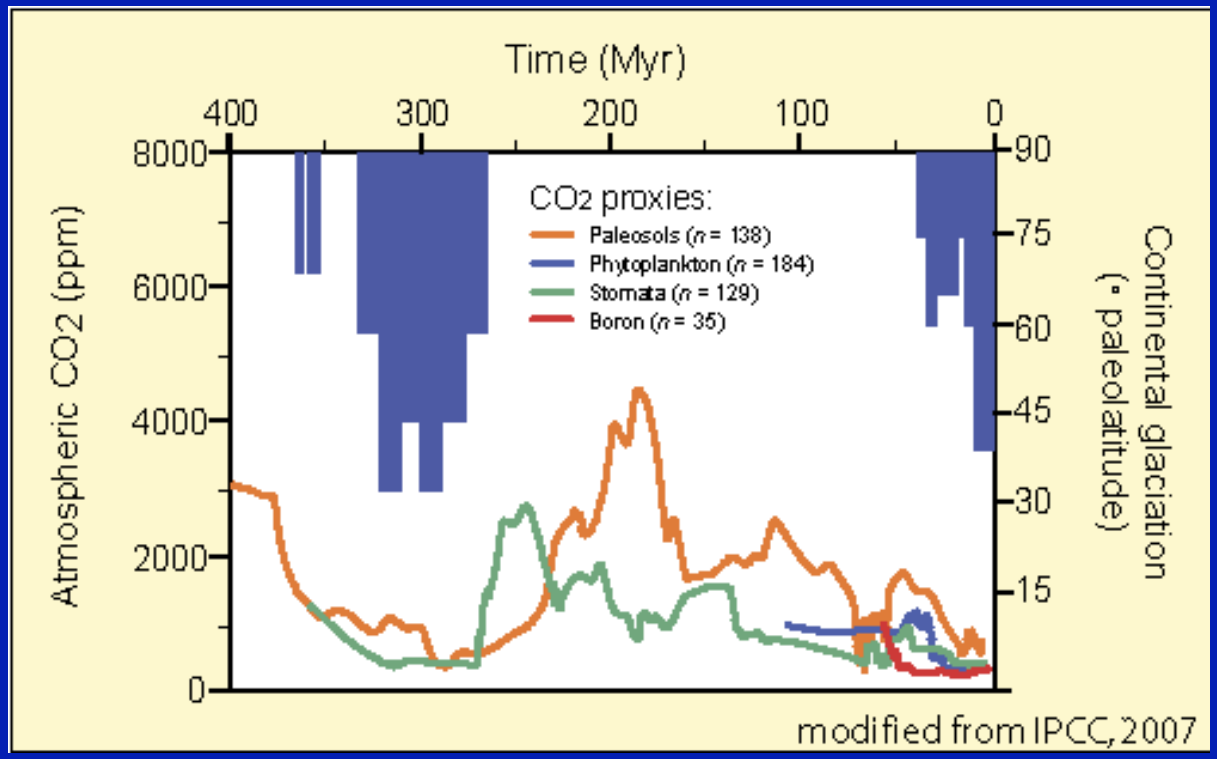
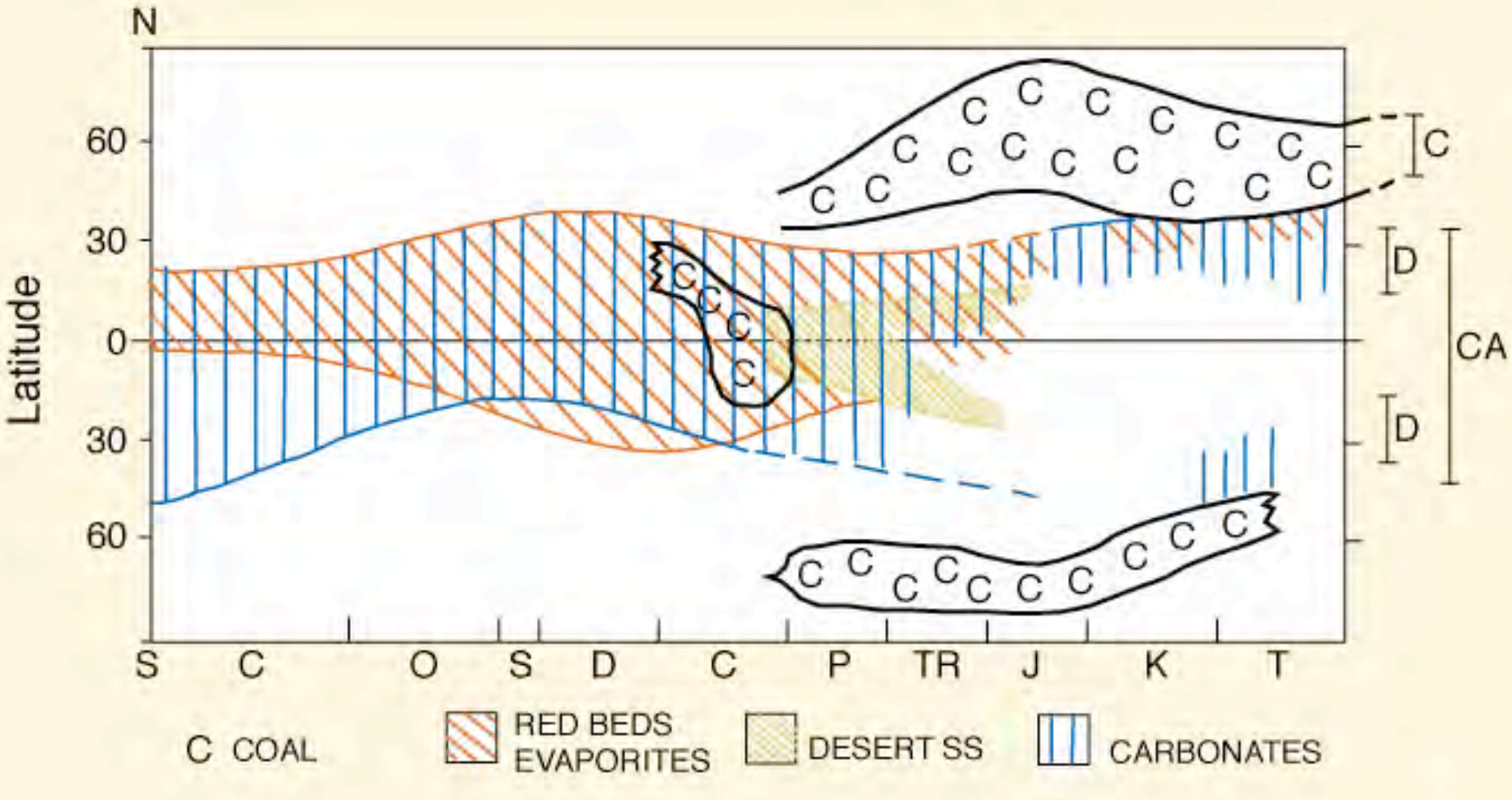
CO_2 Sensitivity and Climates of the Past



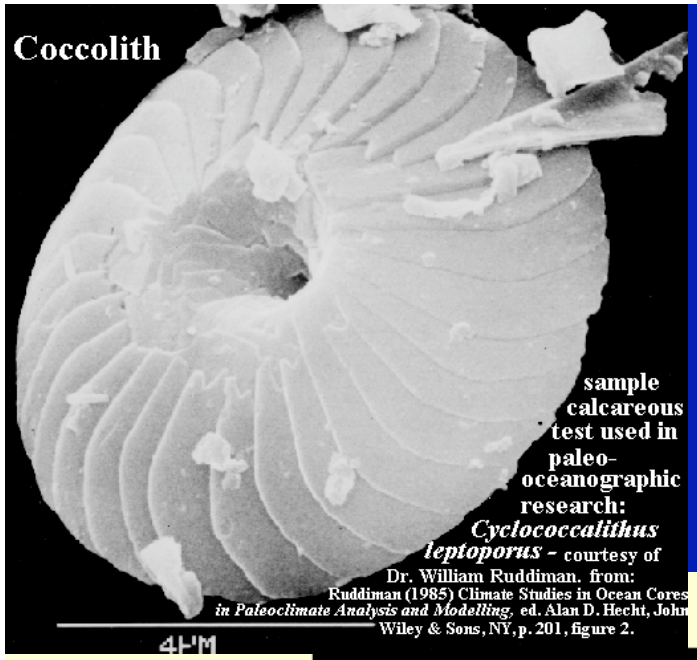
Linda Sohl

GISS Lunch Seminar, Feb. 3, 2009

State of the Art … in the 1960s

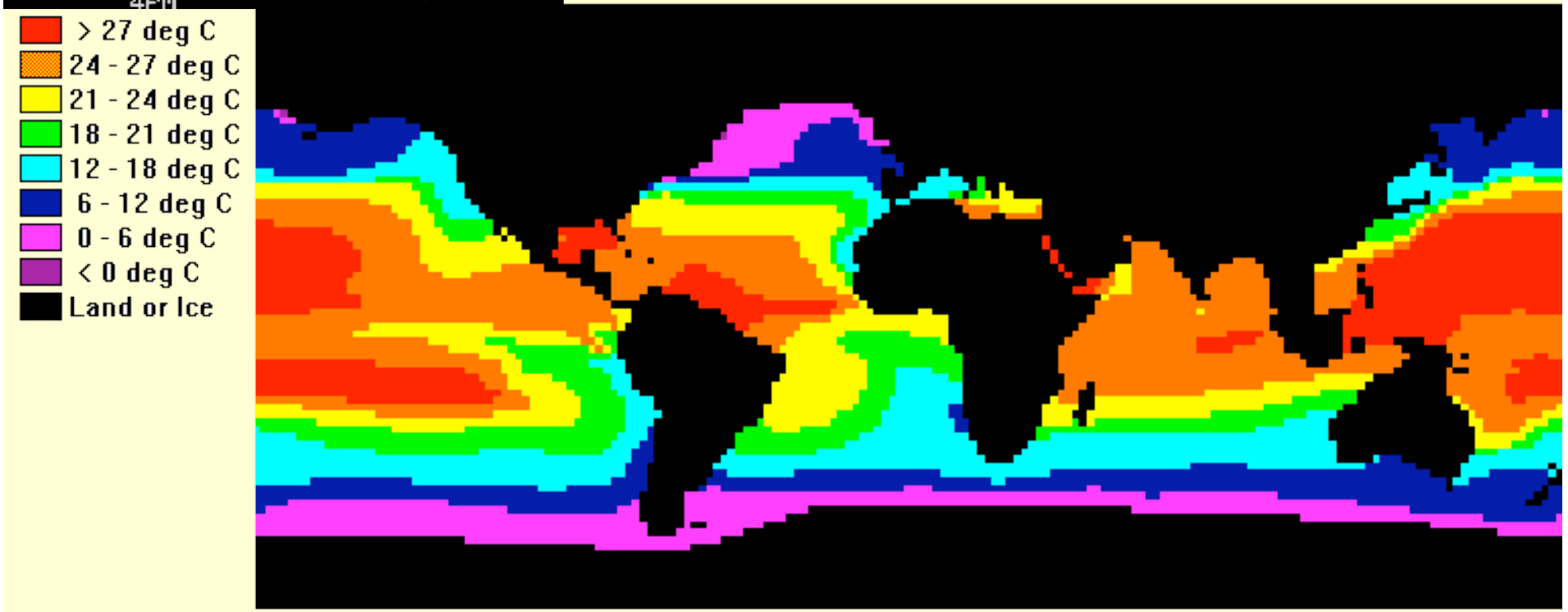


(Briden and Irving, 1964)

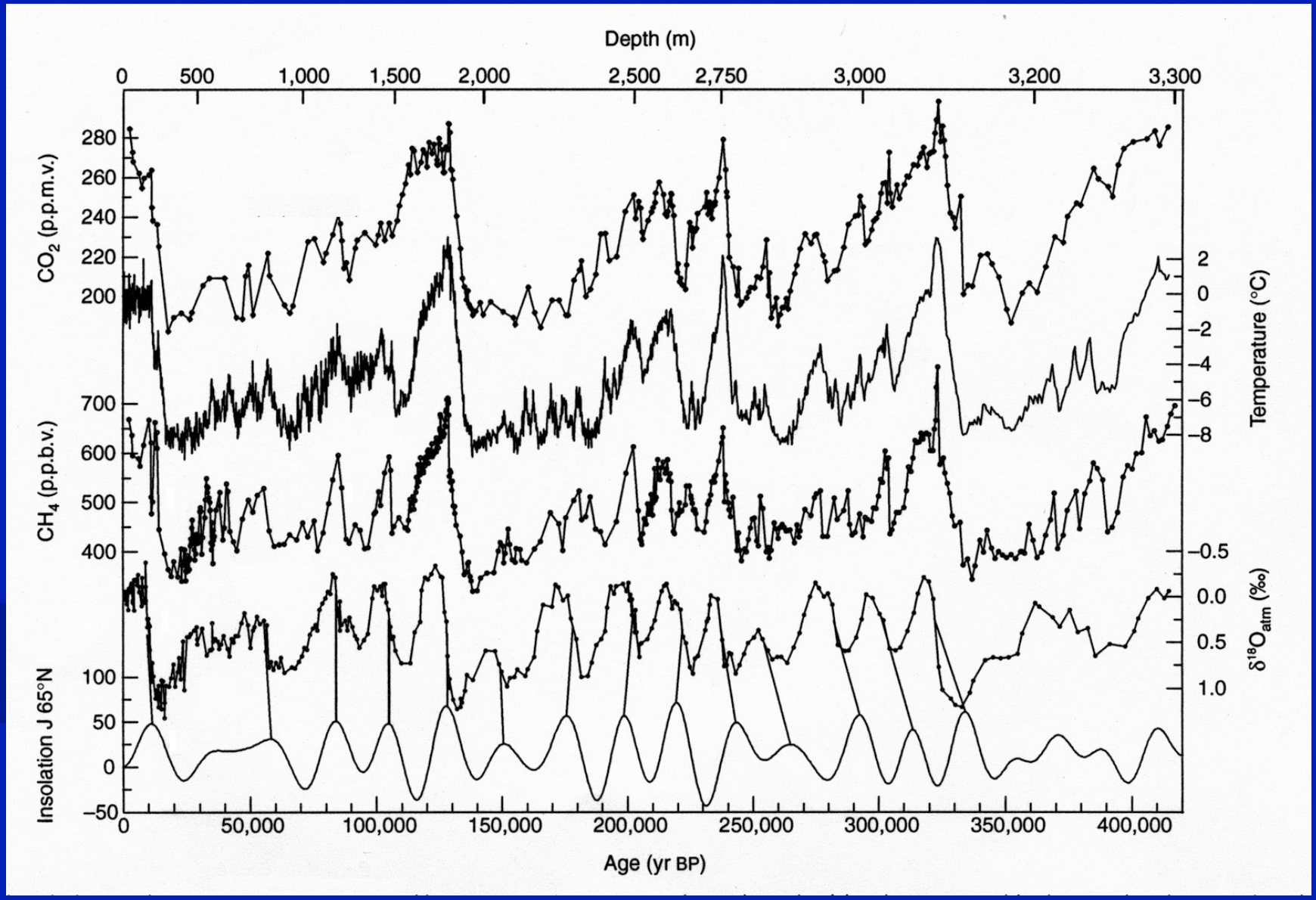


CLIMAP
Late 1970s – Early 1980s

August SST reconstruction, 18 ka



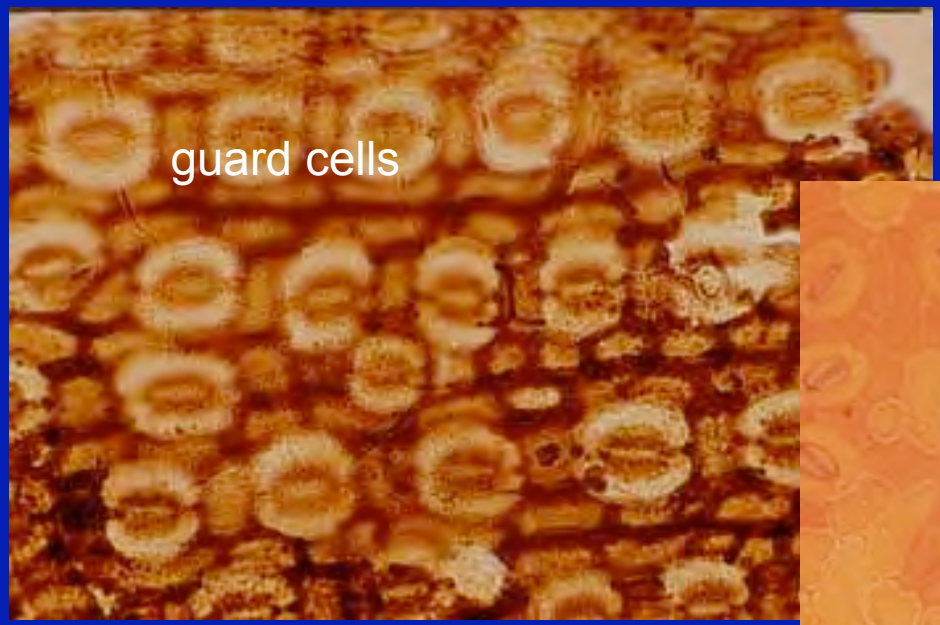
Ice Core Data – 1970s to Present

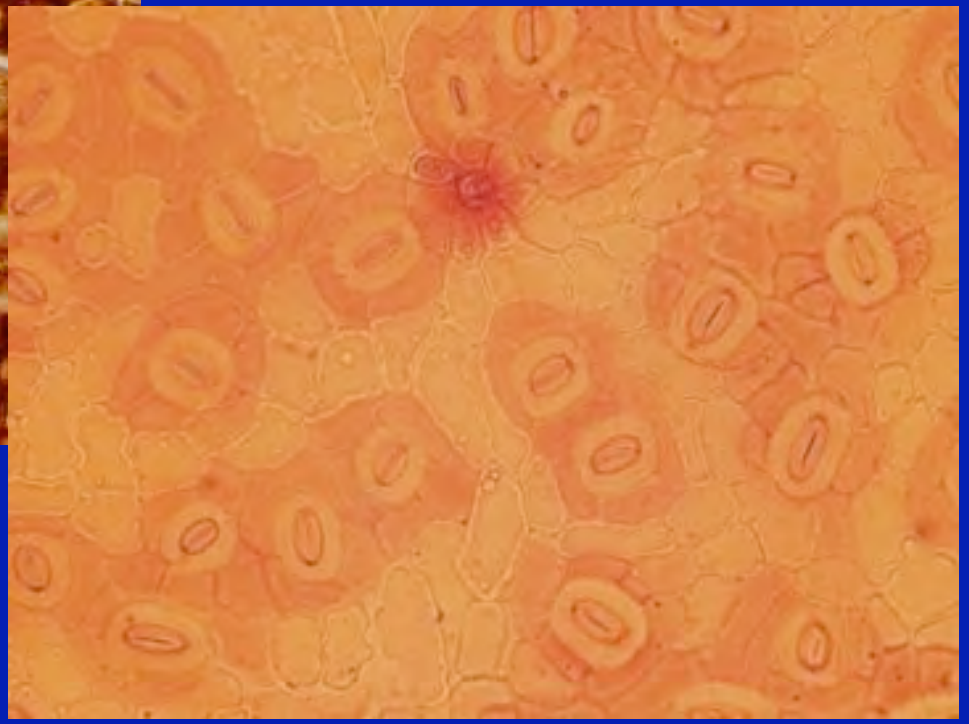


Common proxies for paleo-pCO_2

- Terrestrial proxies
  - Leaf stomata density / index
  - Paleosols
- Marine proxies
  - Phytoplankton $\delta^{13}C$
  - Boron isotopes / pH of the ocean

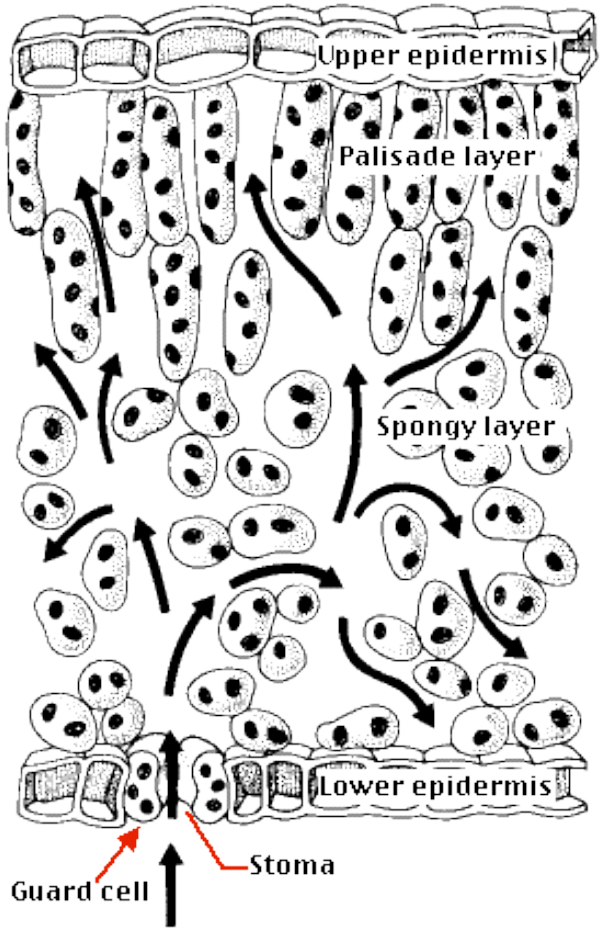
A paleobotanical proxy for pCO2





Stomatal density increases as pCO2 decreases

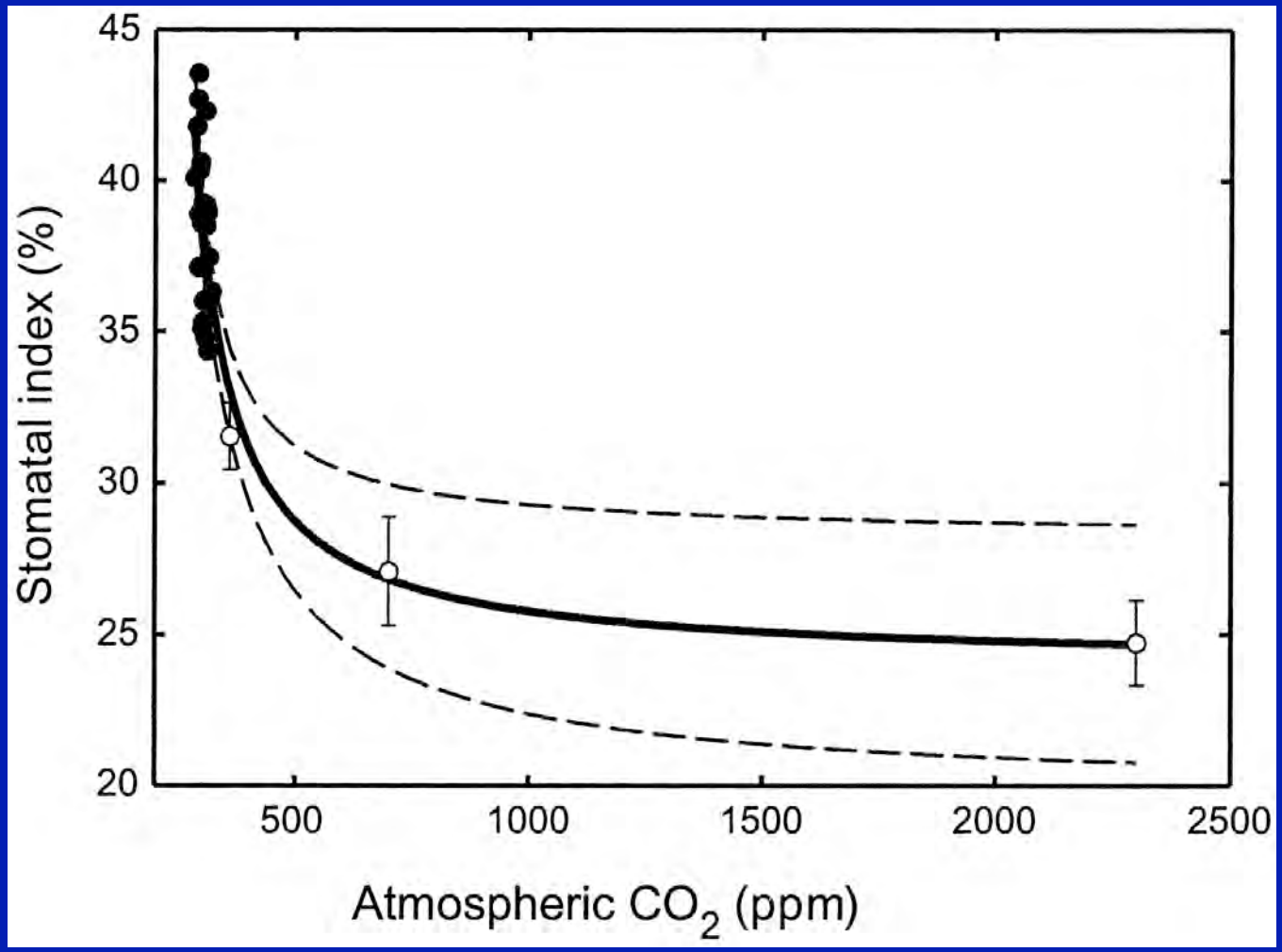
Stomatal index = # stomata / total # cells in a given area



Stomata regulate the passage of gases and water into and out of the leaf

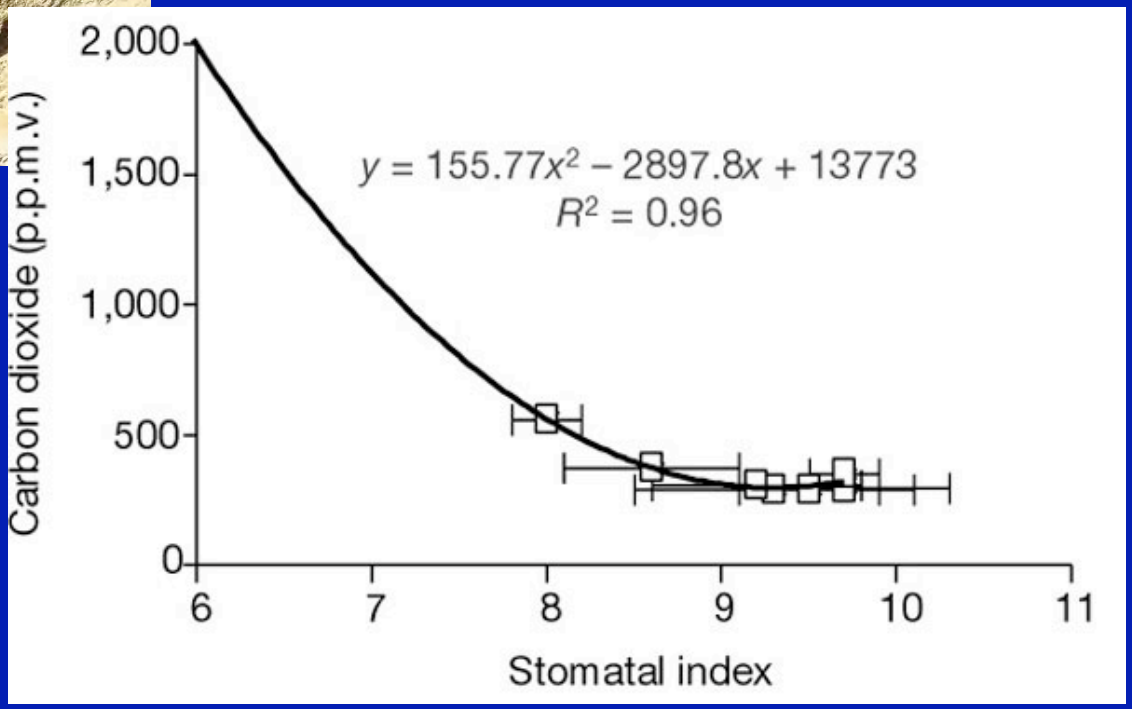
Plants can adjust the number and density of stomata in response to light intensity, humidity and temperature

Leaf responses to historical and experimental levels of CO2



Beerling, D. J. et al. (2002) Proc. Natl. Acad. Sci. USA 99, 7836-7840

Gingko trees provide a unique long-term perspective



G. Retallack, A 300-million-year-old record of atmospheric carbon dioxide from fossil plant cuticles: *Nature* 411: 287, 2001.

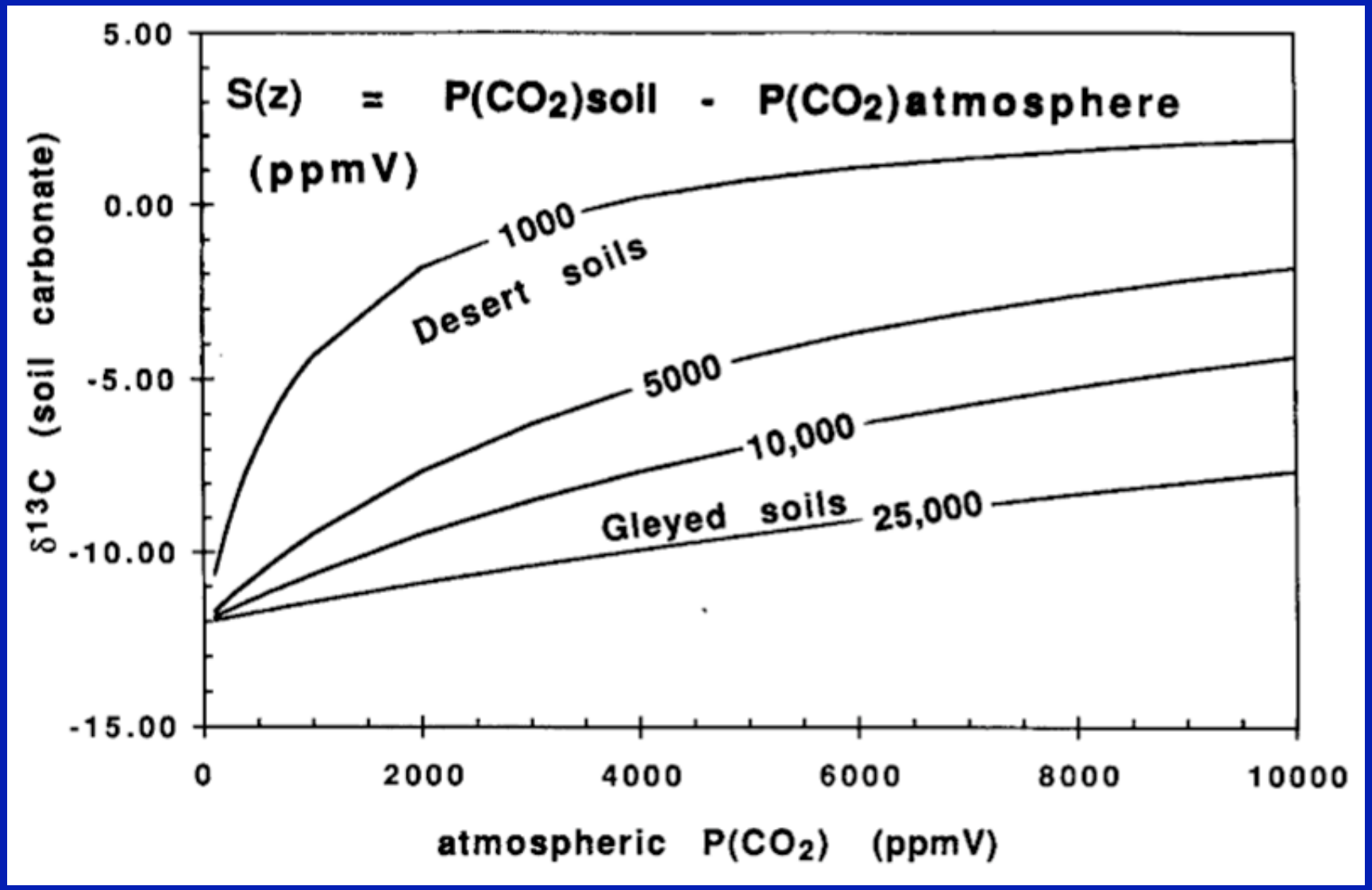
Ancient soil horizons (paleosols)

Carbonate nodules can form within soil horizons during pedogenesis

Assuming two sources for soil CO_2, soil-respired CO_2 and atmospheric CO_2, pCO_2 can be calculated as:

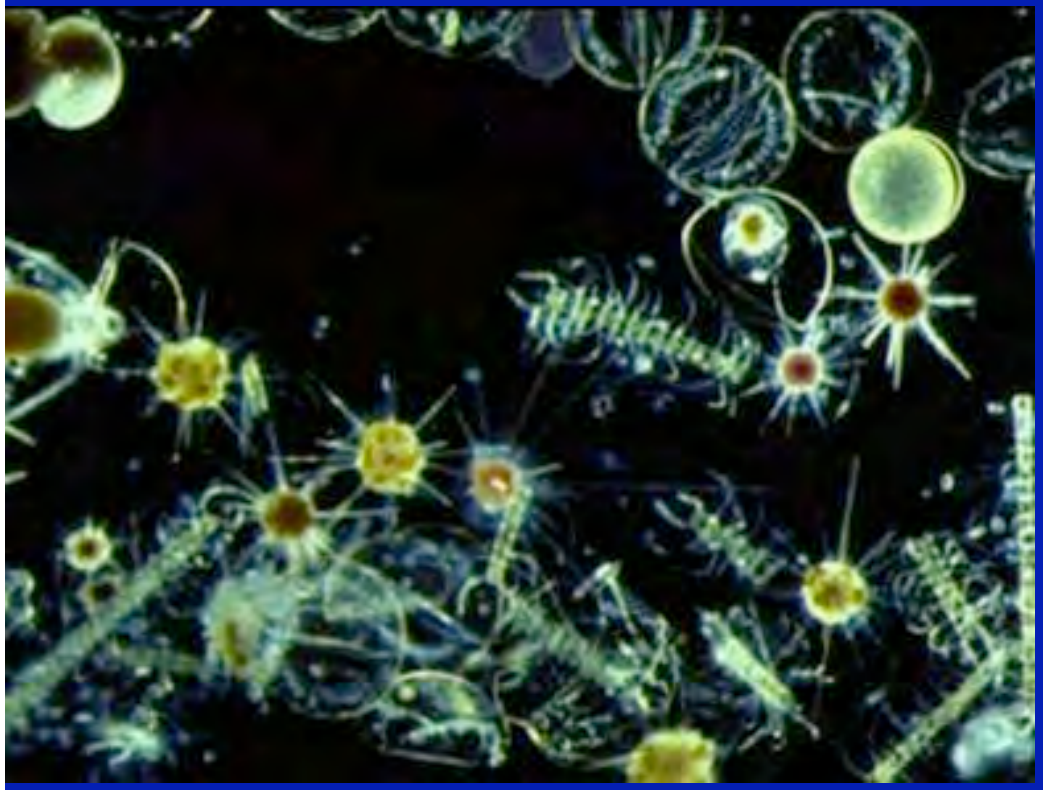
$$C_a = S_z \frac{[\delta^{13}C_s - 1.0044\delta^{13}C_r - 4.4]}{[\delta^{13}C_a - \delta^{13}C_s]}$$

where C_a is atmospheric CO2 (ppmv),
S_z is soil-respired CO2 (ppmv), and
$\delta^{13}C_s$, $\delta^{13}C_r$, and $\delta^{13}C_a$ are isotopic values for soil CO_2, soil-respired CO_2 and atmospheric CO_2

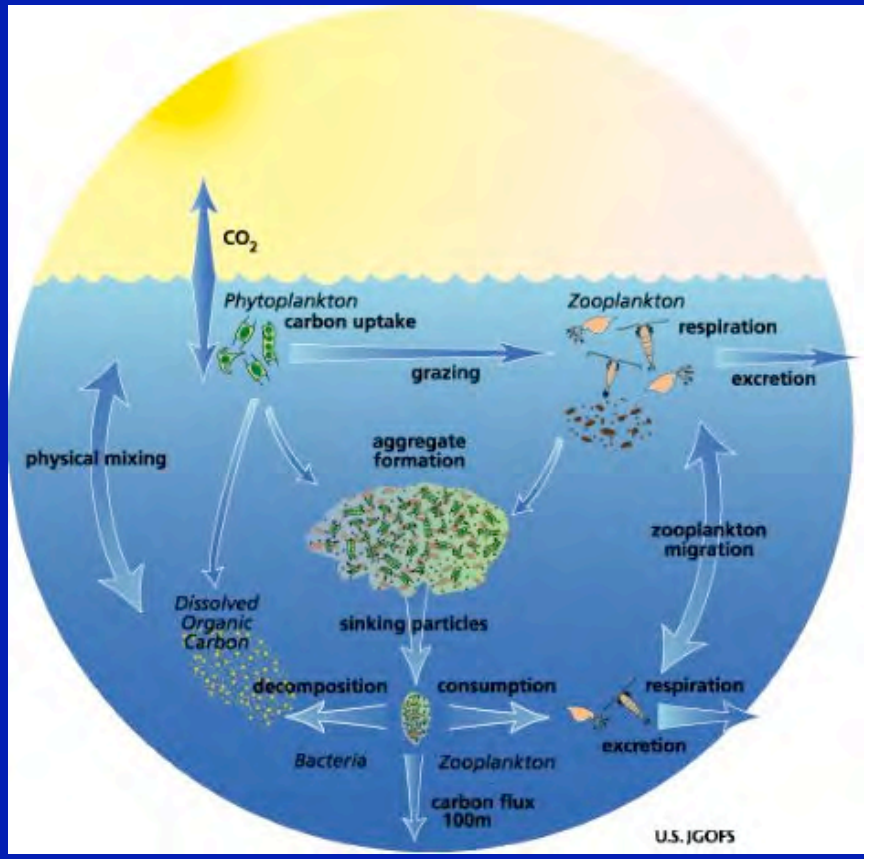


T.E. Cerling, Carbon dioxide in the atmosphere: evidence from Cenozoic and Mesozoic paleosols: *American Journal of Science* 291: 377, 1991.

Phytoplankton as pCO_2 indicators



Phytoplankton prefer ^{12}C during photosynthesis

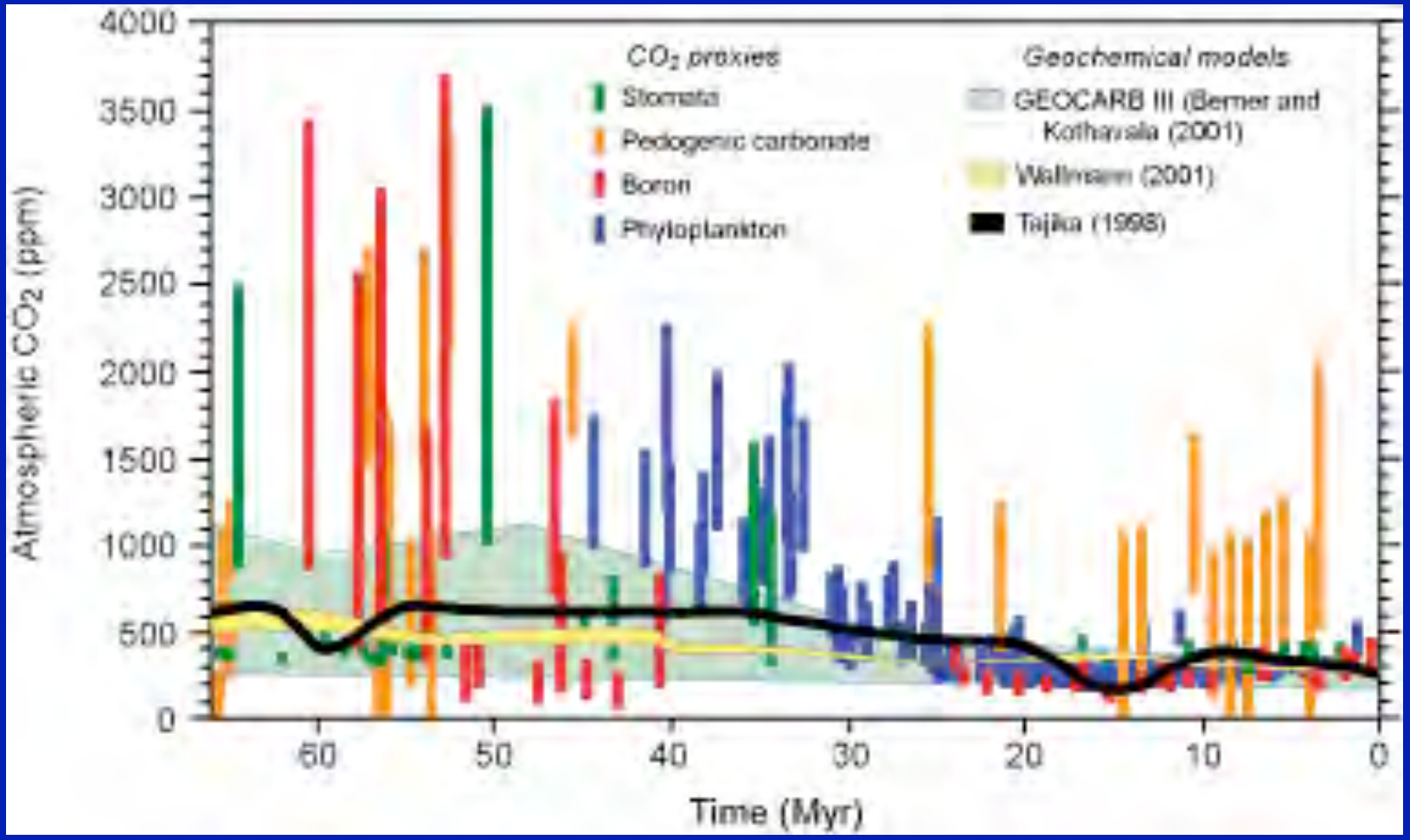


$\delta^{13}C$ values are more depleted when pCO_2 is higher

Boron ($\delta^{11}B$) Isotope Fractionation

- Boron ($\delta^{11}B$) in aqueous solution occurs as two species, $B(OH)_3$ and $B(OH)^-_4$, between which the equilibrium is strongly pH-dependent
- Boron incorporation into marine carbonates is largely from $B(OH)^-_4$
- The pH of seawater closely reflects atmospheric pCO_2 in areas away from coastal upwelling

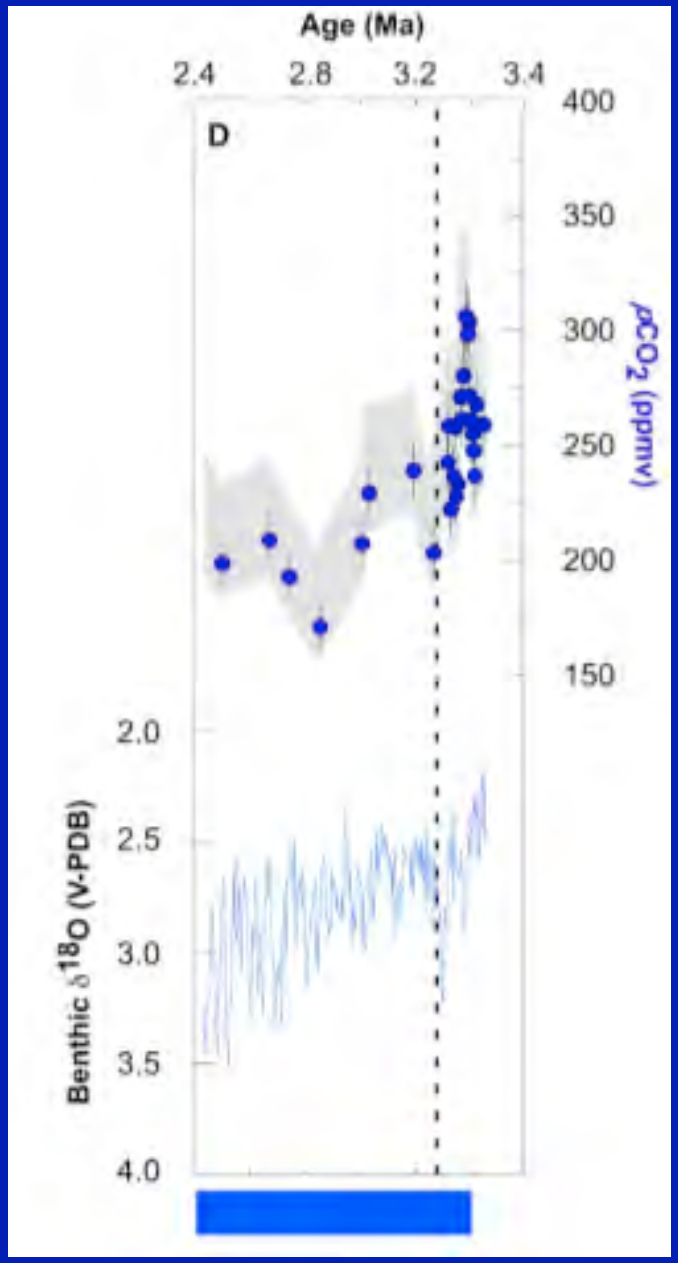
Reconstructed pCO_2 for the past 65 million years



IPCC AR4, 2007

B/Ca Ratio

- B/Ca ratios in foraminifera are used to estimate $B(OH)_4^-/HCO_3$ ratios, which are in turn related to pCO_2 and pH of seawater

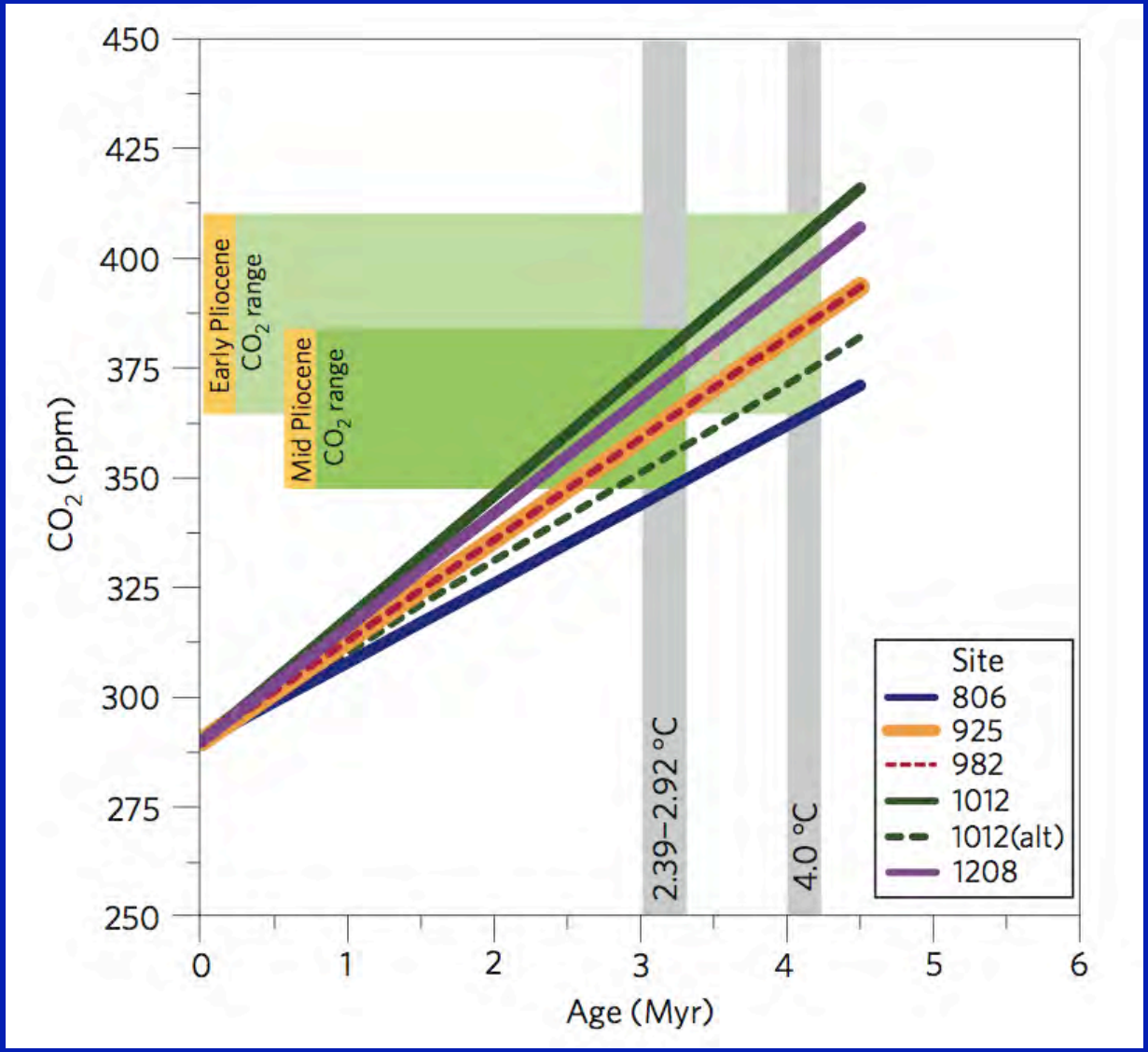


Tripati et al., 2009

Alkenones

- Alkenones are long-chained organic compounds produced by certain photoautotrophic algae
- pCO_2 estimates are based on stable carbon isotopic composition and fractionation within these organic compounds

pCO_2 from Alkenones



Pagani et al., 2010

“Earth-System Climate Sensitivity”

A focus on fast feedbacks in climate modeling may be underestimating the longer-term impacts of anthropogenic warming

… but will anyone care?