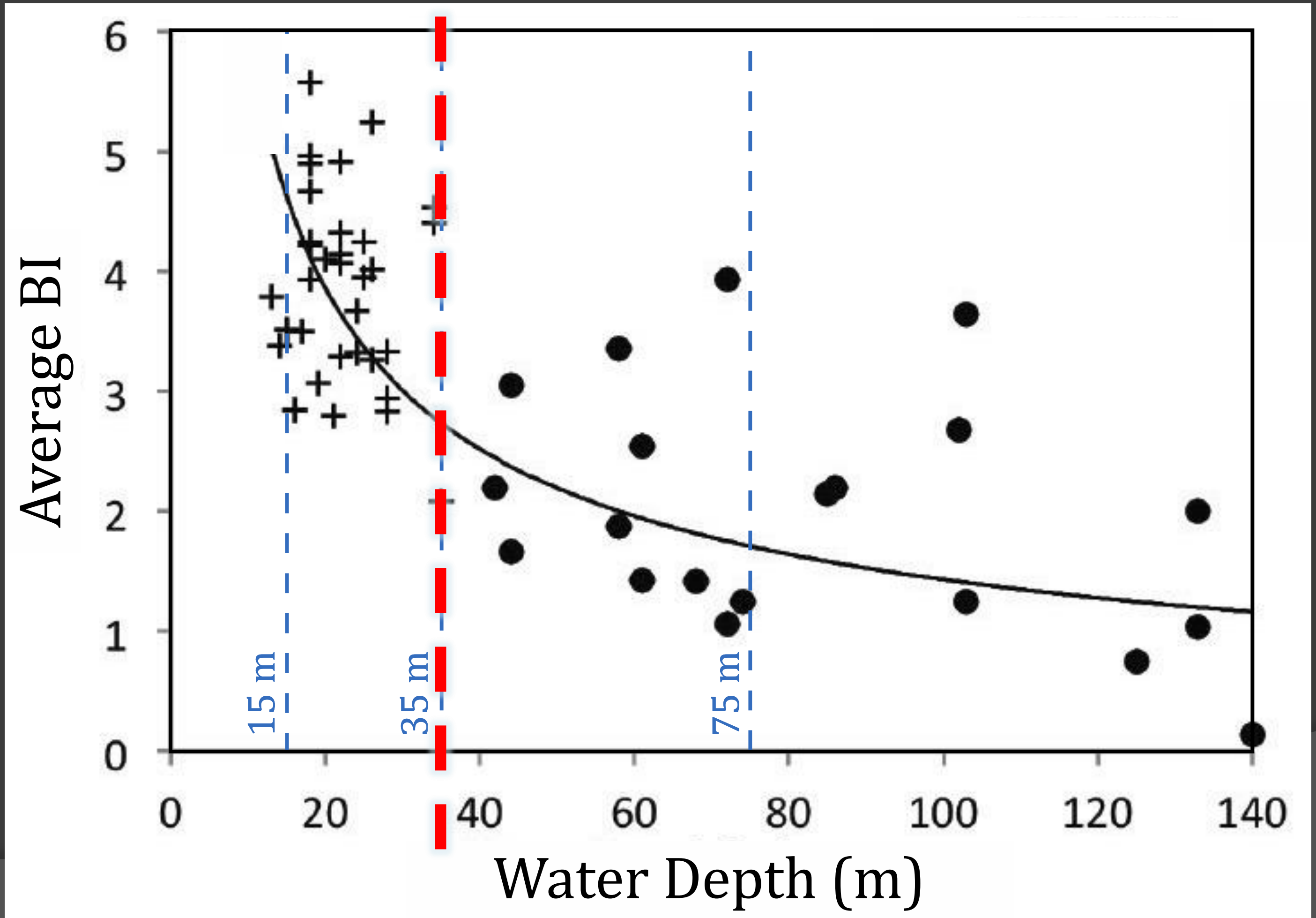
26 Pipe Cores: 70 – 200 cm high, 13 to 133 m WD



(From Dashtgard et al., 2015)

Bioturbation Intensity

BI 1 to 2 in sediments below 35 m water depth
BI of 1 typical for sediments below 100 m WD

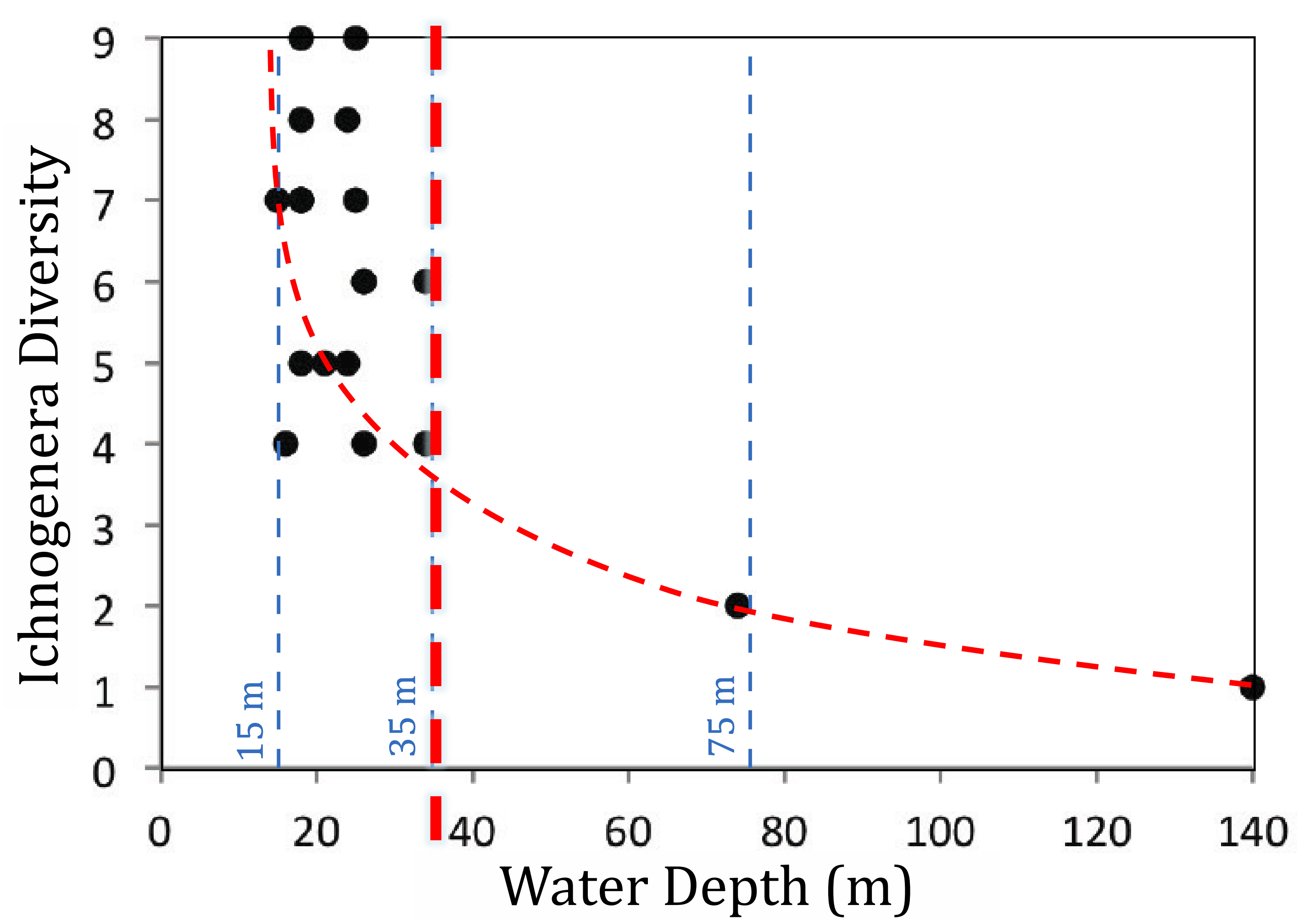


(From Dashtgard et al., 2015)

Data from Snedden (1985) and White (1985)

Bioturbation Diversity

Trace diversity below 35 m WD < 50% of the diversity above 35 m WD. Decreases offshore.

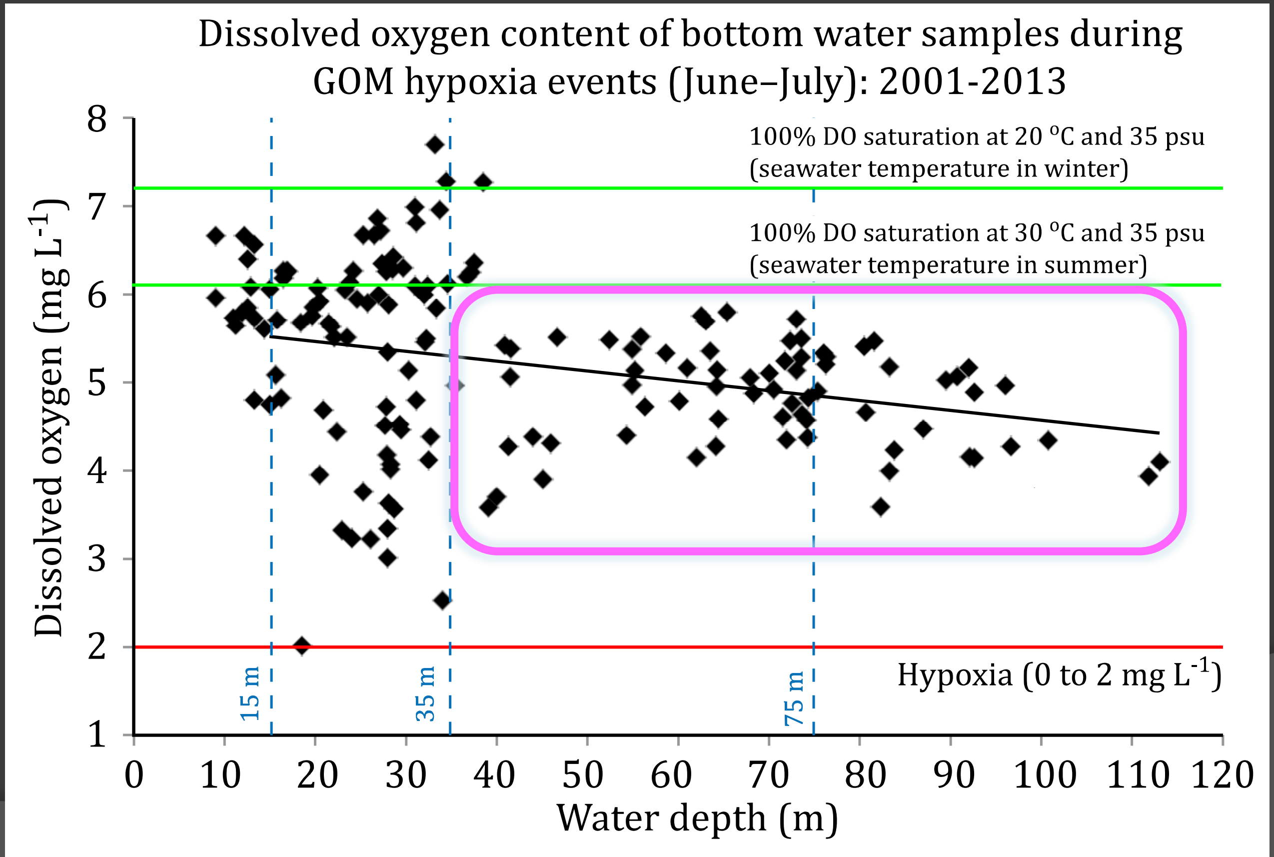


(From Dashtgard et al., 2015)

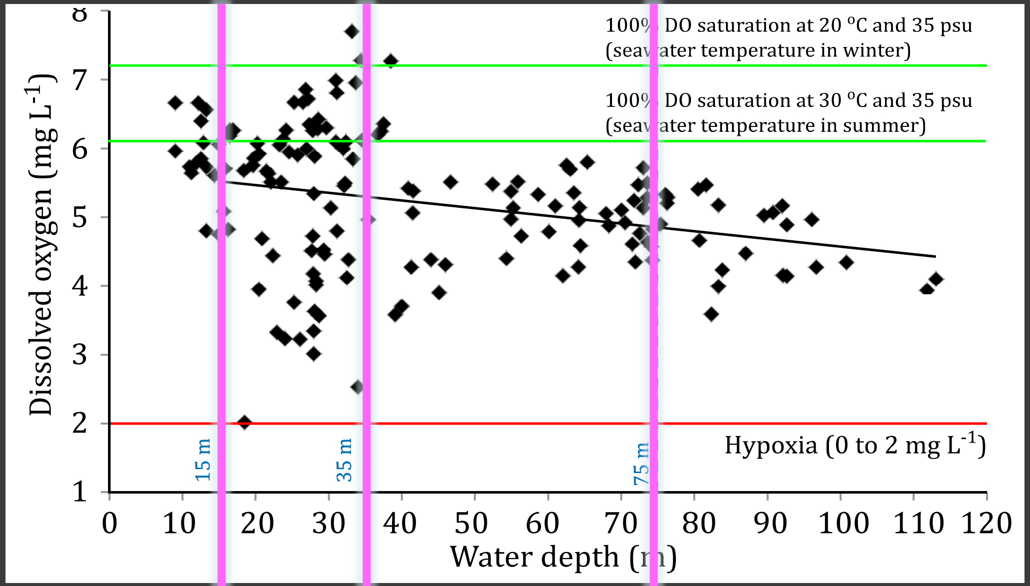
Dissolved Oxygen

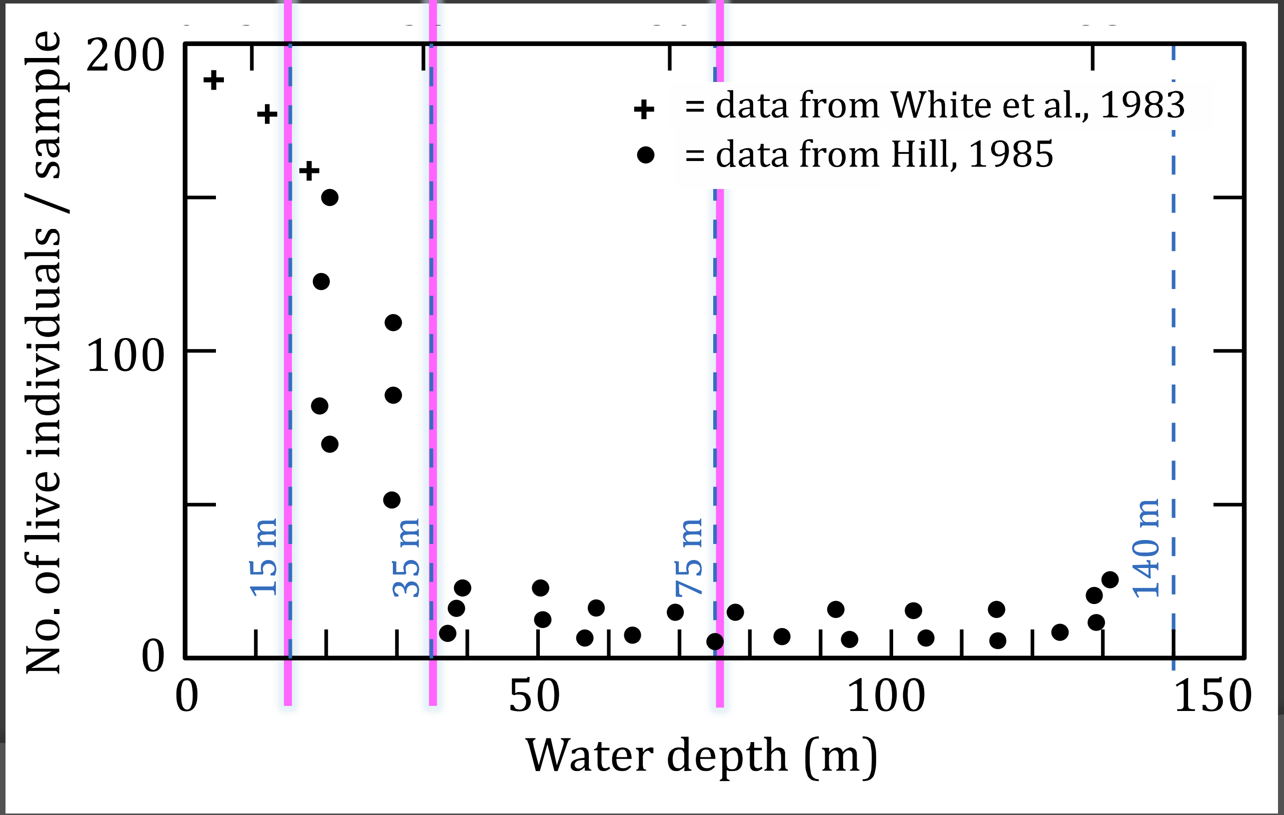
Below 35 m WD: DO is consistently < 80% saturation and decreases offshore

BUT – Water is still **OXIC**! [Low oxic 2 < DO < 5 mg L^{-1}]



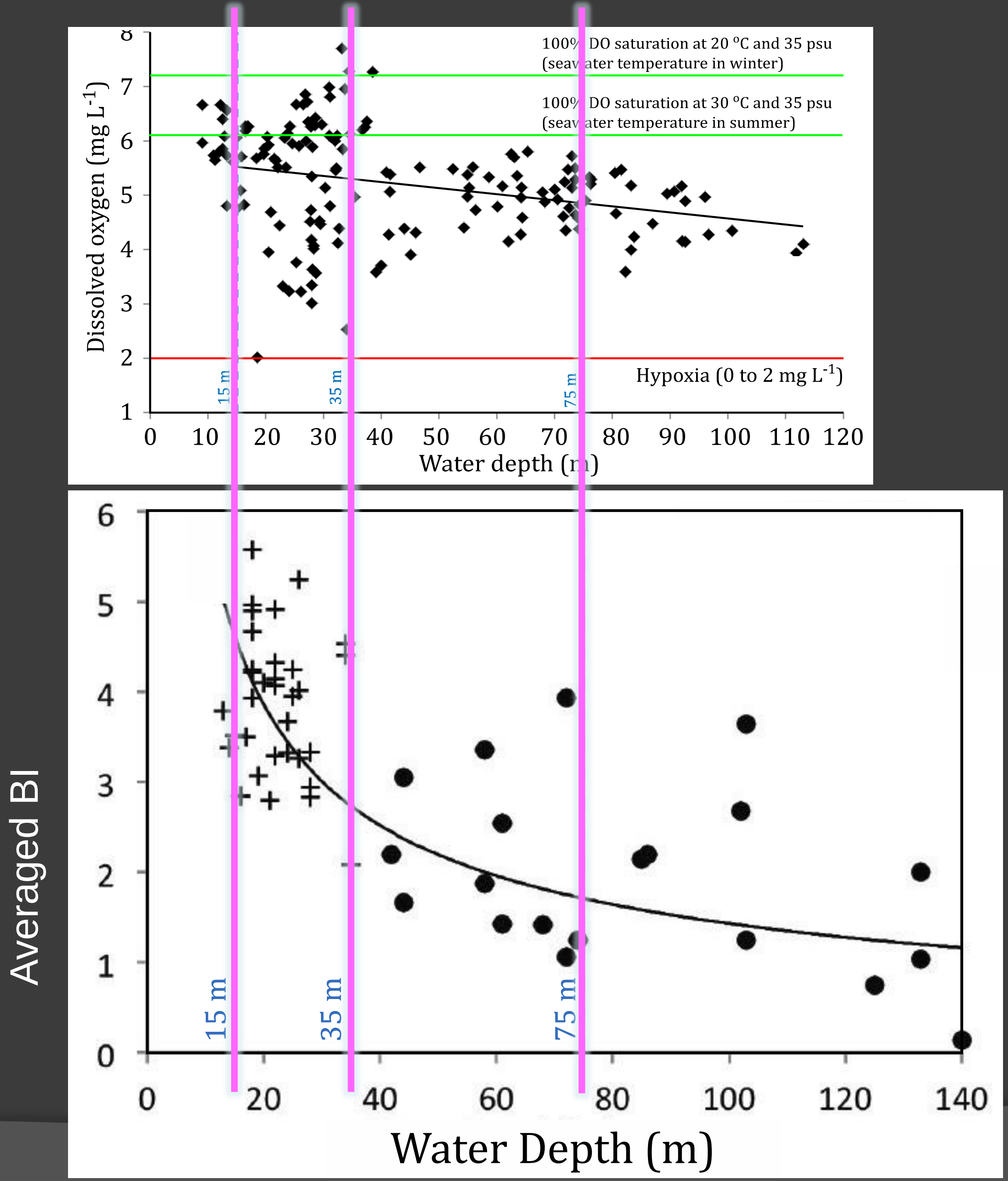
(From Dashtgard et al., 2015)





Bioturbation trends track major decrease in infauna density and diversity when:

Dissolved Oxygen decreases from 100% saturation to < 80% saturation



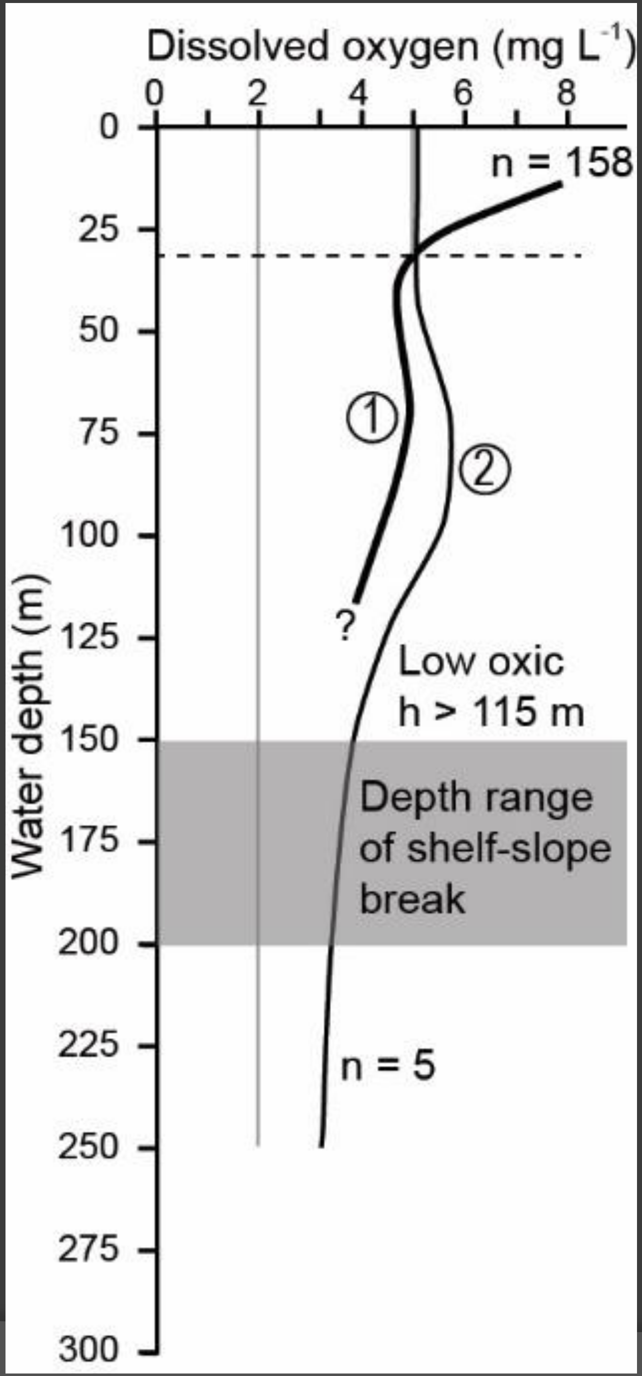
Major decrease in average bioturbation intensity (and trace diversity) correlates to:

Decrease in Dissolved Oxygen from 100% saturation to < 80% saturation

Gulf of Mexico Summary

Infauna are not prevalent when Dissolved Oxygen saturation drops below 80% saturation [Low oxic $2 < DO < 5$ mg L^{-1}]

A lack of infauna = a lack of bioturbation (low BI mudstones)



High Oxic

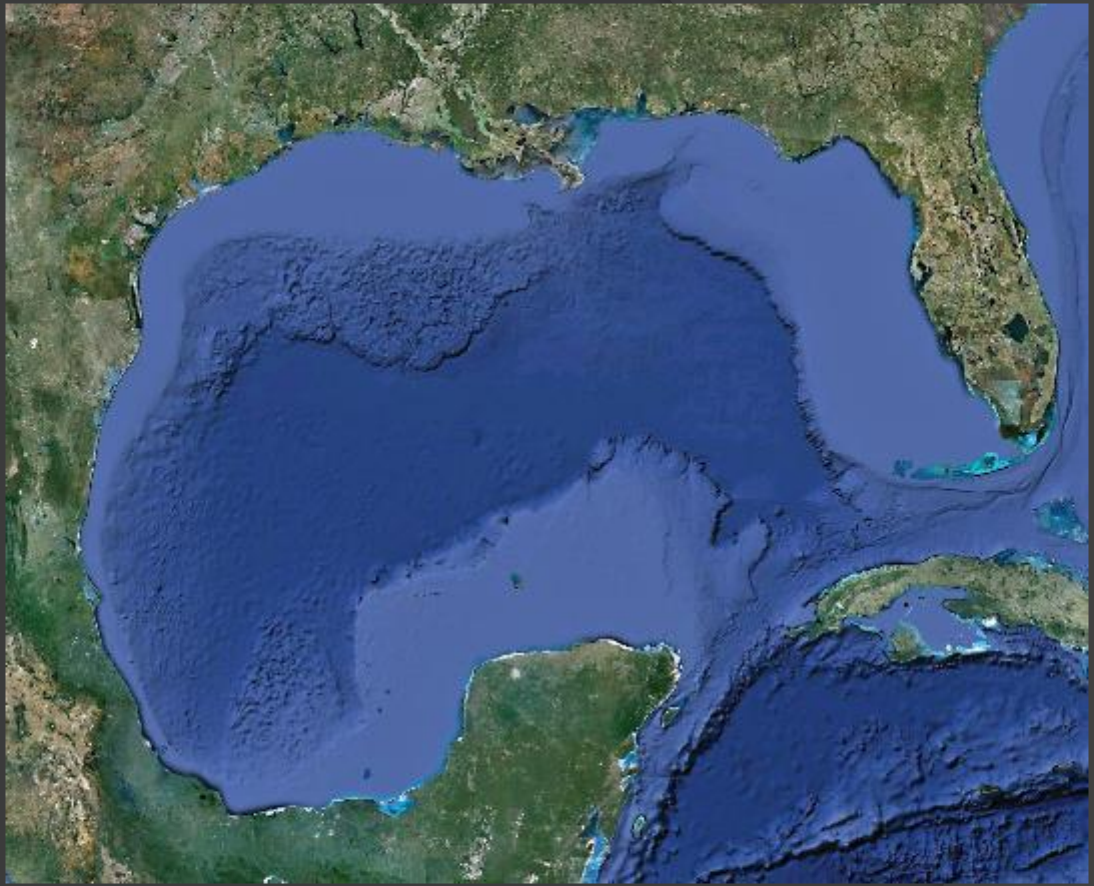
Low Oxic

Gulf of Mexico

Semi-enclosed seaway

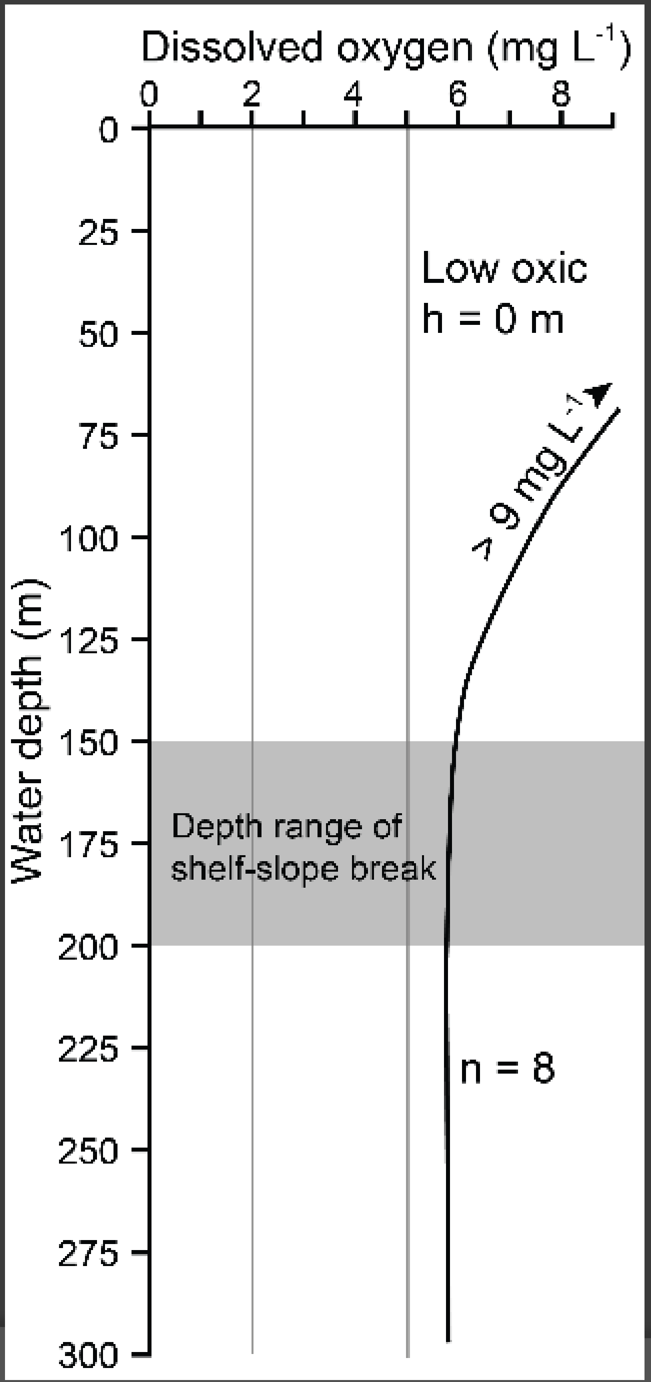
Surface water T: 27 ºC

T at 200 m: 15 ºC



Low oxic conditions prevalent below storm-wave base to > 200 m water depth.

Dashtgard and MacEachern, 2016



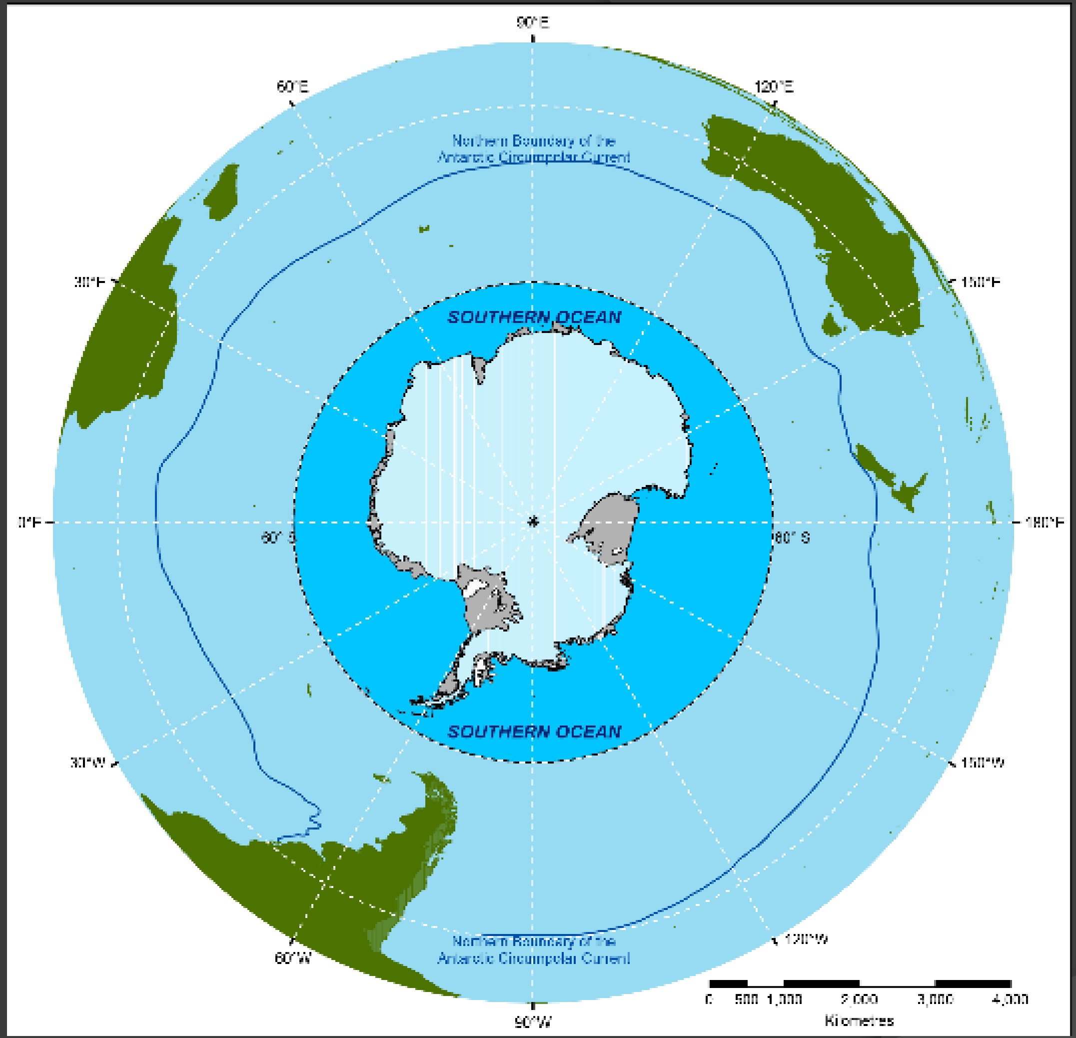
High Oxic

Antarctic Ocean

Open polar ocean

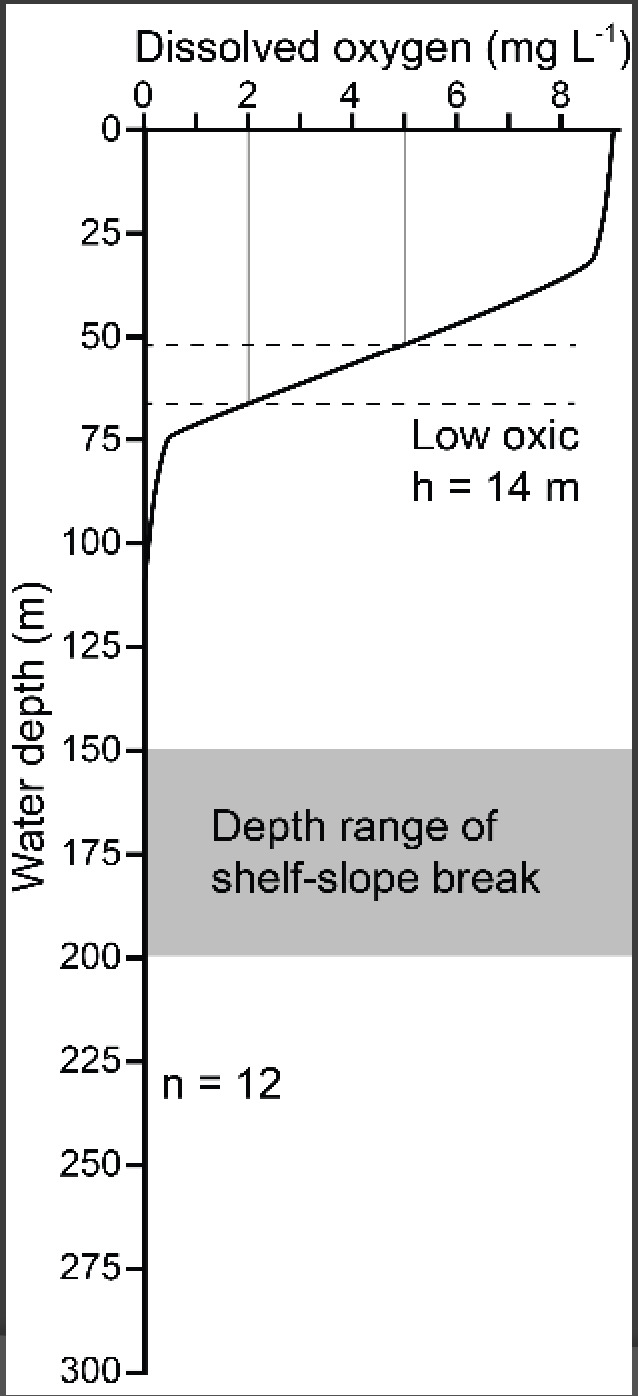
Surface water T: -0.5 ºC

Water T at 200 m: 2 ºC



http://data.aad.gov.au

Cold waters sustain high oxic conditions. No low oxic zone developed.



High Oxic

Low Oxic

Suboxic / Anoxic

Black Sea

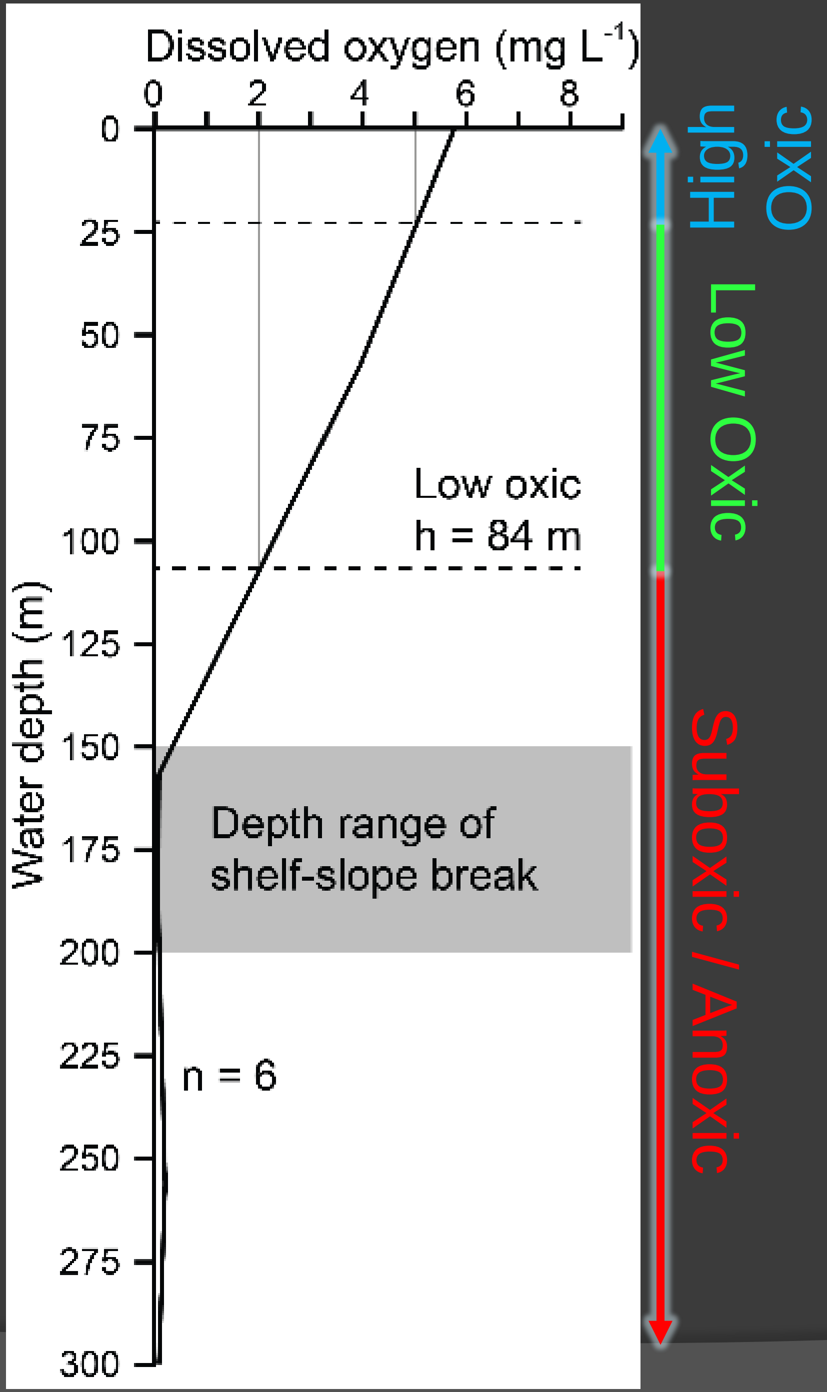
http://earthobservatory.nasa.gov/

Restricted basin

Surface water T: 15 ºC

T at 200 m: 9 ºC

Low oxic conditions developed in a narrow vertical zone. Likely not well expressed. Mostly anoxic.

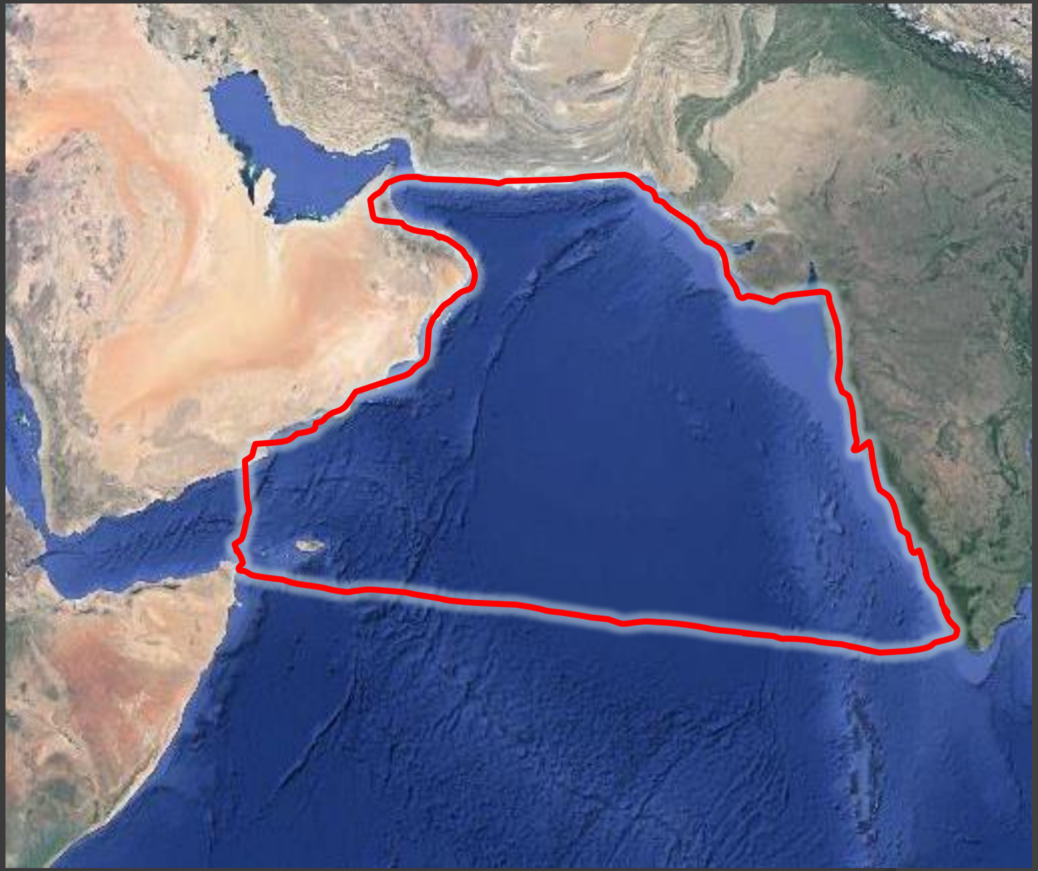


Arabian Sea

Open tropical ocean

Surface water T: 26 ºC

Water T at 200 m: 18 ºC

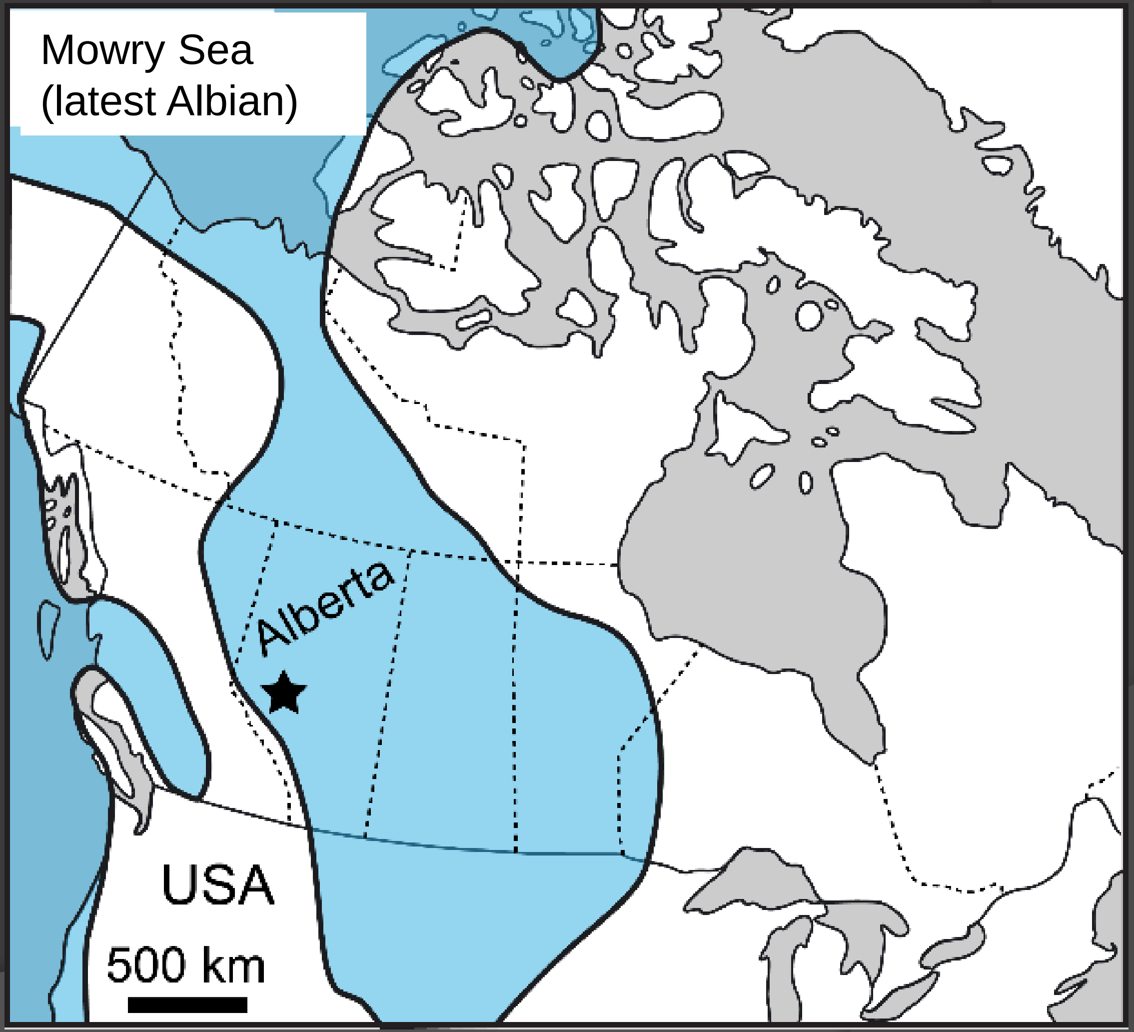


Google Earth

Low oxic conditions prevalent in shallow water (below storm-wave base)

Summary of Ocean Oxygenation

Low oxic conditions are expected in **warm**, **shallow** basins [with ocean circulation]



From Dashtgard and MacEachern, 2016

Summary Slide 1

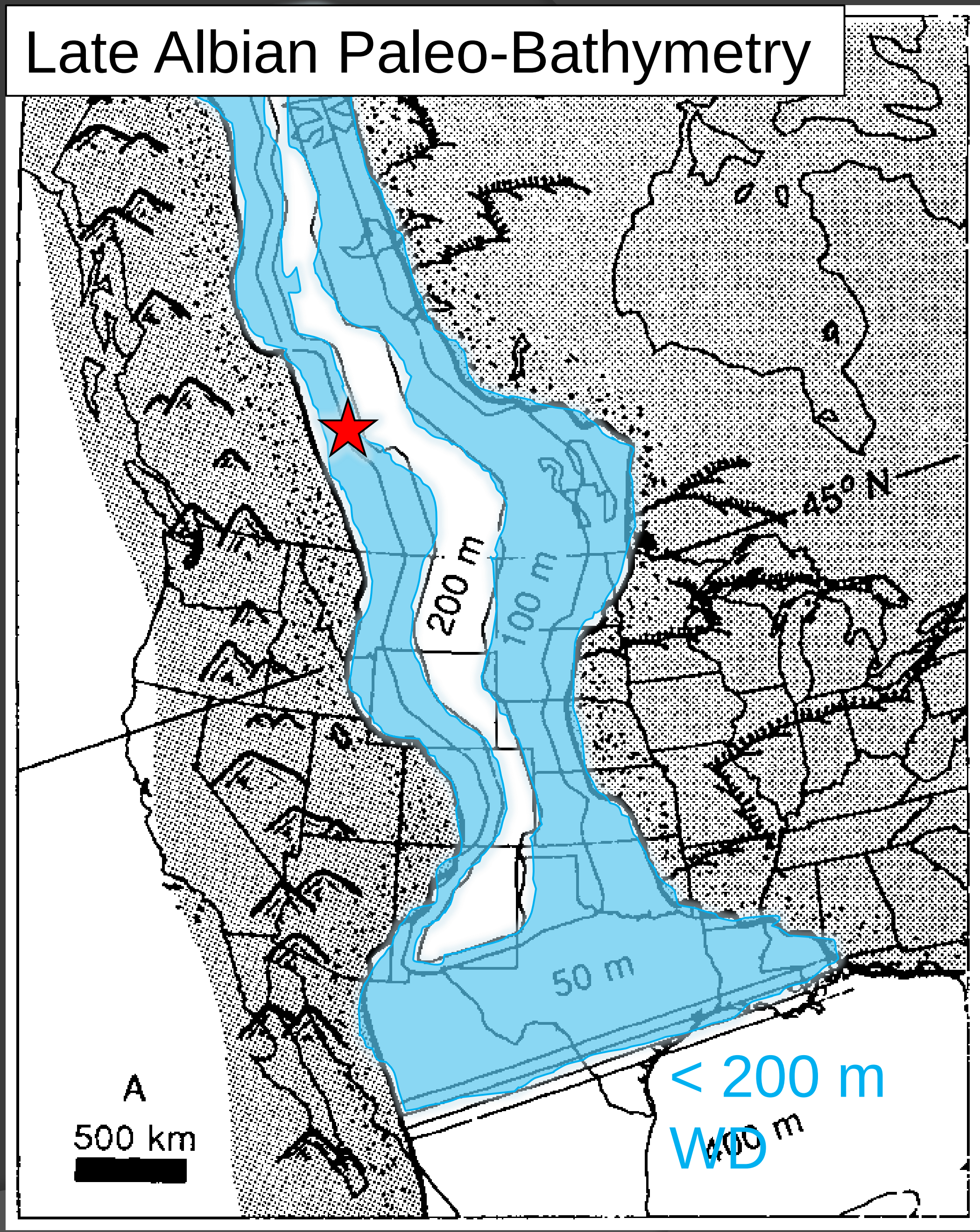
Unbioturbated Mudstone ≠ Anoxia or suboxia (< 2 mg l^{-1}; < 1.5 ml l^{-1})

Decrease in bioturbation correlates to a *reduction in dissolved oxygen* in oxygenated (oxic) seawater

= low oxic conditions! [Low oxic 2 < DO < 5 mg L^{-1}]

Summary Slide 2A

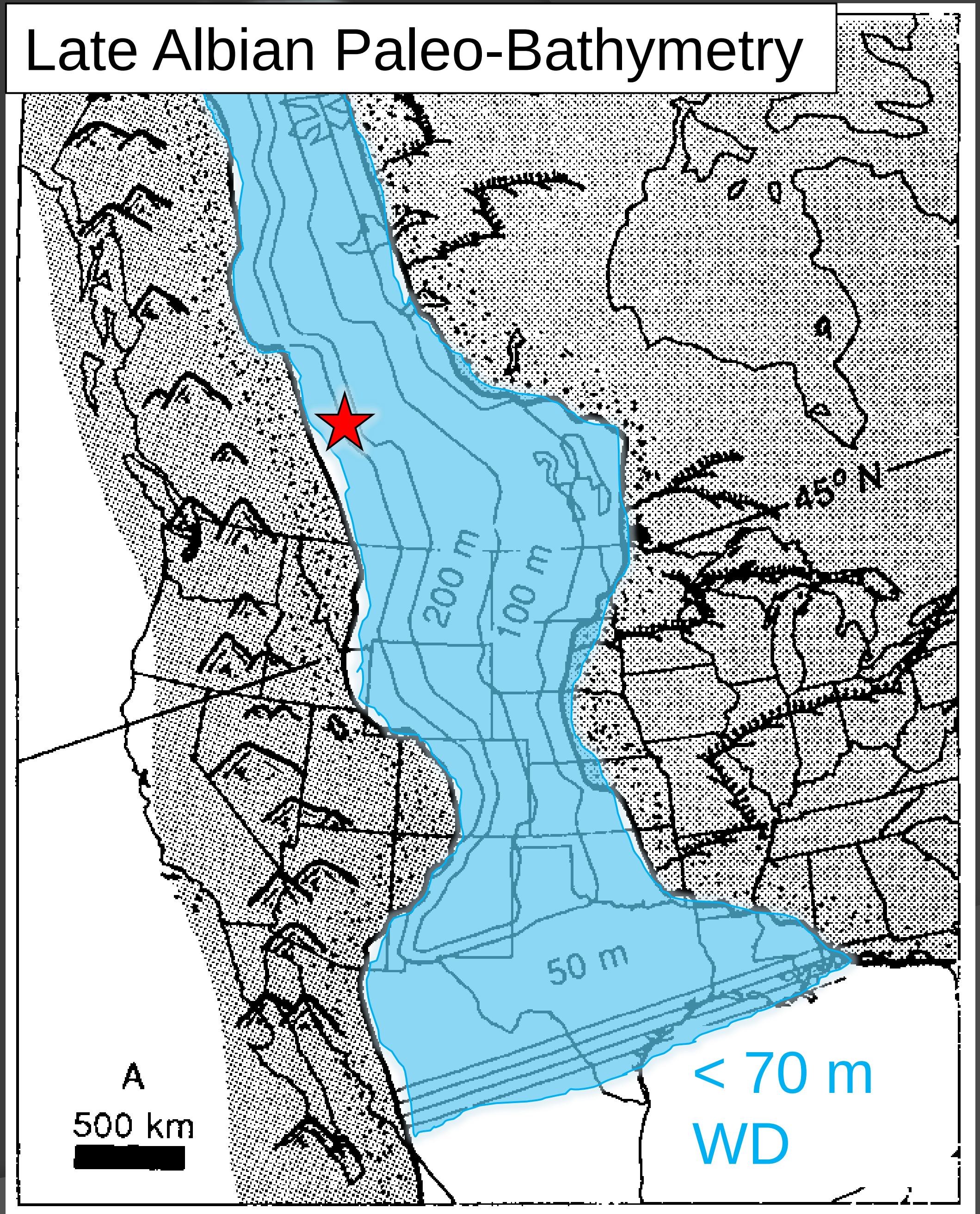
Propose that most unburrowed dark shales simply reflect development of low oxic conditions rather than suboxia/anoxia especially in the Western Interior Seaway



From Kauffman (1984) reproduced in Ericksen and Slingerland (1990)

Summary Slide 2B

Propose that most unburrowed dark shales simply reflect development of low oxic conditions rather than suboxia/anoxia especially in the Western Interior Seaway



Maximum Water Depth for the Western Interior Seaway from Plint et al., 2012

Thank you