Expanded Oxygen Minimum Zones in the Oceans during the Paleocene/Eocene Thermal Maximum indicated by I/Ca in Planktic Foraminifera

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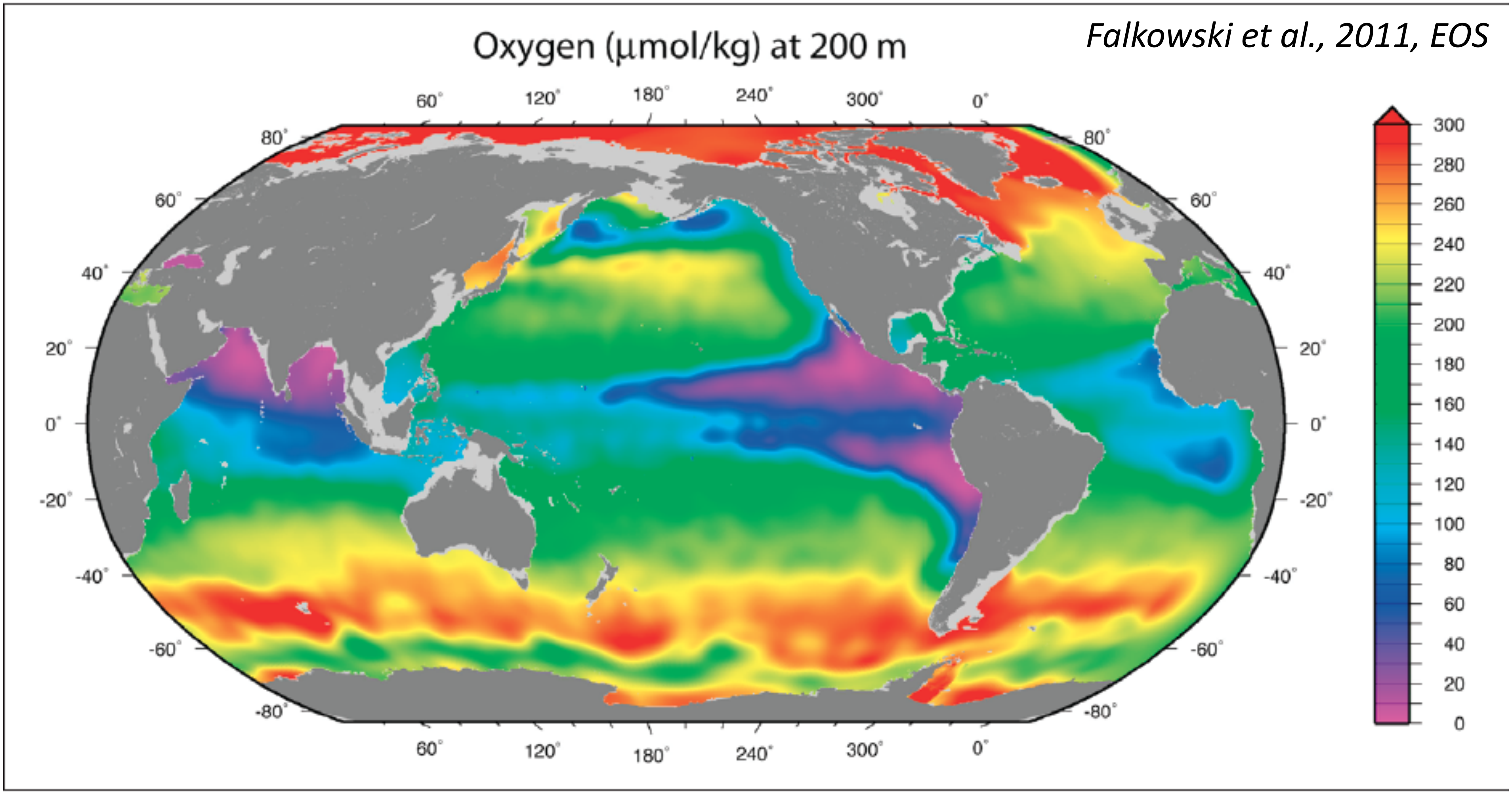


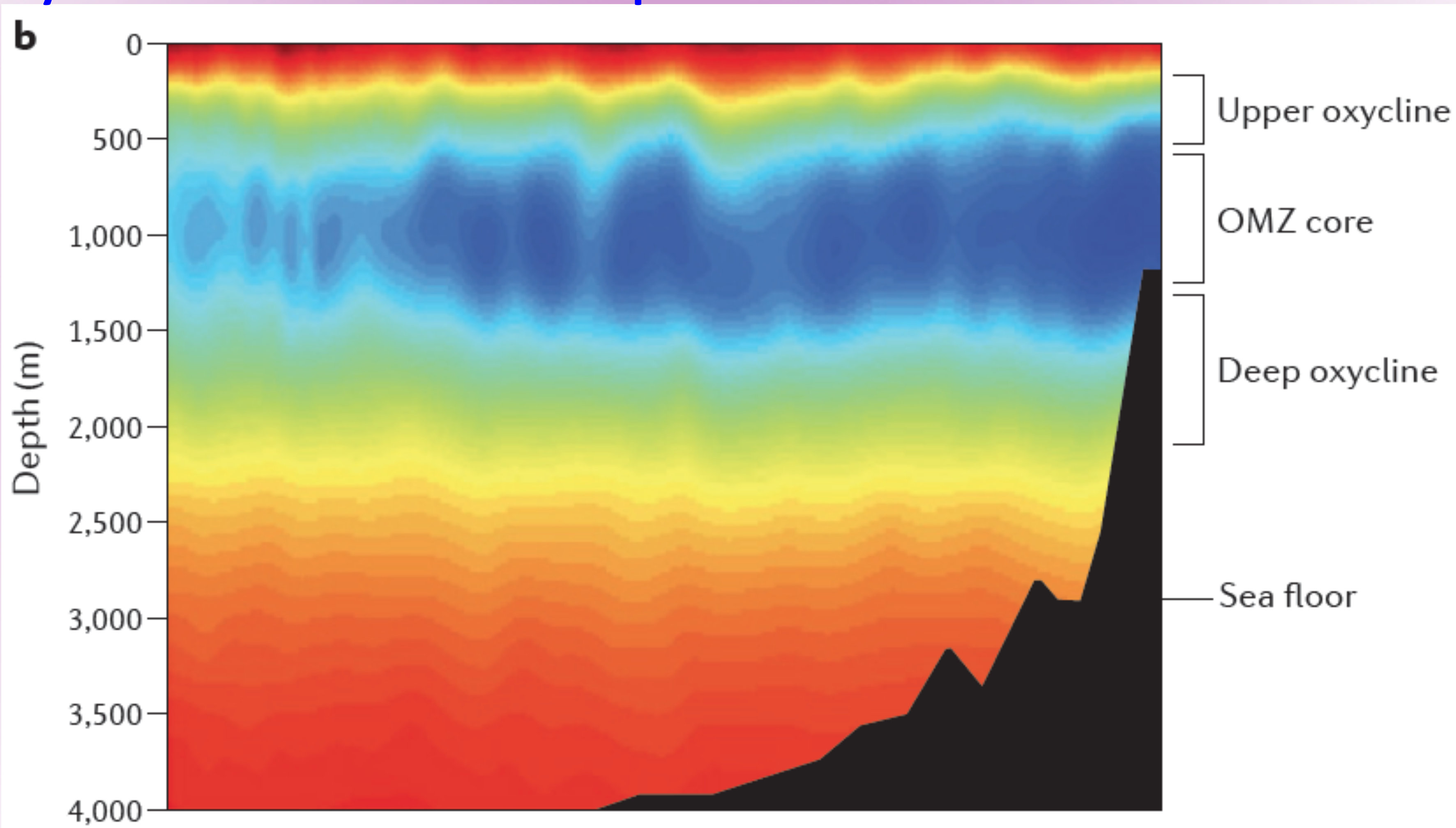
*Fig. 1. Mean global ocean oxygen concentrations at 200 meters below the surface. Note the extensive regions of low oxygen (oxygen minimum zones) throughout the low-latitude oceans and the subarctic Pacific. Data from the World Ocean Circulation Experiment Global Hydrographic Climatology [*Gouretski and Koltermann, *2004].*

WILL OXYGEN MINIMUM ZONES EXPAND IN A WARMING WORLD?
LESSONS FROM THE GEOLOGICAL PAST.

WHAT PROXIES CAN WE USE TO RECONSTRUCT PALEOXYGENATION?

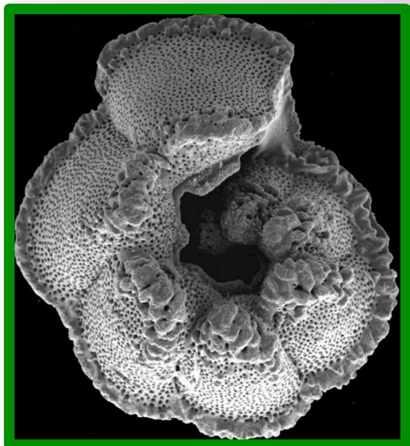
A LARGE VOLUME OF LOW OXYGEN WATERS IN OXYGEN MINIMUM ZONES (OMZ) IS NOT IN CONTACT WITH THE SEA FLOOR:

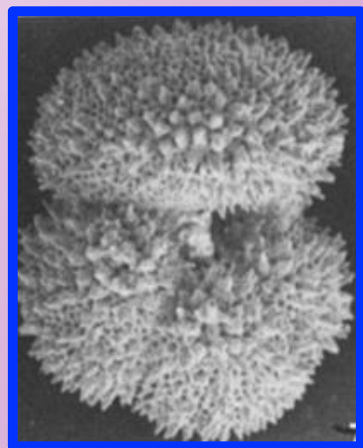
proxy based on calcite shells of planktic foraminifera



CROSS SECTION NE PACIFIC SUBARCTIC OMZ; Wright et al., 2012, *Nature Reviews in Microbiol.*

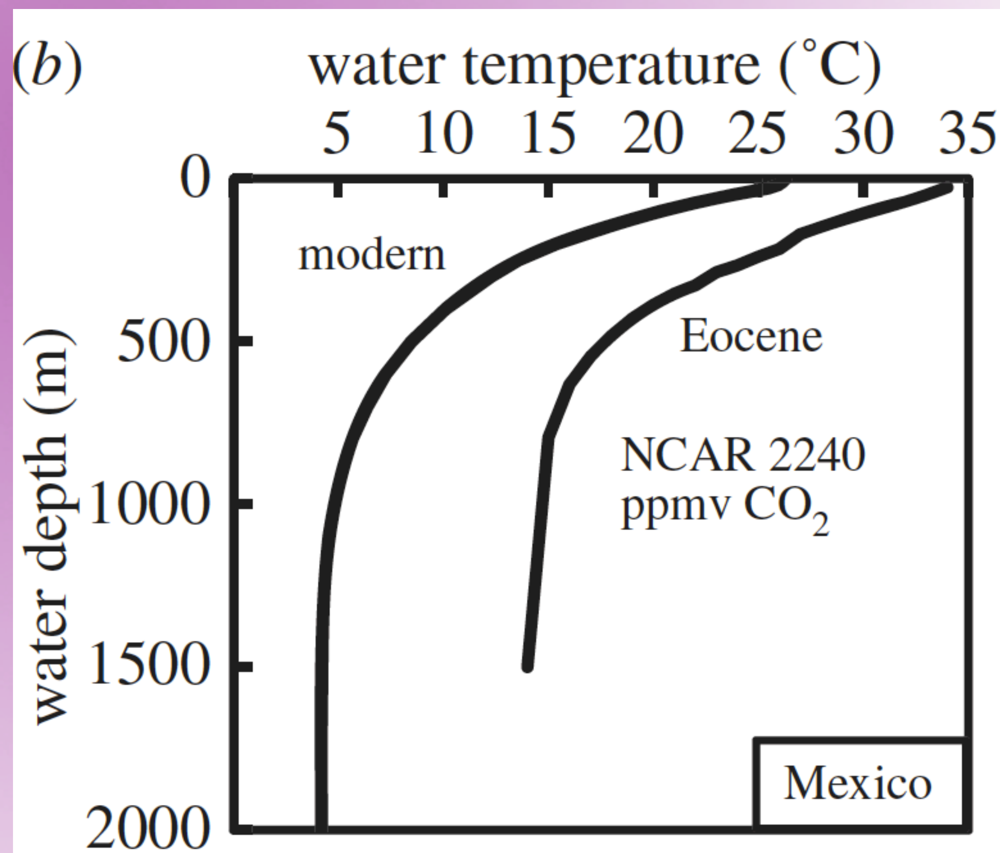
Paleocene-Eocene planktic foraminifera:





Genera *Morozovella*, *Acarinina*: have photosymbionts, calcify in surface mixed layer (M)

Genus *Subbotina*: calcifies in deeper, thermocline waters (D)

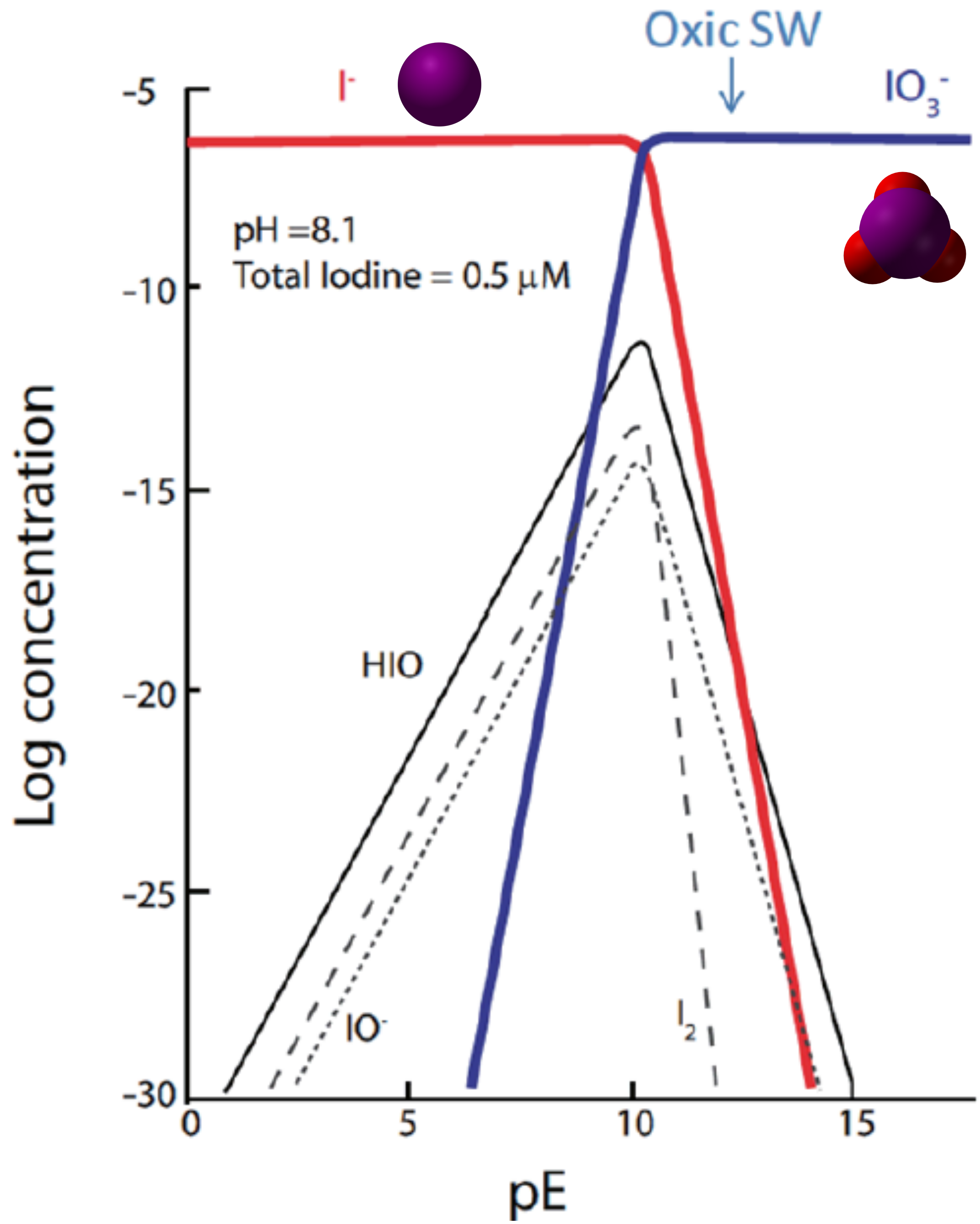


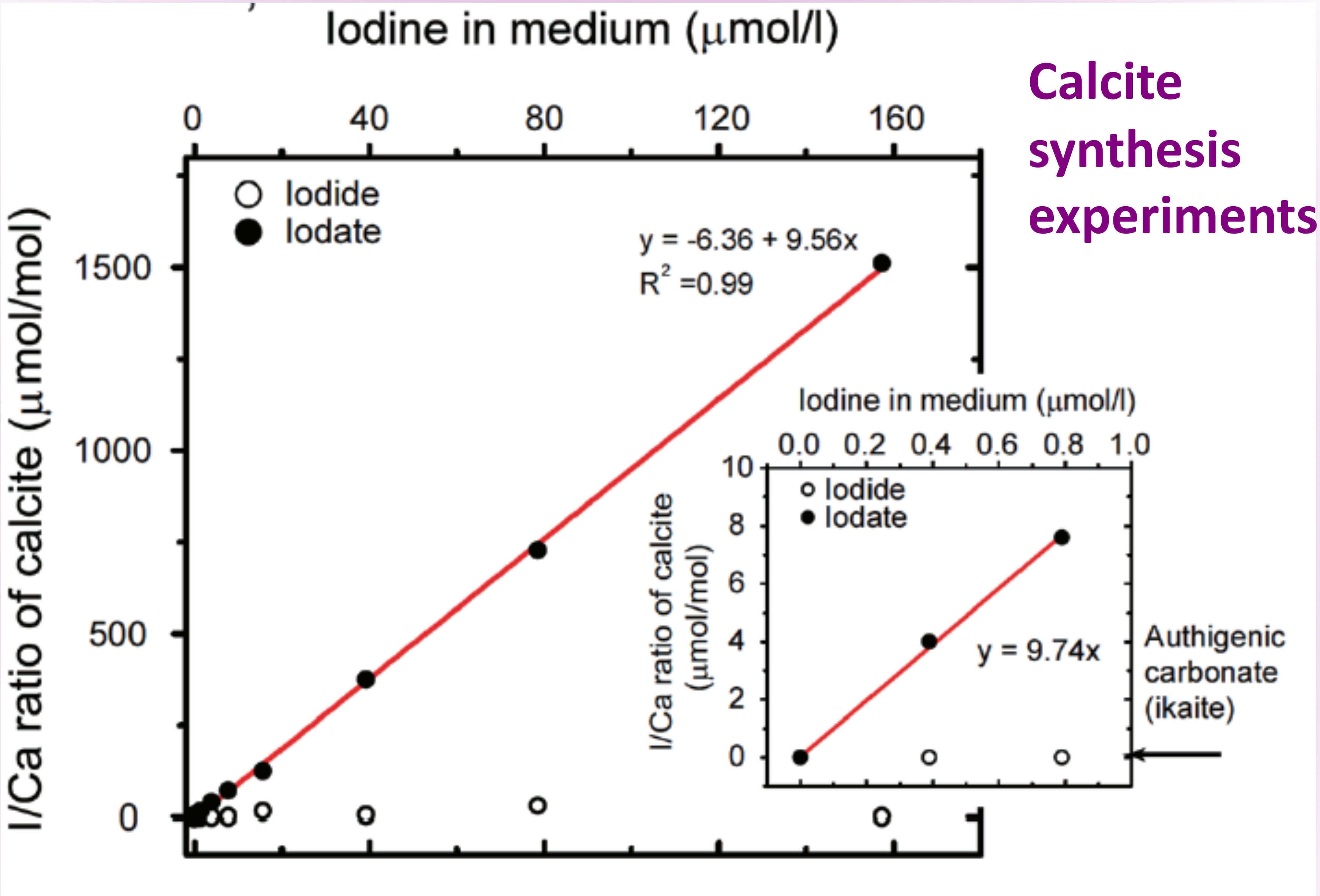
John et al., 2013, Phil. Trans. Roy. Soc. A.

THE I/Ca PROXY (I/Ca in calcite):

- Iodine speciation in the modern oceans: **Iodide (I^-)** vs. **iodate (IO_3^-)**
- **Total iodine** (iodate + iodide) ~ 0.45μM.
- Residence time ~ 300 kyrs.
- Iodate is **micronutrient**: primary productivity -> iodate loss
- **Iodate**, not **iodide** is built into **calcite**
- **I/Ca reflects oxygenation**: high at high iodate (higher oxygen levels)

Wong and Brewer, 1977

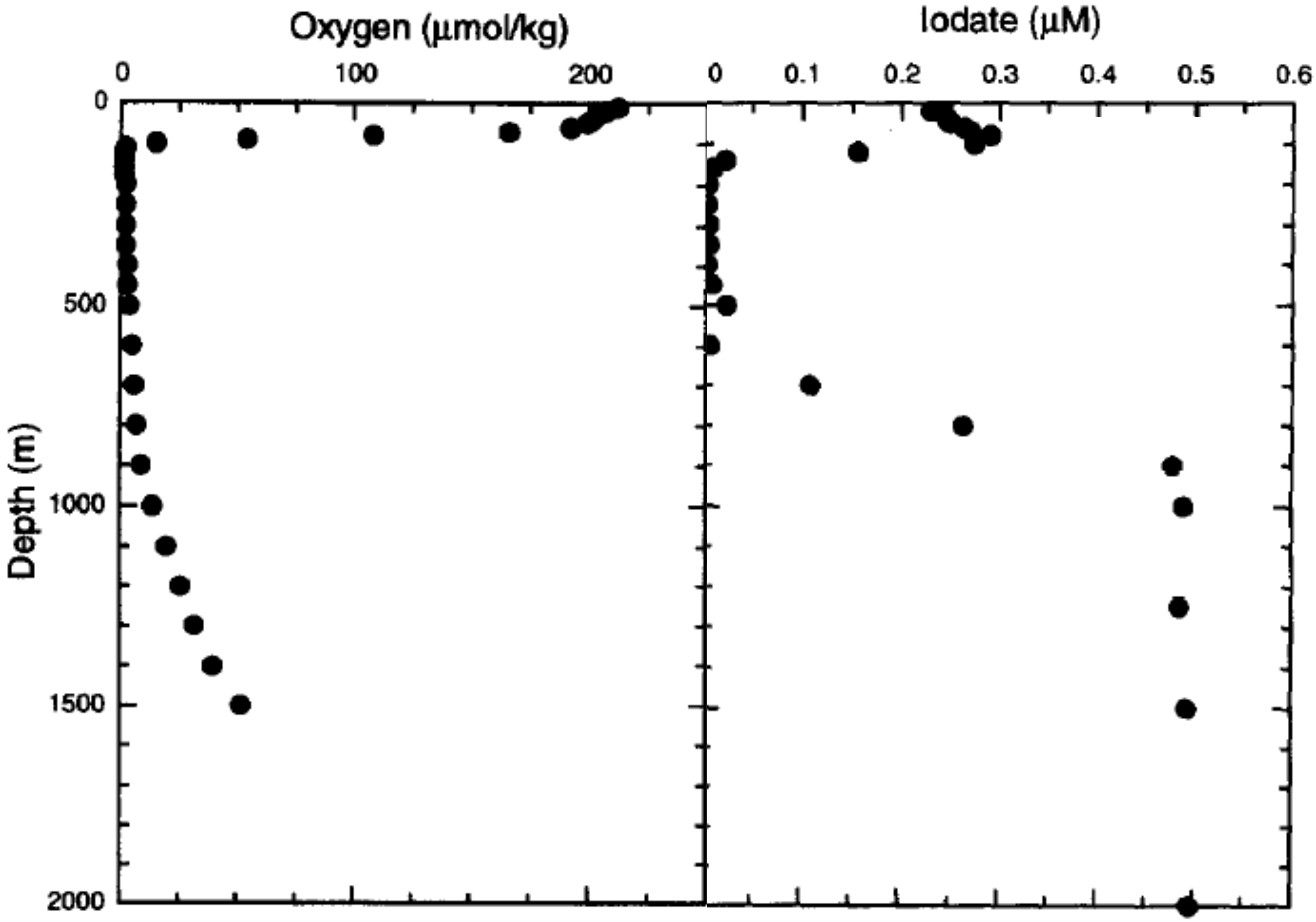




Calcite synthesis experiments

No information on I/Ca in *foraminifera culture experiments*.

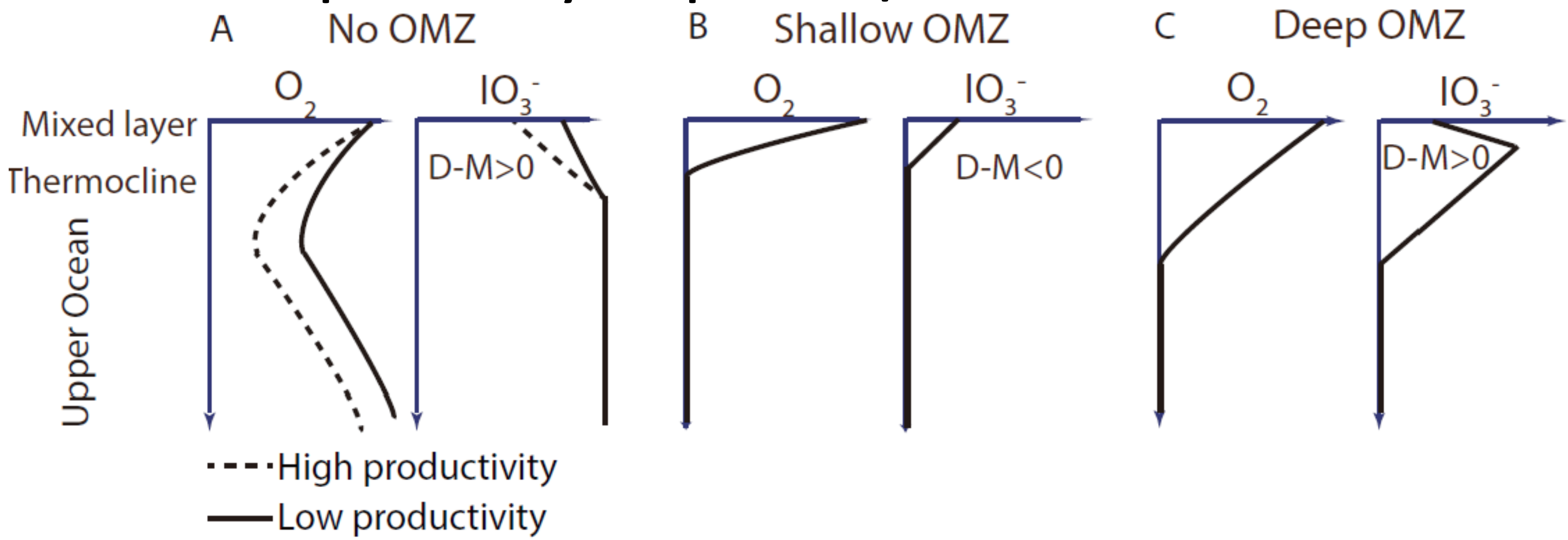
Iodate and Oxygen Minimum Zones



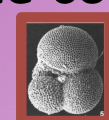
Rue et al., 1997

VERTEX, eastern tropical North Pacific

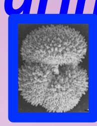
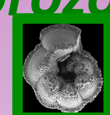
Vertical iodate profile in oceans: productivity and presence/absence of OMZ.



Primary productivity and **O_2** control iodate concentration in seawater -> I/Ca in **planktic foraminiferal calcite**.



D= I/Ca in deep thermocline calcifiers (*Subbotina*); **M=I/Ca in mixed-layer calcifiers (*Acarinina*, *Morozovella*)**

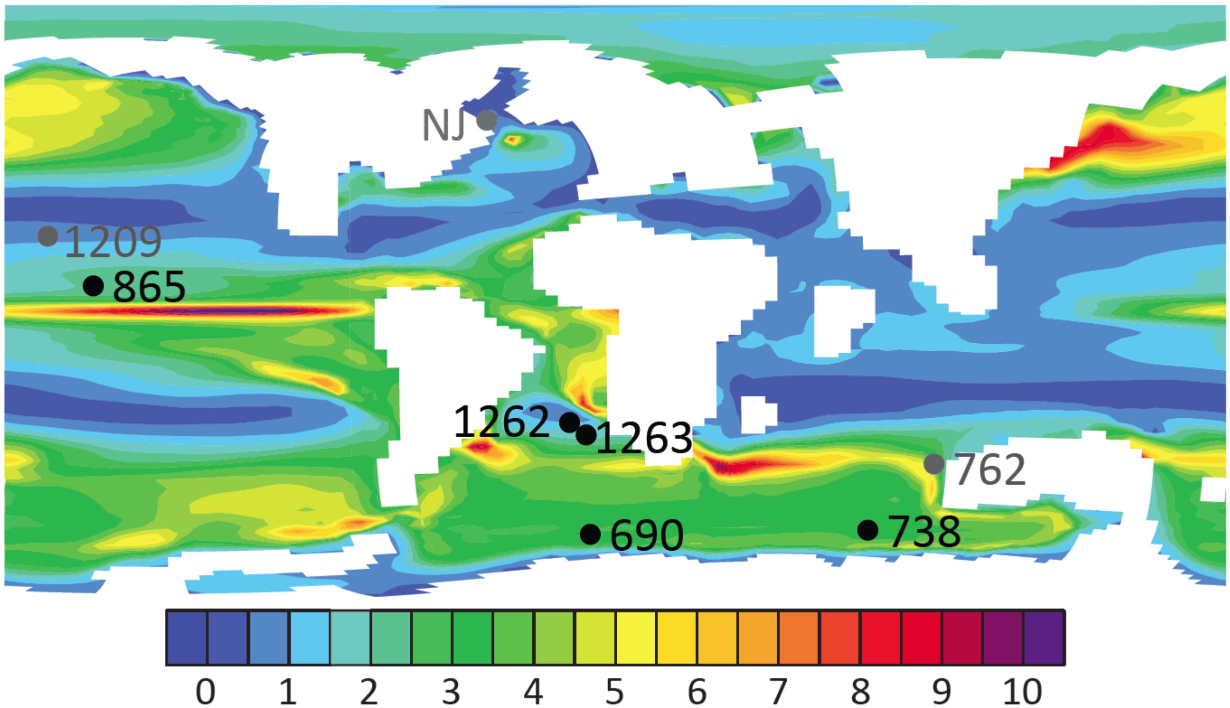
NO OMZ: iodate increases downward from mixed layer, D>M

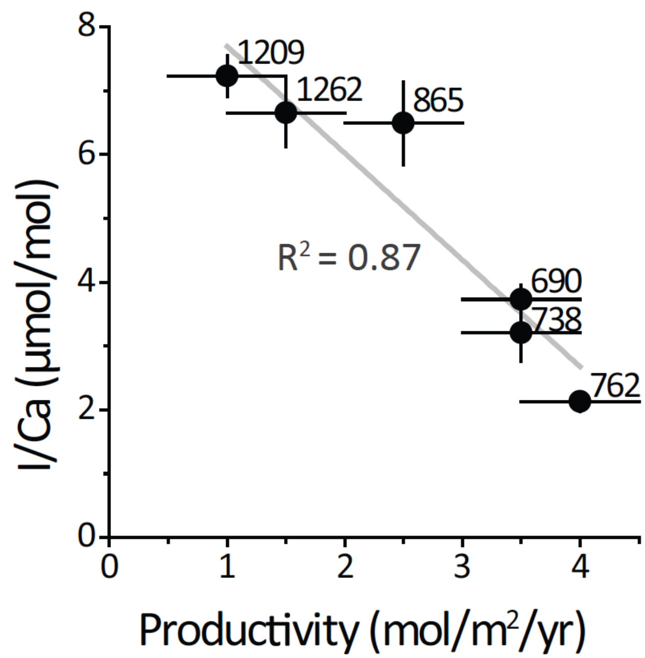
OMZ: at shallow levels: D<M

OMZ: at deep levels, D>M

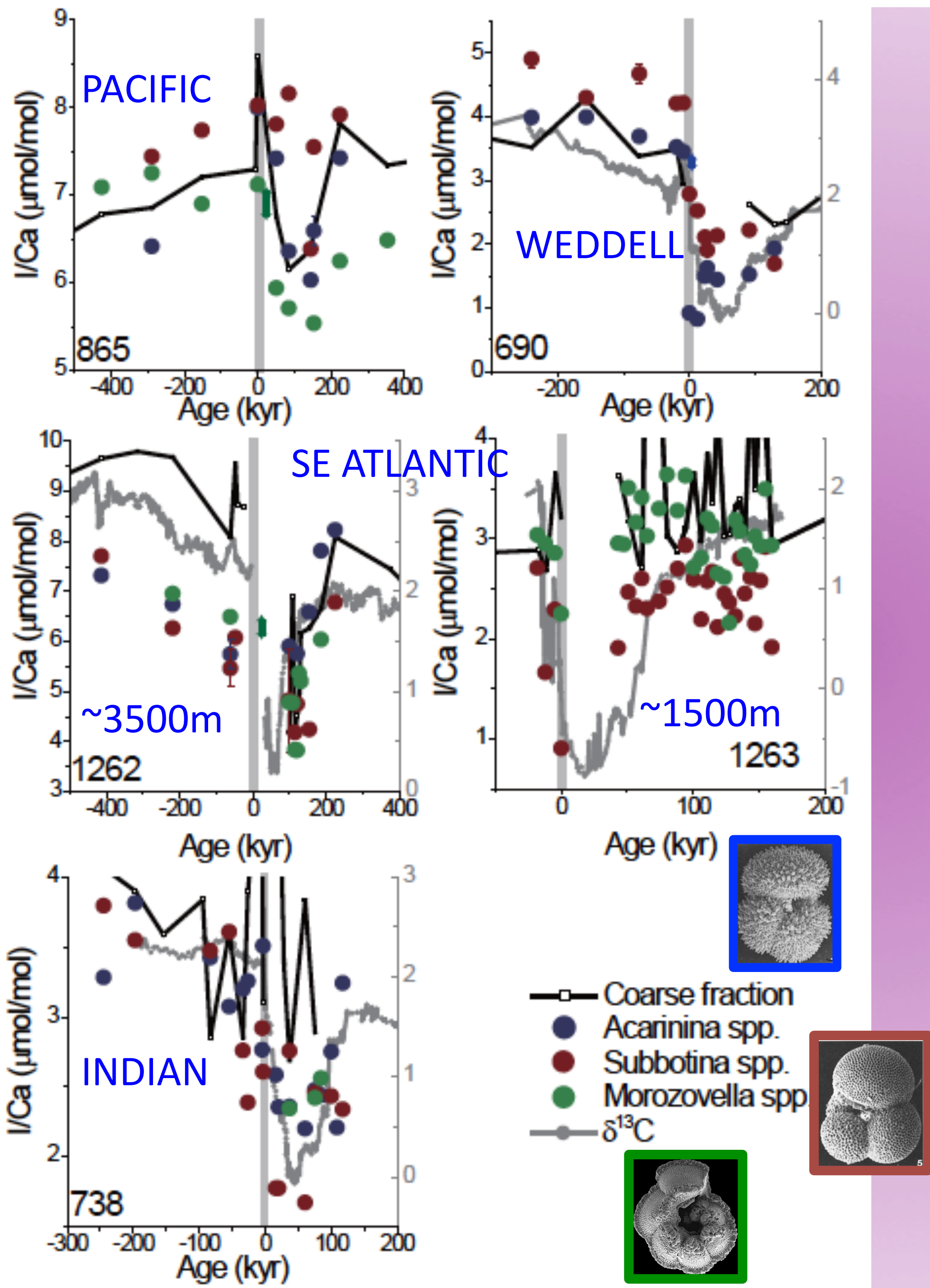
Can we observe a link between productivity and I/Ca in foraminifera in the Paleocene? (in warmer oceans than today, before PETM warming)

Pre-CIE open ocean export production (mol/m²/yr)





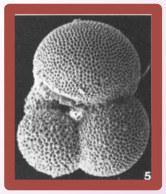
Average I/Ca in mixed-layer planktics (*Acarinina*, *Morozovella*) compared to **modeled export productivity** (Winguth *et al.*, 2012, *Geology*), and **microfossil evidence** for productivity levels.



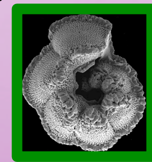
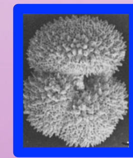
PETM RECORDS:

I/Ca values decreased overall, minimum values around PETM, indicated by grey curve (Carbon Isotope Excursion).

Likely due to **deoxygenation** *(increased stratification, increased remineralizatrion organic matter)***:** no evidence for widespread increased productivity.



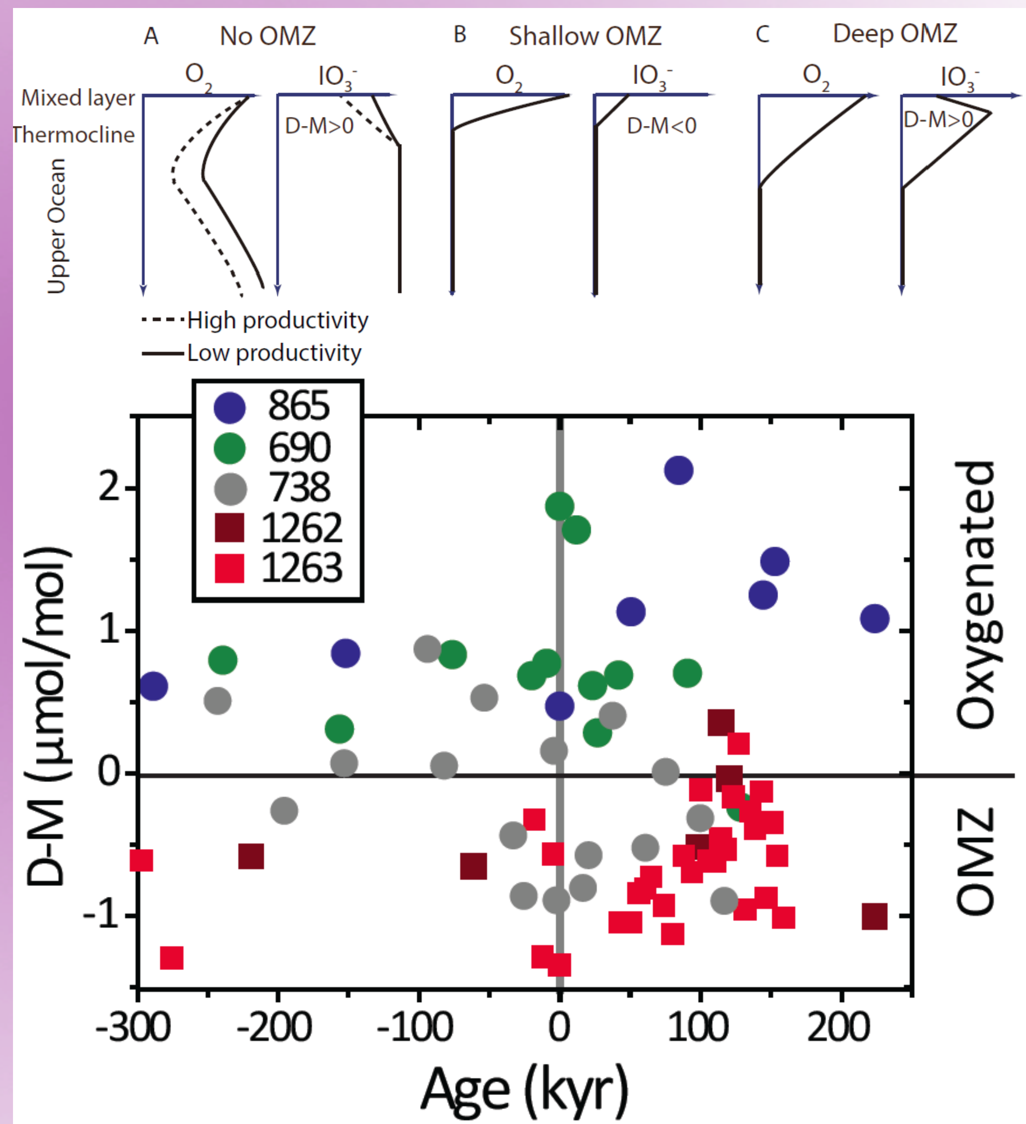
D(thermocline) - M (mixed layer) I/Ca

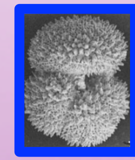
Sites 865 (Pacific), 690 (Weddell): + D-M values -> no or deep OMZ.

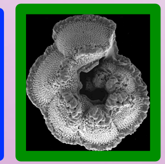
Site 738 (Indian): D-M values declining, deep OMZ is shoaling.

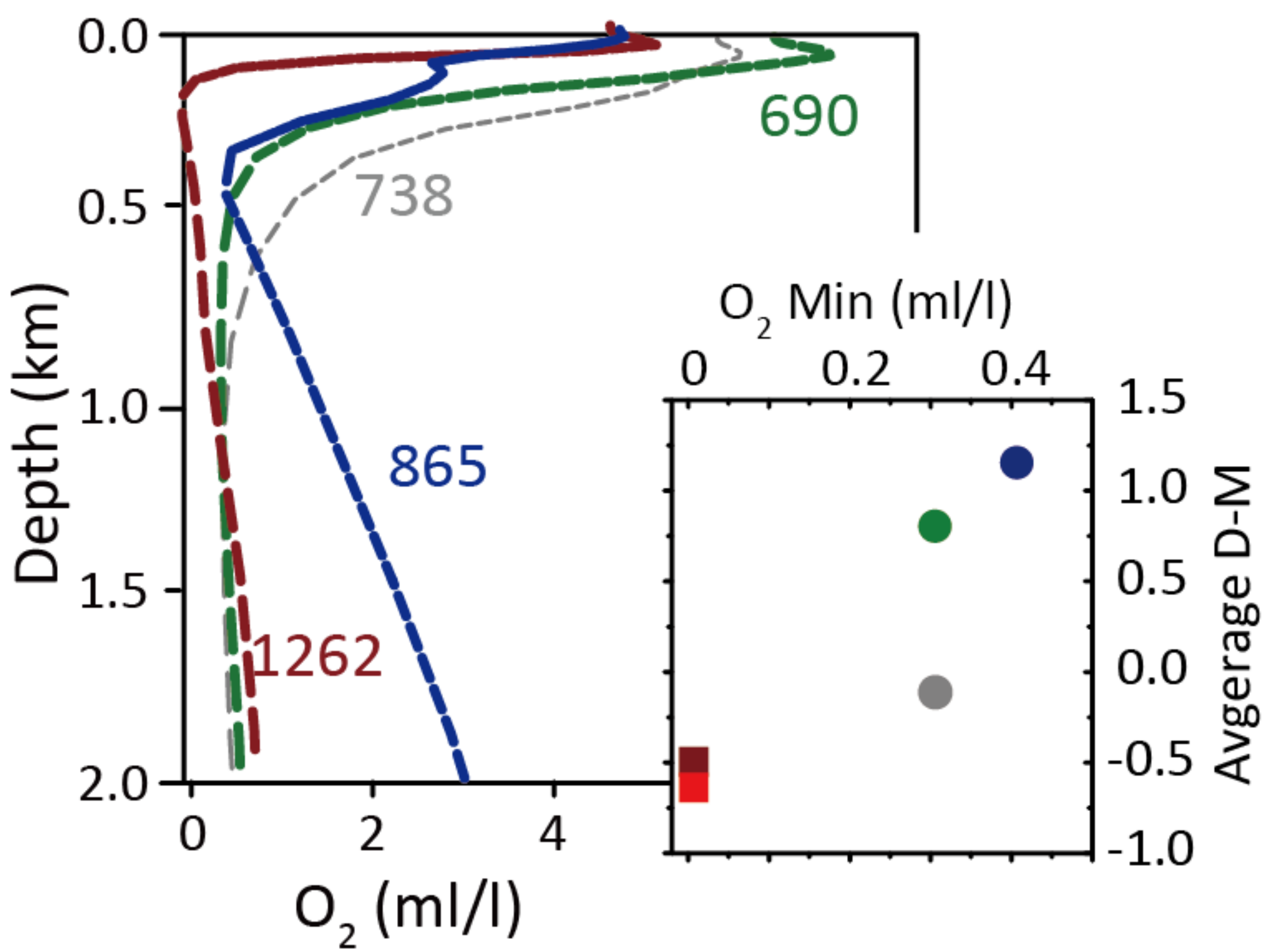
Sites 1262-1263 (Walvis Ridge): - D-M values, lower at shallower site. OMZ over Site 1263 throughout, intensified deoxygenation



D-M

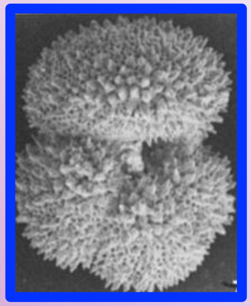






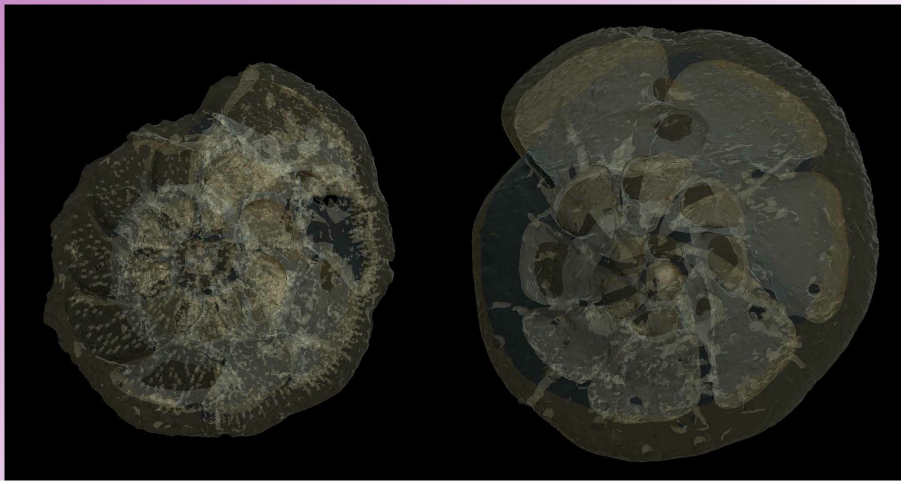
Positive correlation: **average D-M value** and **modeled minimum oxygen levels** in the water column.

CONCLUSIONS



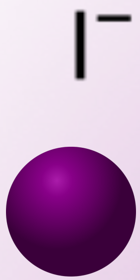
✧ **I/Ca in foraminiferal tests is a promising proxy for oxygen levels throughout the water column, more testing and calibration is necessary (e.g., effects of temperature, carbonate saturation state, vital effects).**

Preliminary benthic data, Site 1263, Walvis Ridge: infaunal (*O. umbonatus*, right) MUCH lower I/Ca than epifaunal (*N. truempyi*, left), as expected. Large variability during PETM.



SPECULATIVE CONCLUSIONS

- **Widespread expansion of OMZs might have influenced PETM pelagic ecosystems during past global warming (PETM), as predicted for the future.**
- Compression of the zone above the OMZ may have been a (partial) cause of changes in planktic foraminiferal assemblages during hyperthermal events, commonly attributed to changes in ocean stratification.
- Enrichment in fish debris above the base of the CIE at Pacific Ocean sites might reflect a mortality event due to expansion of the OMZ.



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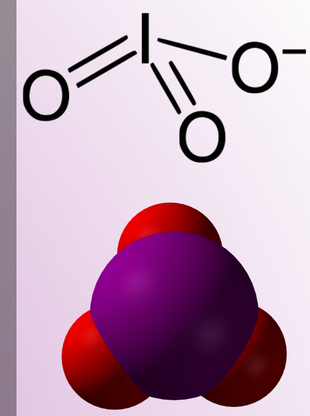

- **NSF Grant OCE-1232413**
- **IODP samples**

Zhou et al., 2014: I/Ca evidence for upper ocean deoxygenation during the PETM; Paleoceanography, doi: 10.1002/2014PA002702