

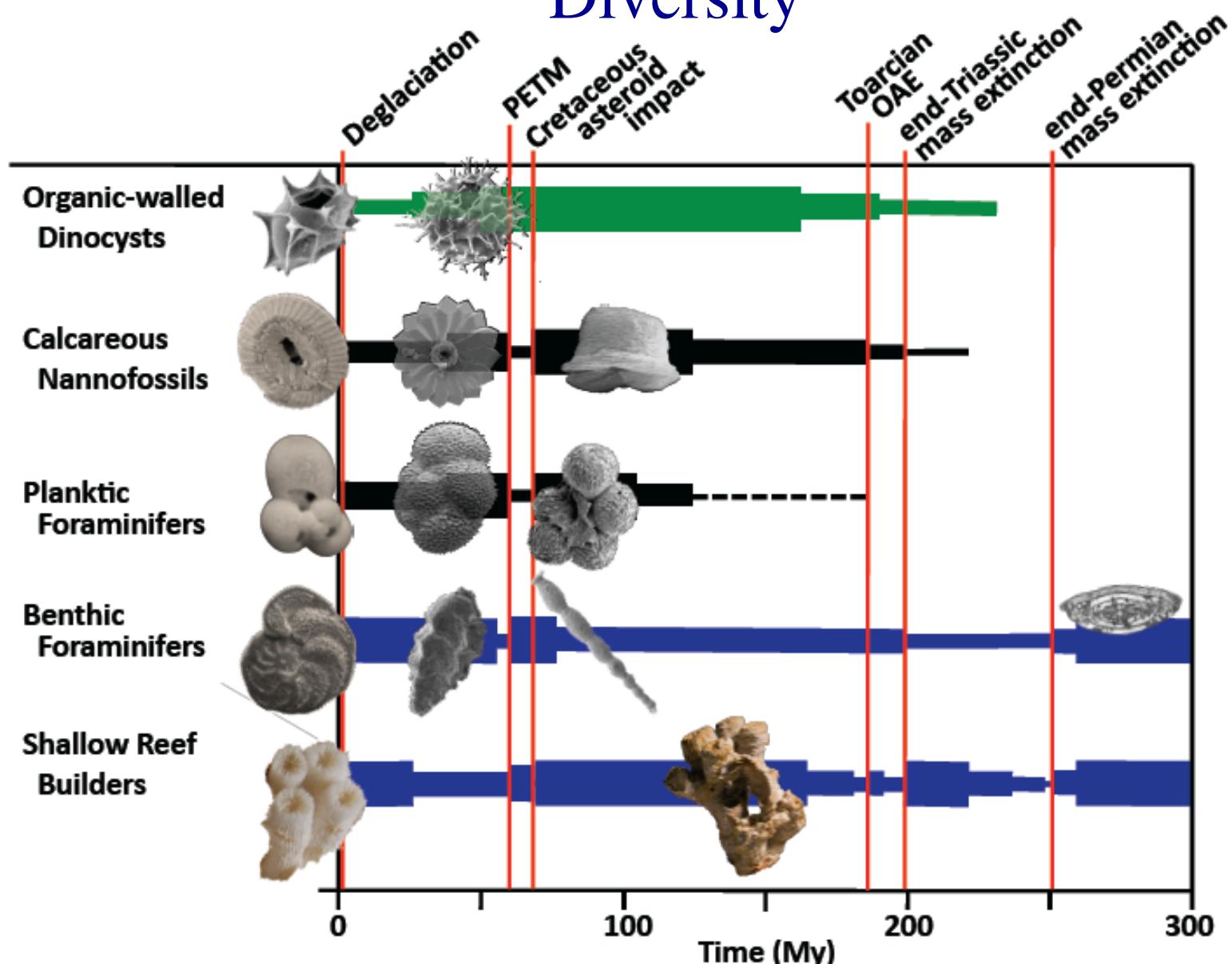
# Boron constraints on Ocean Acidification During the PETM

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# Past Episodes of Ocean Acidification & Marine Diversity



# The Paleocene Eocene Thermal Maximum; A case study for assessing oceanic carbon system response to massive carbon release

- **Global Warming (+5 to 6°C)**
  - multi-proxy (e.g.,  $\delta^{18}\text{O}$ , Mg/Ca,  $\text{Tex}_{86}$ ) constraints
- **Fast Rate of Carbon Release**
  - Estimated 4500 to 6800 PgC – Based on CCD shoaling (i.e., deep sea saturation)
  - Carbon isotope Excursion
  - < 5 kyr, so roughly 1 PgC/yr
- **Rate of C emission slower than rate of oceanic overturning**
  - Does not mimic modern surface ocean  $\Delta\text{pH}$

# Deep Sea Isotope & %CaCO<sub>3</sub> records

## Massive Carbon Input

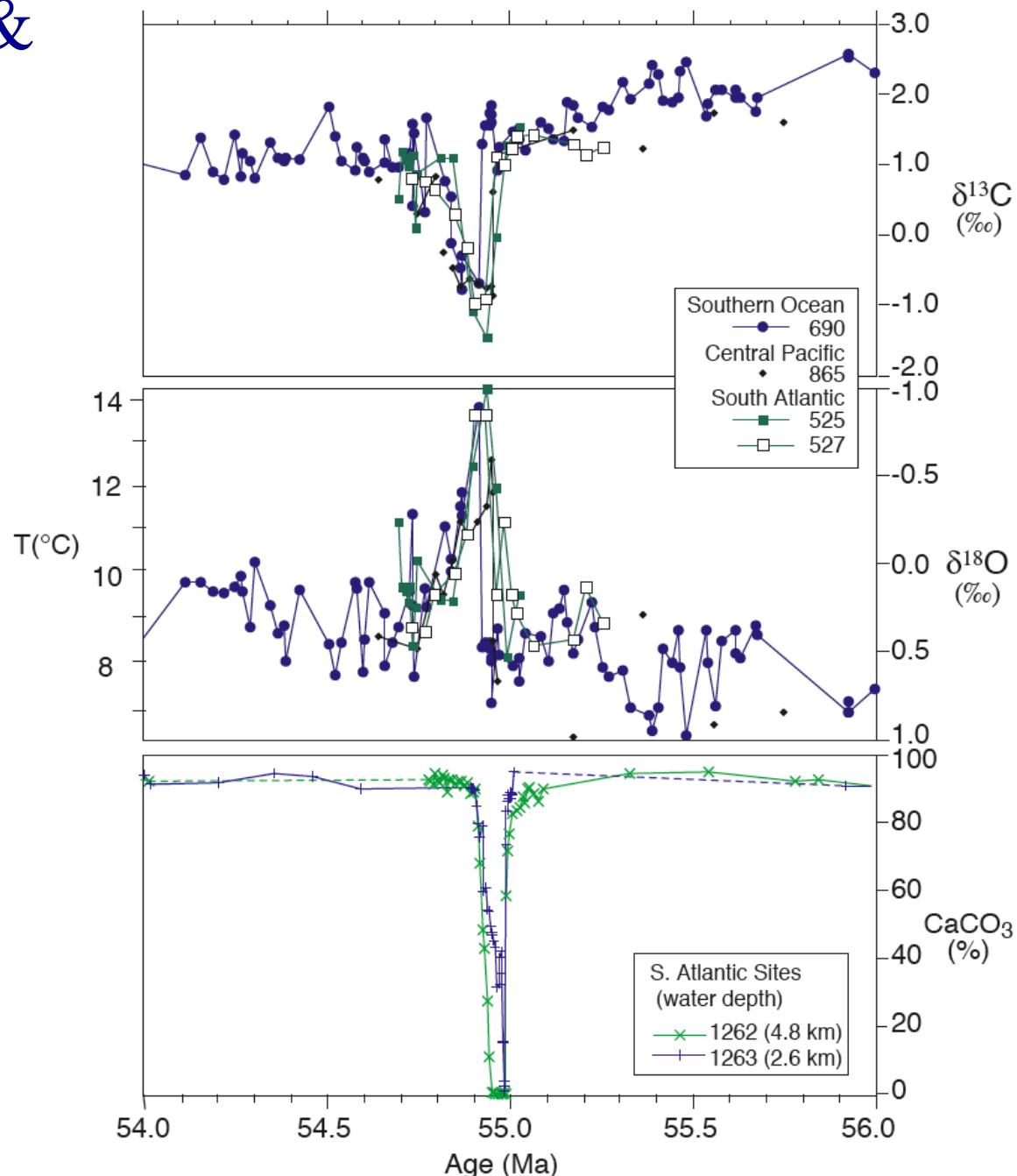
- Carbon Isotope Excursion (CIE) of -3.0‰

## Global Warming

- Oxygen Isotope Excursion (5 to 6°C)

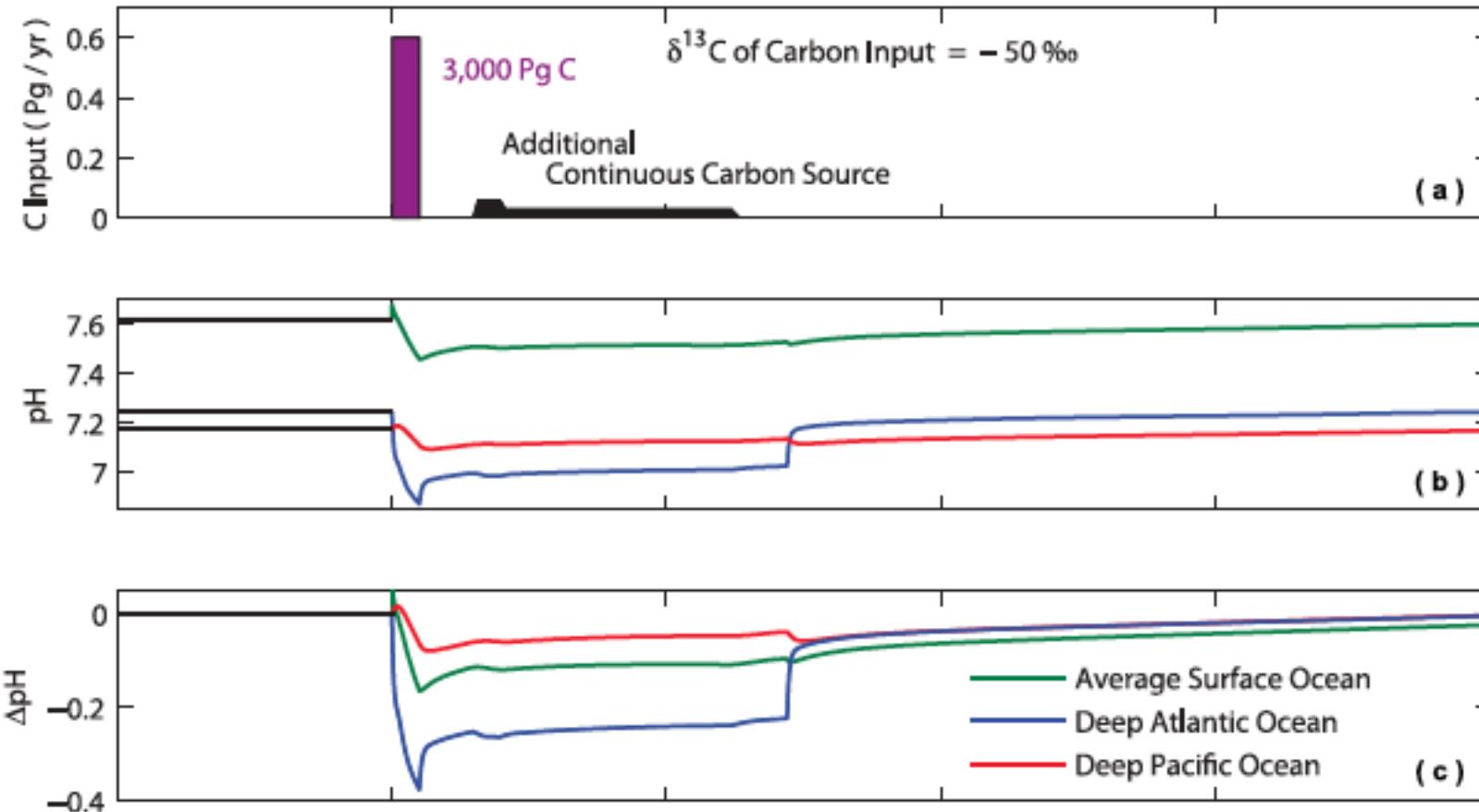
## Ocean Acidification

- Calcite Dissolution Horizon - direct evidence of massive carbon release



Zachos et al., 2001; IPCC 2008

# PETM Simulated pH change (LOSCAR)

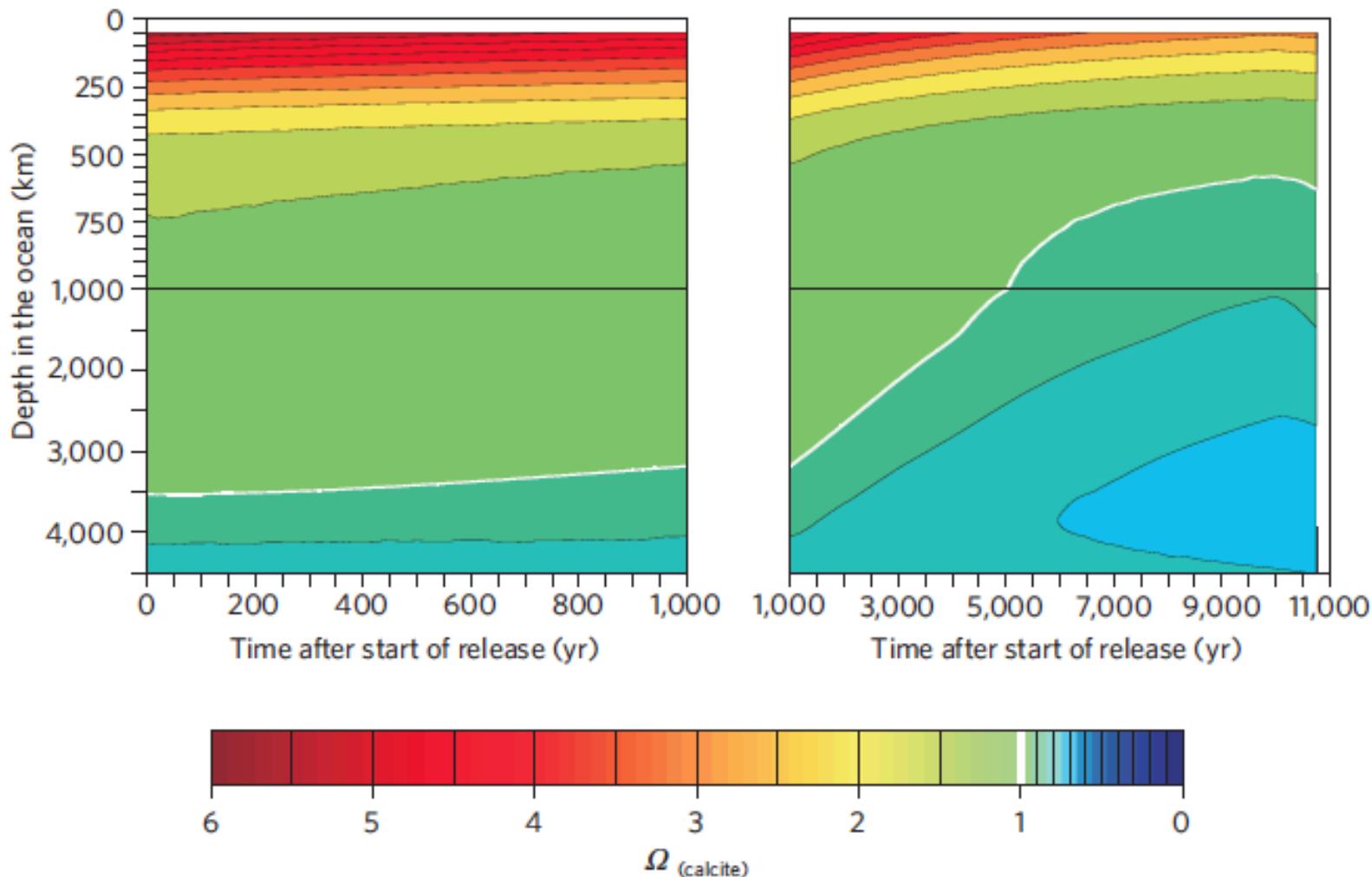


3000 PgC (5 kyr) + 1500 PgC (50 kyr)

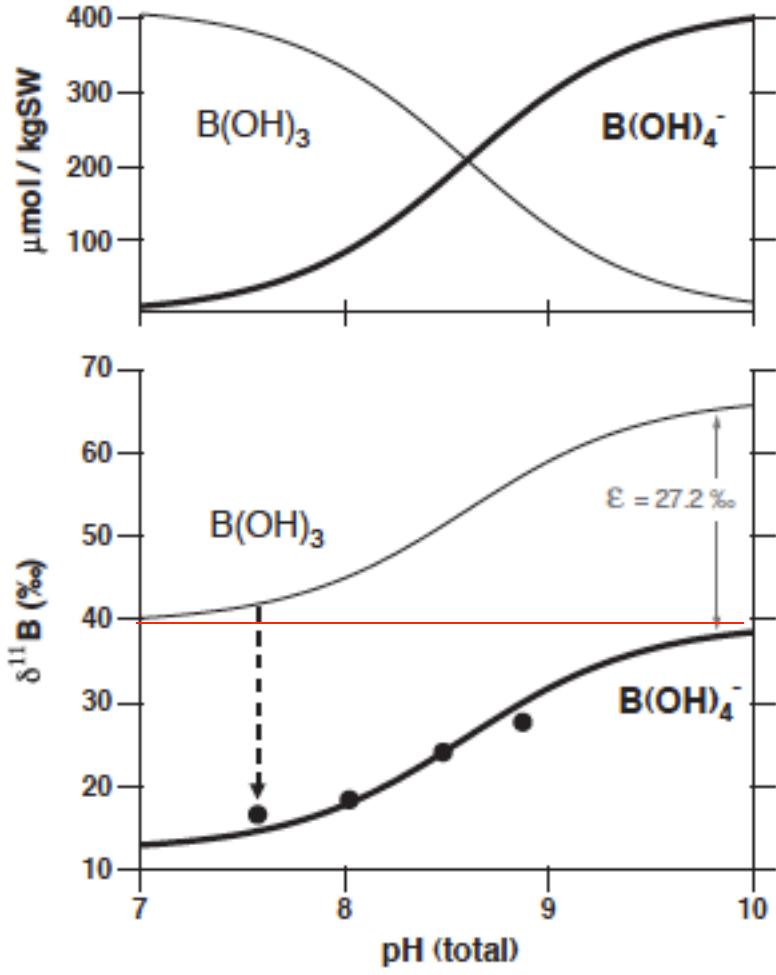
$\Delta\text{pH}_{\text{surf}} = <-0.2$

# Simulated $\Delta$ Carbonate Saturation (GENIE)

- GENIE (*Ridgwell & Schmidt, 2010*)
- 6840 PgC input over 10 kyr ( $\Delta\text{pH} = -0.3$ )

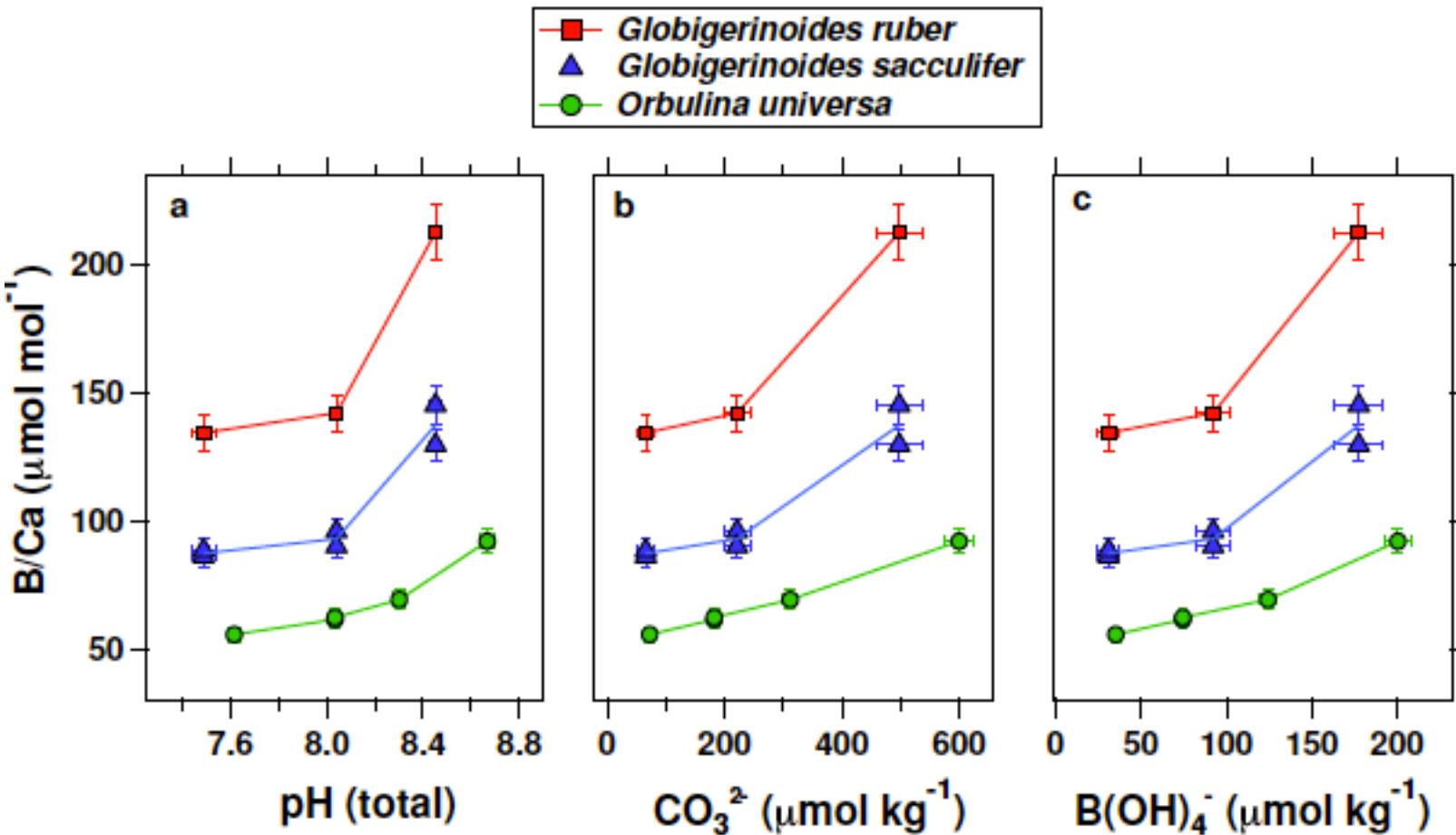


# Reconstructing PETM $\Delta\text{pH}$ : Speciation/Partitioning of B and $\delta^{11}\text{B}$ in seawater/calcite –sensitivity to pH

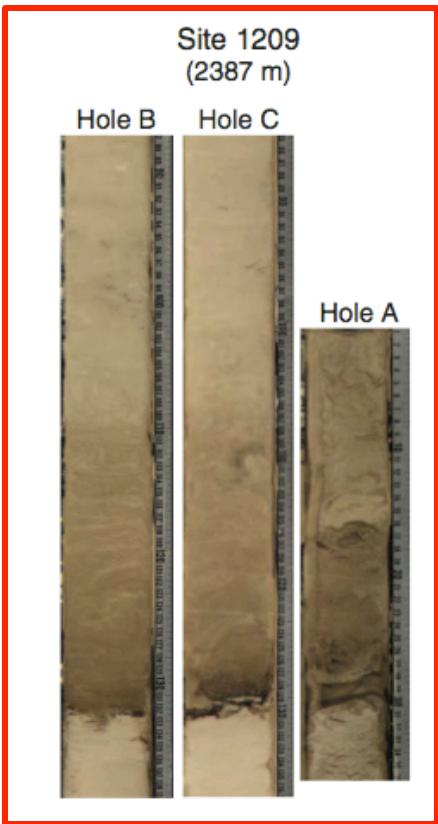


- With increasing pH, the  $\delta^{11}\text{B}$  of  $\text{B(OH)}_4^-$  approaches that of  $\delta^{11}\text{B}_{\text{sw}}$
- Assuming borate is primary form of B in the calcite lattice  
 $\text{CaCO}_3 + \text{B(OH)}_4^- \rightarrow \text{Ca(HBO}_3\text{)} + \text{HCO}_3^- + \text{H}_2\text{O}$
- with an estimate of pH and with constraints on another carbonate system parameter, can compute  $\text{pCO}_2$ .

# Planktonic Foram B/Ca Calibrations

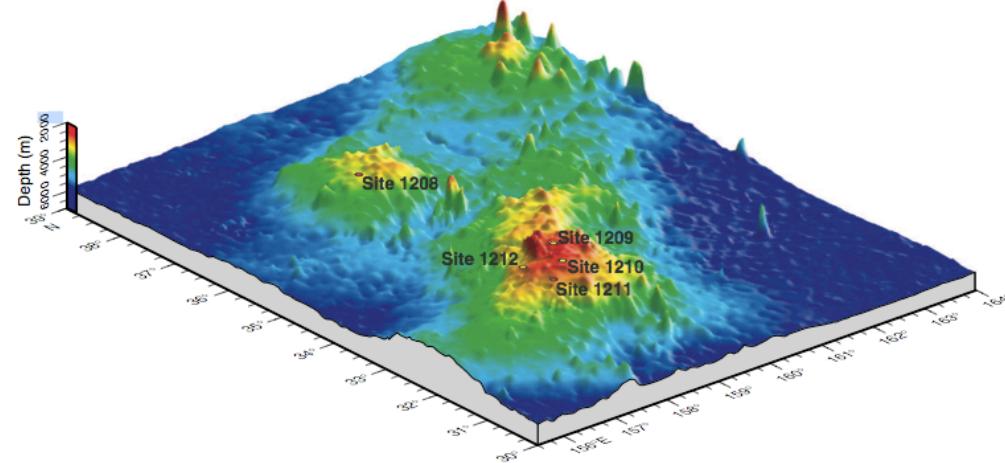


- The PETM at Shatsky Rise



Site 1210 (2573 m)

Hole A Hole B

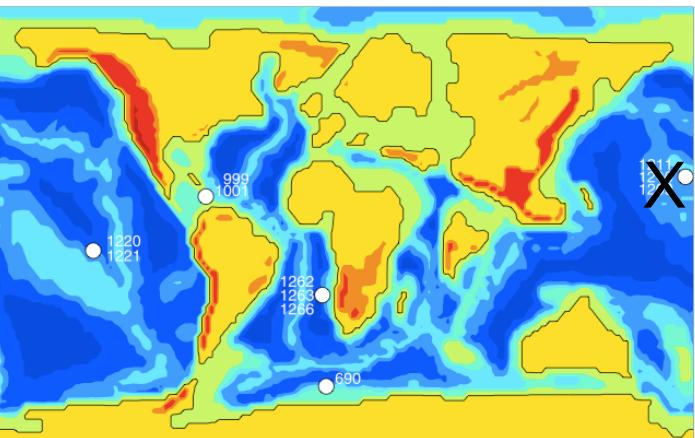


Hole A Hole C



Site 1208 (3346 m)

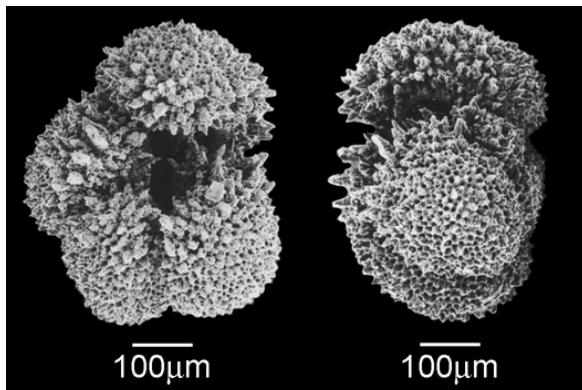
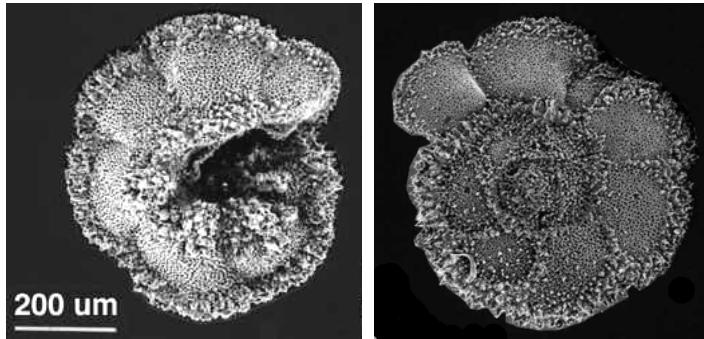
Hole A



Paleolatitude  $\sim 20^\circ\text{N}$   
 Paleodepth  $\sim 2000\text{m}$

• Bralower et al., 2002

# Paleocene Planktonics



## Mixed-layer Taxa:

- *Morozovella velascoensis*
  - Photosymbiont-bearing mixed-layer planktonic foraminifer (e.g., *O. universa*)
  - Cosmopolitan distribution
- *Acarinina soldadoensis*
  - Photosymbiont-bearing mixed-layer planktonic foraminifer (e.g., *O. universa*)
  - Cosmopolitan distribution

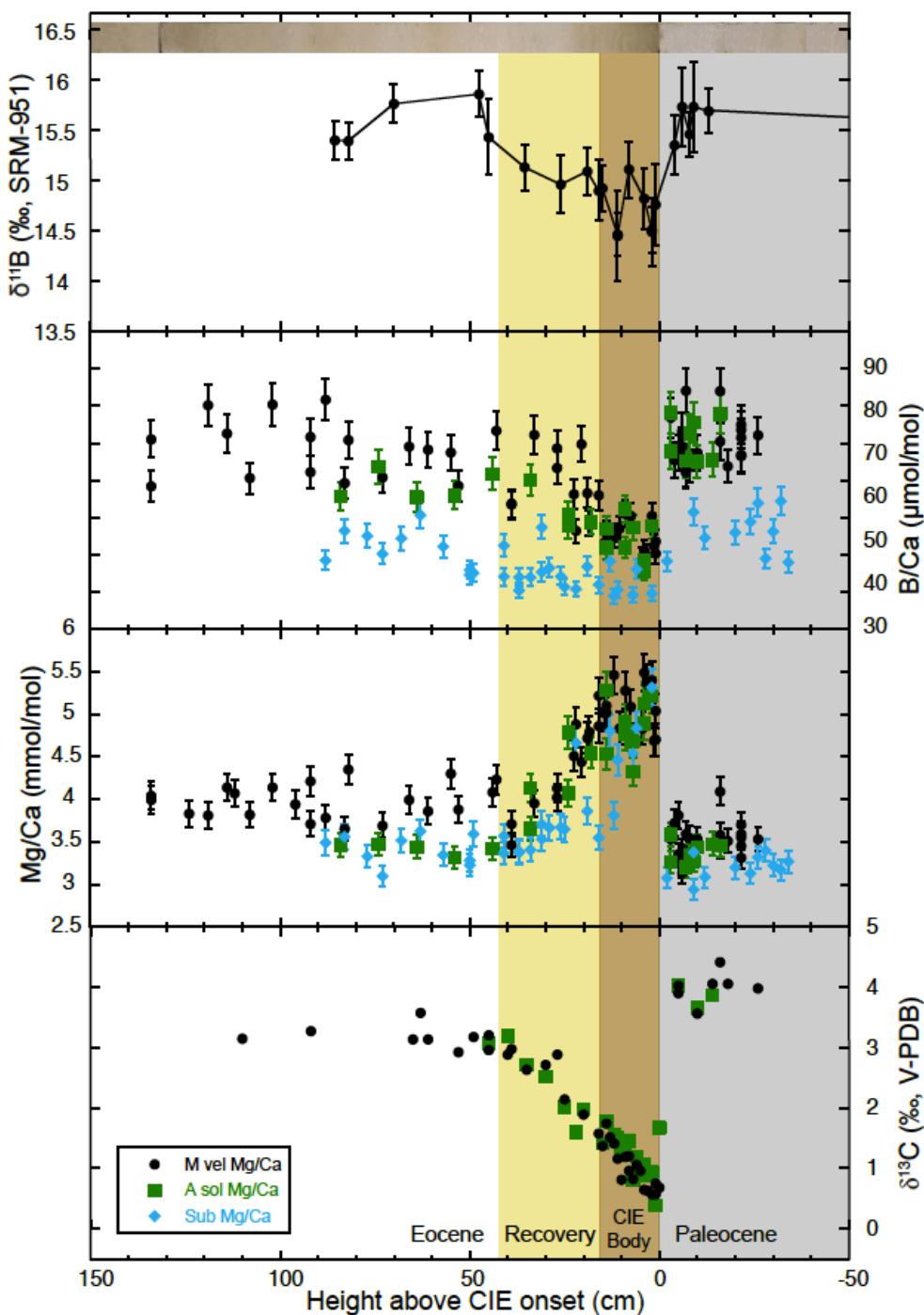
## Thermocline Taxa:

- *Subbotina spp.*
  - lacked photosymbionts

# Site 1209

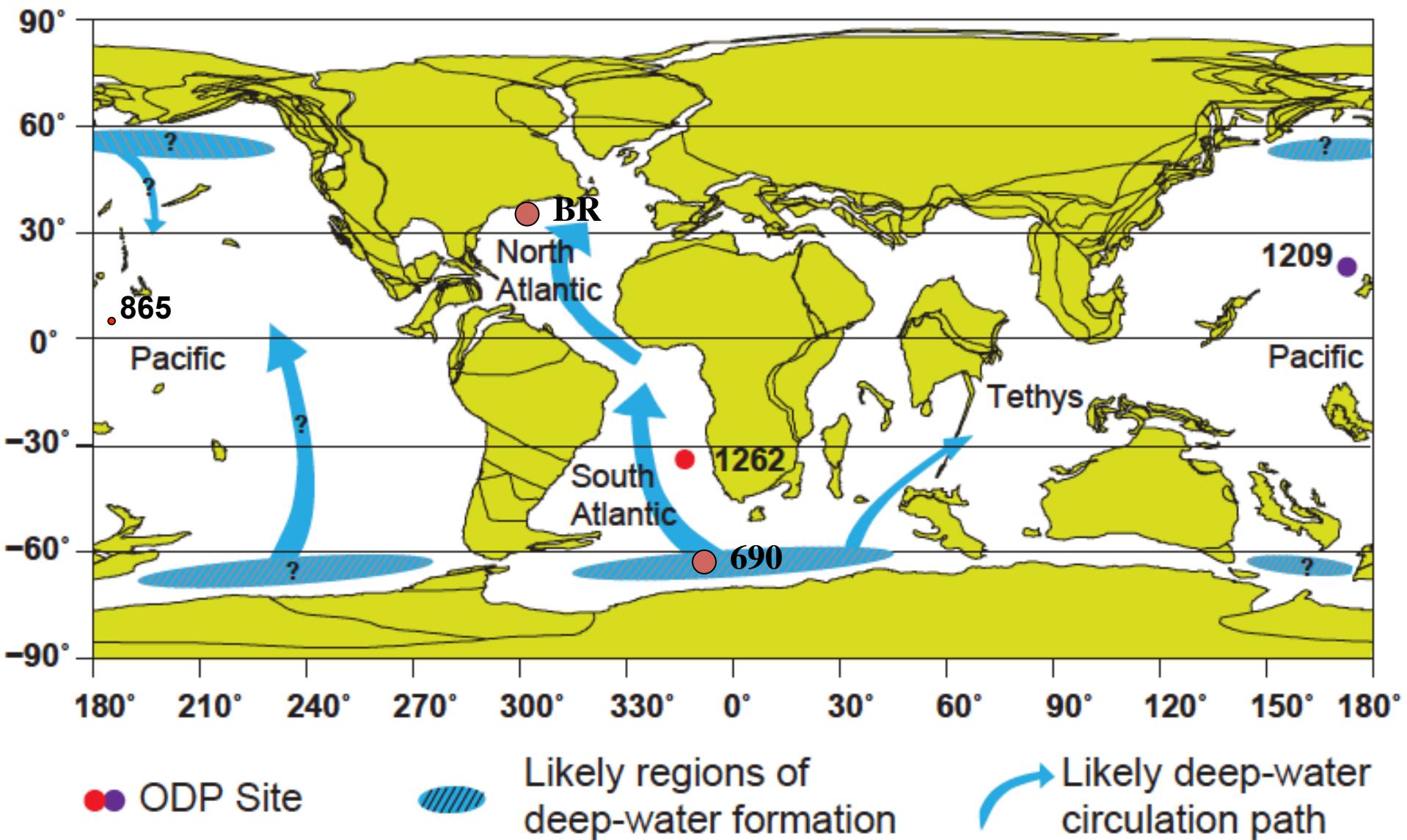
- Mixed-layer forams
  - $\delta^{11}\text{B}$  (-1.2‰)
  - B/Ca (-40%)
  - Mg/Ca (+5°C)
  - $\delta^{13}\text{C}$  (-3.5‰)
- Thermocline forams
  - B/Ca (-20%)
  - Mg/Ca (+4°C)

(Penman et al., 2014)



# Sites 690/689: Atlantic, Southern Ocean

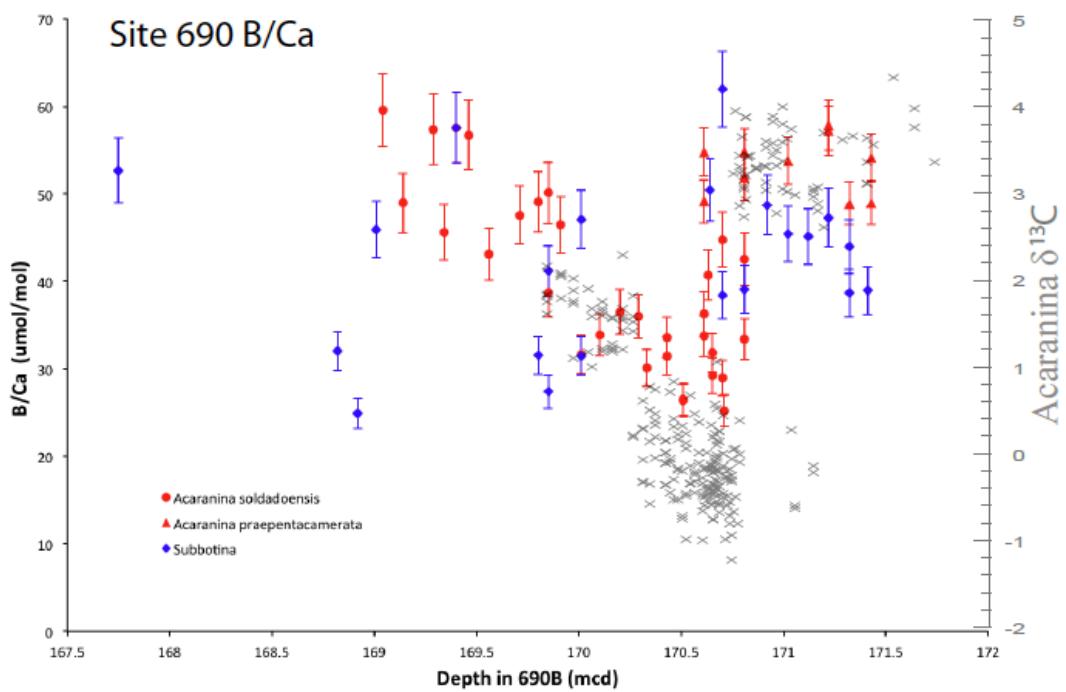
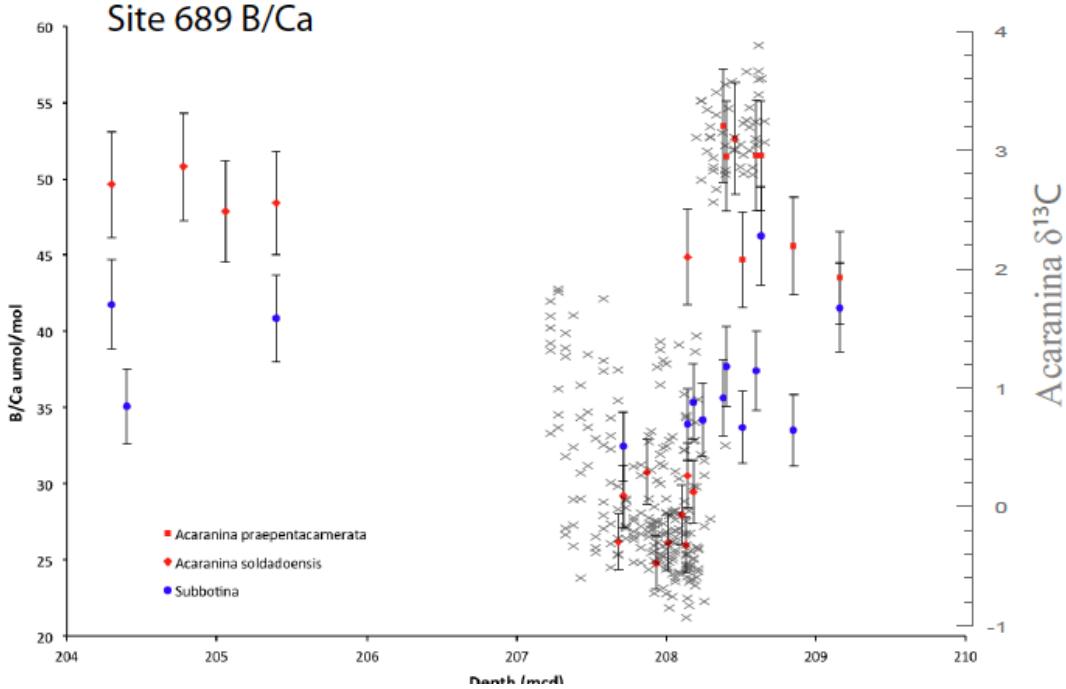
55 Ma reconstruction



# Sites 689/690: Southern Ocean, Atlantic

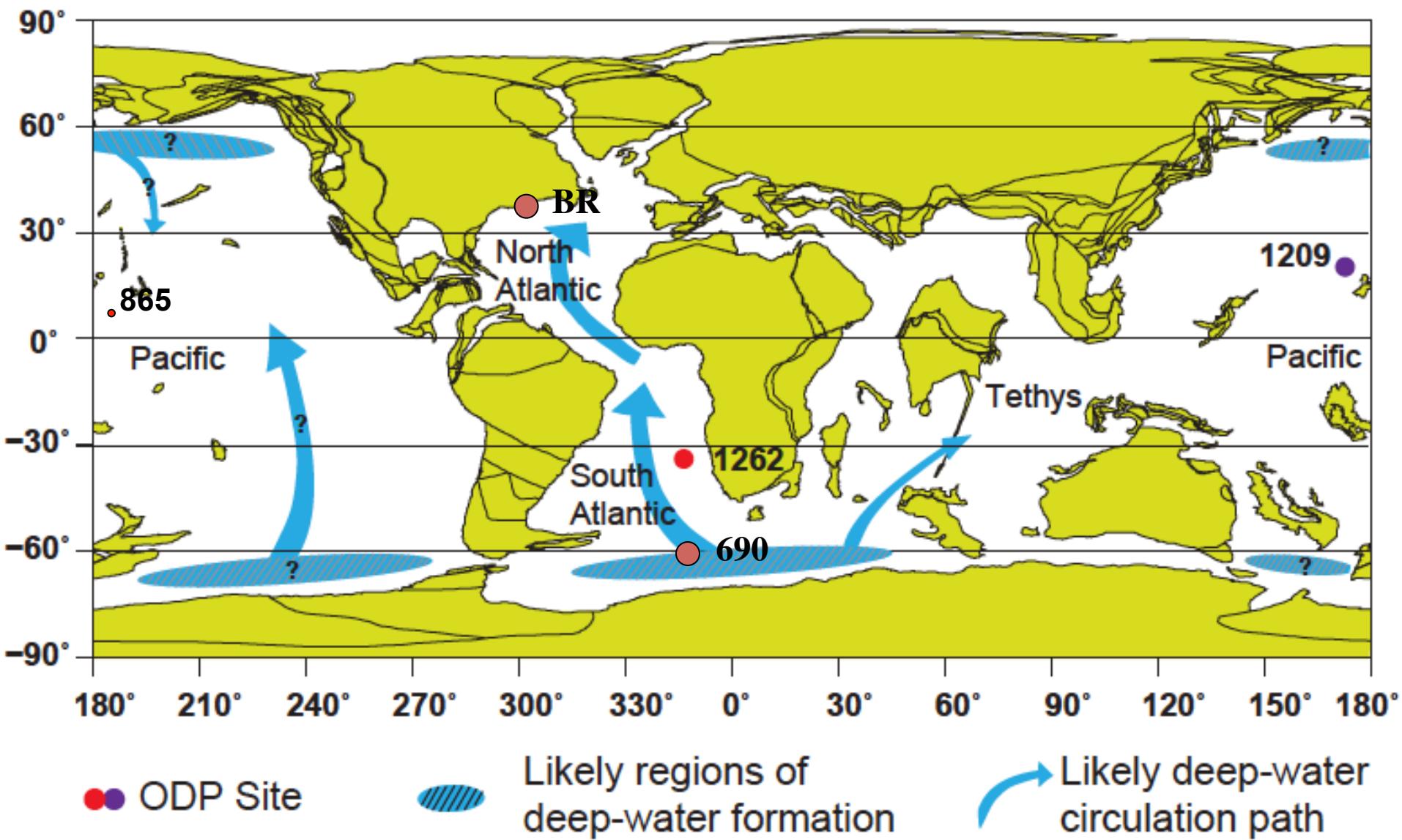
- Mixed-layer forams
  - $\Delta B/Ca$  (-40%)
  - $\Delta \delta^{13}C$  (-3.5‰)
- Thermocline forams
  - $B/Ca$  (-20%)

(Penman et al., in prep;  
Thomas et al., 2001; Kelly  
et al., 2005)

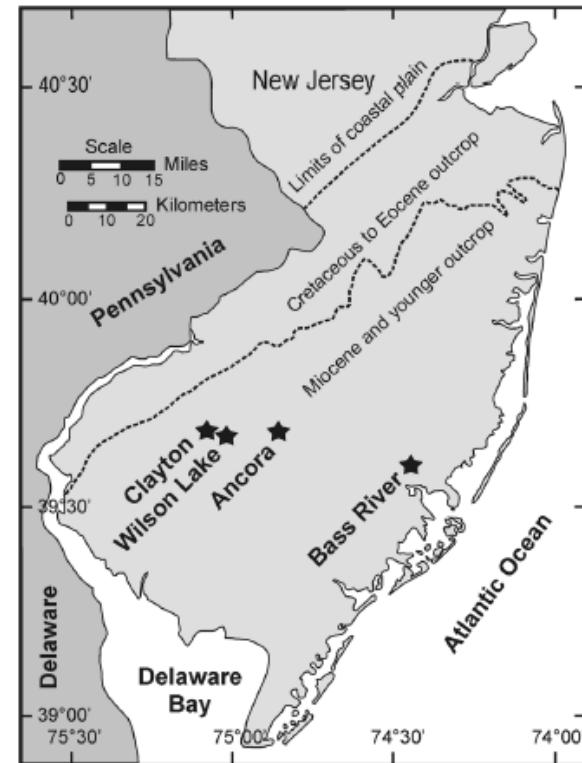
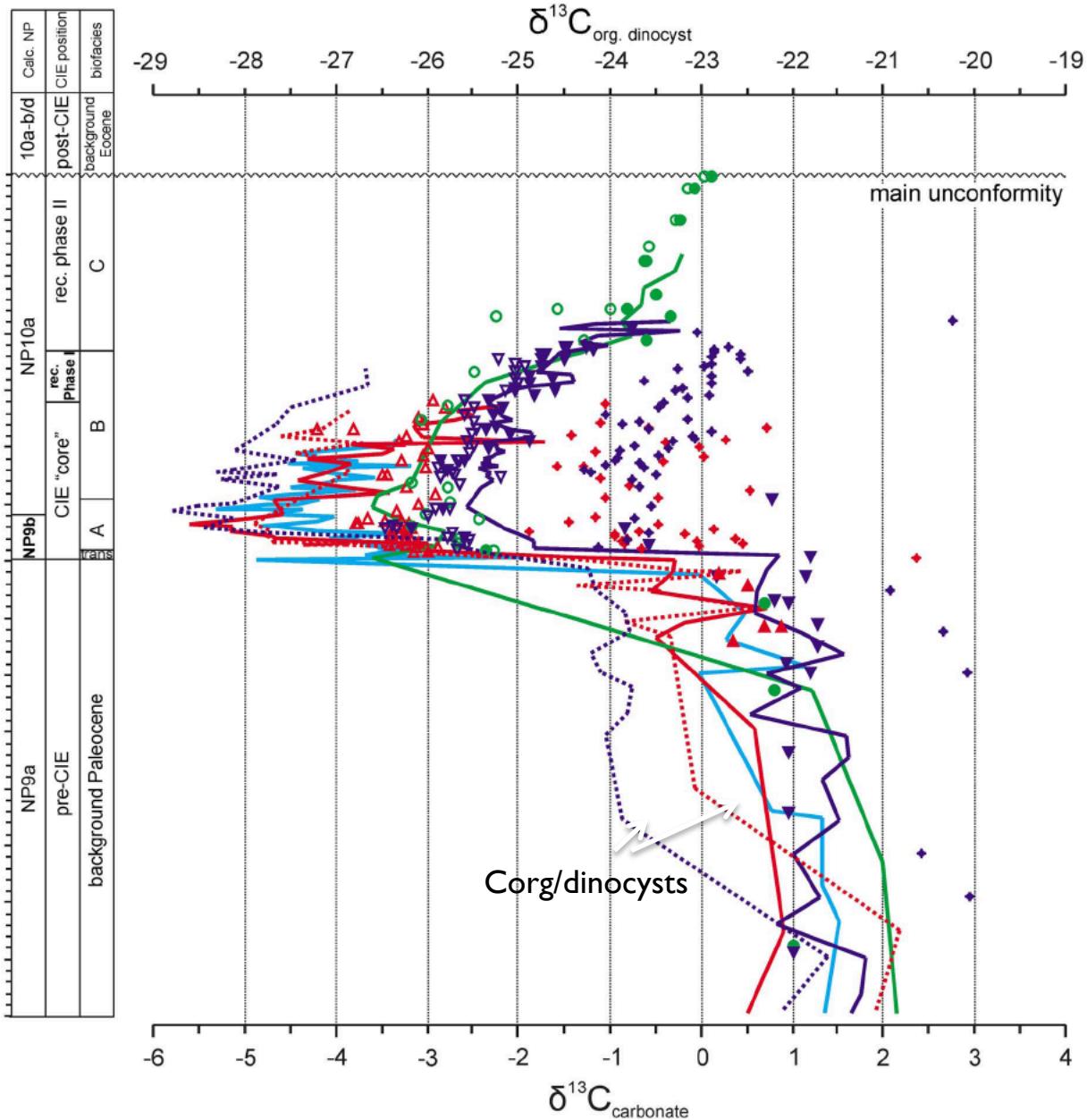


# Bass River: N. Atlantic, NA Margin

55 Ma reconstruction

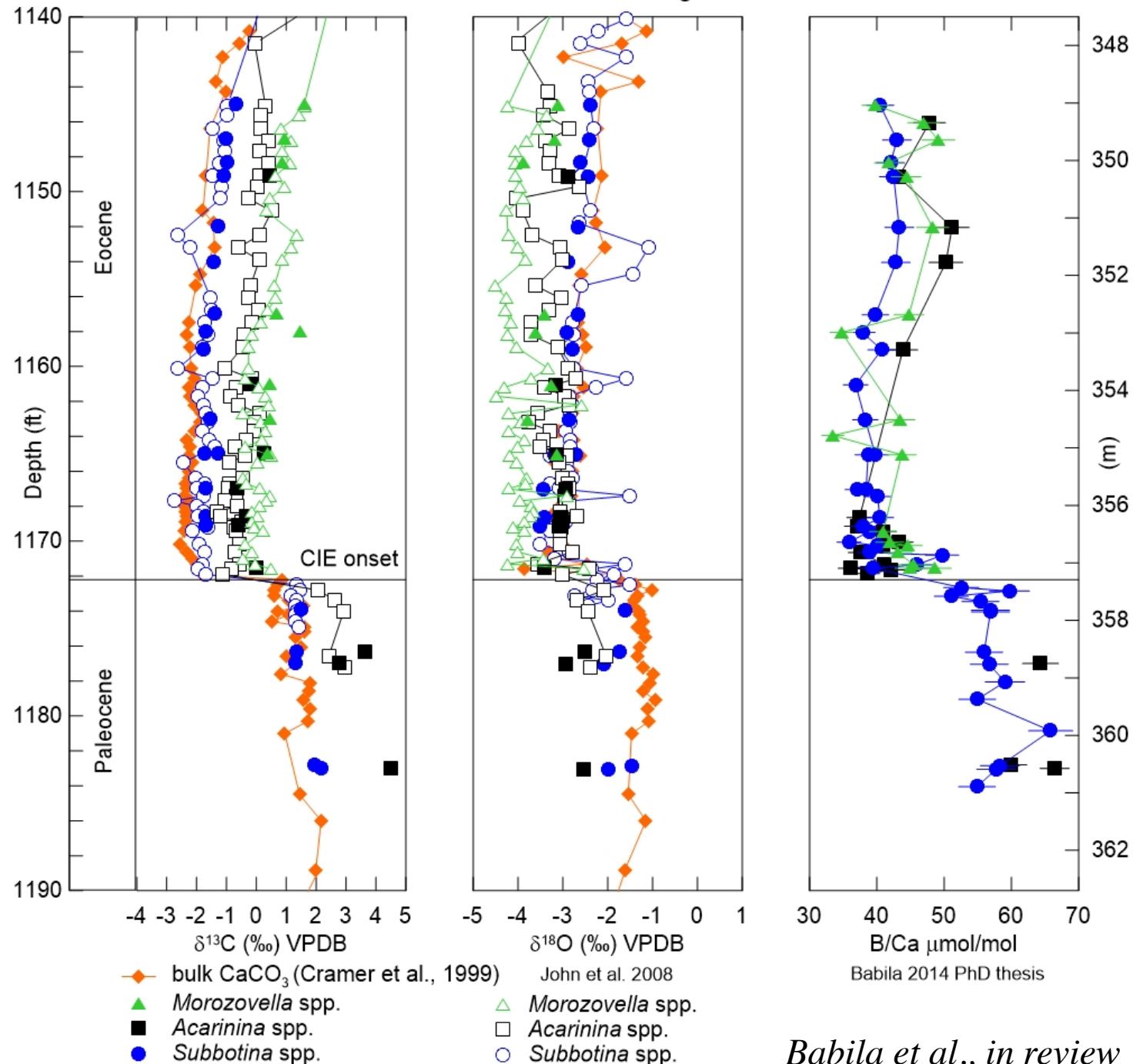


# Shallow Marine/Coastal Ocean Acidification?



Bass River Drill Core

# Bass River ODP Leg 174AX

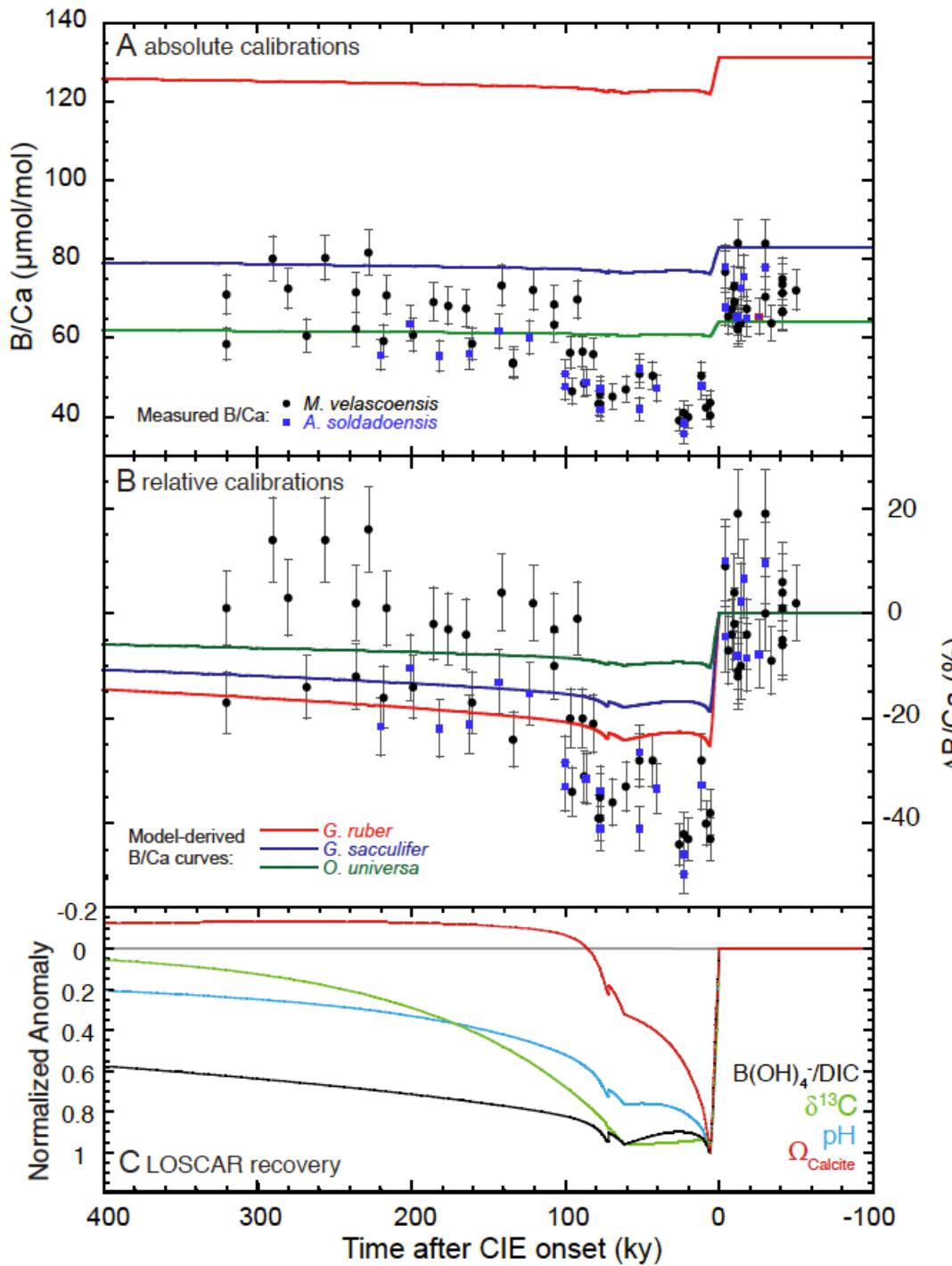


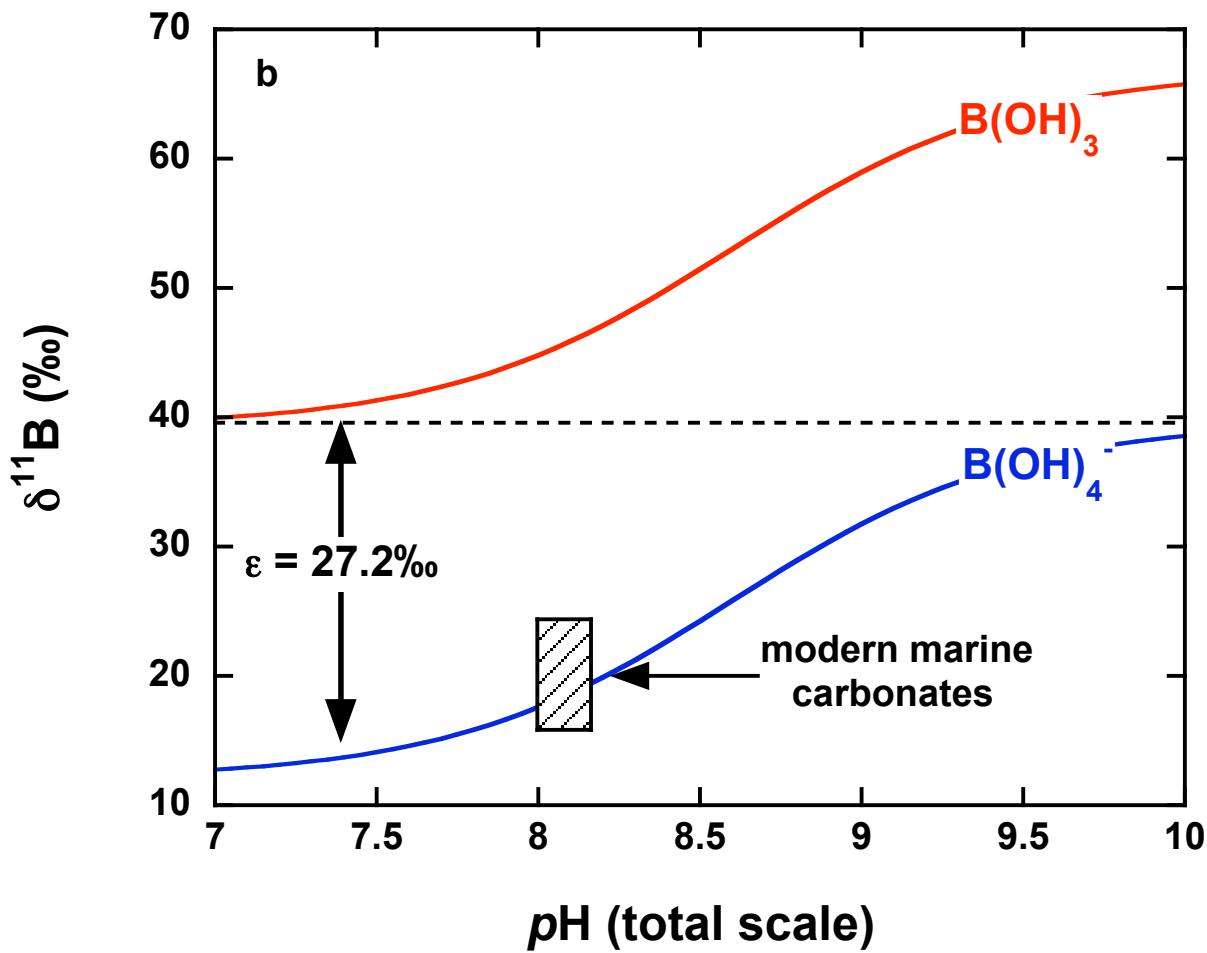
*Babila et al., in review*

# Simulating the $\Delta B/Ca_{\text{Mixed-layer}}$

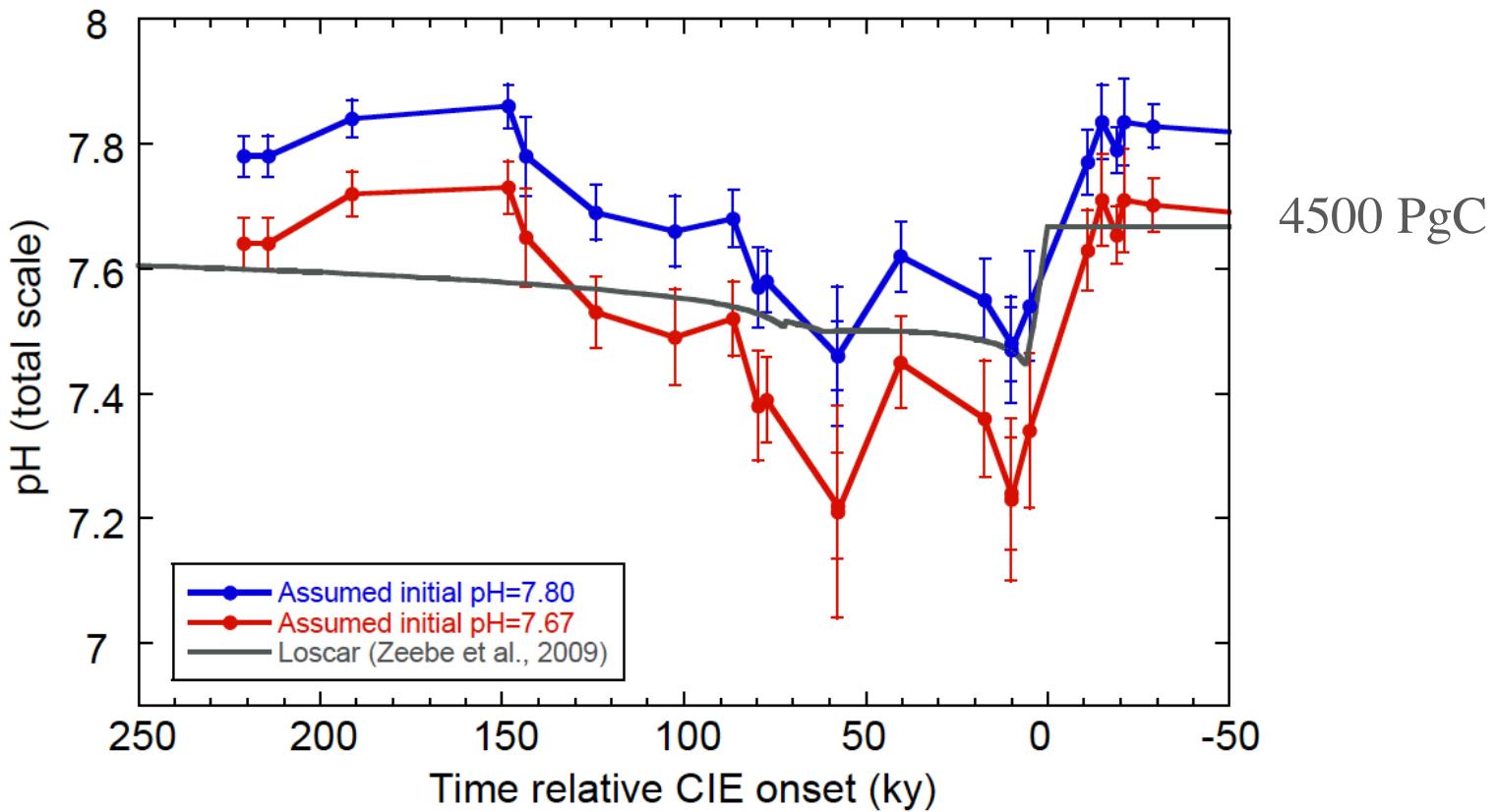
- LOSCAR
- 3000 + 1500 PgC
- modern planktic calibrations
- $\Delta B/Ca_{\text{obs}} > \Delta B/Ca_{4500}$

(Penman et al 2014)





# PETM – Estimated and simulated $\Delta\text{pH}$ mixed-layer

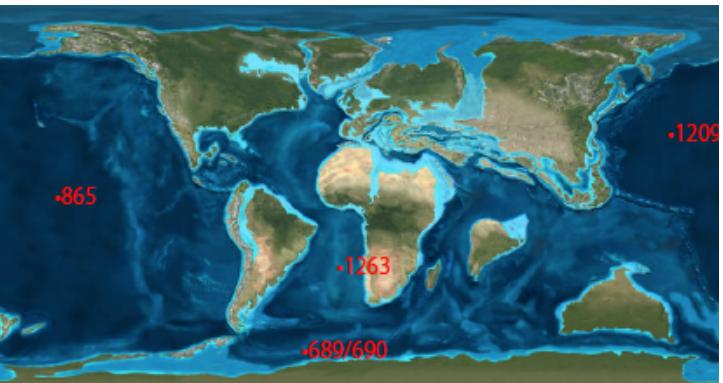


$$\Delta\text{pH} = -0.35 (\pm 0.15)$$

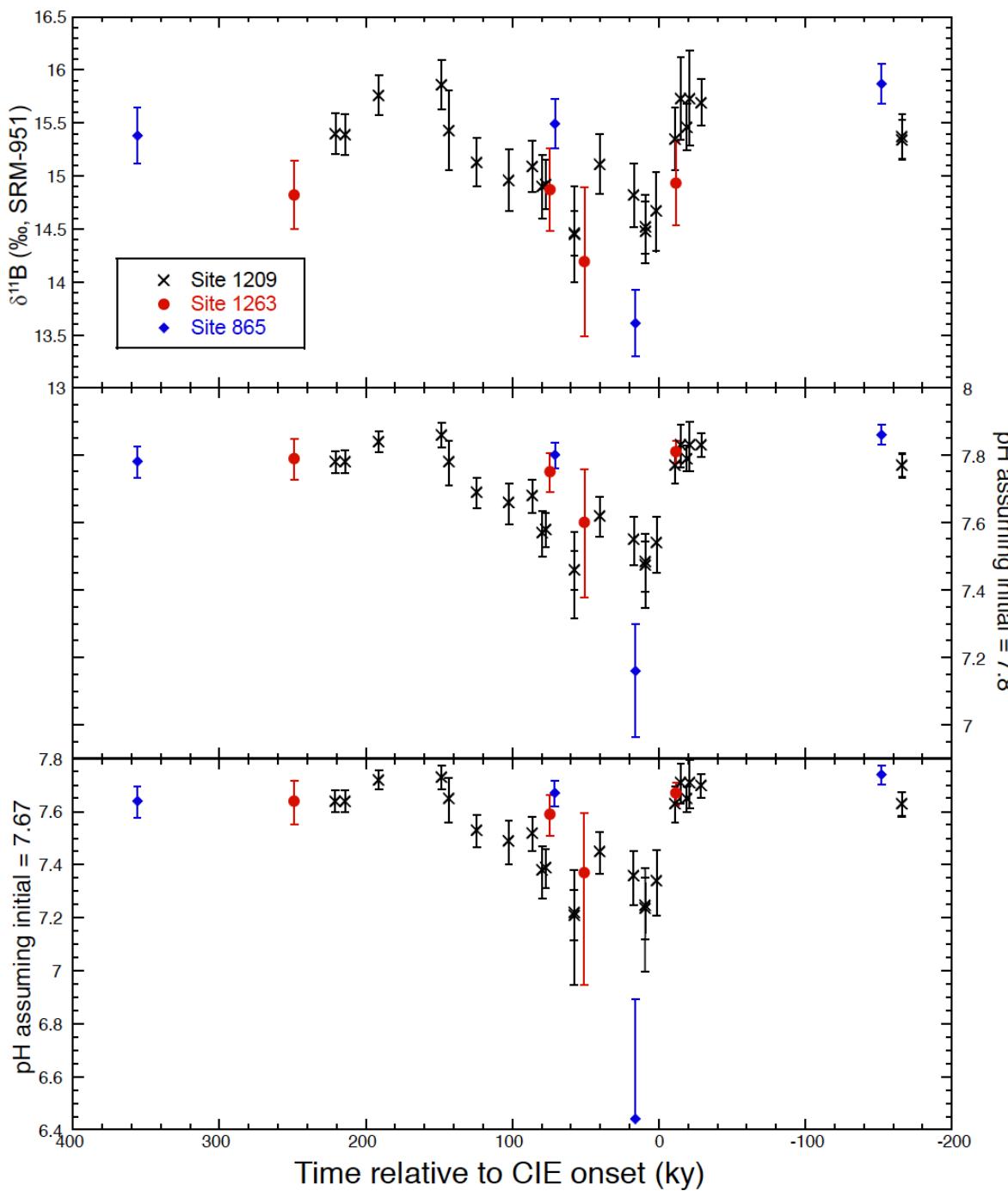
(Penman *et al.*, 2014)

# PETM - $\Delta p\text{H}$ Pacific & Atlantic Sites

$$\Delta p\text{H} = -0.32 (\pm 0.15)$$



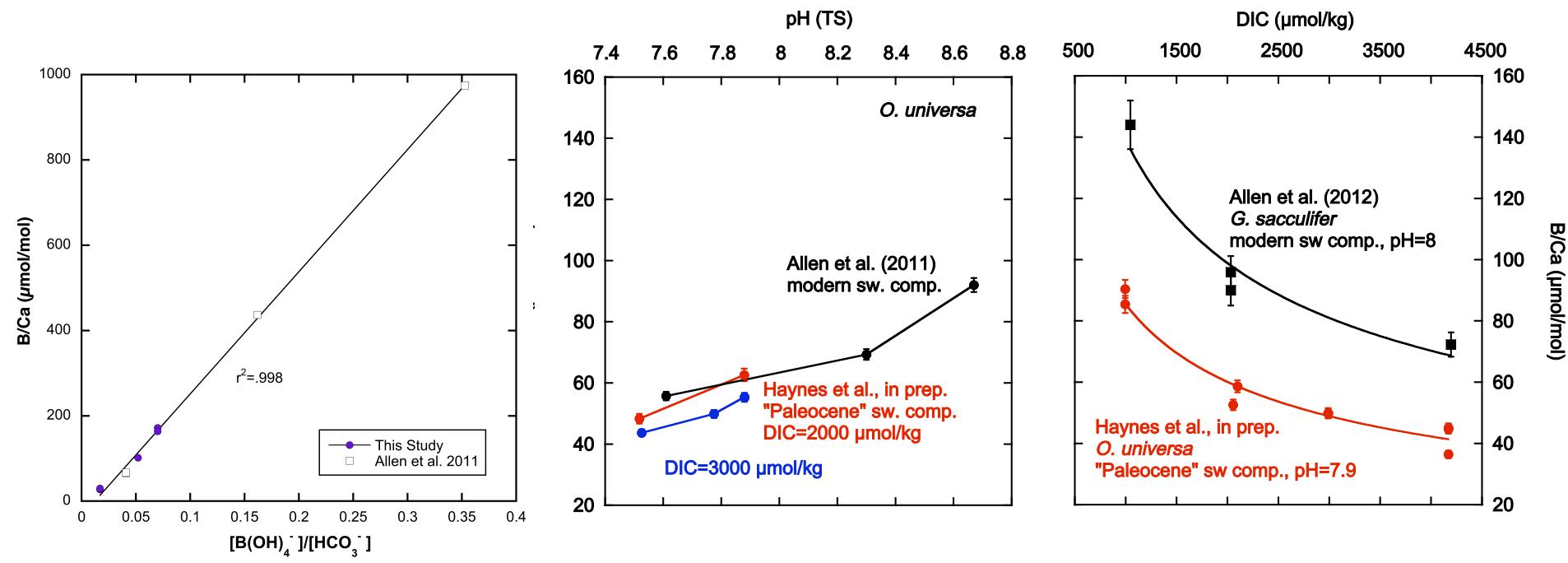
(Penman et al., 2014)



# PETM Acidification Summary

- Based on B Isotope data – Surface Ocean  $\Delta\text{pH}$  of -0.32
- 40-50% decline in B/Ca in mixed-layer foraminifera – relatively uniform including coastal ocean
- Both observations are consistent with >6000 PgC release over 5 kyr or longer
- Impacts on marine calcifiers?
  - major extinctions limited to deep sea benthic organisms, possibly corals
  - reductions in diversity of pelagic planktonic calcifiers

# Testing the B/Ca proxy under “Paleocene” seawater conditions



# Testing the B/Ca proxy under “Paleocene” seawater conditions

