Are Unbioturbated Mudstones Indicative of Anoxia?*

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Abstract

X-radiographs of sediment box cores acquired from the western Gulf of Mexico reveal limited bioturbation in sediment deposited at water depths greater than 35 m. Between 15 and 35 m, sediments are thoroughly bioturbated, with averaged bioturbation indices (for all beds in a core) between 2.1 and 5.6, and trace diversities between 2 and 9 distinct burrow forms. Below 35 m water depth, box cores exhibit trace diversities of 1–3 and core-averaged bioturbation indices range between 0.3 and 3.6. There is an overall decrease in trace diversity and bioturbation intensity in the offshore direction. Cross-shore ichnological trends are compared to dissolved oxygen (DO) contents of bottom waters. Dissolved oxygen decreases by an average of 0.117 mg/l per one-meter increase in water depth, such that bottom waters in 100 m water depth contain an average of 4.55 mg/l oxygen. Above 35 m, DO content shows pronounced variability ranging from 100% O_2 saturation through to hypoxia (DO < 2.0 mg/l), and reflect the periodic introduction of hypoxic waters during June-July ocean hypoxia events. Below bathymetries of 35 m, the DO contents of bottom waters are consistently 60–75% oxygen saturation of Gulf of Mexico seawater, and oxygen concentrations decrease offshore. Although the present dataset is limited, there is a direct correlation between: a) the density of infauna and the diversity and density of burrows, and b) DO concentrations of bottom water. These trends indicate that the degree of bioturbation is significantly reduced in waters that are oxic but below 80% O_2 saturation — the low bioturbation intensities and diversities do not reflect hypoxia or anoxia. Instead, reduced oxygen contents, but well above hypoxia, have a dramatic impact on the health of infaunal communities, which is reflected by severe reductions in the ichnological character of the sediments. Based on these results, we propose that unbioturbated and under-bioturbated marine mudstones and shales may simply reflect reduced DO concentrations of bottom water rather than anoxia in the paleoenvironment.

Reference Cited

Dashtgard, S.E., J.W. Snedden, and J.A. MacEachern, 2015, Unbioturbated Sediments on a Muddy Shelf: Hypoxia or Simply Reduced Oxygen Saturation?: Palaeogeography, Palaeoclimatology, Palaeoecology, v. 425, p. 128-138.

Hill, G.W., 1985, Ichnofacies of a Modern Size-Graded Shelf, Northwestern Gulf of Mexico, *in* H.A. Curran (ed.), Biogenic Structures: Their Use in Interpreting Depositional Environments: SEPM Society for Sedimentary Geology Special Publication 35, p. 195–210.

MacEachern, J.A., C.R. Stelck, and S.G. Pemberton, 1999, Marine and Marginal Marine Mudstone Deposition: Paleoenvironmental Interpretations Based on the Integration of Ichnology, Palynology, and Foraminiferal Paleoecology, *in* K.M. Bergman, and J.W. Snedden (eds.), Isolated Shallow Marine Sand Bodies: Sequence Stratigraphic Analysis and Sedimentologic Interpretation: SEPM Society for Sedimentary Geology Special Publication 64, p. 205–225.

Murray, J.W., 2001, The niche of benthic foraminifera, critical thresholds and proxies: Mar. Micropaleontol., v. 41, p. 1–8.

Snedden, J.W., 1985, Origin and Sedimentary Characteristics of Discrete Sand Beds in Modern Sediments of the Central Texas Continental Shelf: PhD Dissertation, Louisiana State University, Baton Rouge, Louisiana, 280 p.

White, D.C., 1985, Quantitative Physical-Chemical Characterization of Bacterial Habitats, *in* J. Poindexter and E. Leadbetter (eds.), Bacteria in Nature II, Plenum Press, New York, p. 177-203.

ARE UNBIOTURBATED MUDSTONES INDICATIVE OF ANOXIA?

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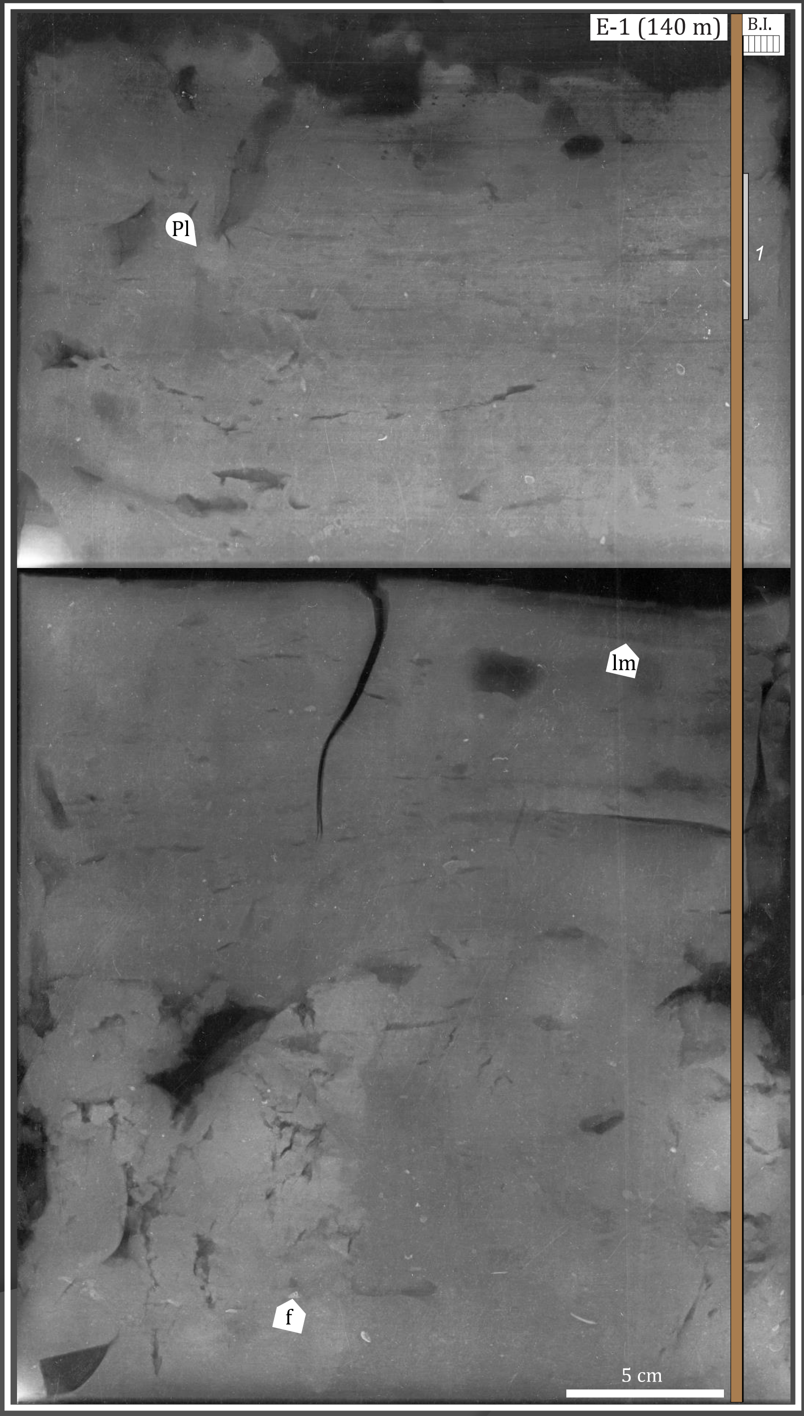
Applied Research in Ichnology and Sedimentology

SFU

Objective

Does a paucity of bioturbation in marine muds and mudstones indicate anoxia?

Consider both modern and rock record examples



Conclusion

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

Decrease in bioturbation in dark marine shales and mudstones correlates to a *reduction in dissolved oxygen* in oxygenated (oxic) seawater but not to anoxia

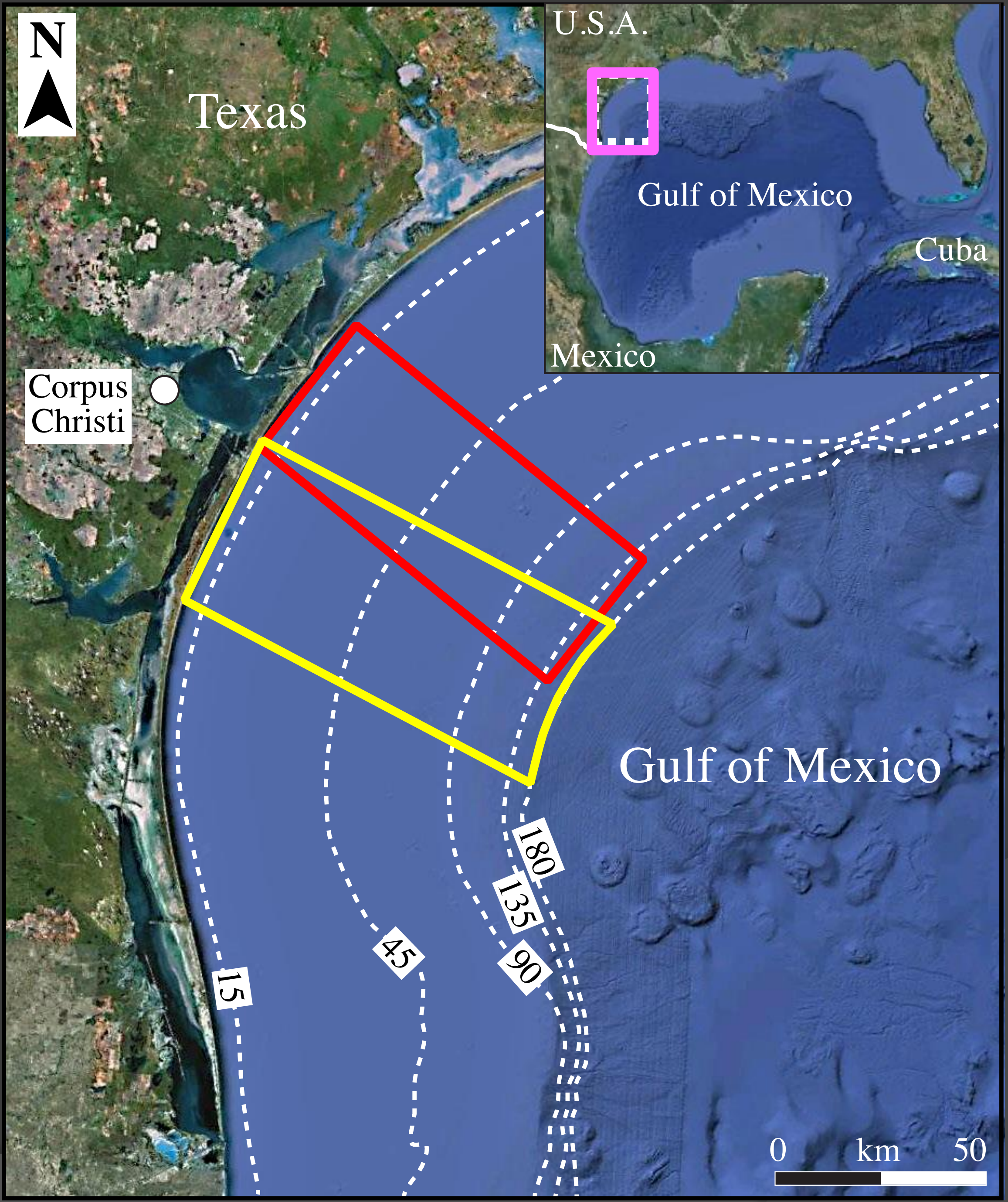
Modern Example

Western Gulf of Mexico

Two data sets:

Snedden Ph.D. (1985) – red box

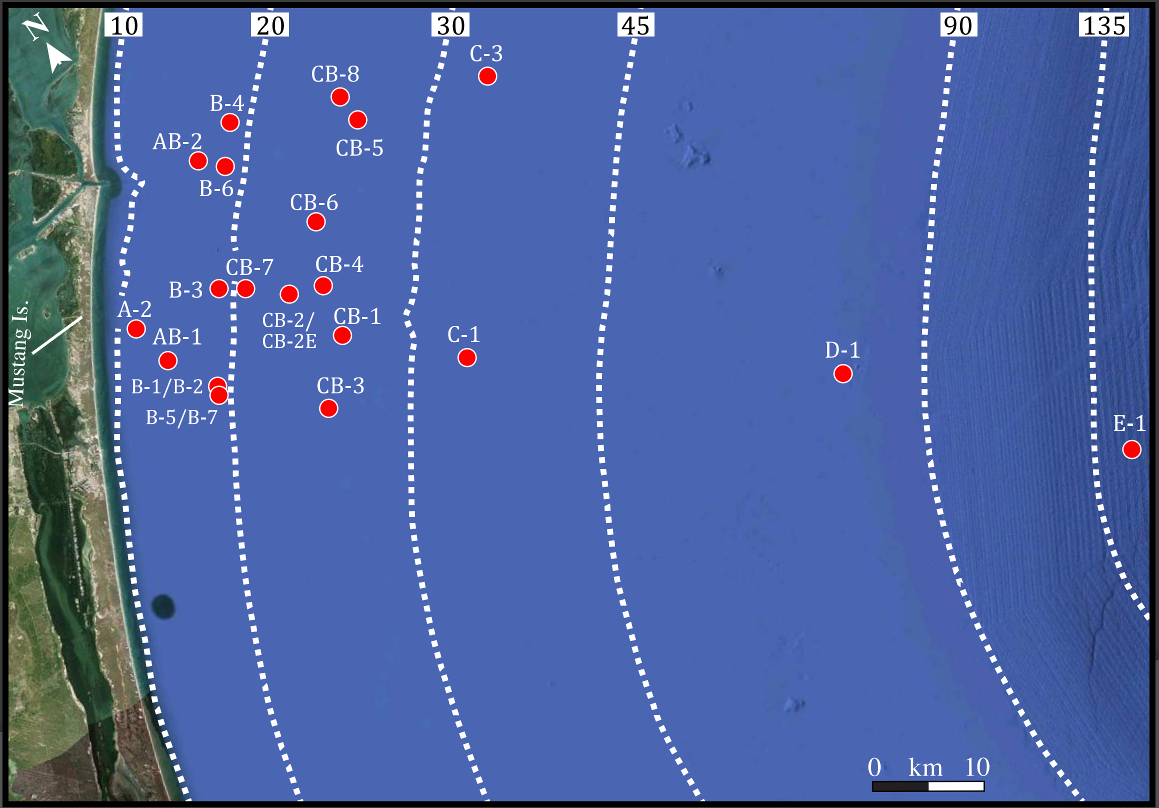
Hill (1985) – yellow box

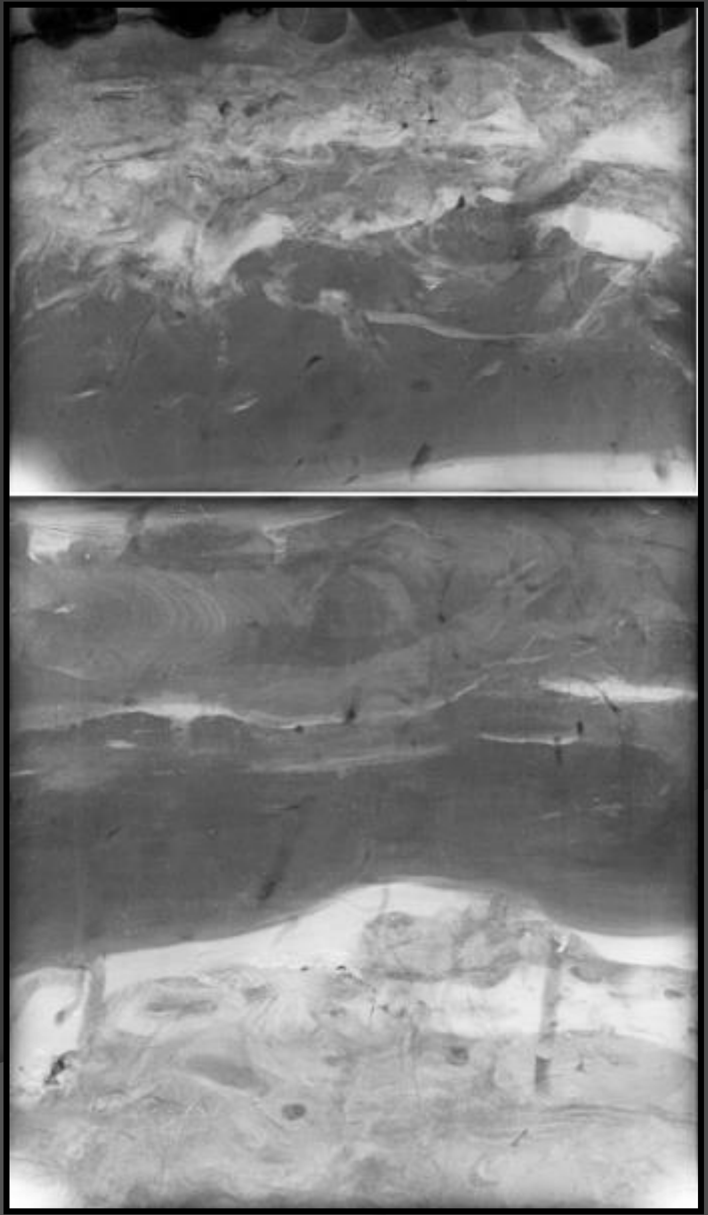


Dataset 1 – Snedden (1985)

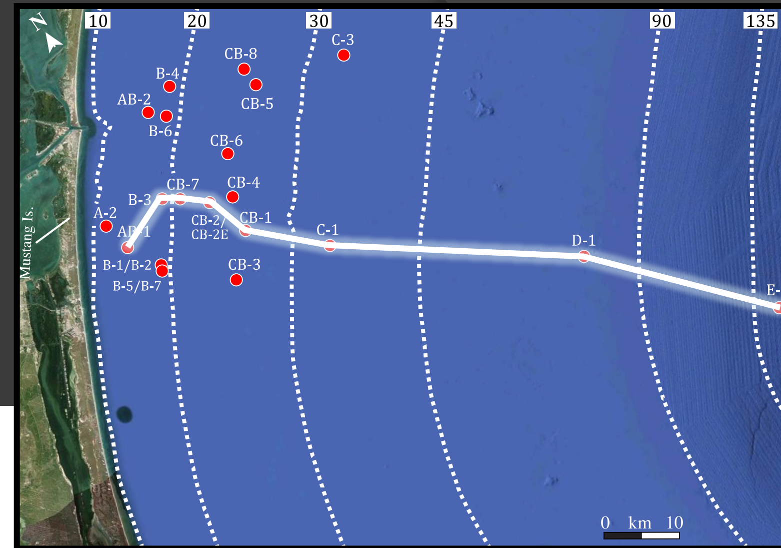
22 Box Cores: 12 to **50 cm** high, 12 to 140 m WD

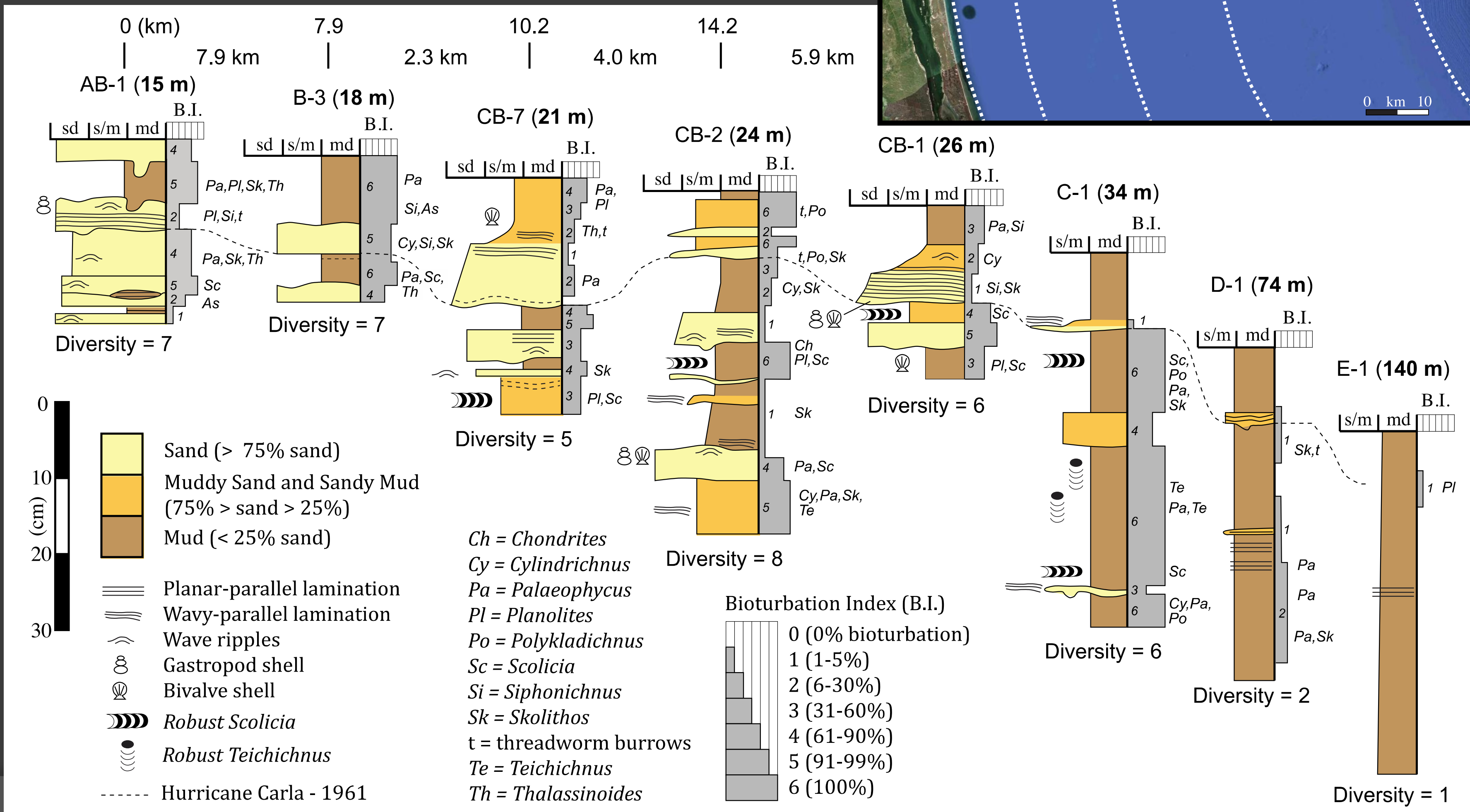
All x-rayed.





Modern Example – Dataset 1





34 m Water Depth

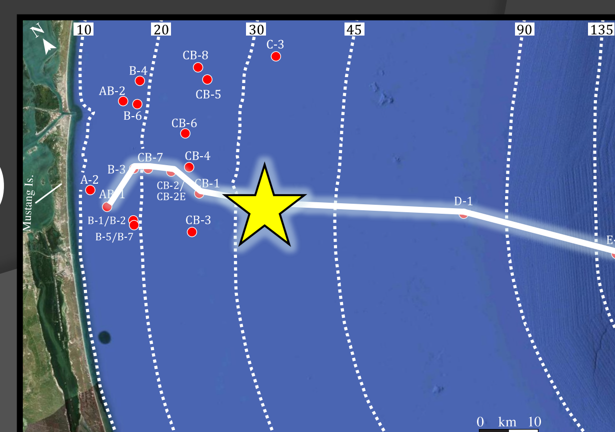
Mostly Mud

Averaged BI: 4.4

BI of individual beds: 0 to 6

Trace Diversity: 6

Cylindrichnus (Cy)
Palaeophycus (Pa)
Polykladichnus (Po)
Scolicia (Sc)
Skolithos (Sk)
Teichichnus (Te)



74 m Water Depth

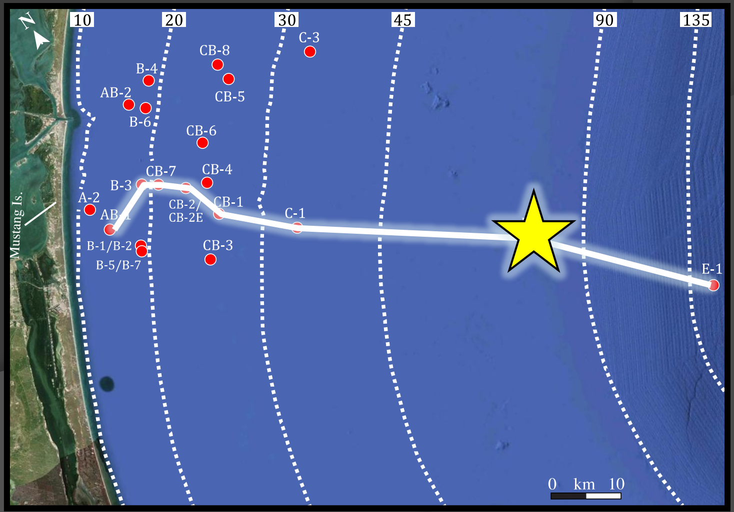
Mud

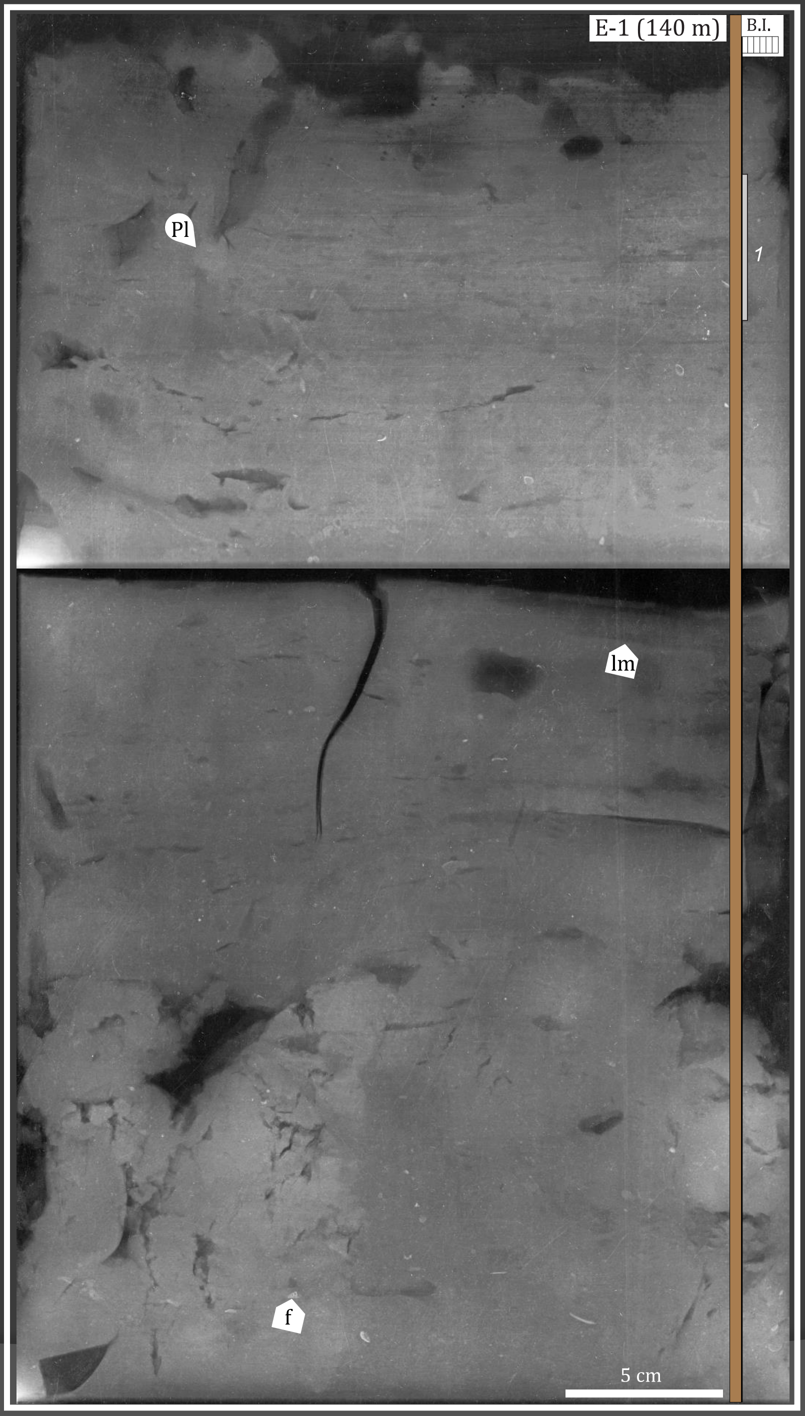
Averaged BI: 1.2

BI of individual beds: 0 to 2

Trace Diversity: 2

Palaeophycus (Pa)
Skolithos (Sk)





140 m Water Depth

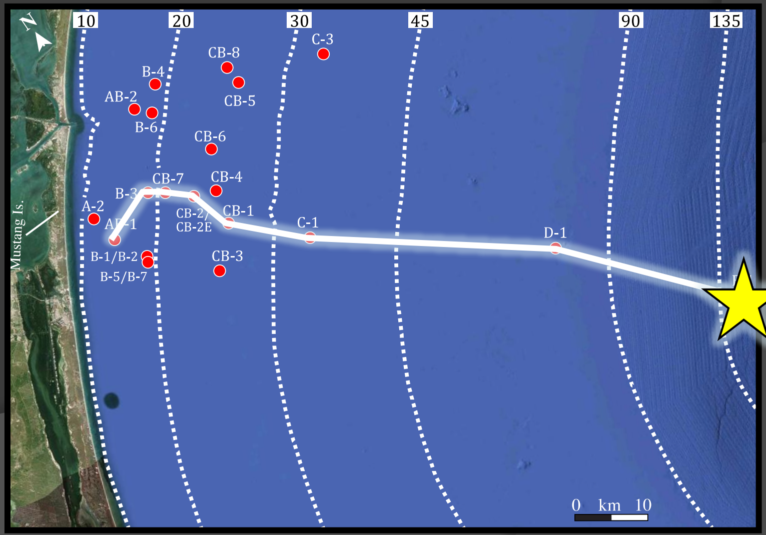
Mud

Averaged BI: 0.1

BI of individual beds: 0 to 1

Trace Diversity: 1

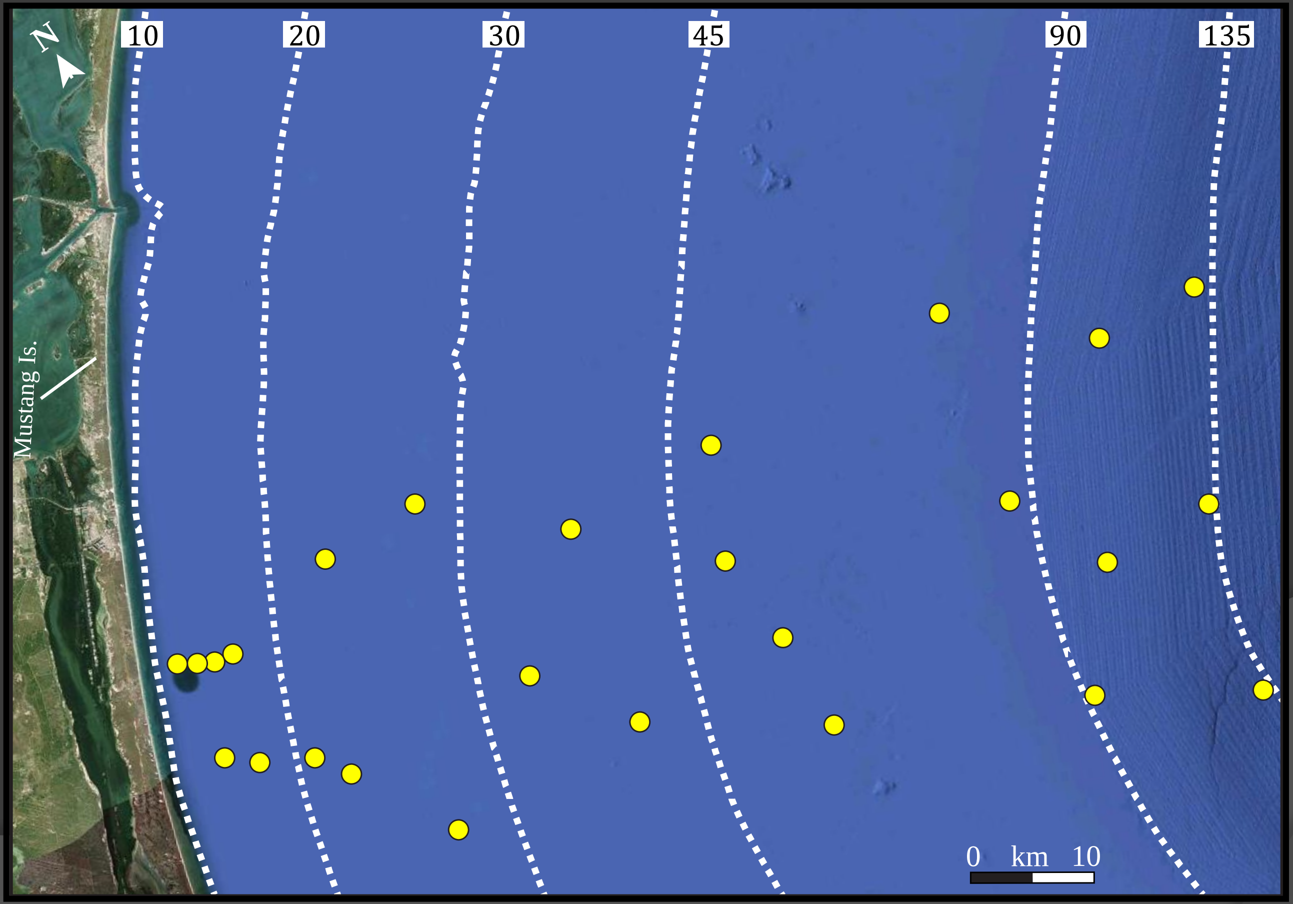
Planolites (Pl)



Dataset 2 – Hill (1985)

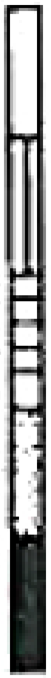
8 Box Cores: 50 cm high, 22 to 133 m WD

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

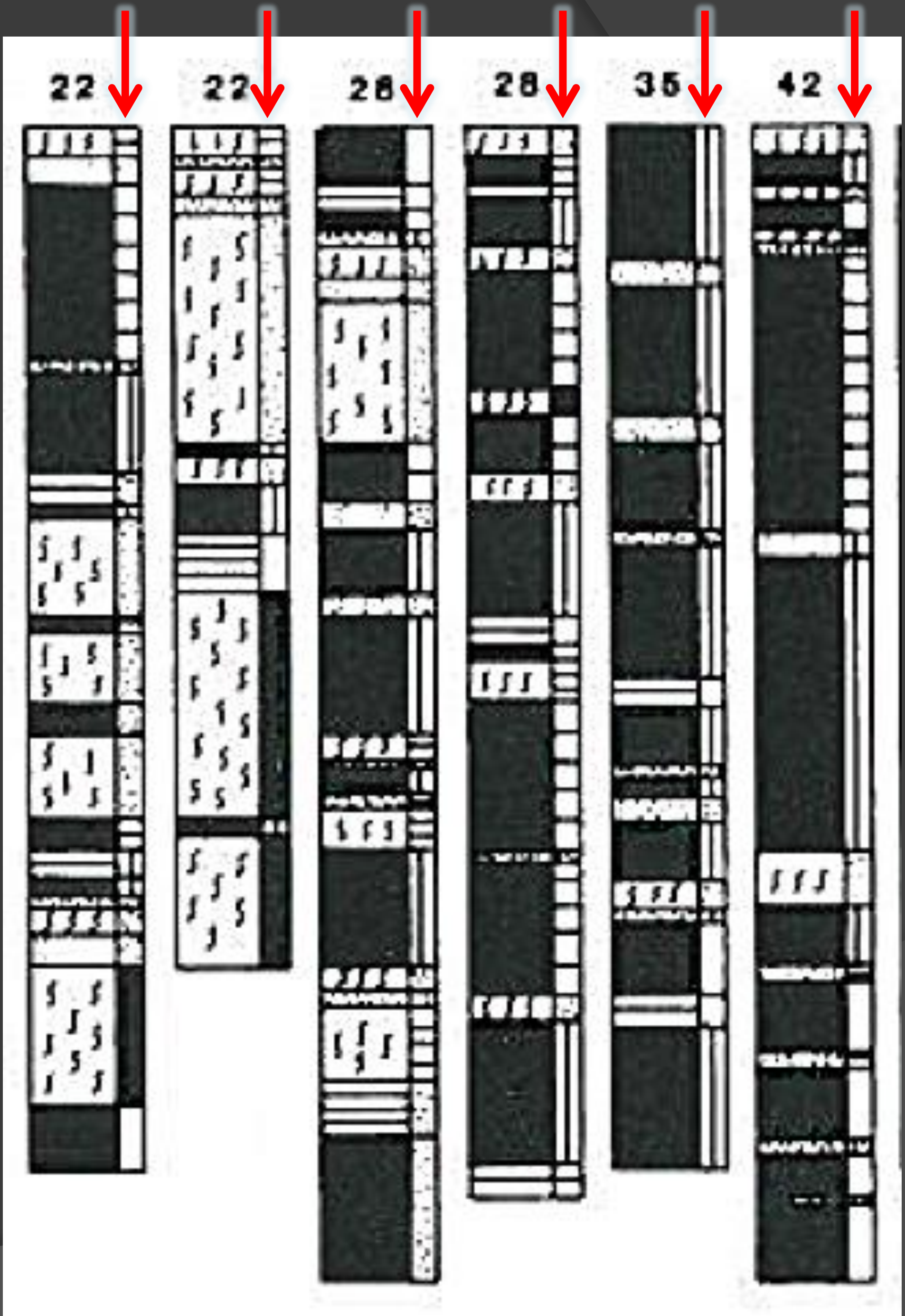


Dataset 2 – Hill (1985)

Bioturbation percentage defined for beds in all cores



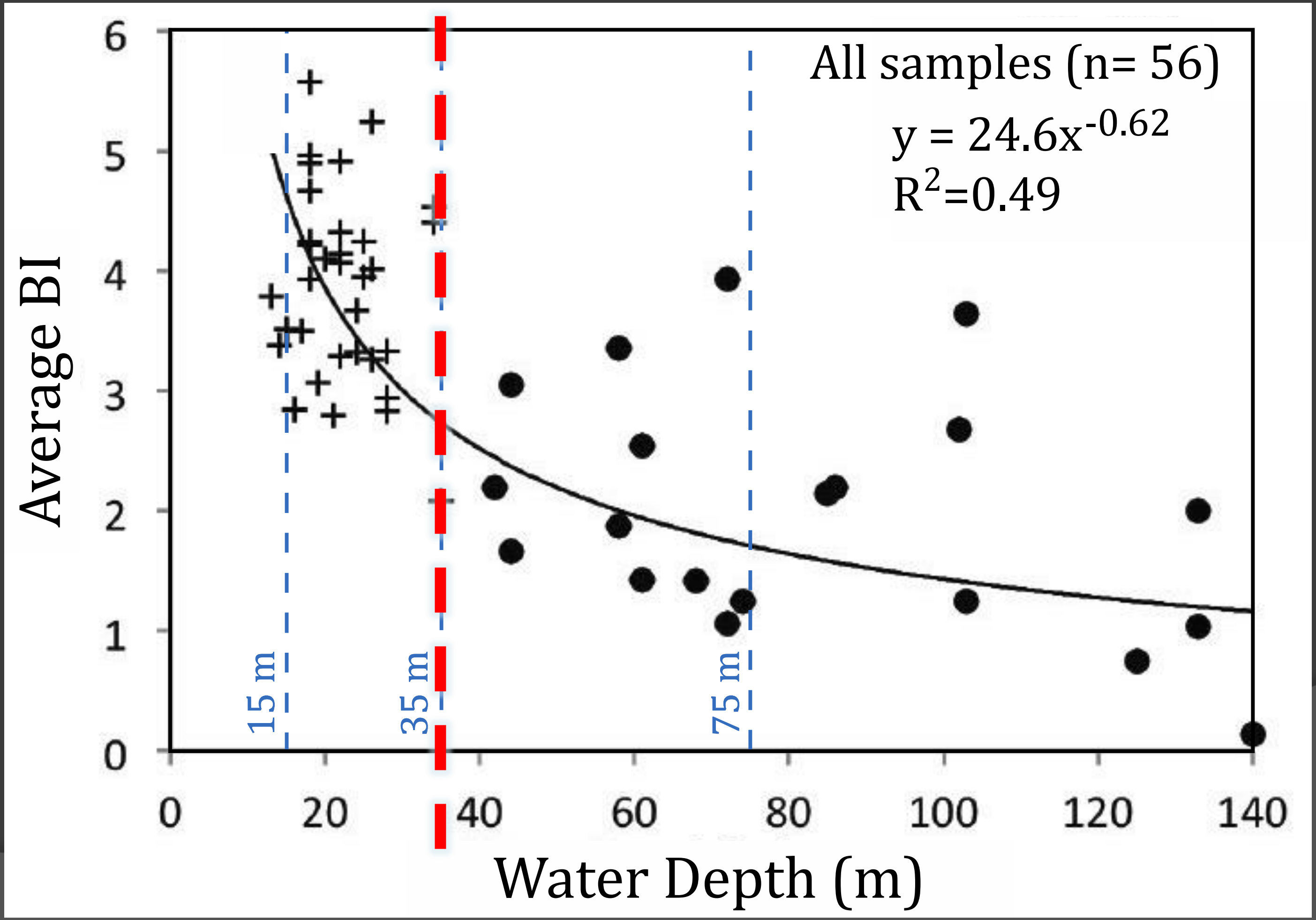
BIOTURBATION	B.I.
0 –Trace	0 to 1 (0.5)
< 30%	2
30 –60%	3
60 – 90%	4
90 – 100%	5 to 6 (5.5)



Bioturbation Intensity

BI 1 to 2 in sediments below 35 m water depth

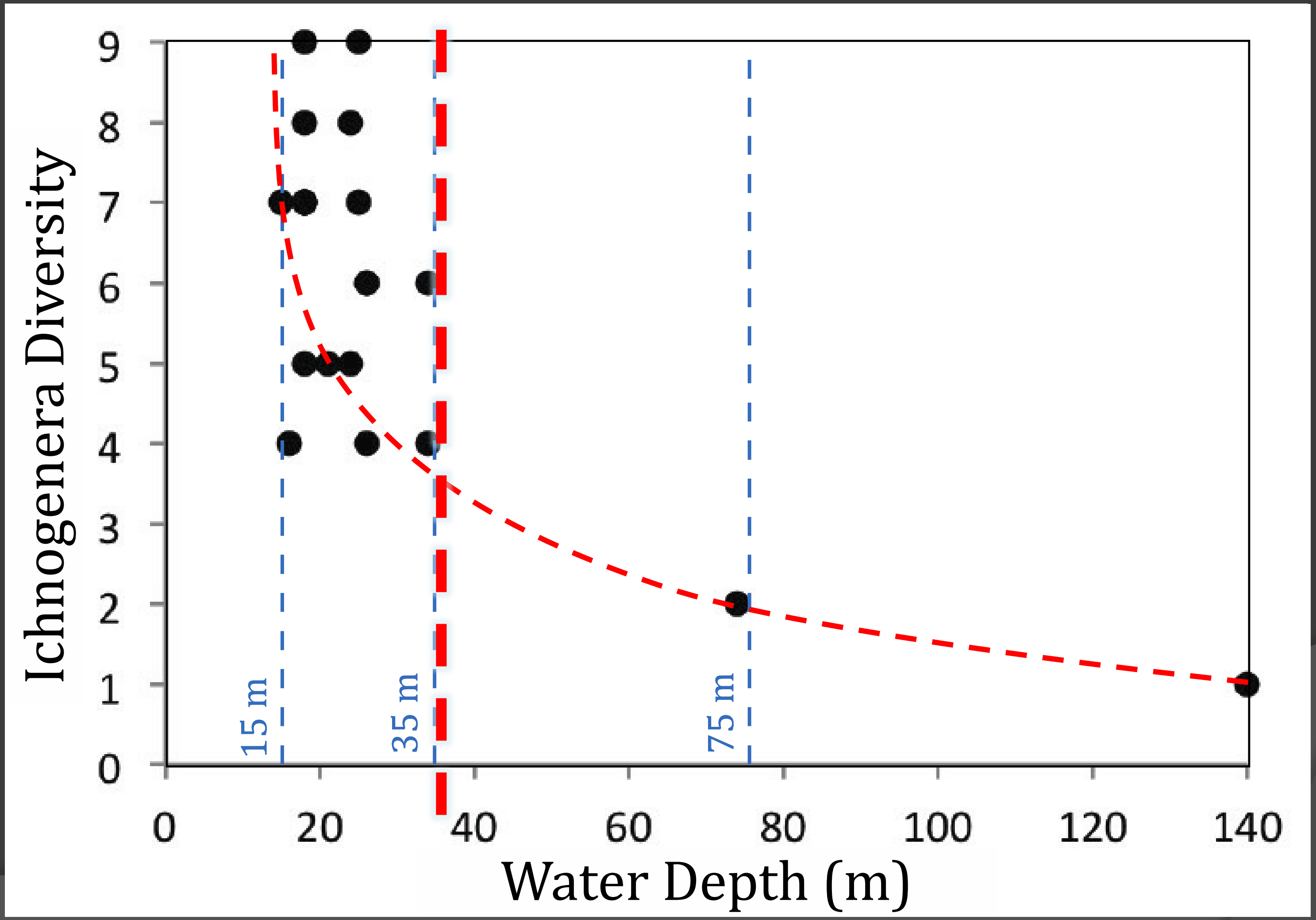
BI of 1 typical for sediments below 100 m WD



Data from Snedden (1985) and White (1985)

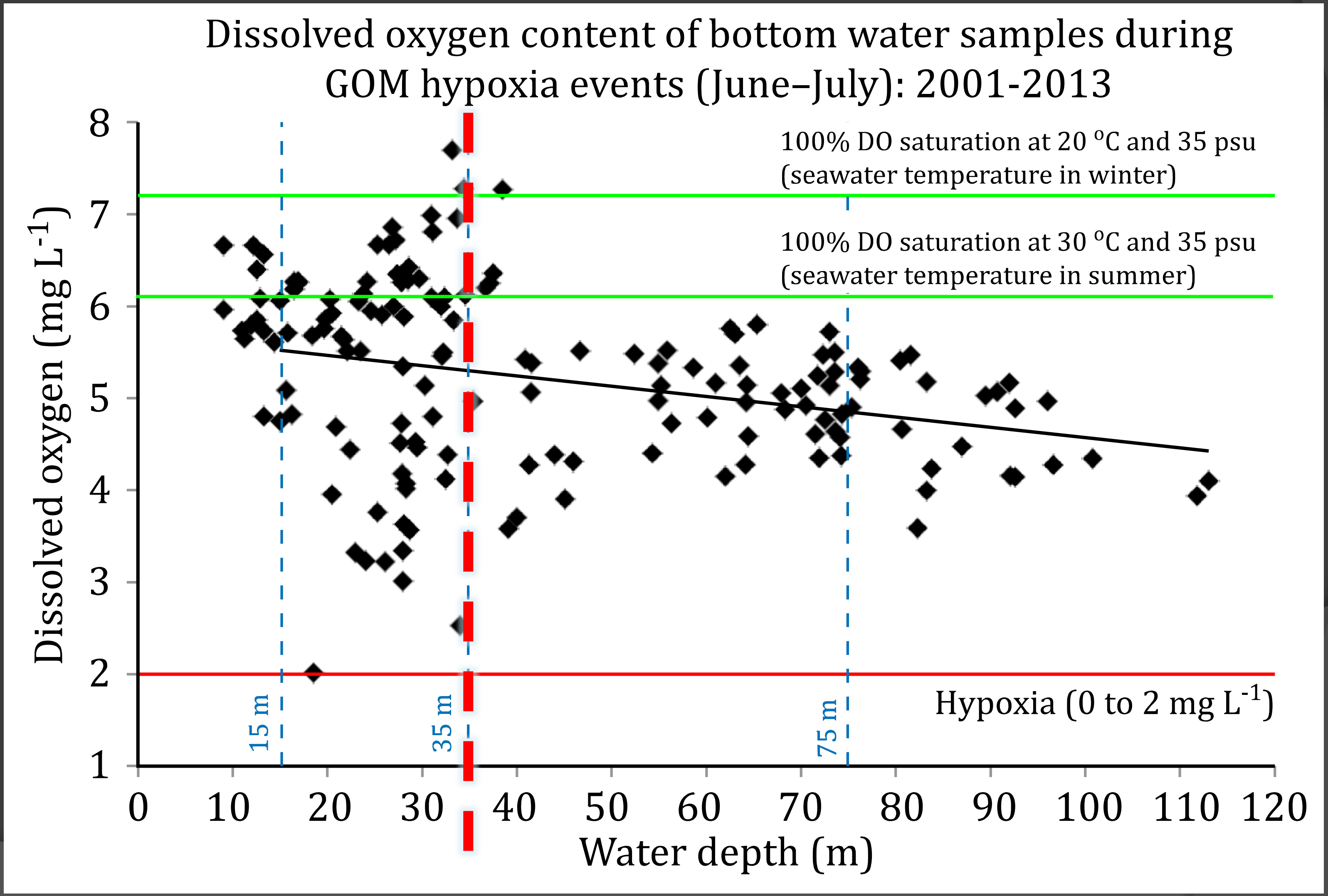
Trace Diversity

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



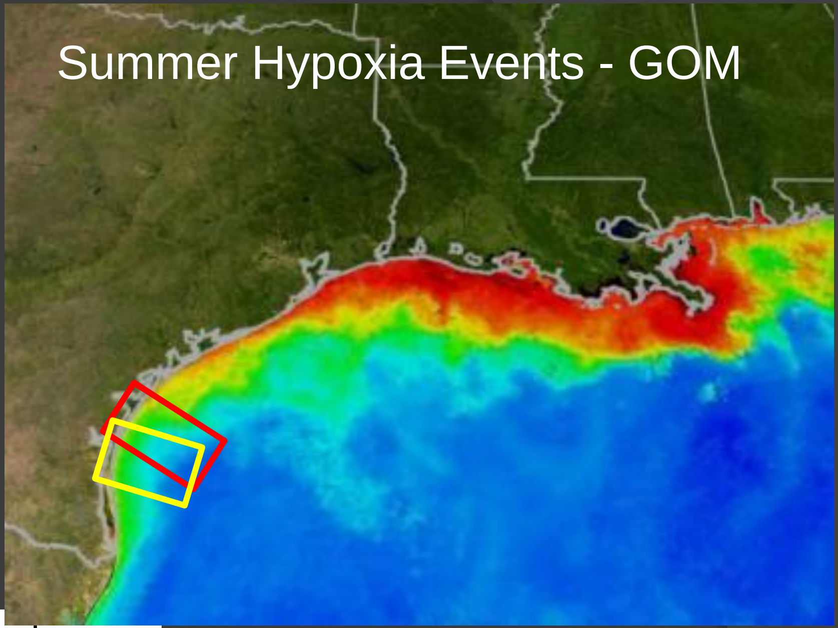
Why?

Dissolved Oxygen of Bottom Water

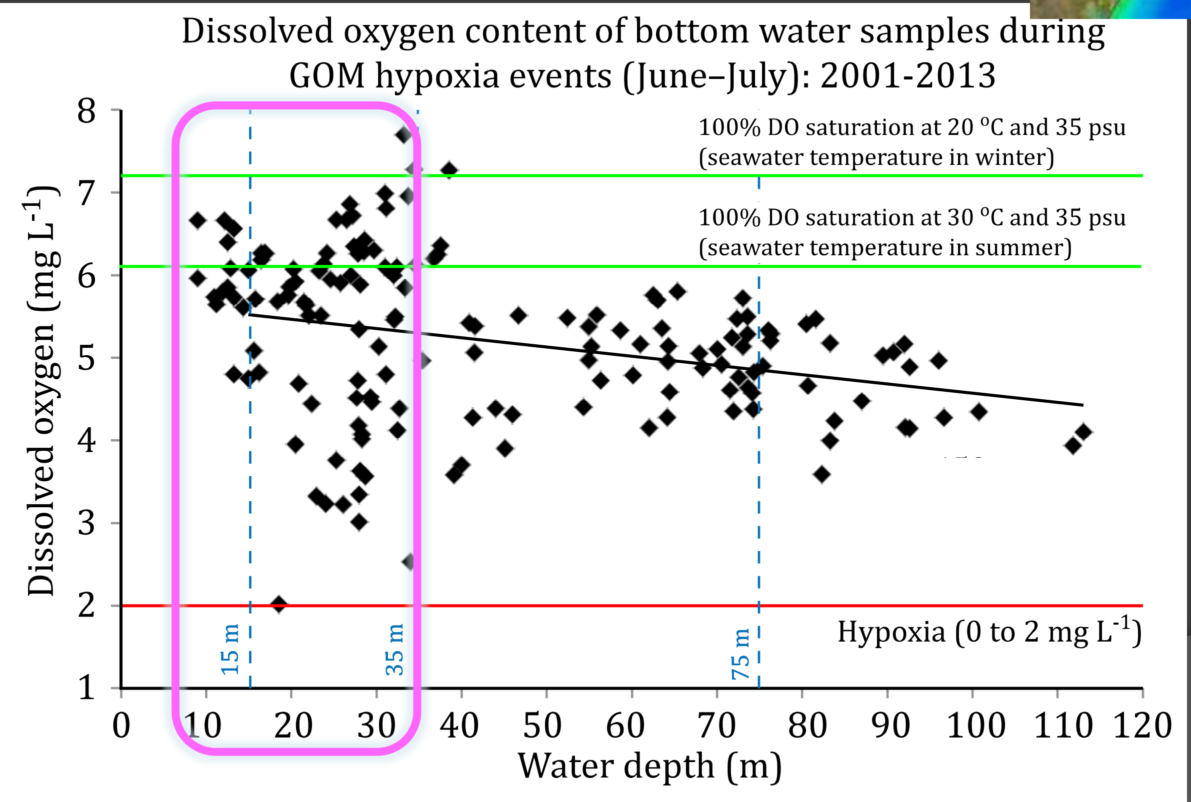


Dissolved Oxygen

Above 35 m WD: DO is 100%, except during summer hypoxia events.



www.nasa.gov/vision/earth/environment/dead_zone

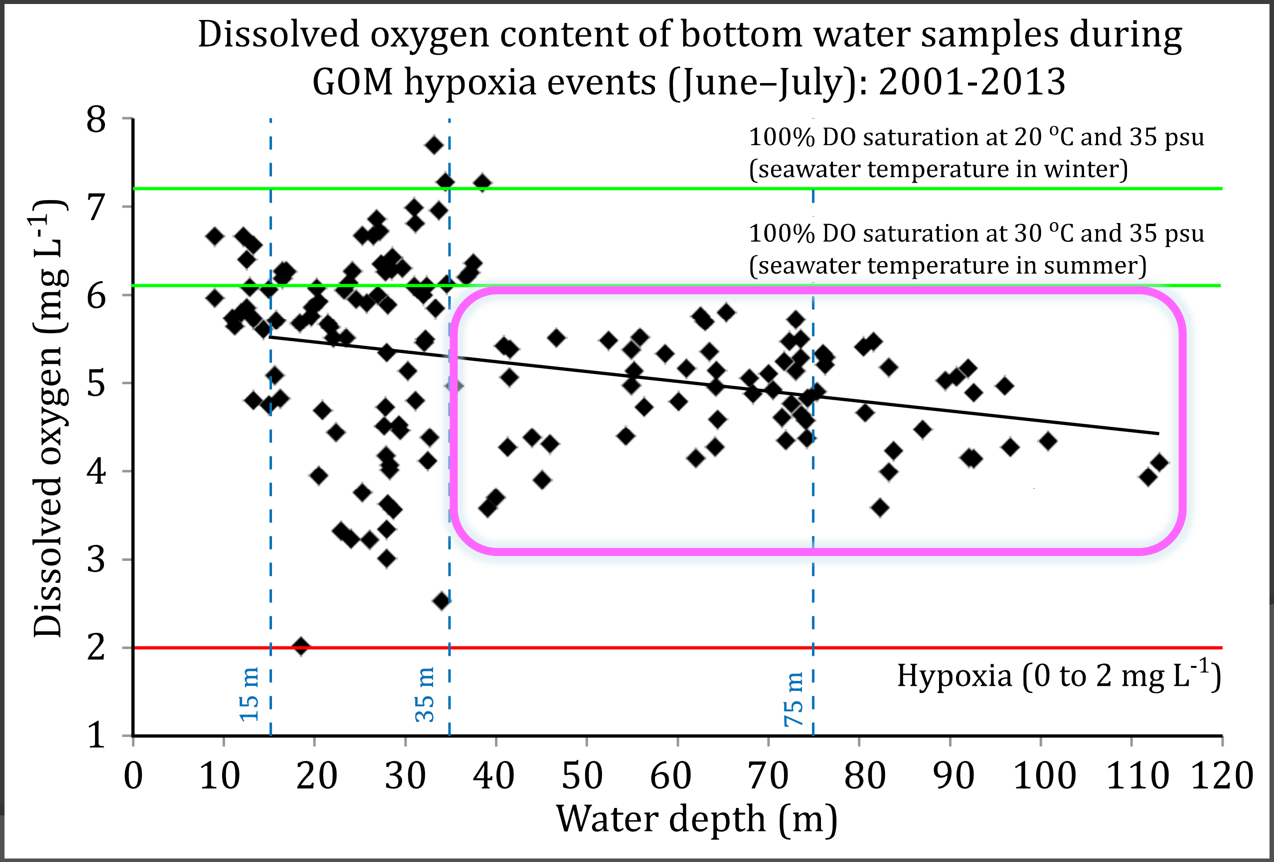


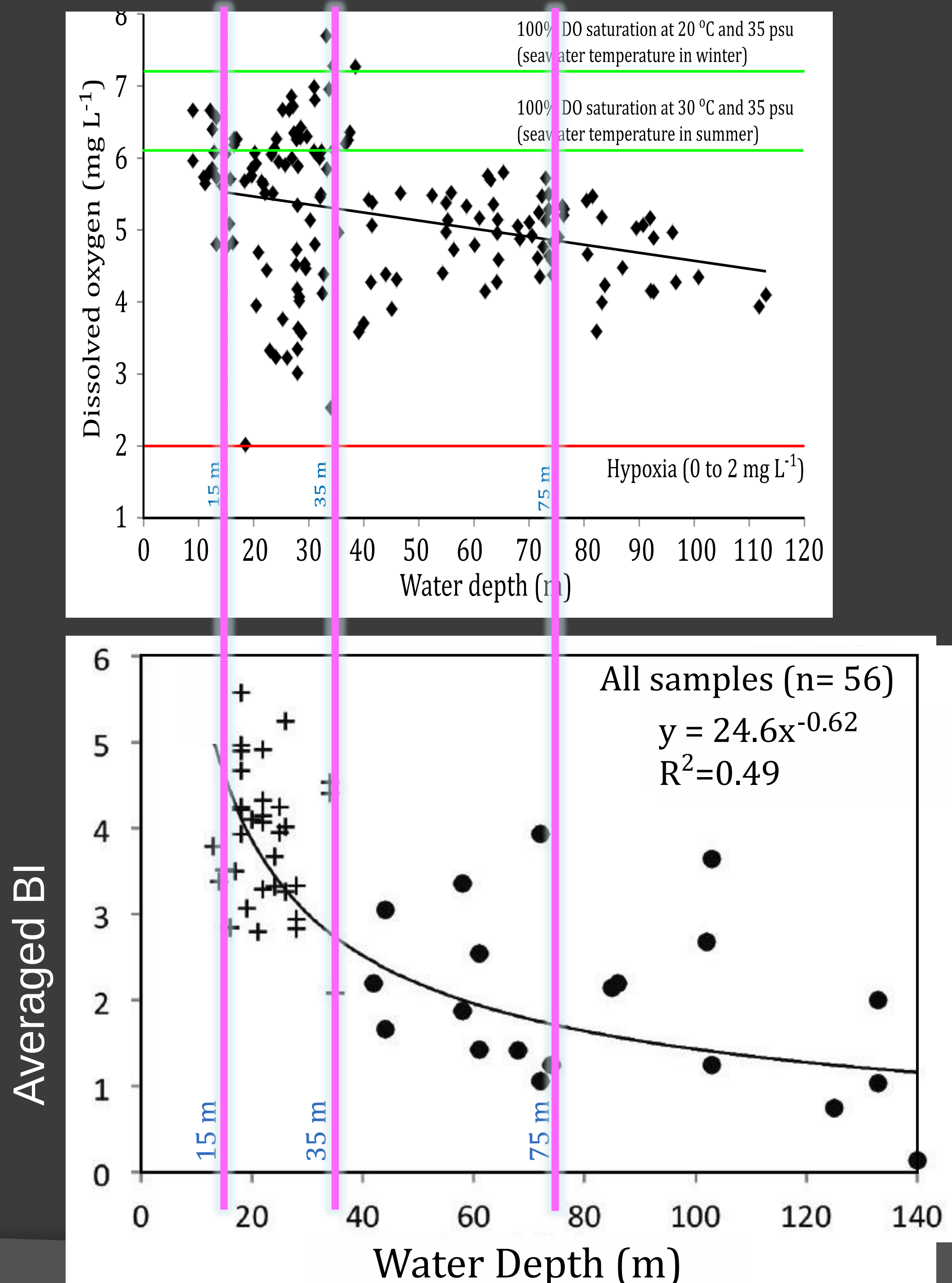
Greater variability in DO above 35 m WD

Dissolved Oxygen

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

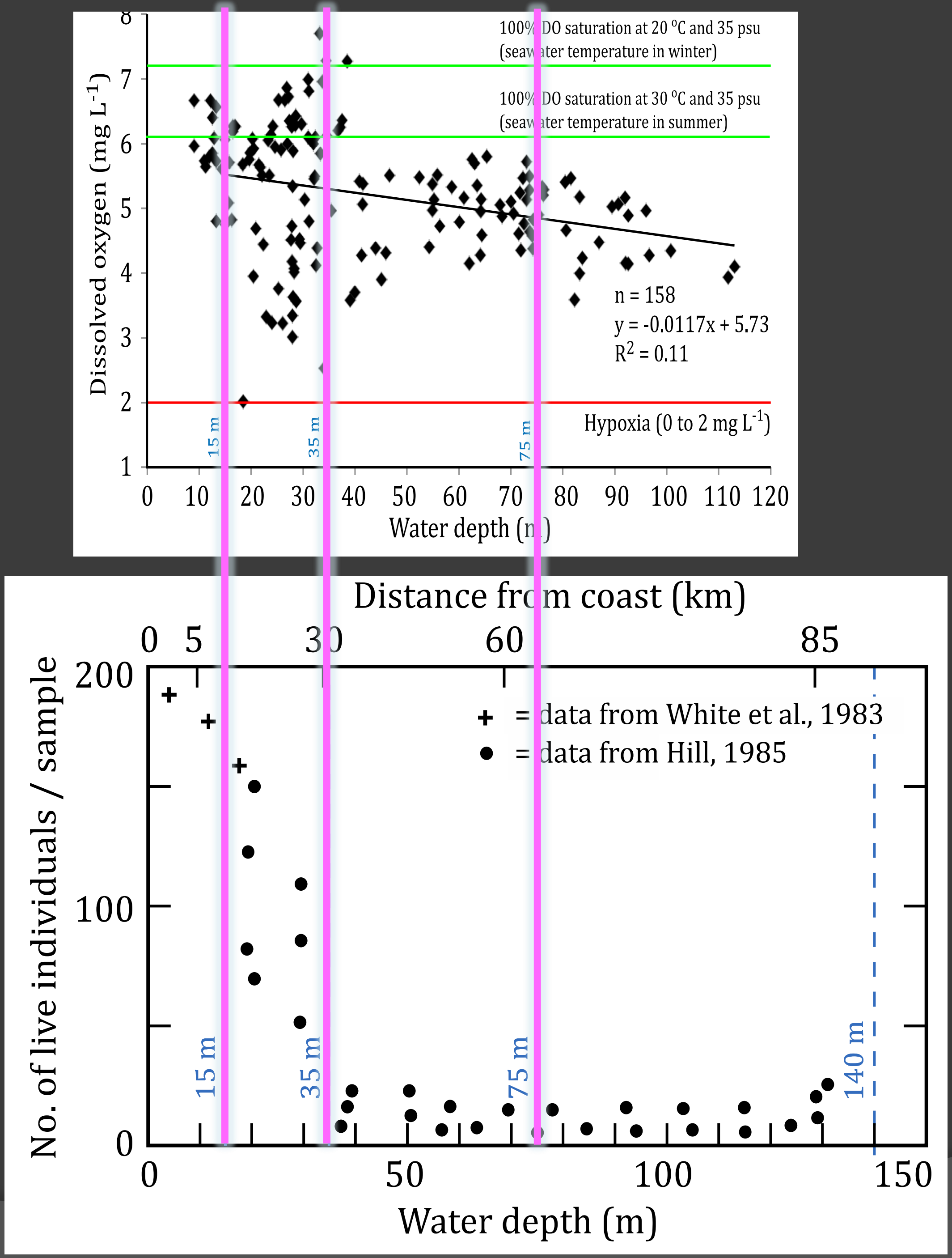
BUT – Water is still **OXIC**!





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

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



Correlates to infaunal diversity and density

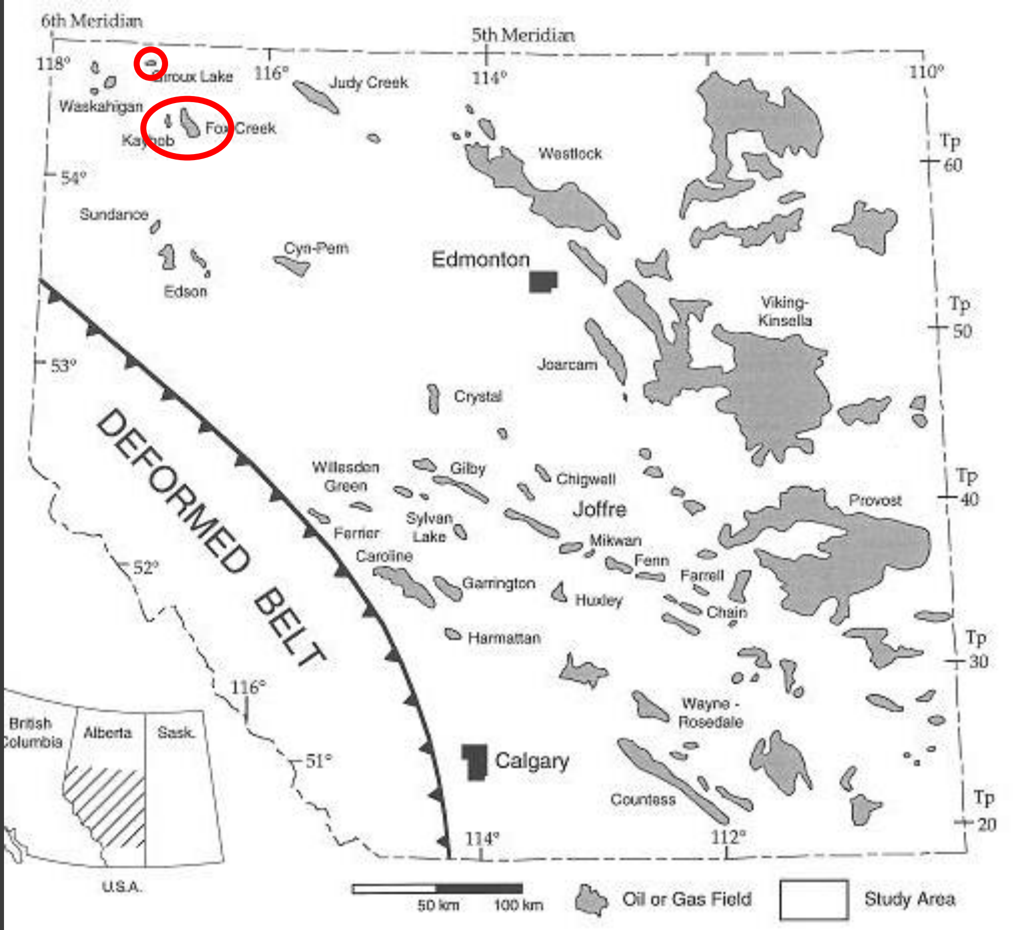
Rock Record Example

Joli Fou – Viking – Westgate formations, Alberta (L Cret.)

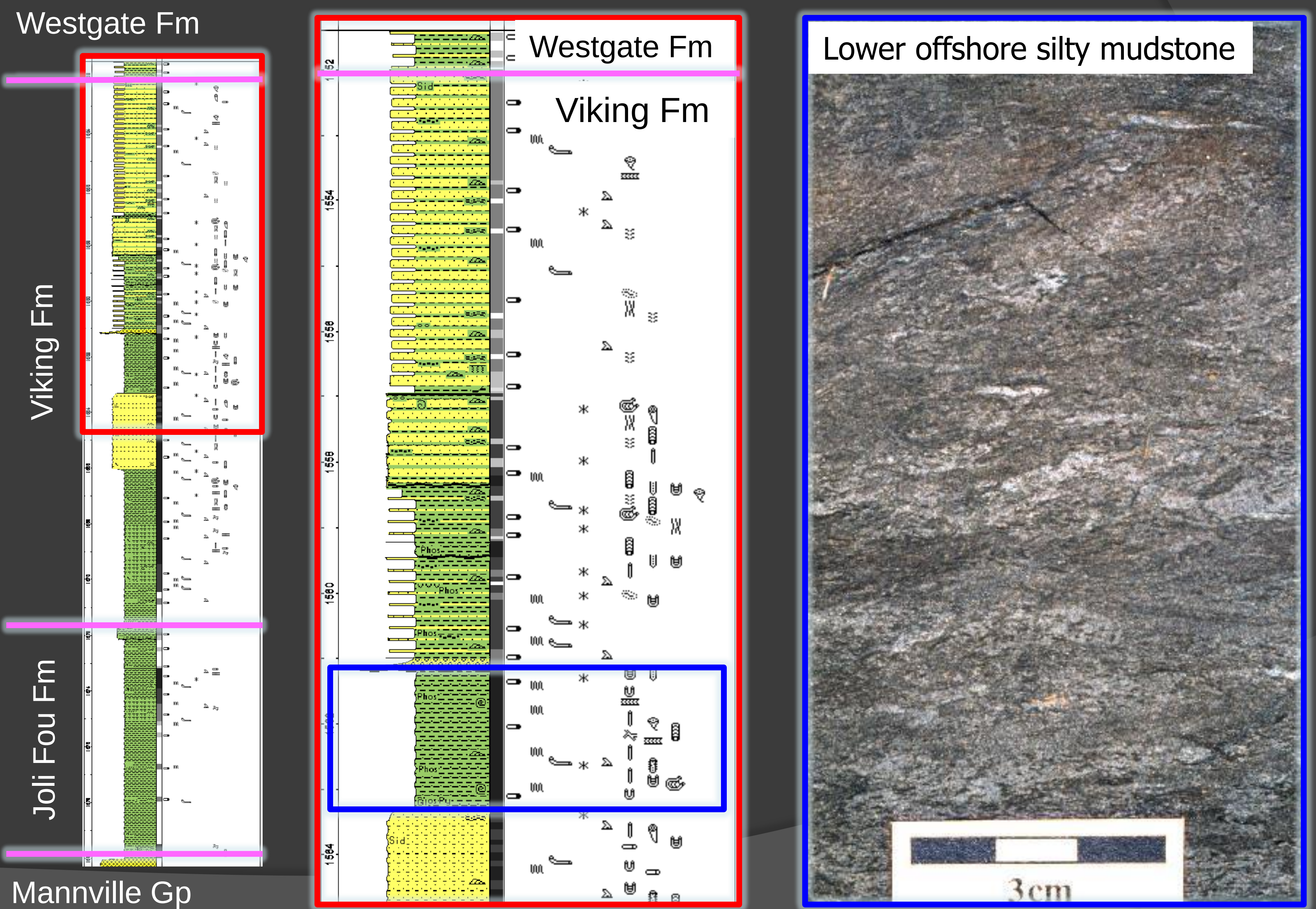
36 mudstone / shale samples
(from MacEachern et al., 1999)

Characterize foraminferal assemblage by facies:

- Lower Offshore silty mudstone
- Upper Offshore sandy mudstone
- Unbioturbated dark mudstones and shale



Viking Formation Benthic Foraminifera



Viking Formation Benthic Foraminifera

Lower offshore silty mudstones

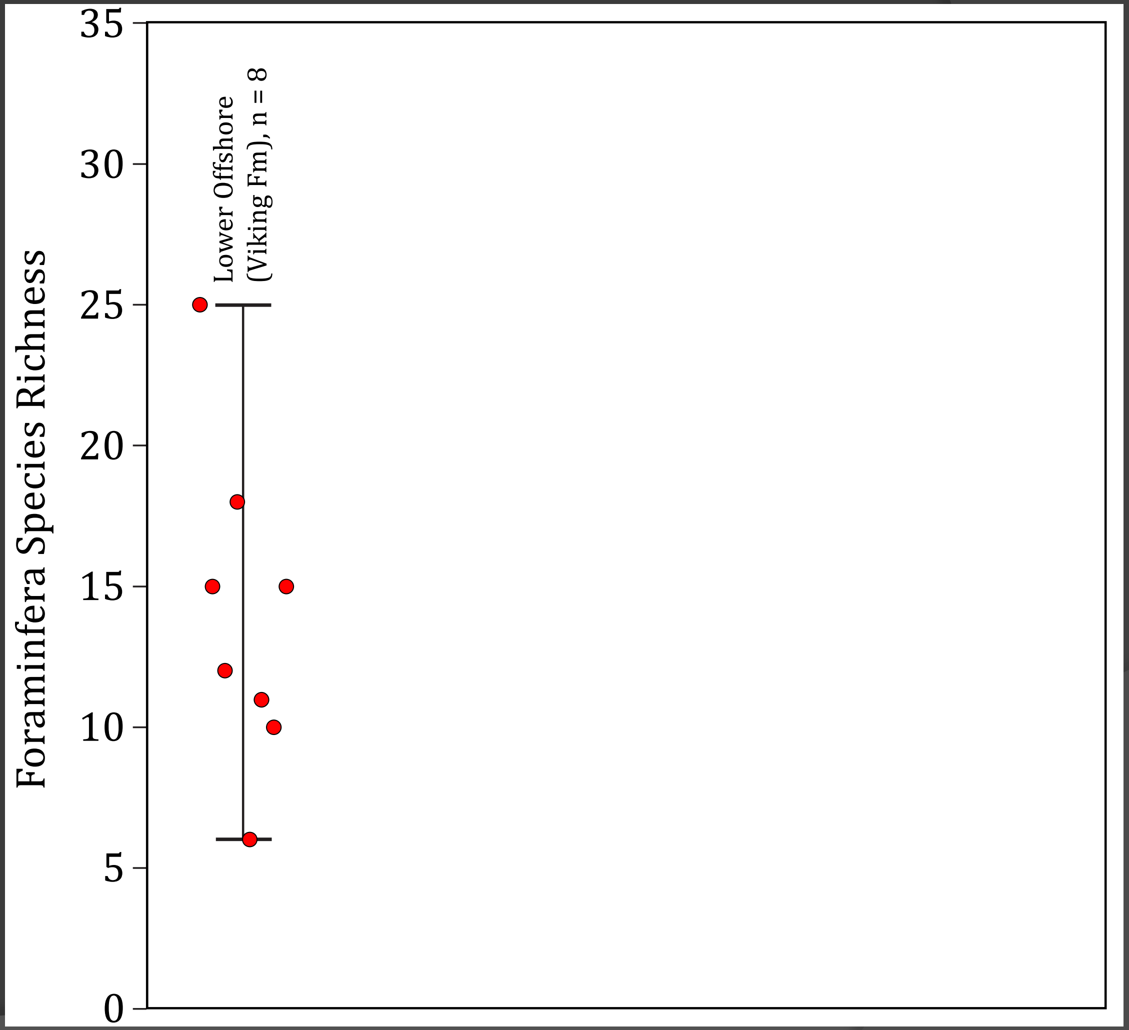
BI: 4-6 (60 to 100% bioturbation)

Trace Fossil diversity: 8-11

Fully marine assemblage

Viking Formation Benthic Foraminifera

Lower offshore silty mudstones

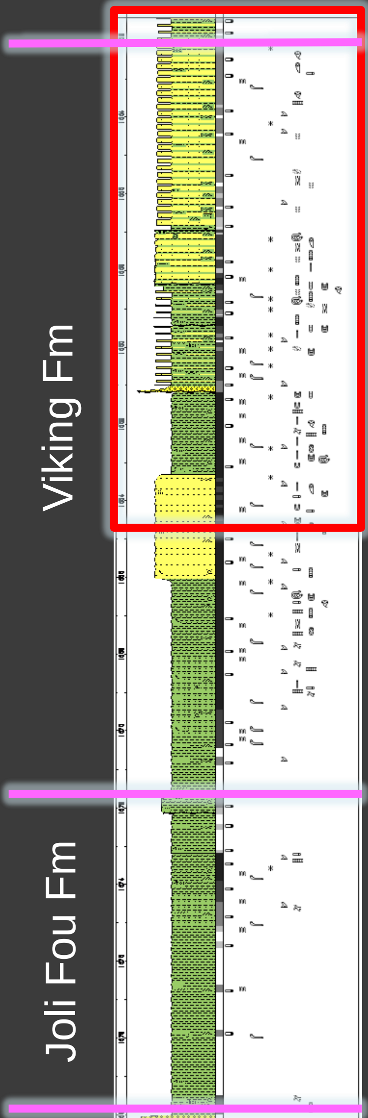


Viking Formation Benthic Foraminifera

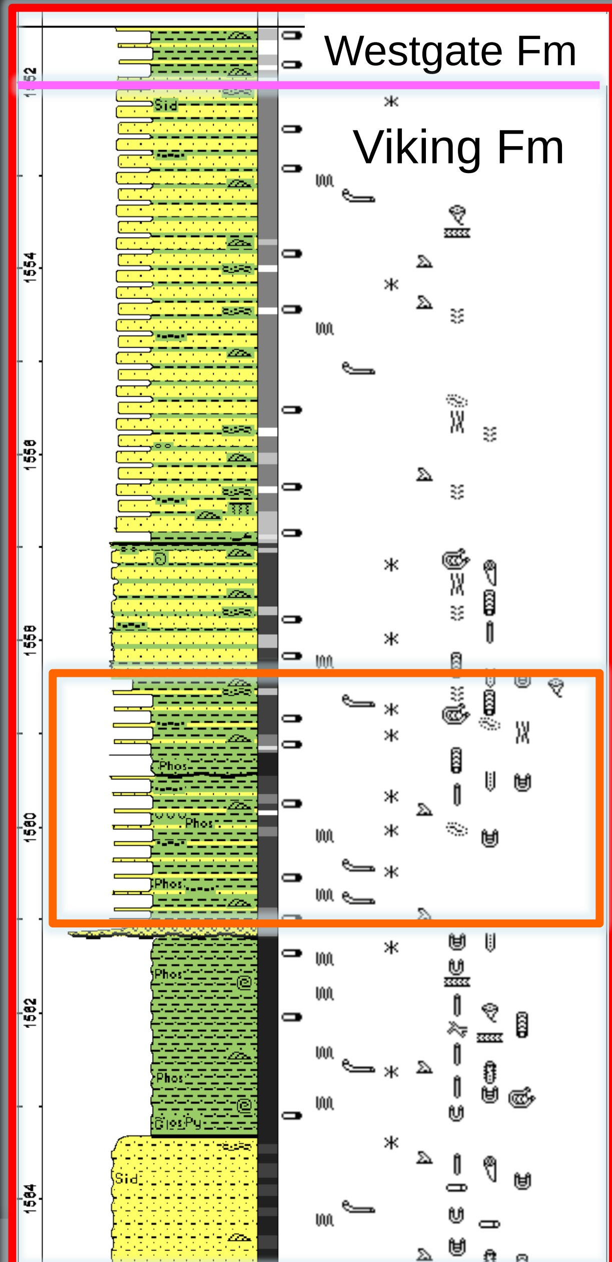
Westgate Fm

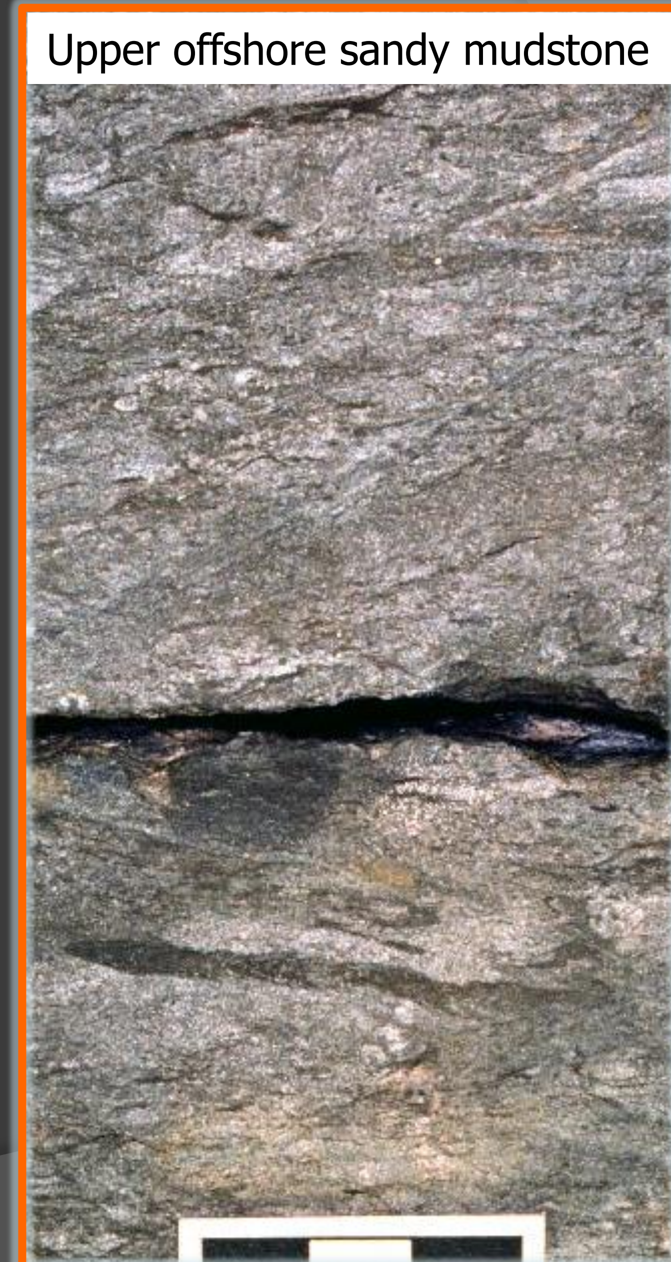
Viking Fm

Joli Fou Fm

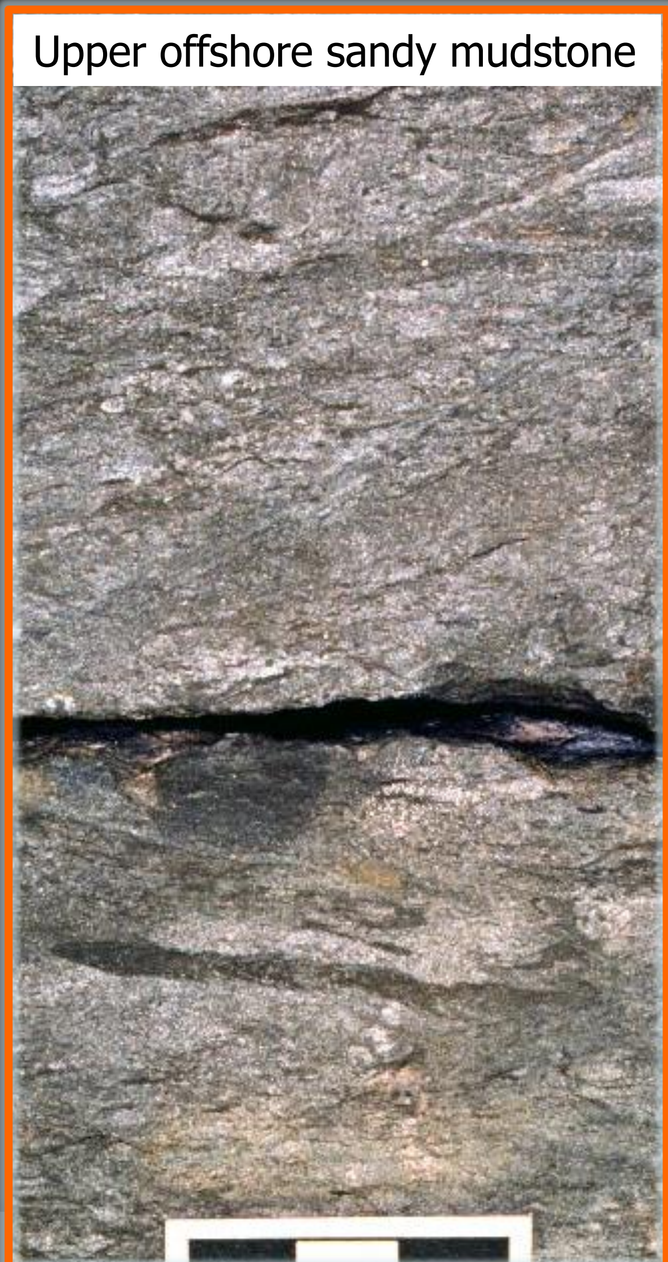


Mannville Gp





Viking Formation Benthic Foraminifera



Upper offshore sandy mudstones

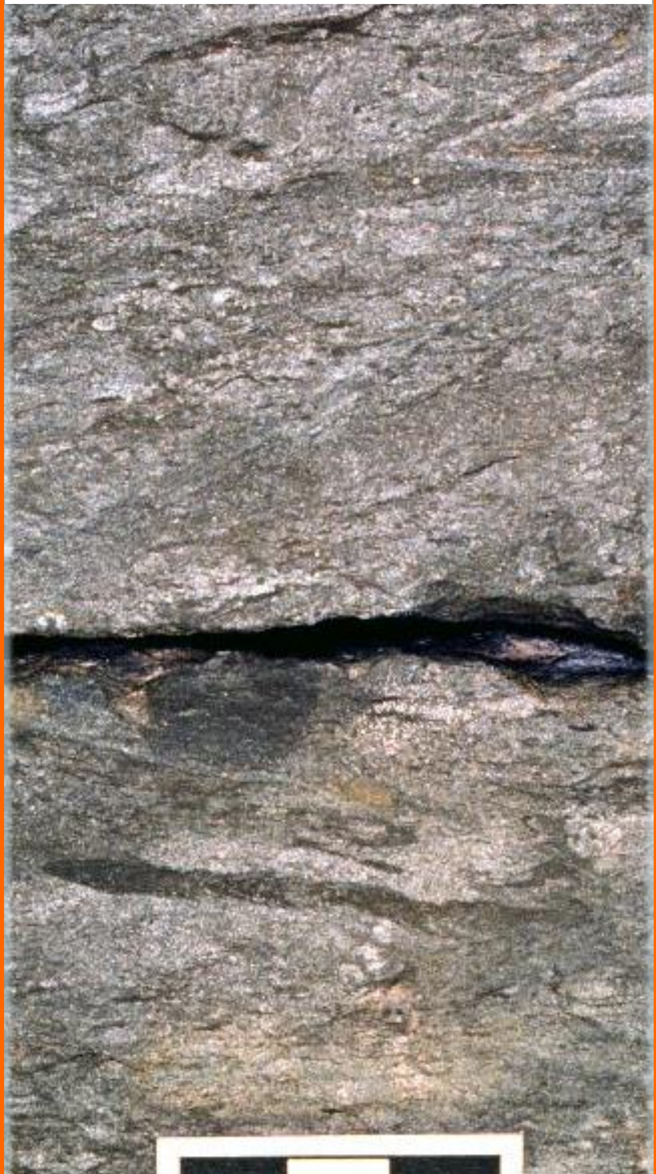
BI: 3-5 (30 to 99% bioturbation)

Trace Fossil diversity: 14-17

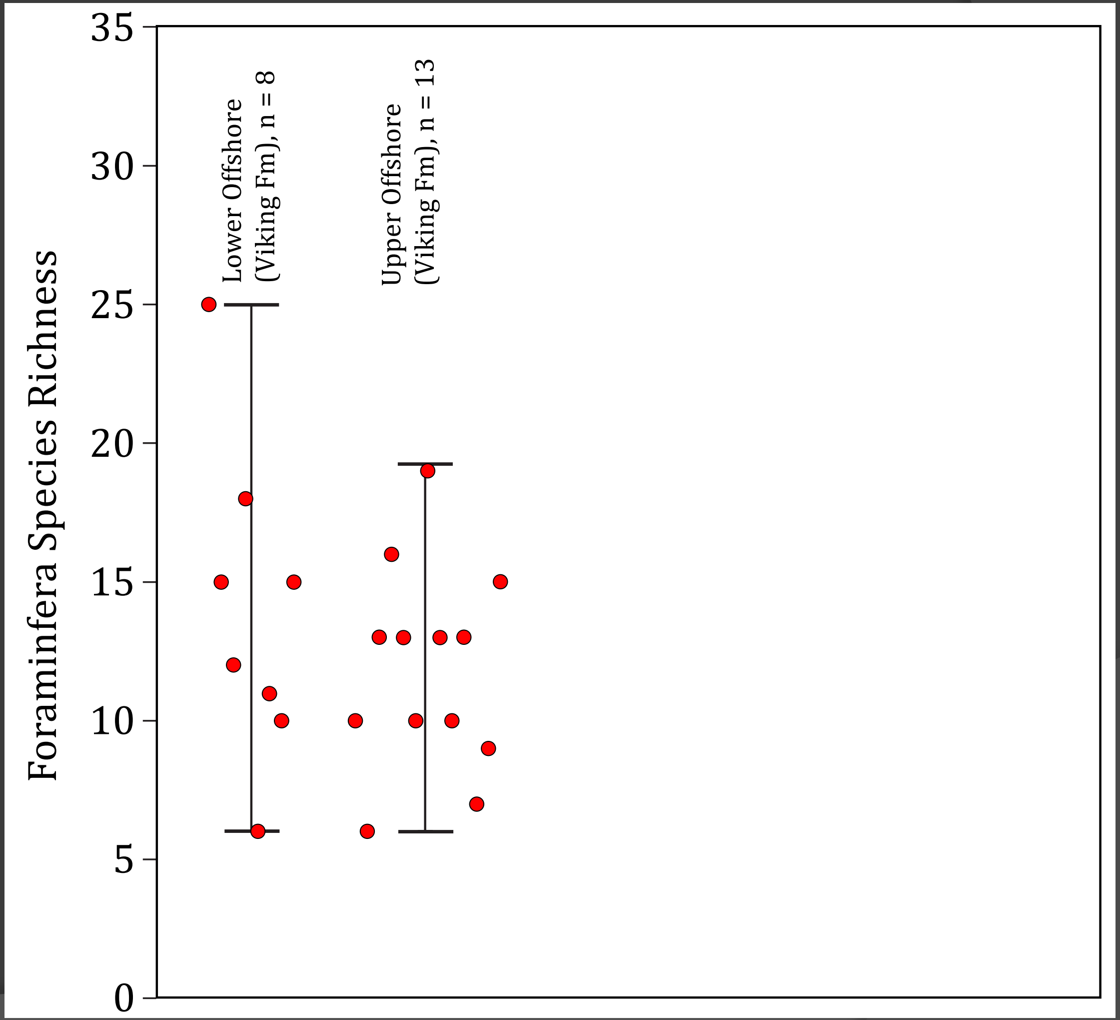
Fully marine assemblage

Viking Formation Benthic Foraminifera

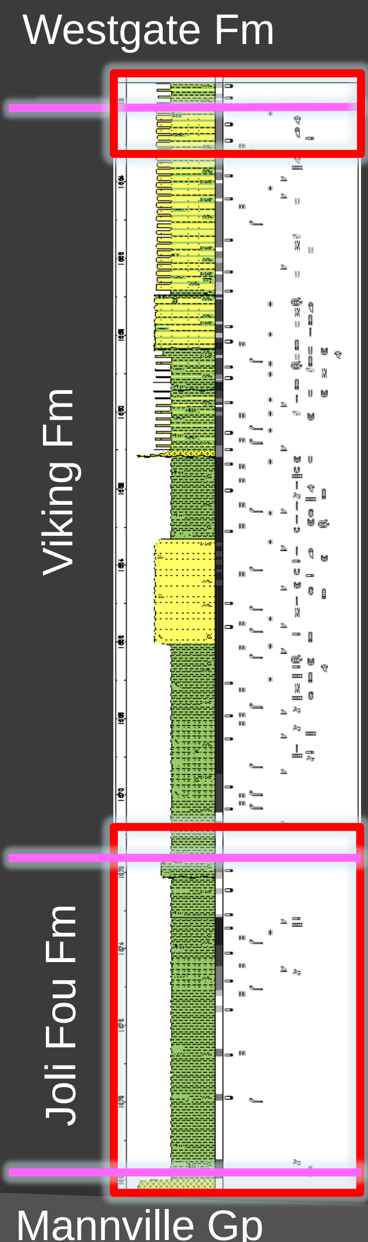
Upper offshore sandy mudstone

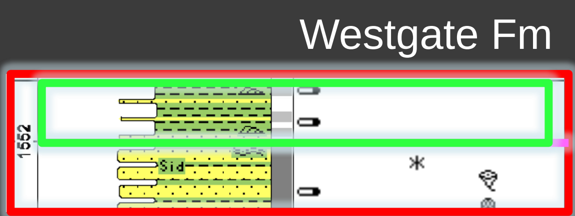


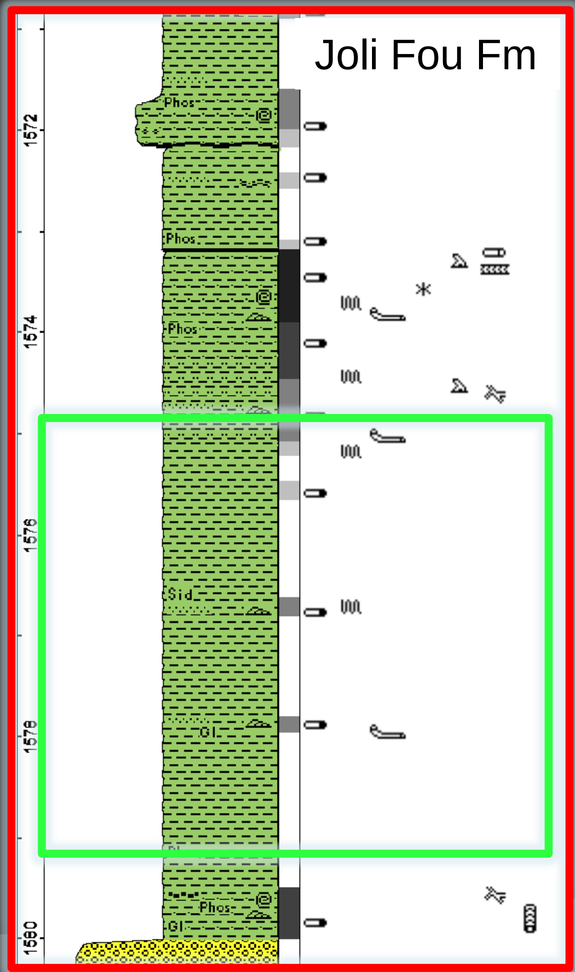
Upper offshore sandy mudstones

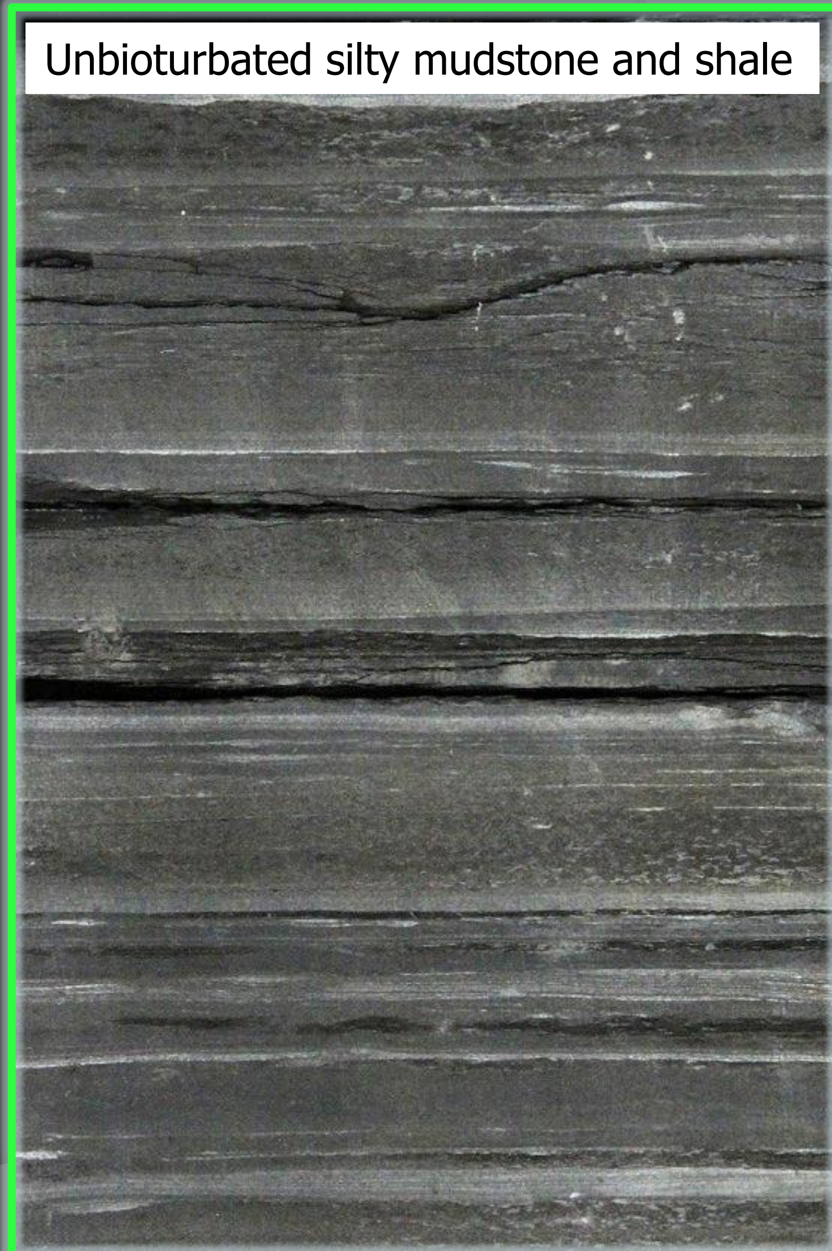


Viking Formation Benthic Foraminifera

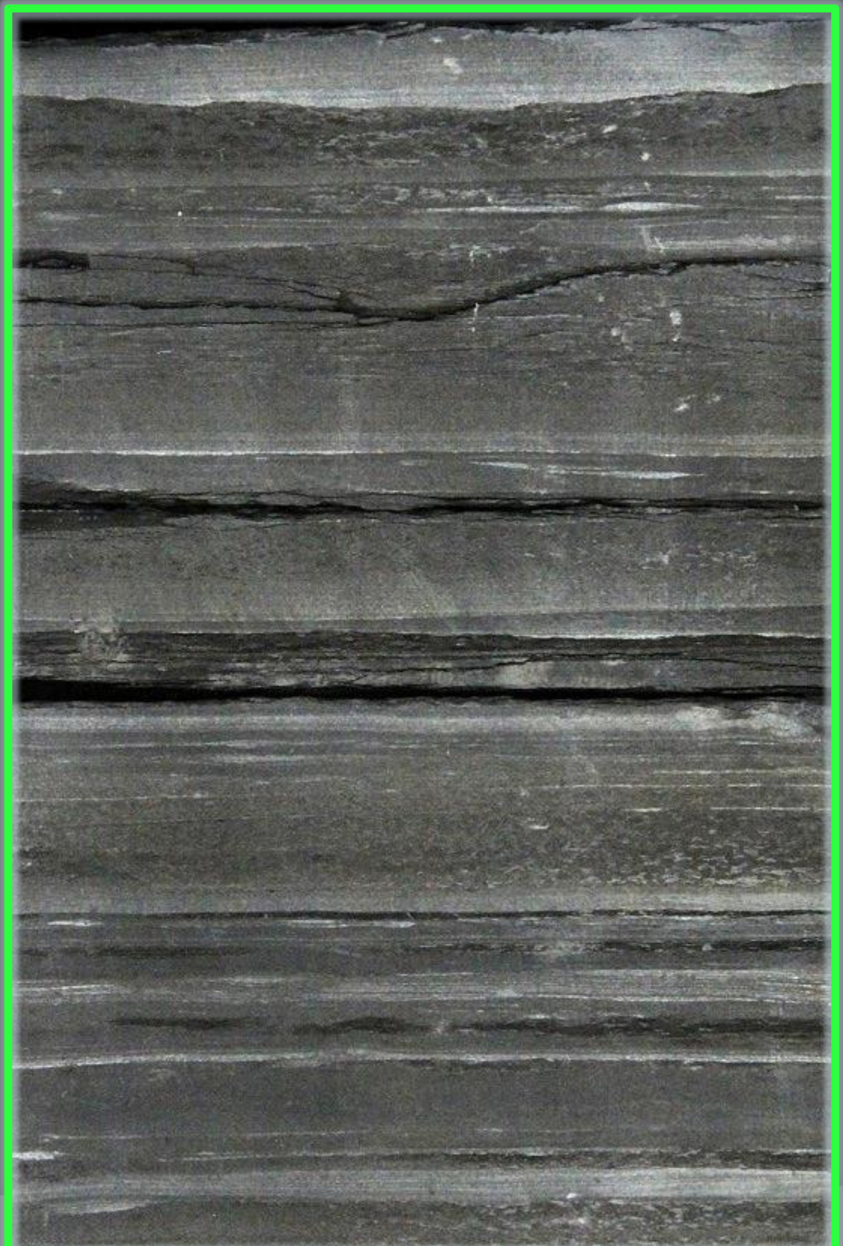








Viking Formation Benthic Foraminifera

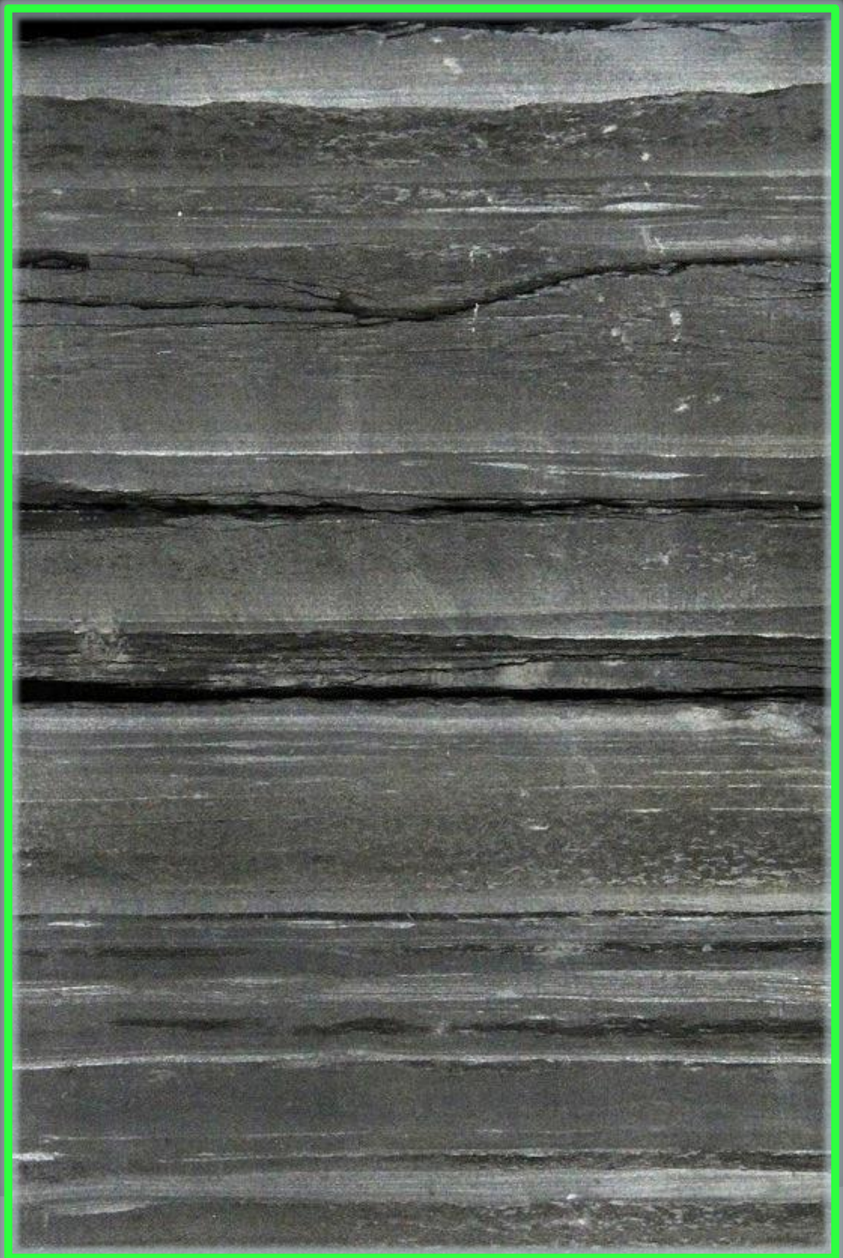


Unbioturbated silty mudstones and shale

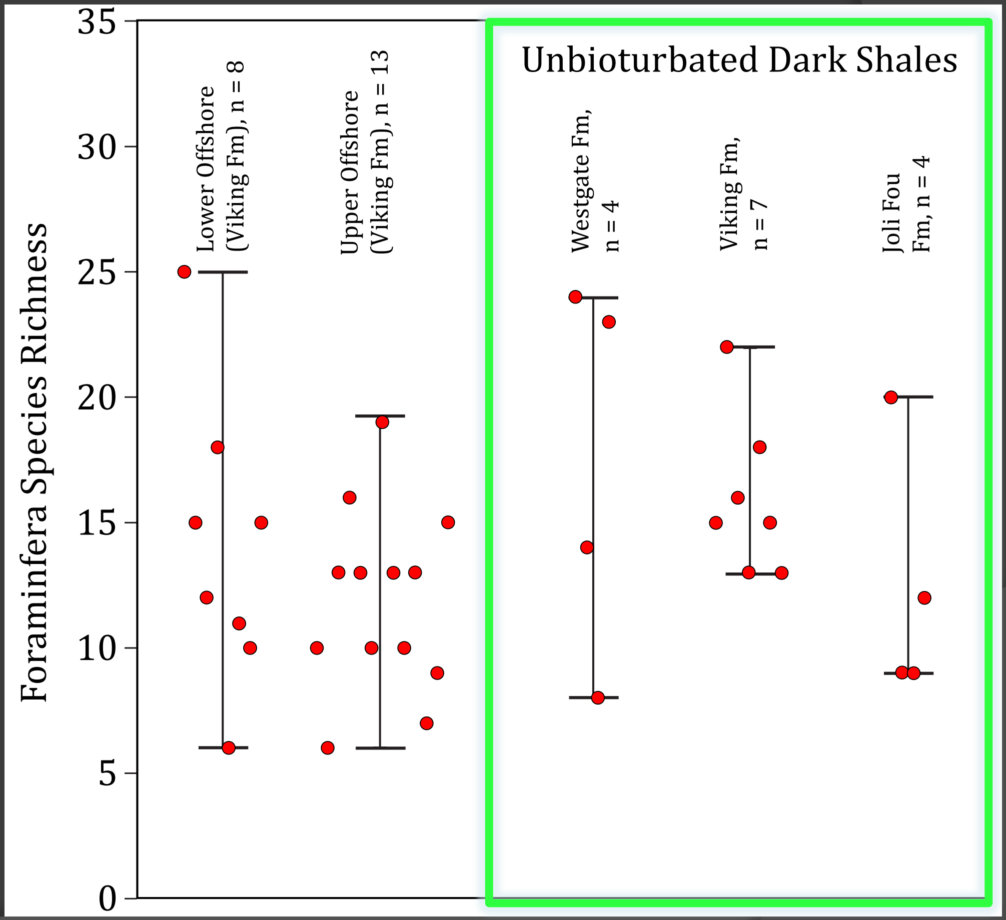
BI: 0-1 (0 to 5% bioturbation)

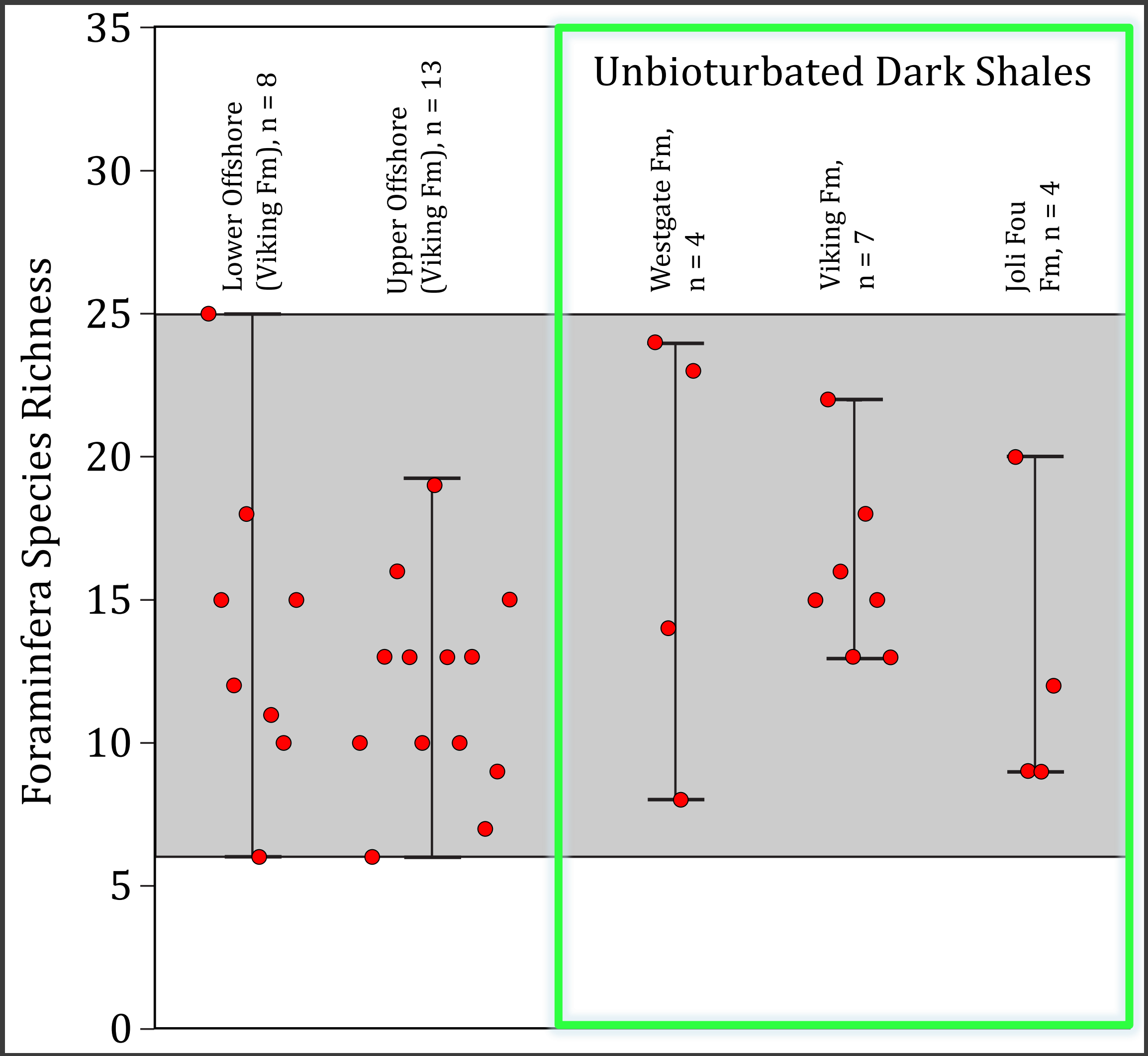
Trace Fossil diversity: 0-3

Viking Formation Benthic Foraminifera



Unbioturbated silty mudstones and shale



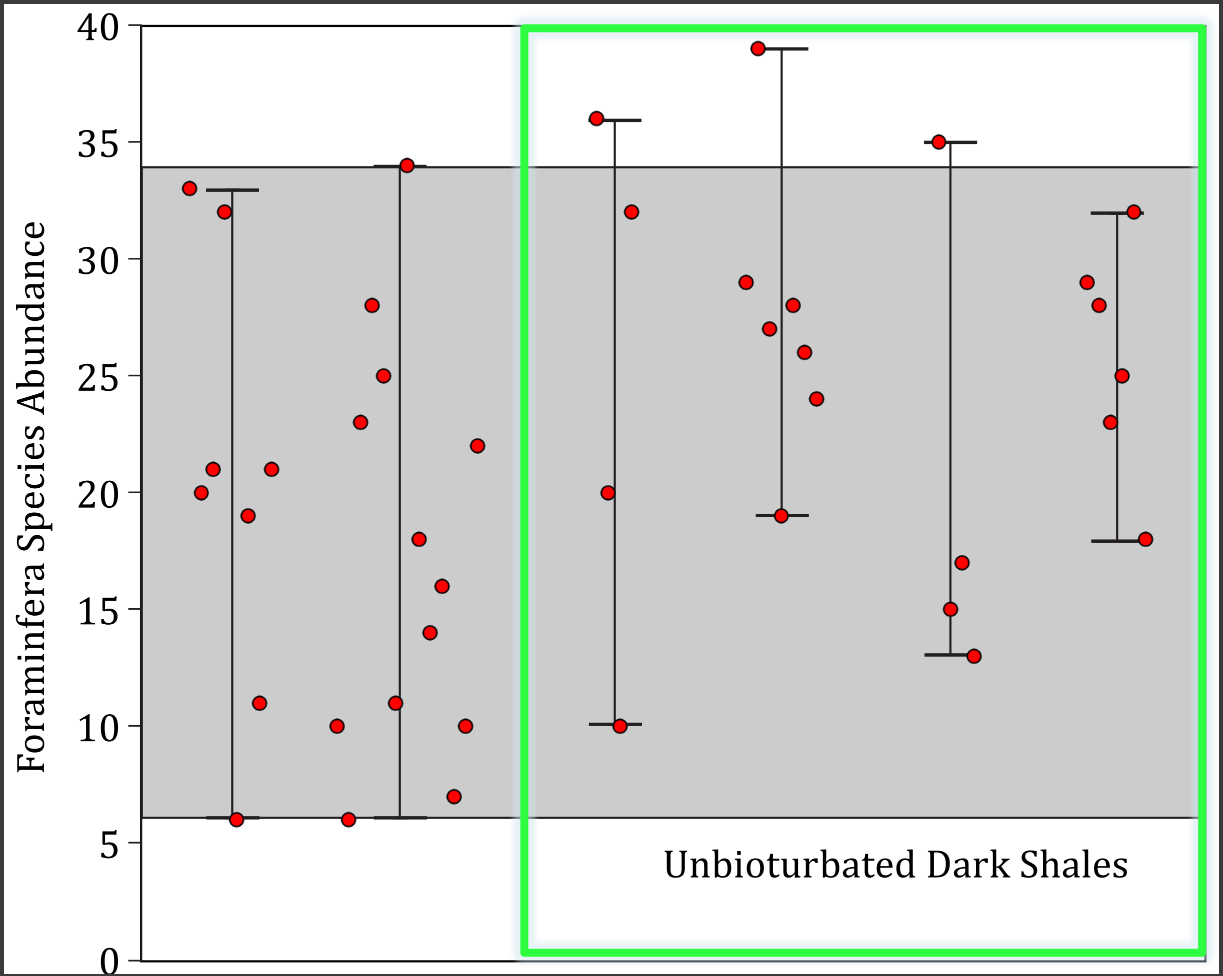


Diversity of benthic forams in unbioturbated dark shales is equivalent to that of highly bioturbated offshore sediments

≠ anoxia (or hypoxia)

= Oxic waters

"For oxygen, foraminifera are potential proxies for the lower limits but once oxygen 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



In fact, abundance of benthic foram (diversity * abundance) in dark shales exceeds that of the bioturbated mudstones!

"For oxygen, foraminifera are potential proxies for the lower limits but once oxygen 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

Conclusion

Decrease in bioturbation in dark marine shales and mudstones correlates to a *reduction in dissolved oxygen* in oxygenated (oxic) seawater but not to anoxia