

Joint MCRN/IMA Math and Climate Seminar

Tuesdays 11:15 - 12:05

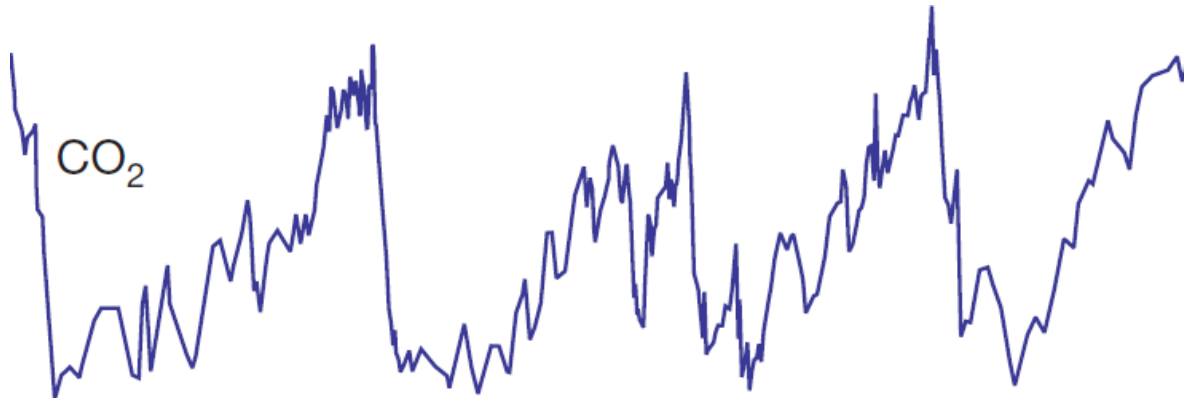
streaming video available at

www.ima.umn.edu



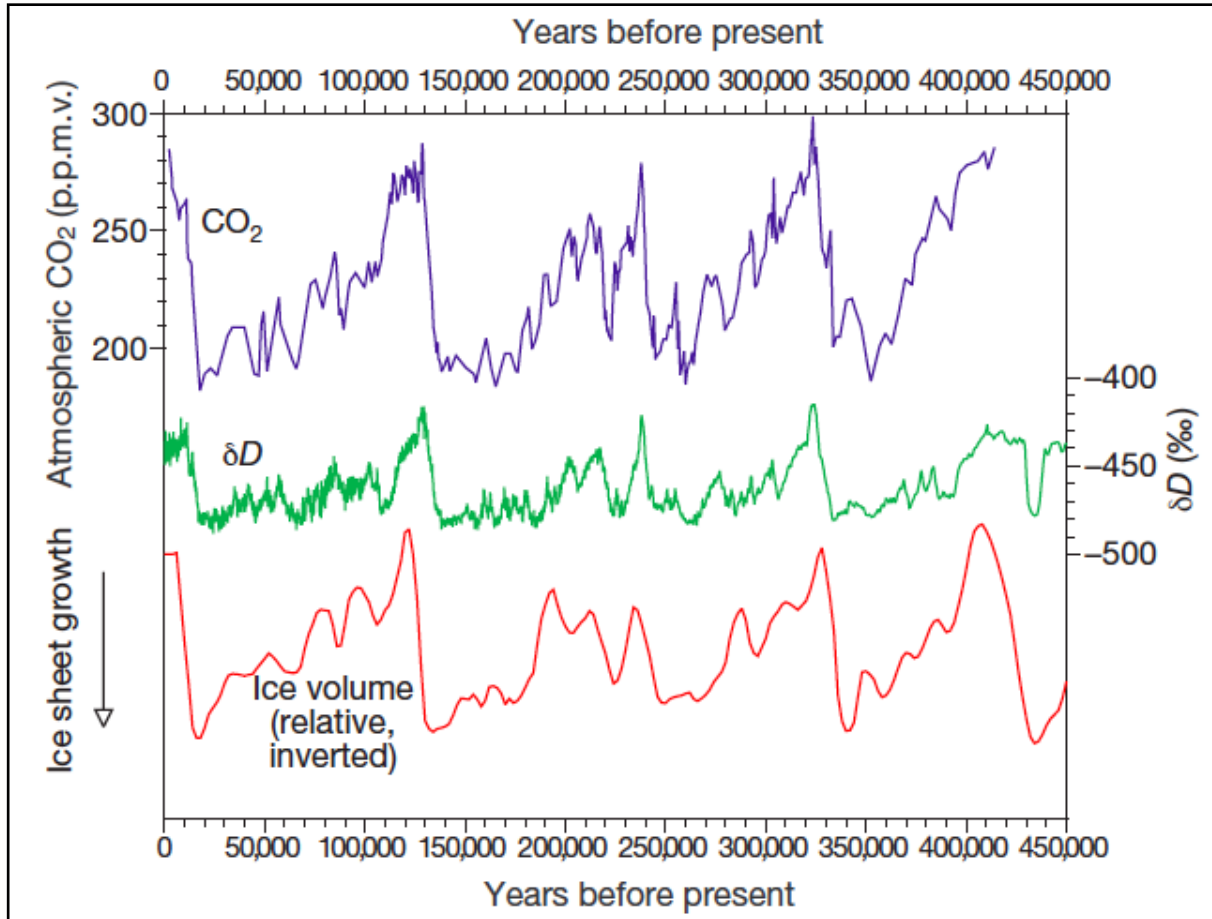
**A report on
“Glacial/interglacial variations in atmospheric carbon dioxide,”
by Sigman and Boyle**

Kate Meyer

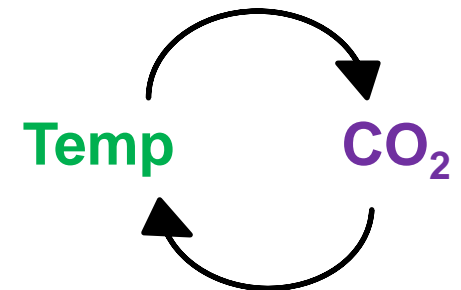


**Seminar on the Mathematics of Climate
School of Mathematics
January 28, 2014**

Q: Where does atmospheric carbon go during glacial maxima?

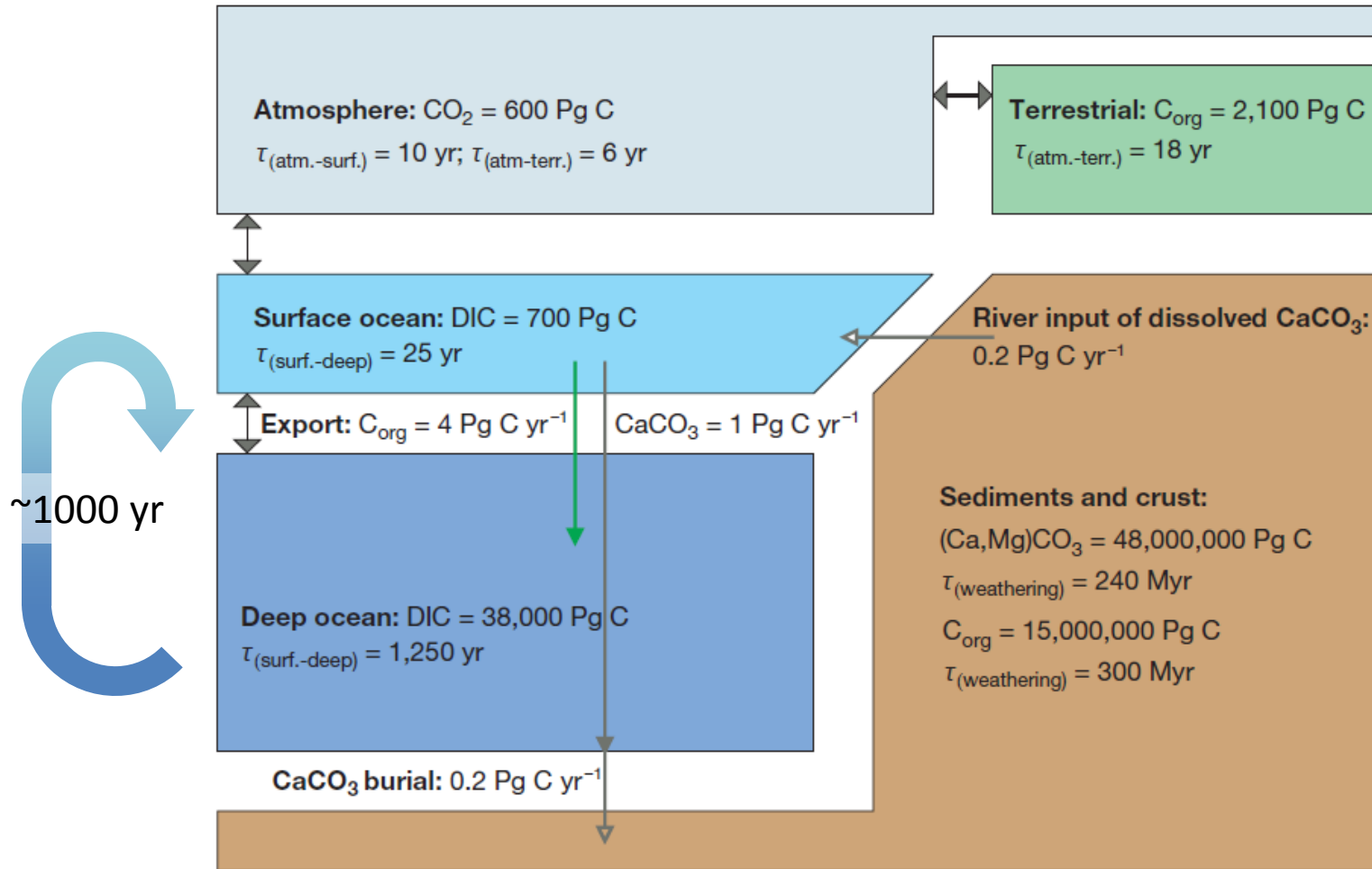


↑ Atmospheric CO₂
~100 ppm lower
during glacial maxima
↓



Sigman & Boyle Figure 1

Q: Where does atmospheric carbon go during glacial maxima?



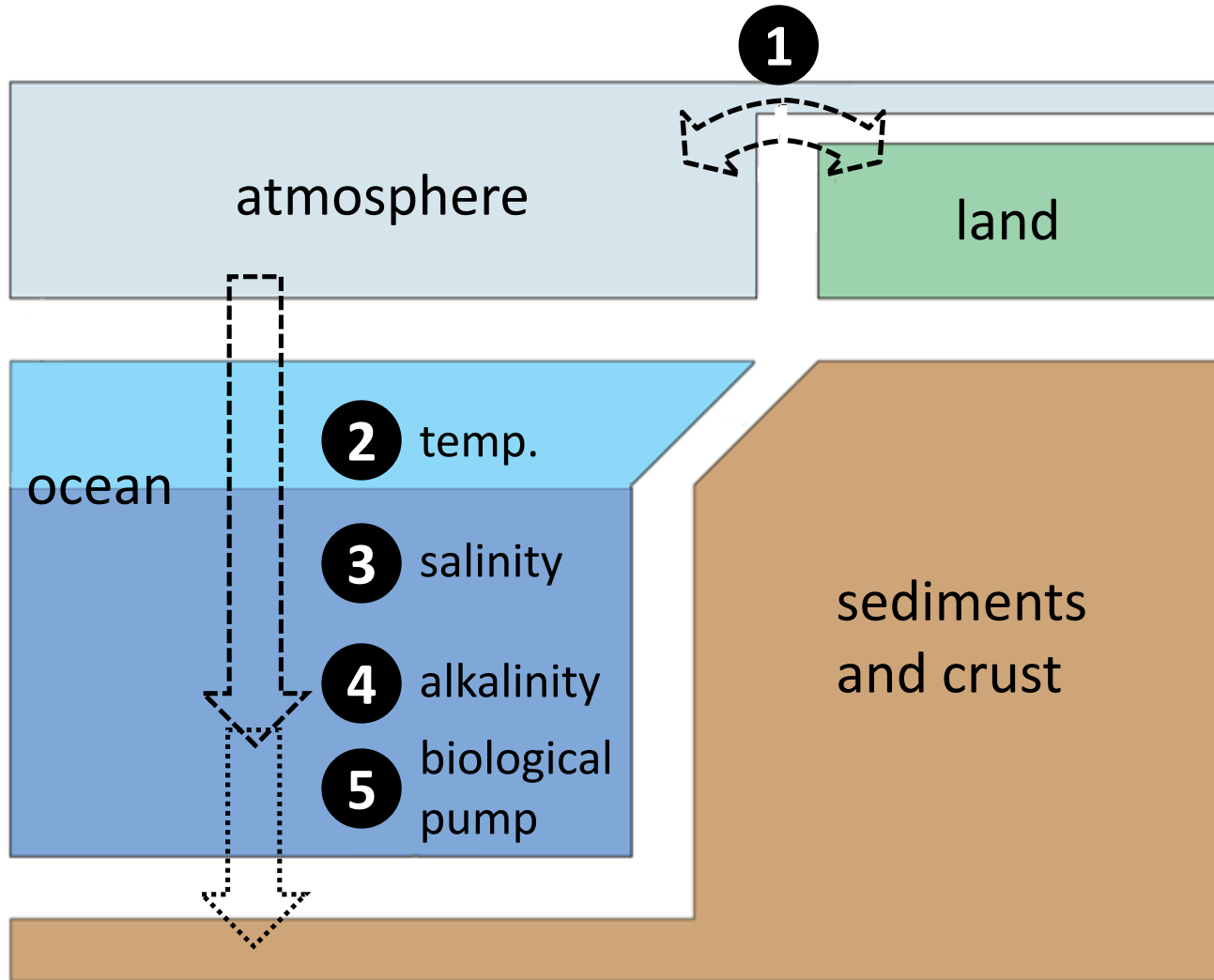
Sigman & Boyle Figure 2

ATMOSPHERE
SURFACE OCEAN

TERRESTRIAL

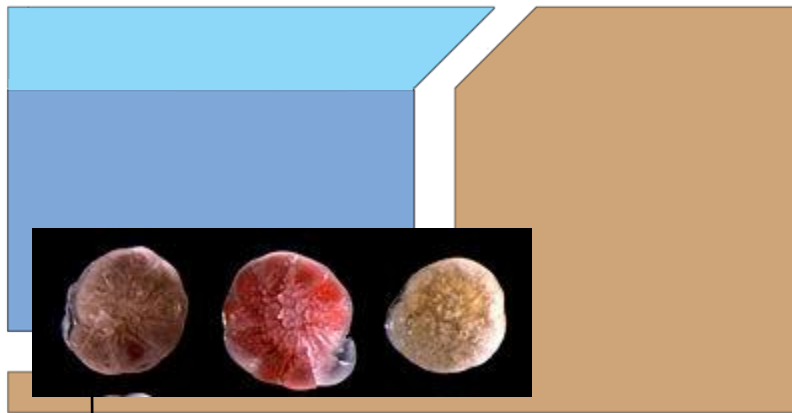
DEEP
OCEAN

Q: Where does atmospheric carbon go during glacial maxima?



Q: Where does atmospheric carbon go during glacial maxima?

1 To the land?



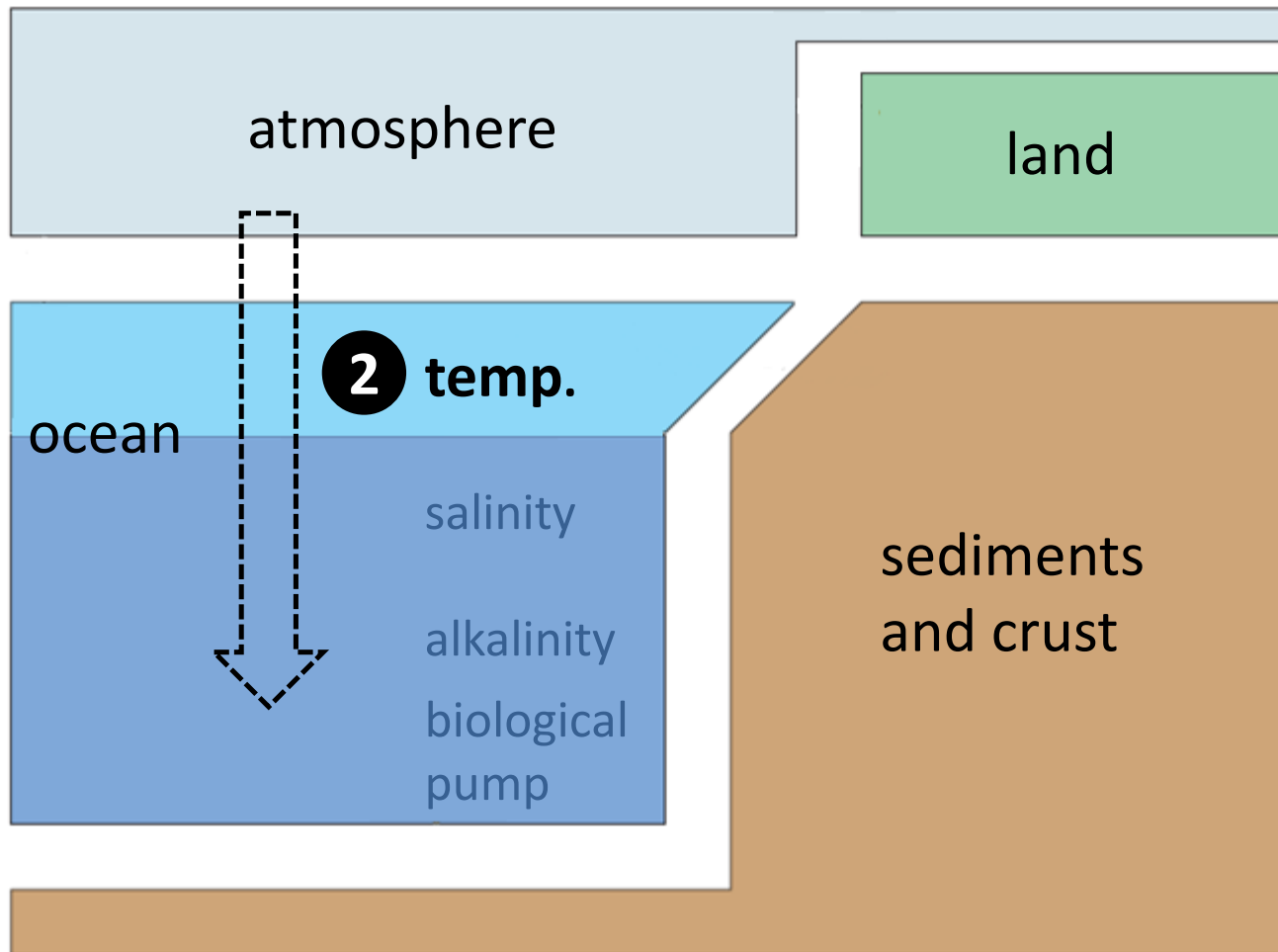
- vegetation → ice
- tropical forest → grassland
- spread of deserts
- organic-rich continental shelves exposed

organic C reservoir

$^{13}\text{C} / ^{12}\text{C}$ ratio in benthic foraminifera:
0.3-0.4% *lower* during glacial periods

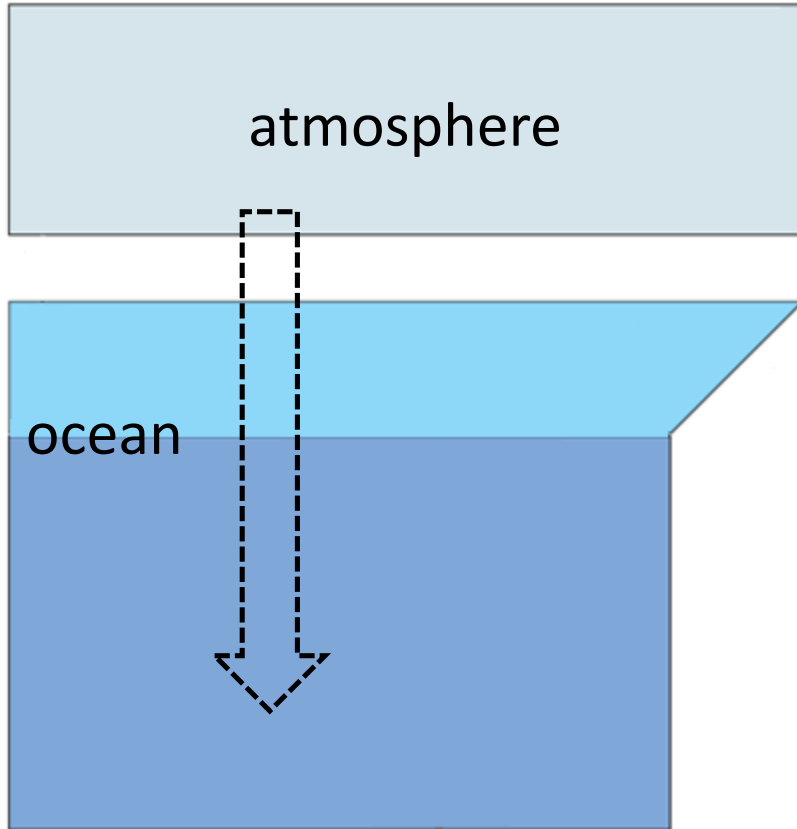
“Source not sink”

Q: Where does atmospheric carbon go during glacial maxima?



Q: Where does atmospheric carbon go during glacial maxima?

2 To the colder ocean?



Colder water
dissolves more CO₂



Q: Where does atmospheric carbon go during glacial maxima?

2 To the colder ocean?

atmosphere

↓ 3-5 °C (low latitude)

↓ < 4 °C

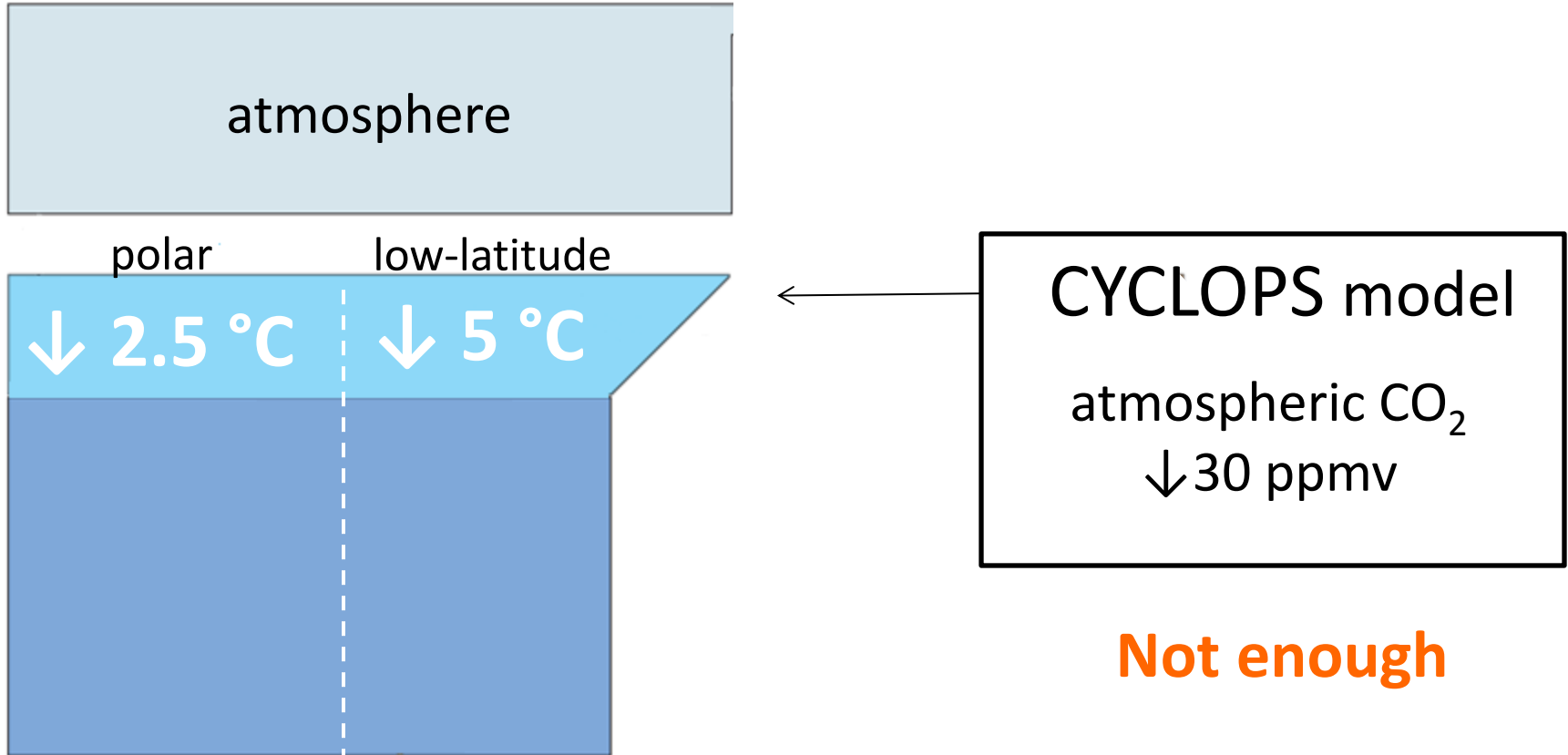
Colder water
dissolves more CO₂

sea water freezes at **-2 °C**

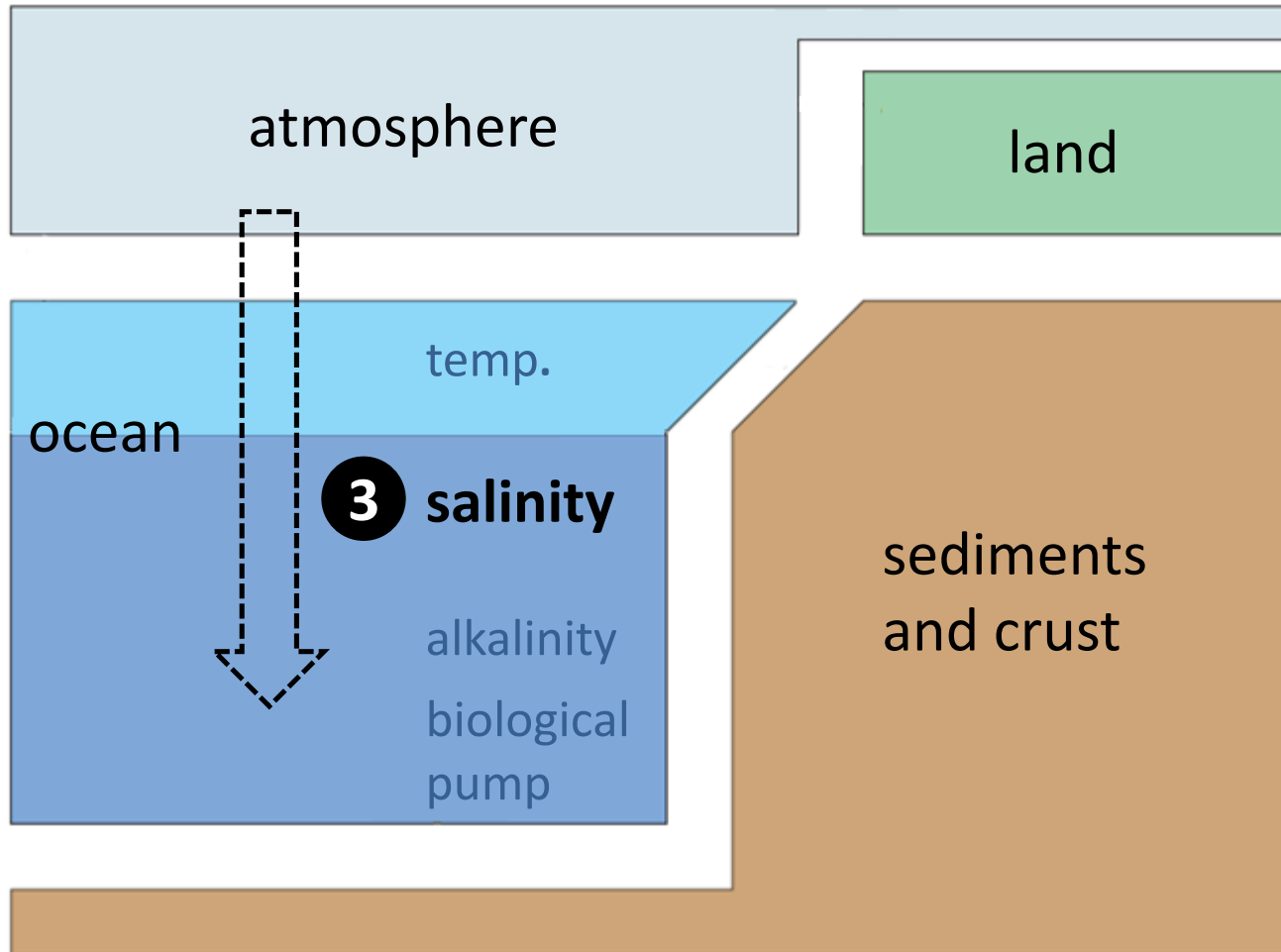


Q: Where does atmospheric carbon go during glacial maxima?

2 To the colder ocean?



Q: Where does atmospheric carbon go during glacial maxima?



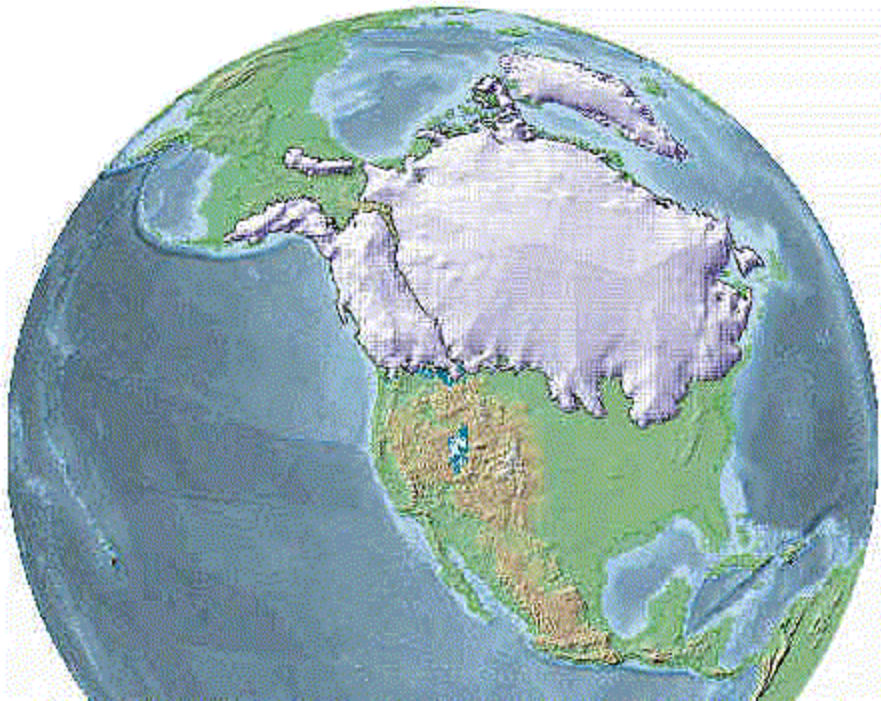
Q: Where does atmospheric carbon go during glacial maxima?

3 Salinity effects?

↑ Glaciers

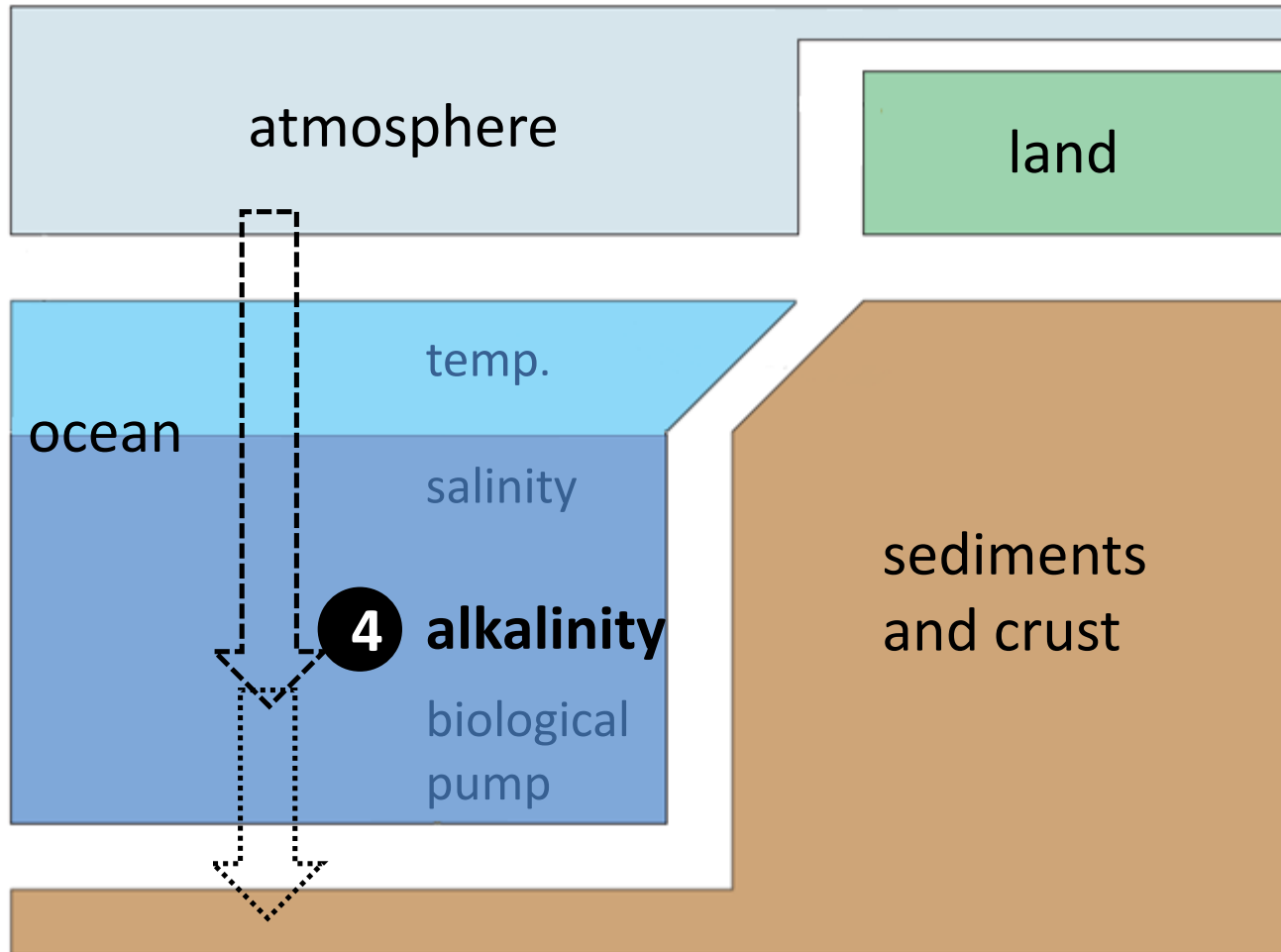
↑ Ocean salinity

↓ Solubility of CO₂

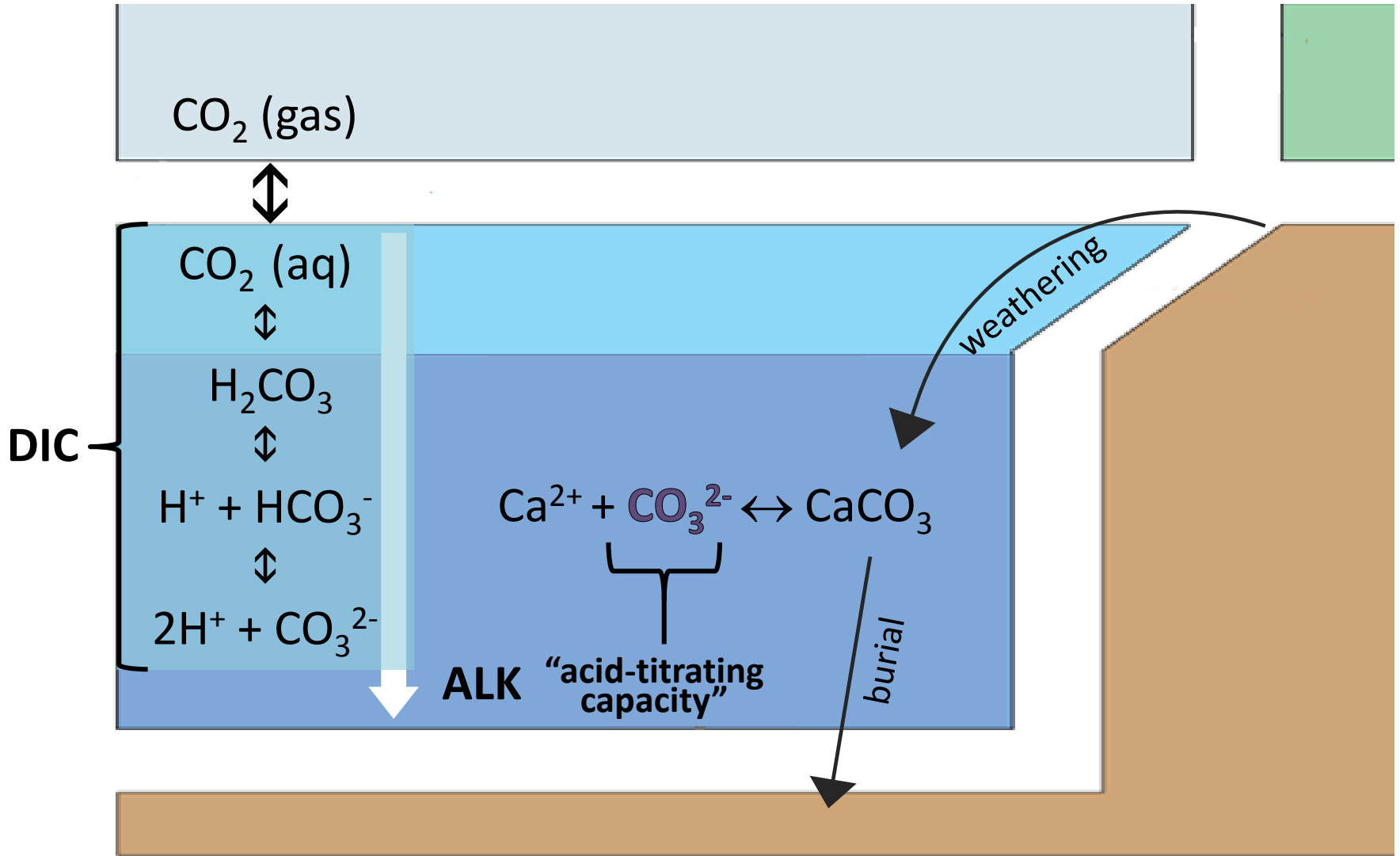


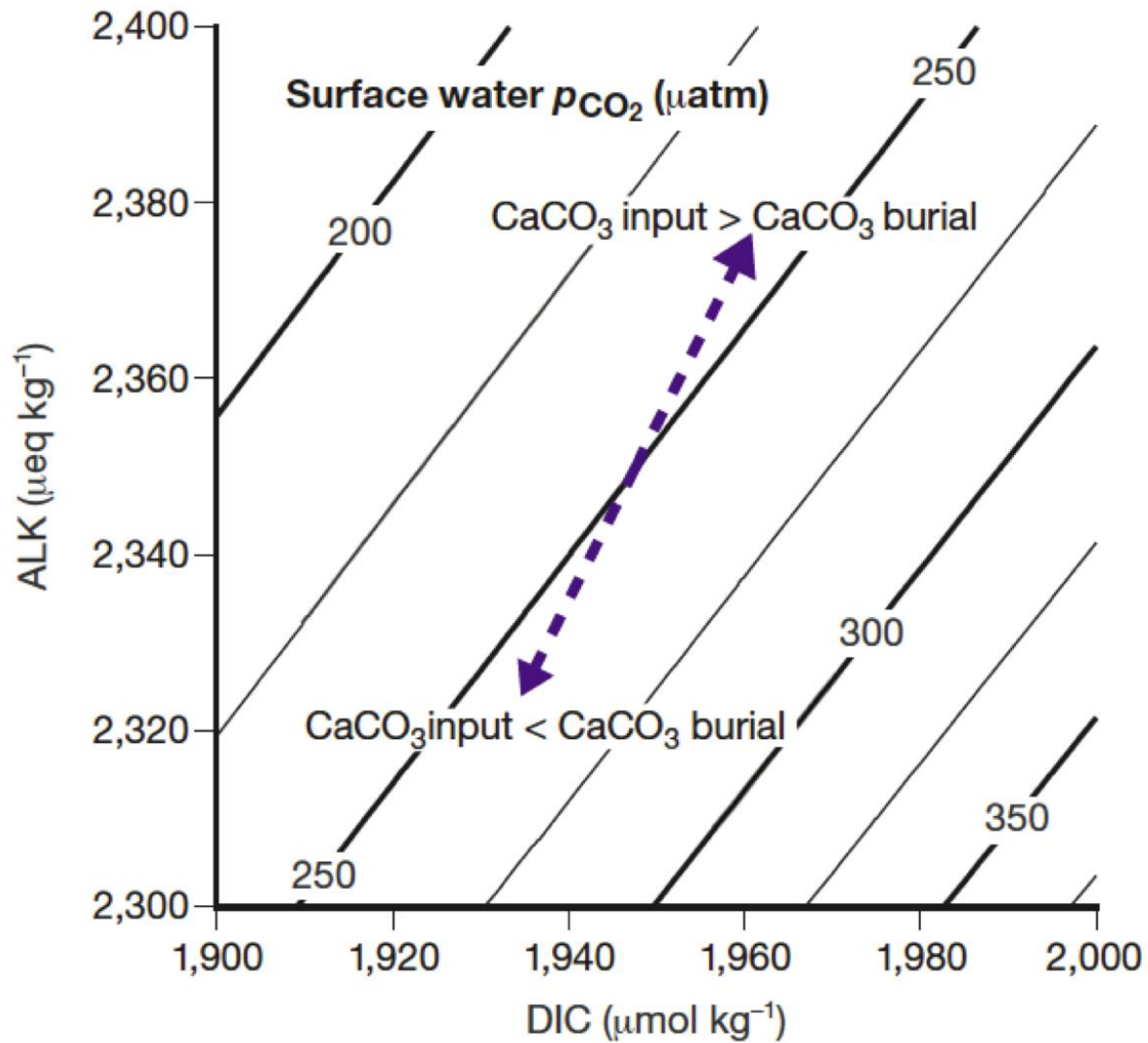
~~↓ 30~~ p.p.m.v.
23.5
8.5

Q: Where does atmospheric carbon go during glacial maxima?



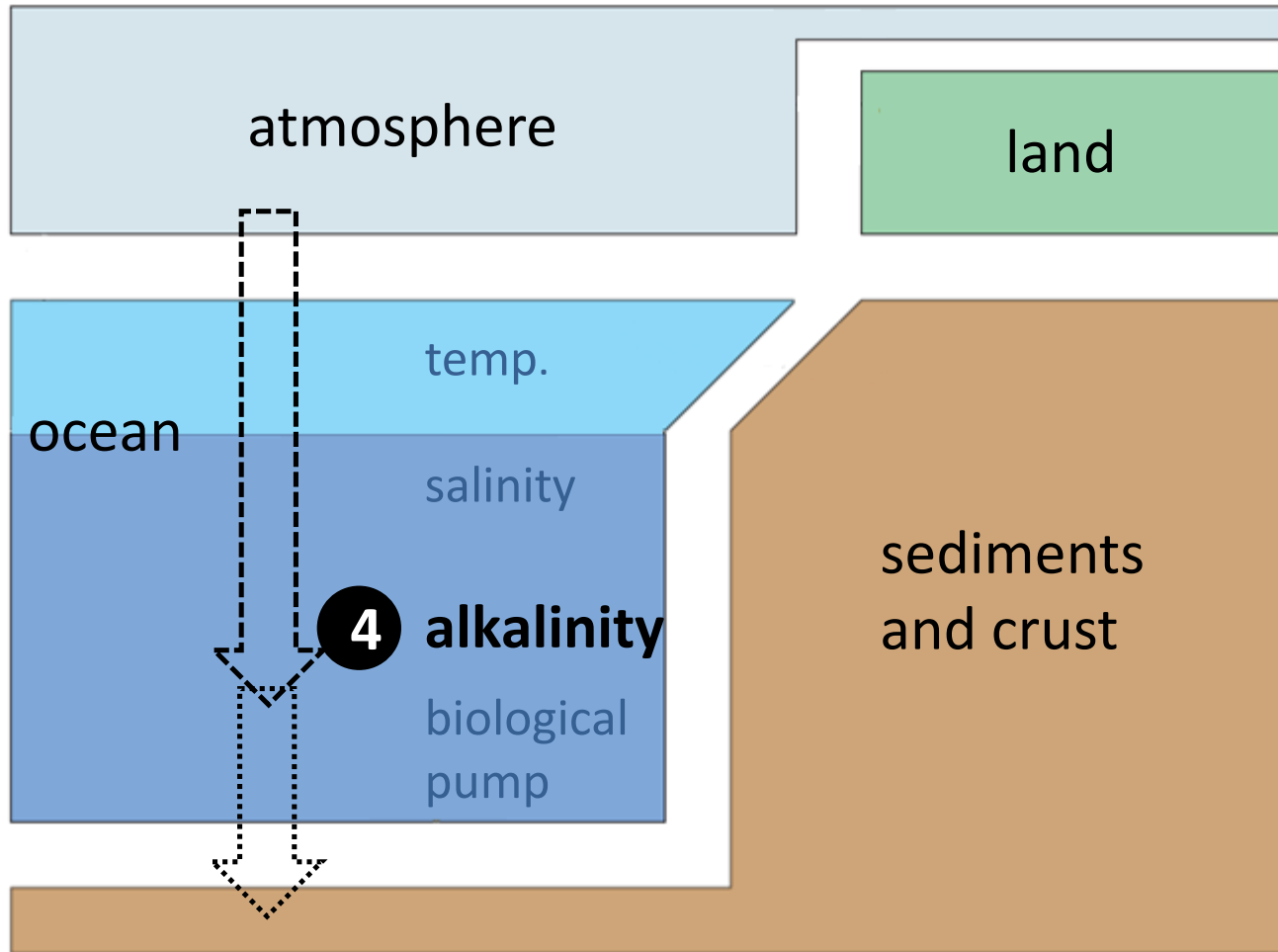
Ocean Alkalinity



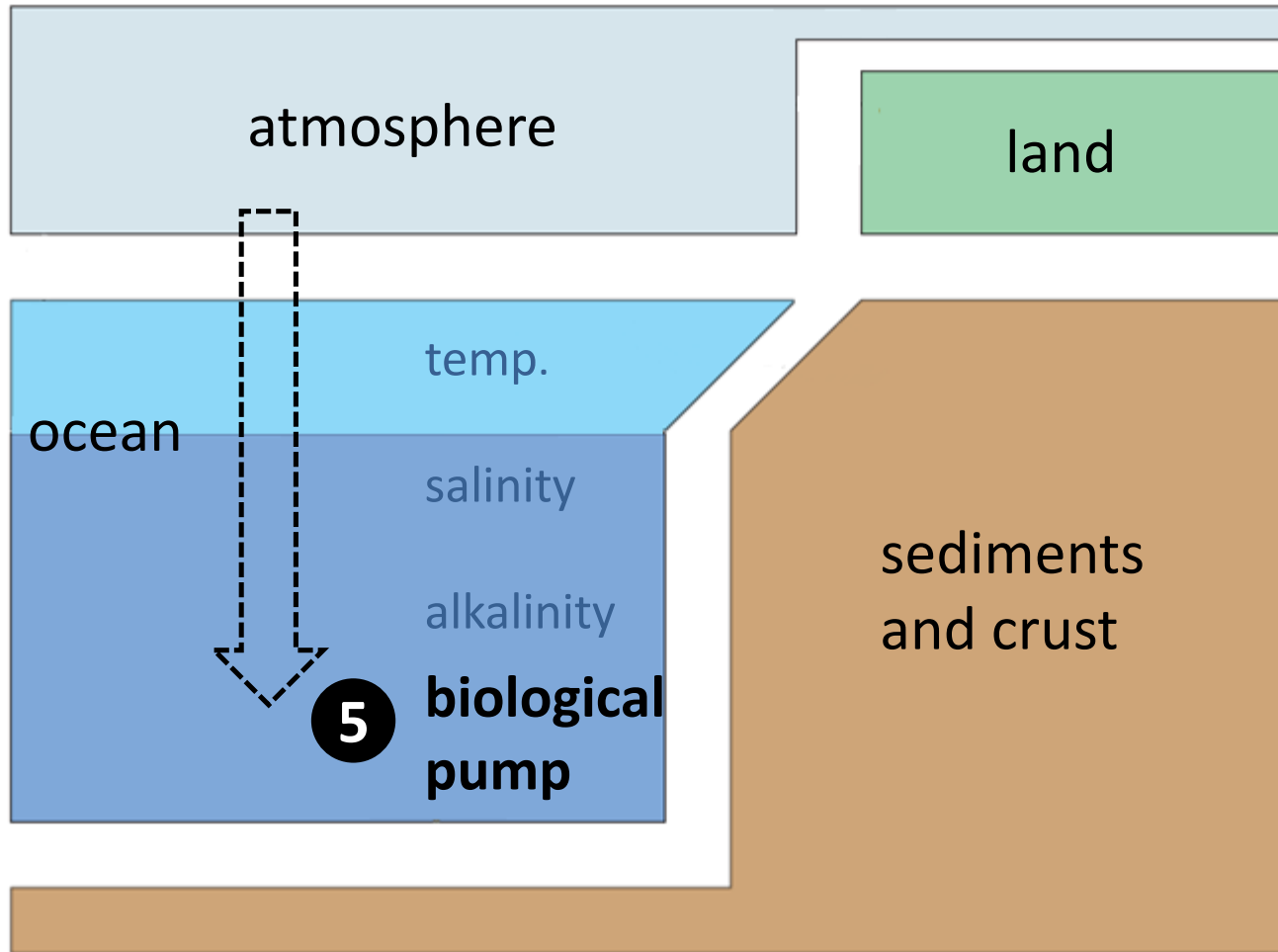


modified from Sigman & Boyle Figure 3

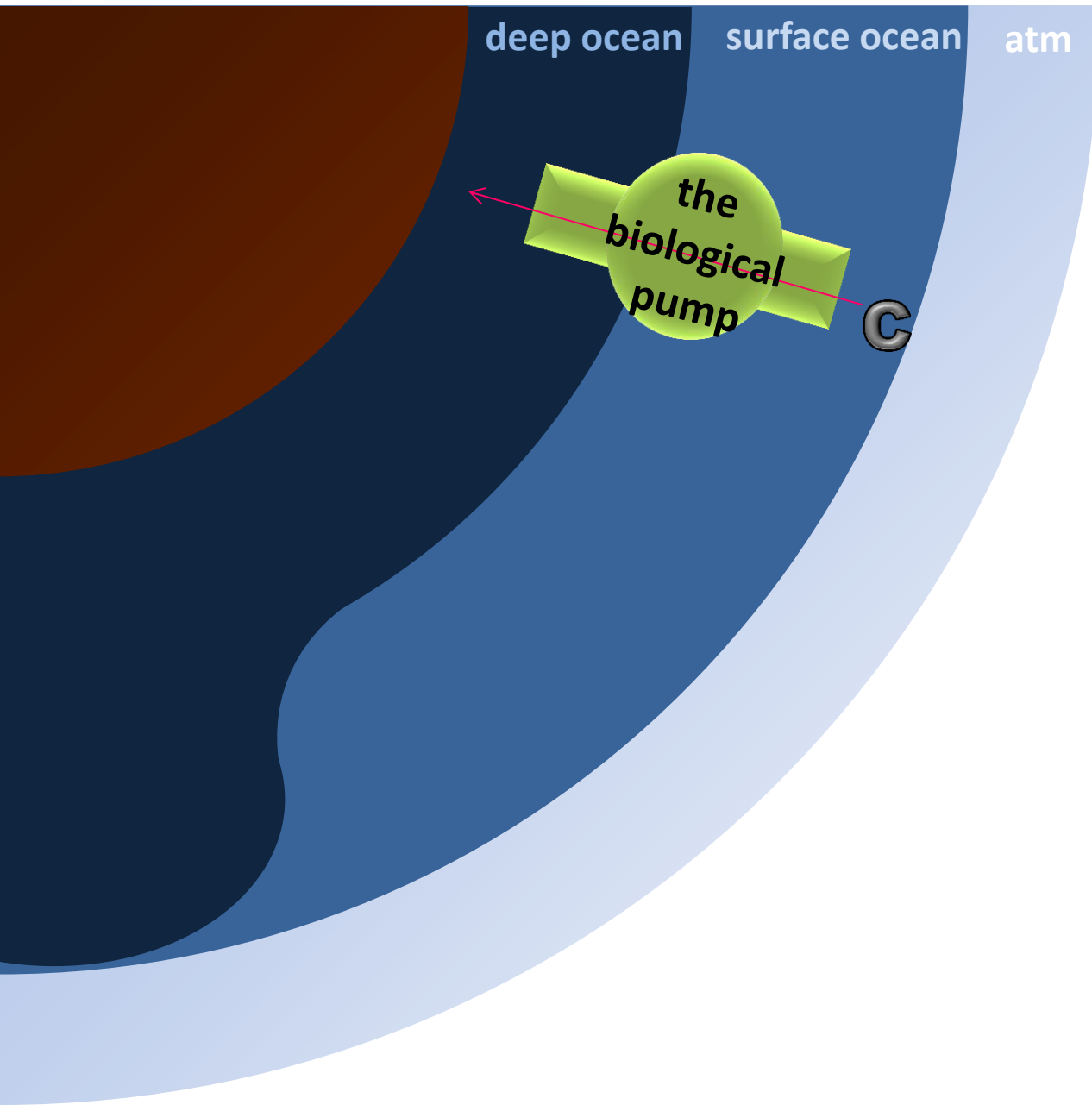
Q: Where does atmospheric carbon go during glacial maxima?



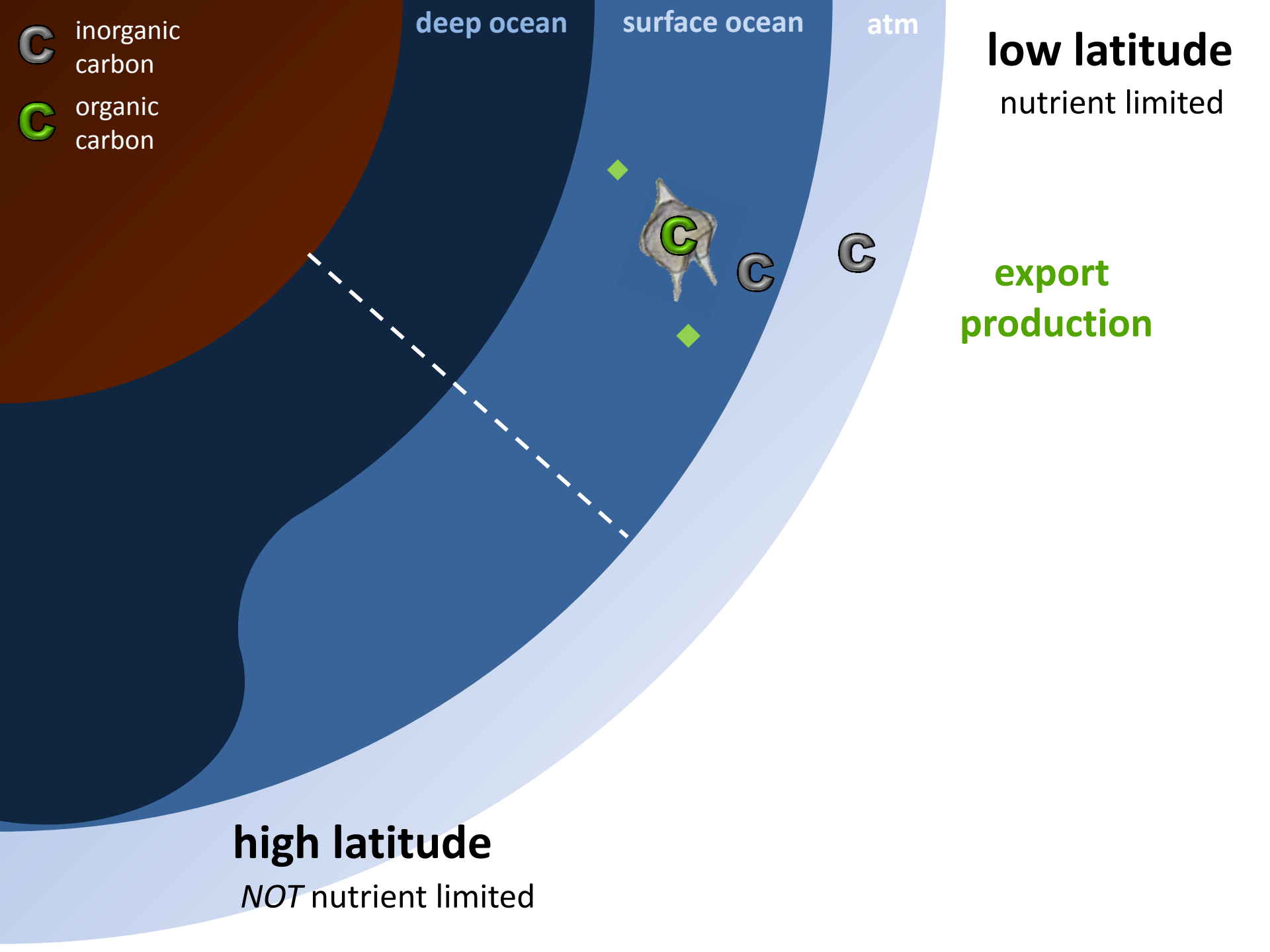
Q: Where does atmospheric carbon go during glacial maxima?



Q: Where does atmospheric carbon go during glacial maxima?



5 Biologically pumped to the ocean interior?



C inorganic carbon

C organic carbon

deep ocean

surface ocean

atm

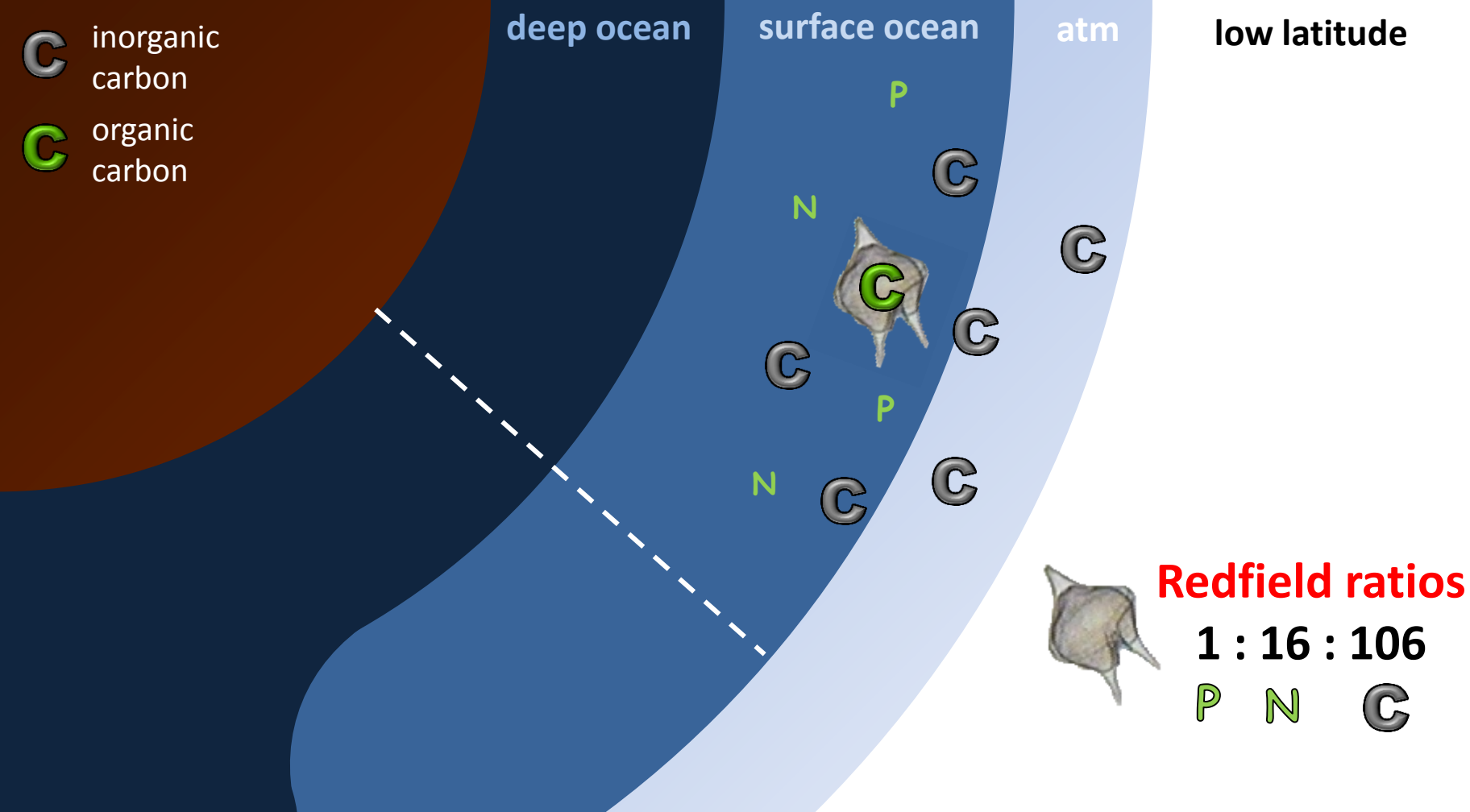
low latitude


nutrient limited


export production

high latitude

NOT nutrient limited

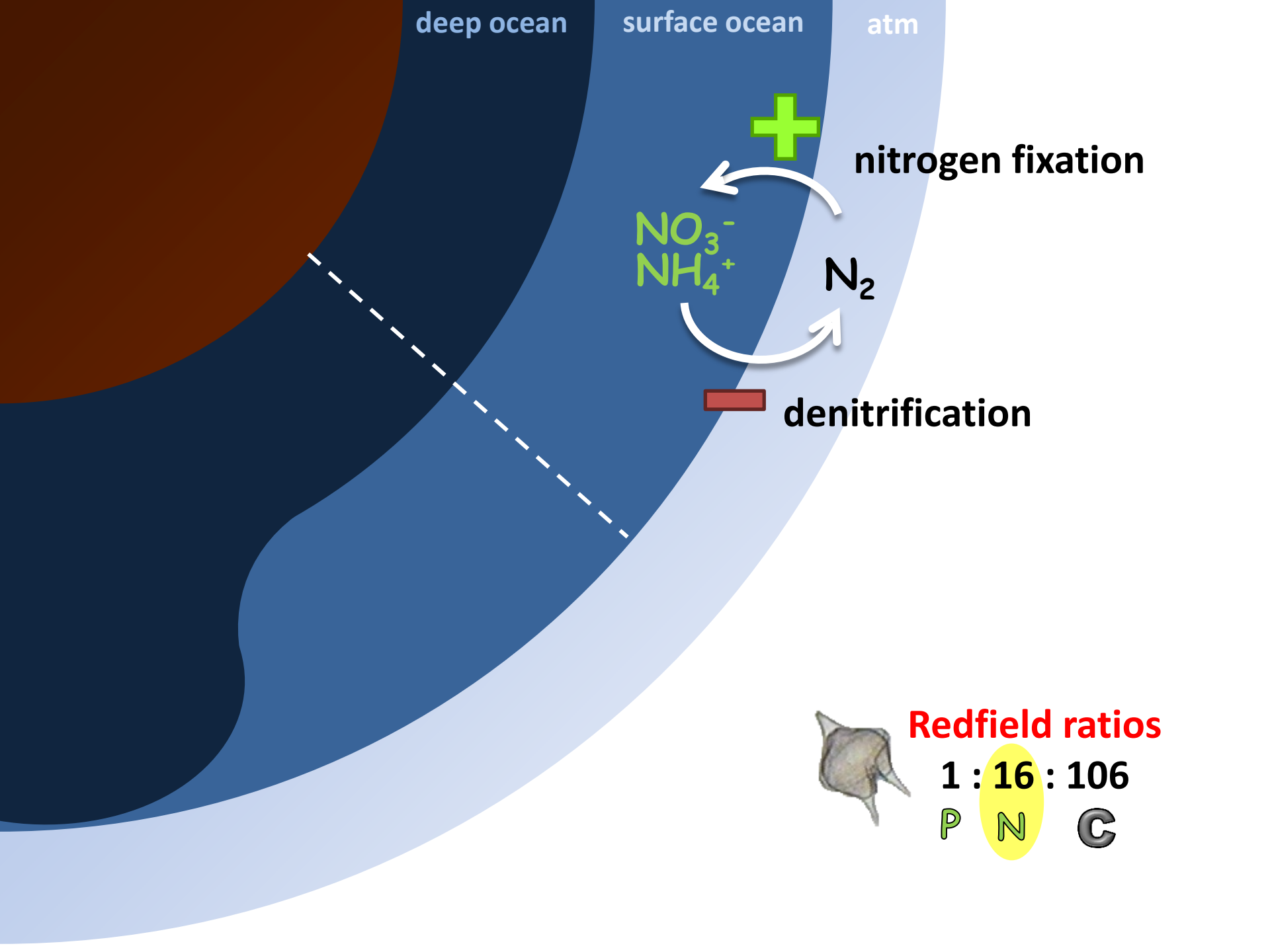


 inorganic carbon

 organic carbon

Redfield ratios
1 : 16 : 106
 P N C

Increase in ocean nutrient res.	CaCO ₃ export	Decrease in atm. CO ₂ (p.p.m.v.)
30%	proportionate	30-45 → 15-25
	constant	50
50%	constant	80



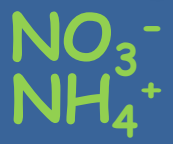
deep ocean

surface ocean

atm



nitrogen fixation



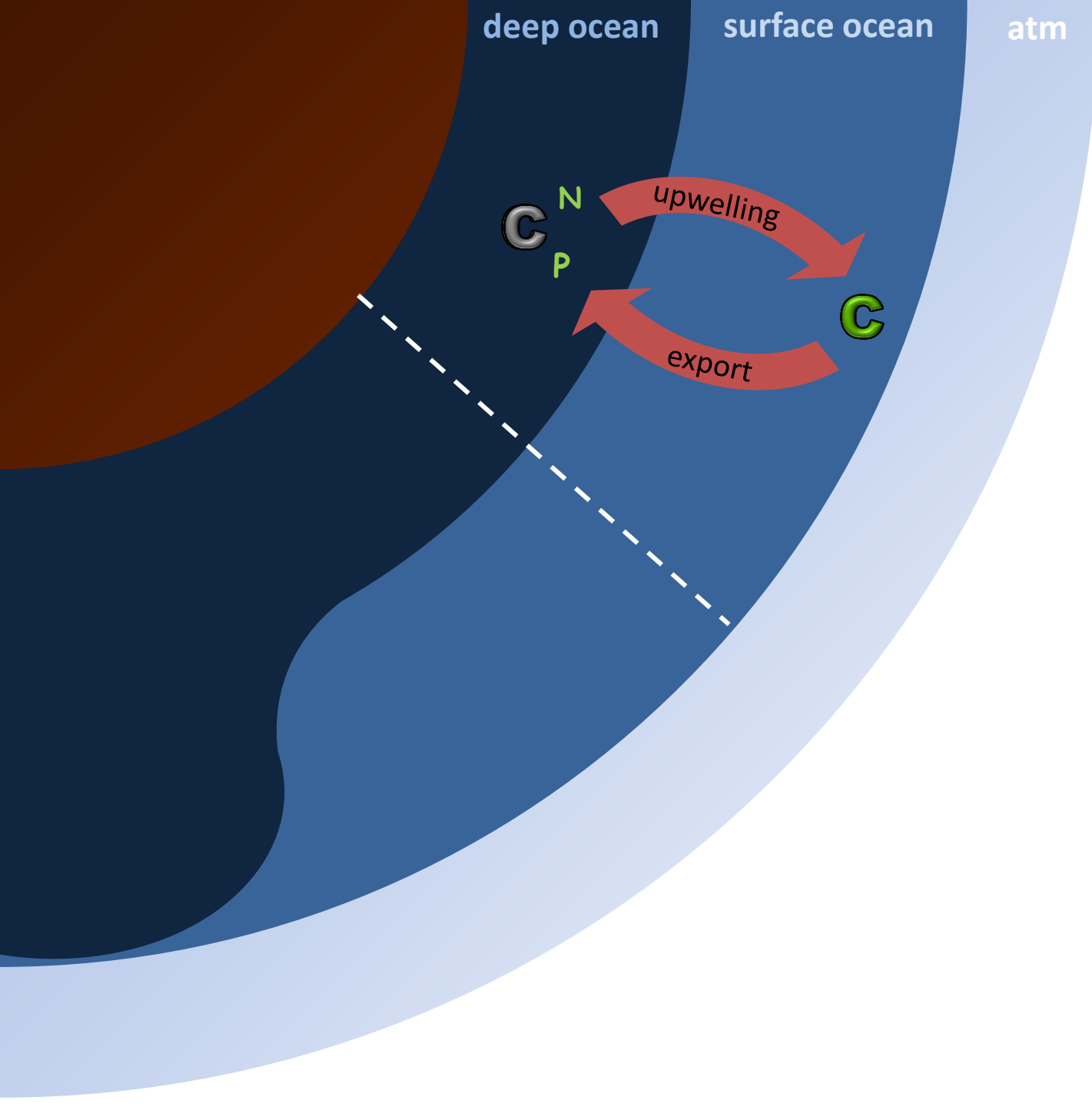
denitrification



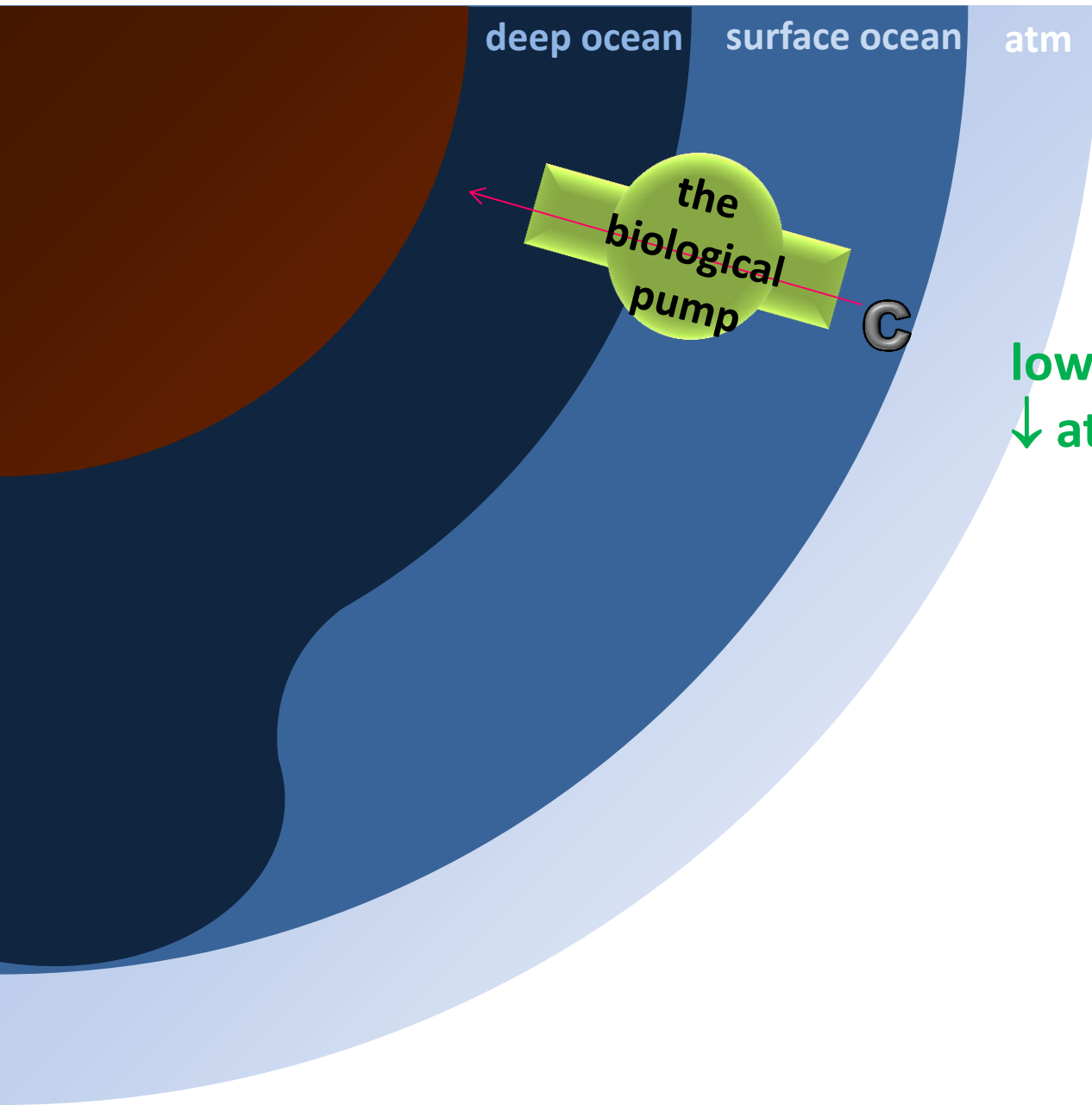
Redfield ratios

1 : 16 : 106

P N C

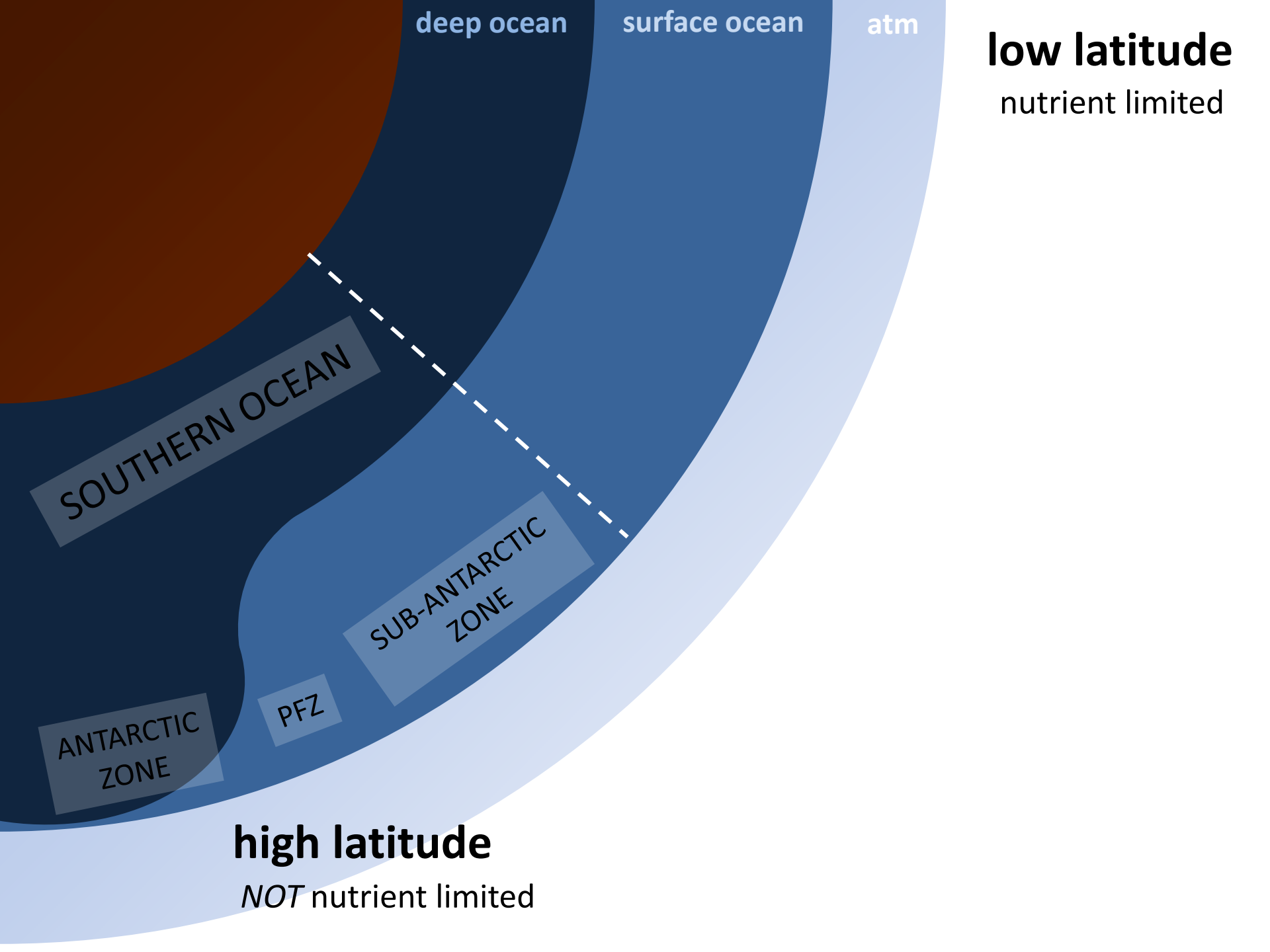


Q: Where does atmospheric carbon go during glacial maxima?



5 Biologically pumped to the ocean interior?

low lat. nutrient reservoir:
↓ atm. CO₂ by 15-80 ppmv



deep ocean

surface ocean

atm

low latitude
nutrient limited

SOUTHERN OCEAN

ANTARCTIC ZONE

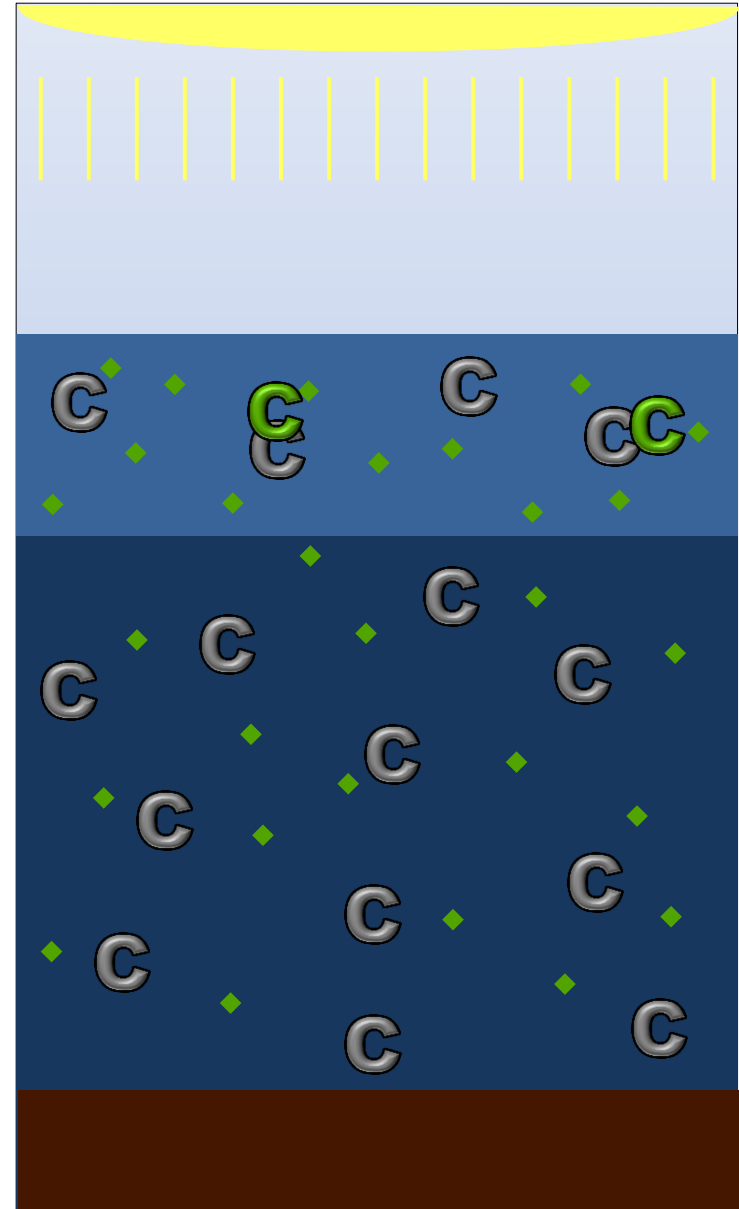
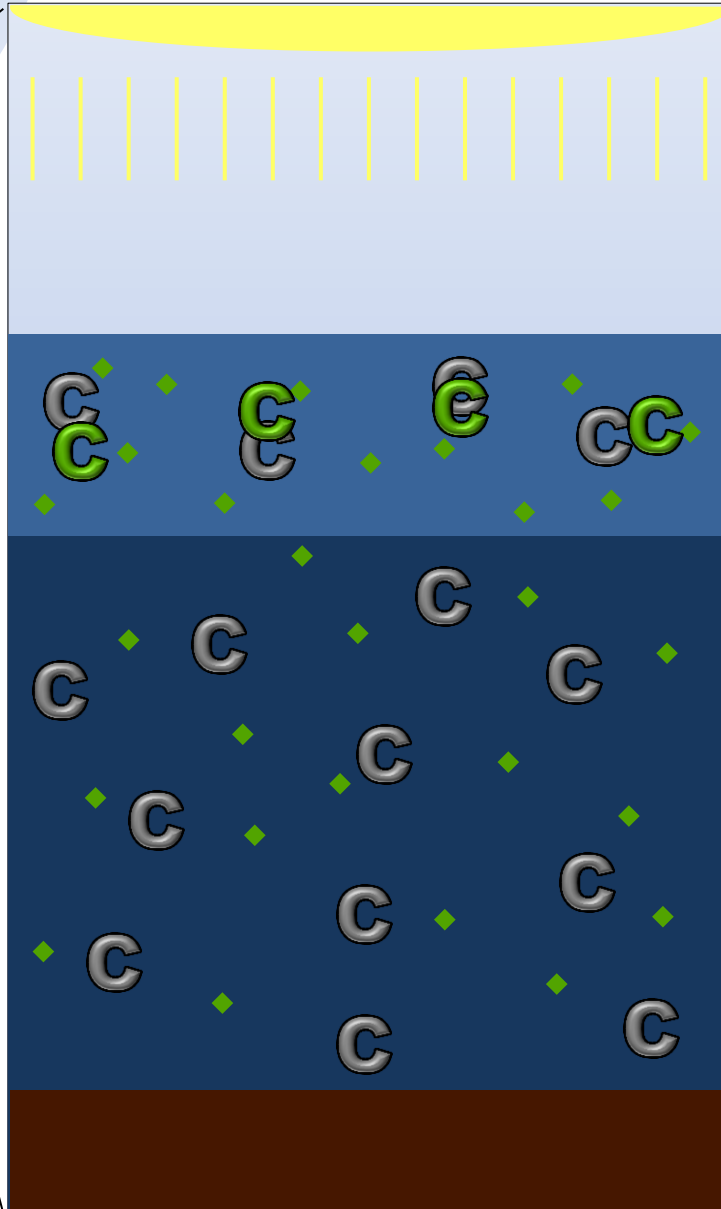
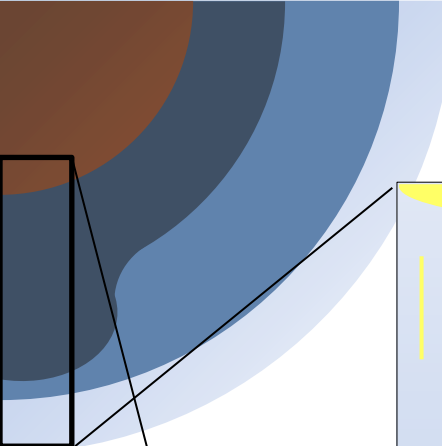
PFZ

SUB-ANTARCTIC ZONE

high latitude
NOT nutrient limited

HIGH NUTRIENT UTILIZATION

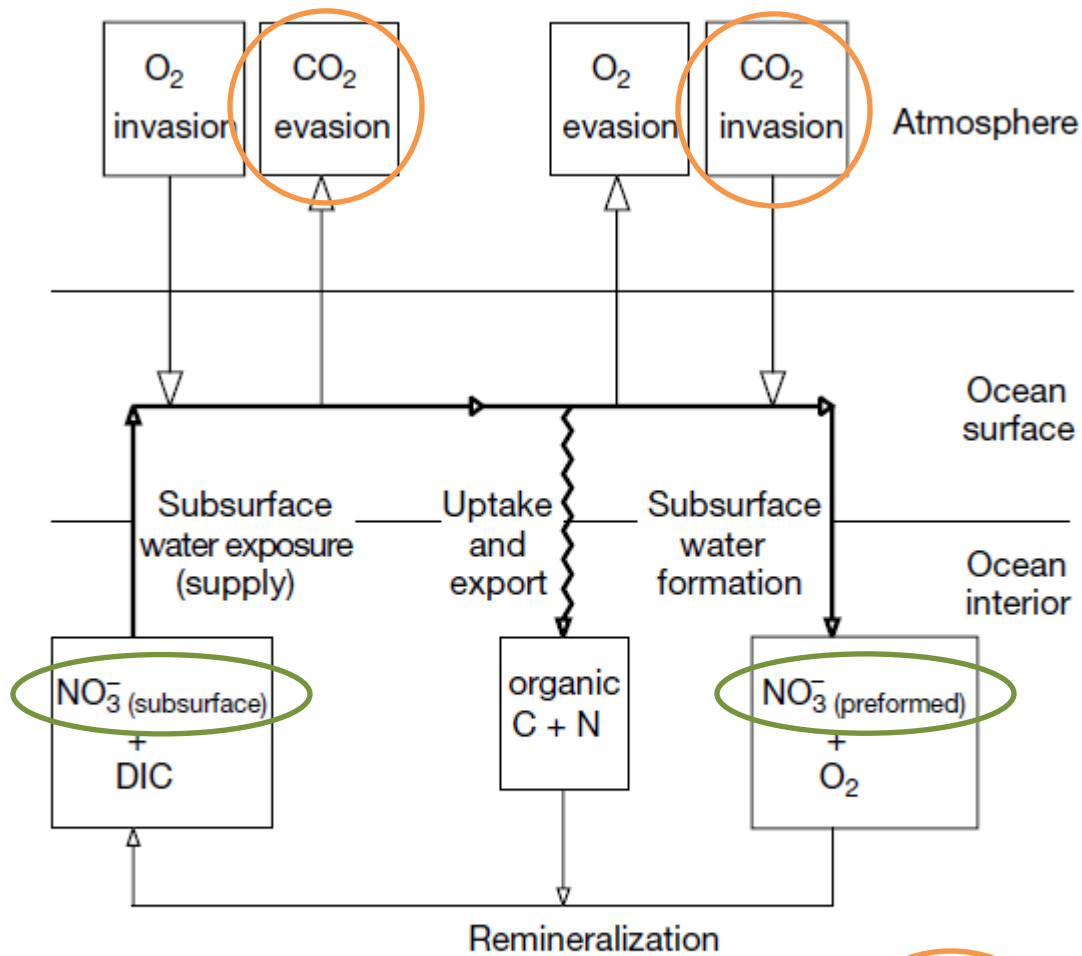
LOW NUTRIENT UTILIZATION



◆ nutrients

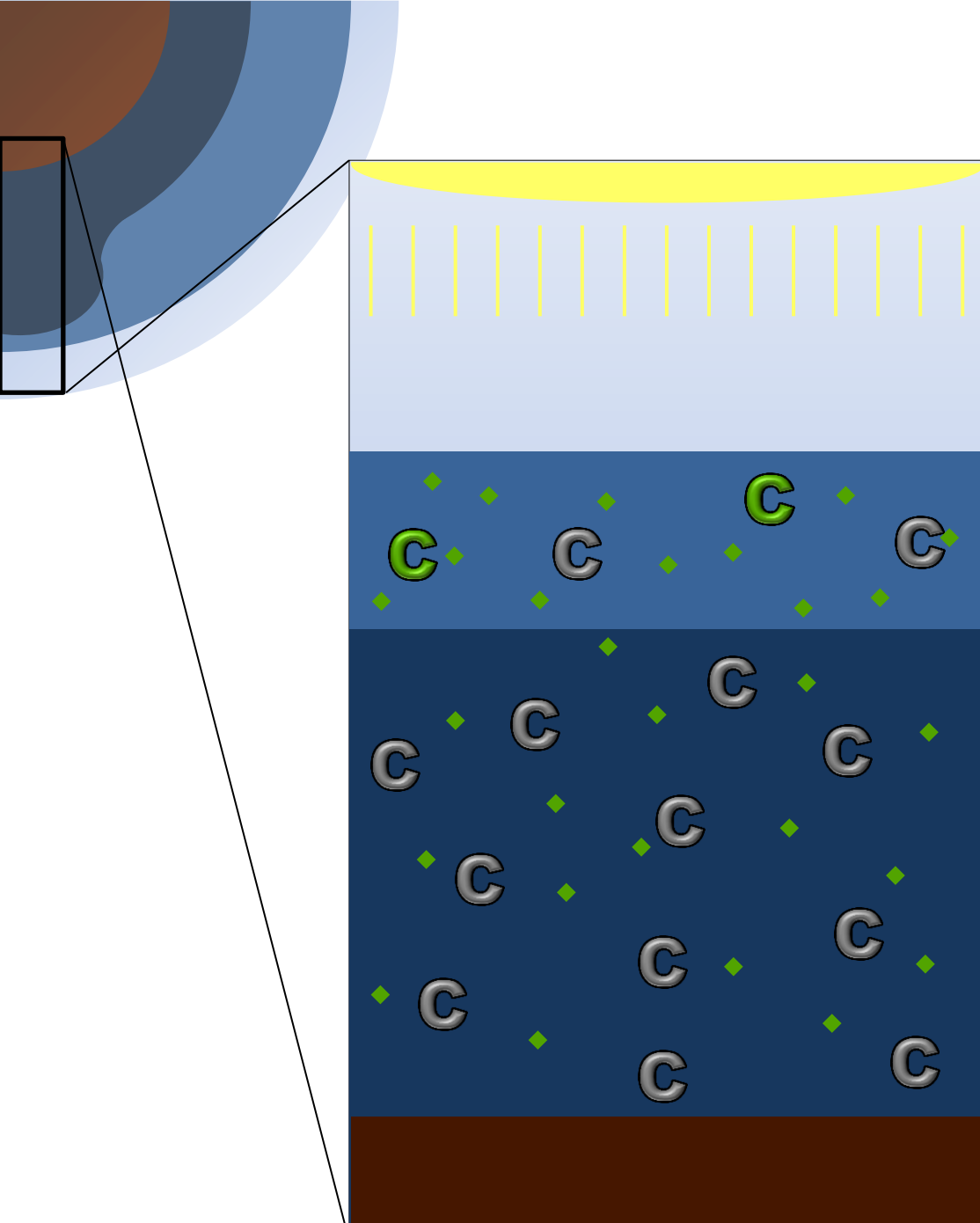
Ⓒ inorganic carbon

Ⓒ organic carbon

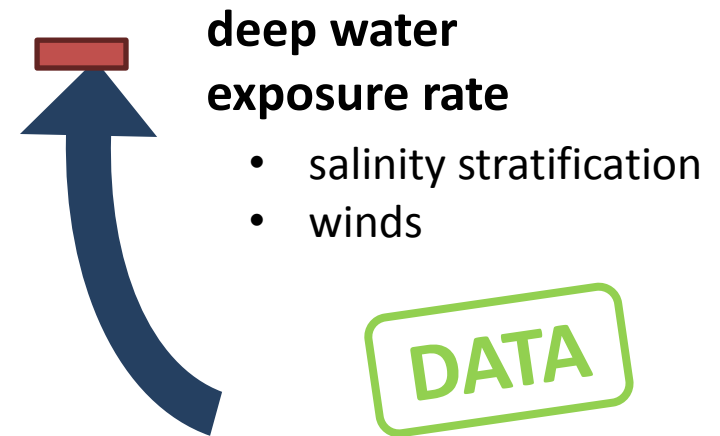


Nutrient utilization =
$$\frac{\text{Uptake}}{\text{Supply}} = 1 - \frac{[NO_3^-]_{\text{preformed}}}{[NO_3^-]_{\text{subsurface}}} \propto \frac{CO_2 \text{ invasion}}{CO_2 \text{ evasion}}$$

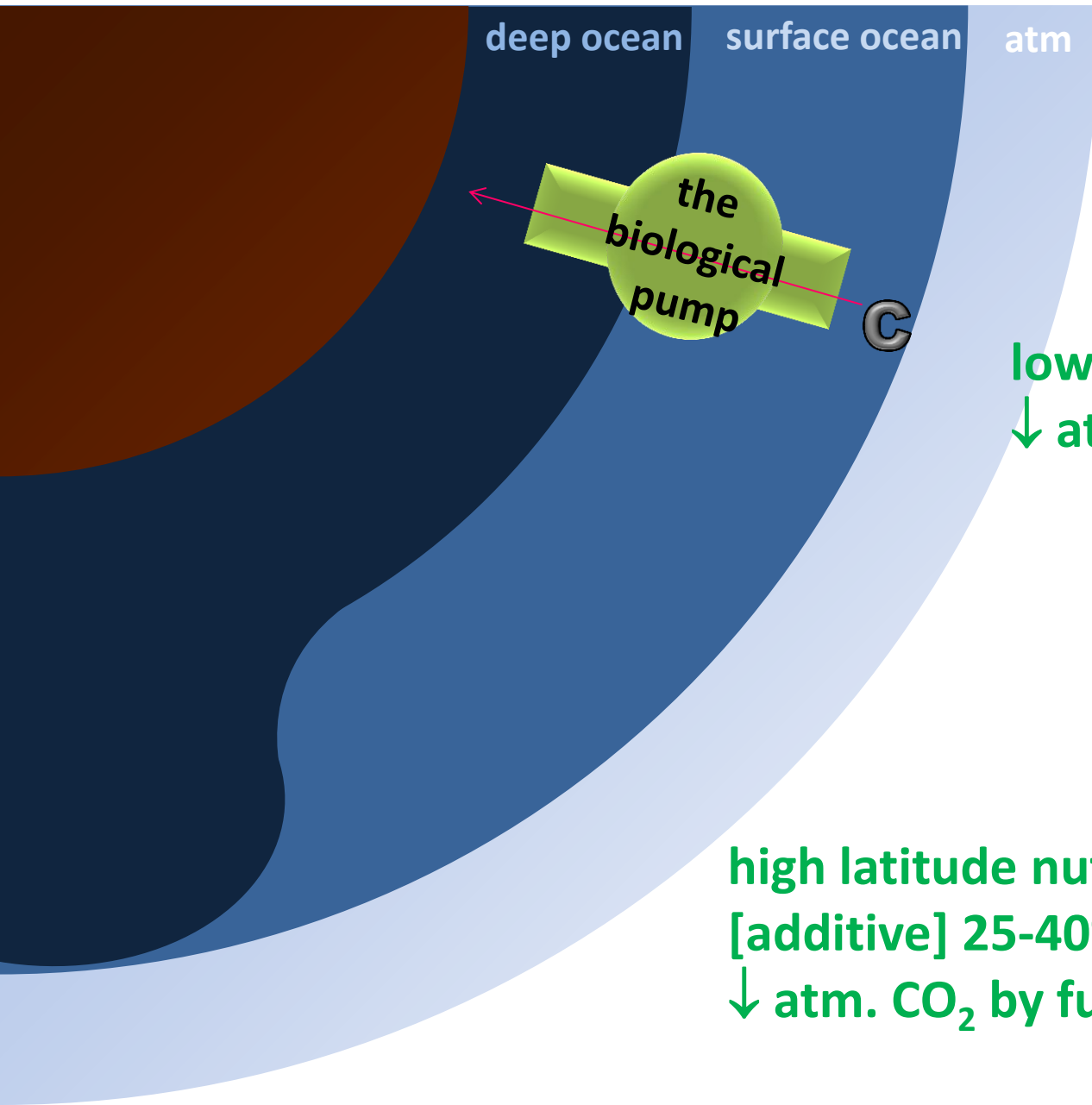
modified from Sigman & Boyle Figure 5



How to Increase NU:



Q: Where does atmospheric carbon go during glacial maxima?

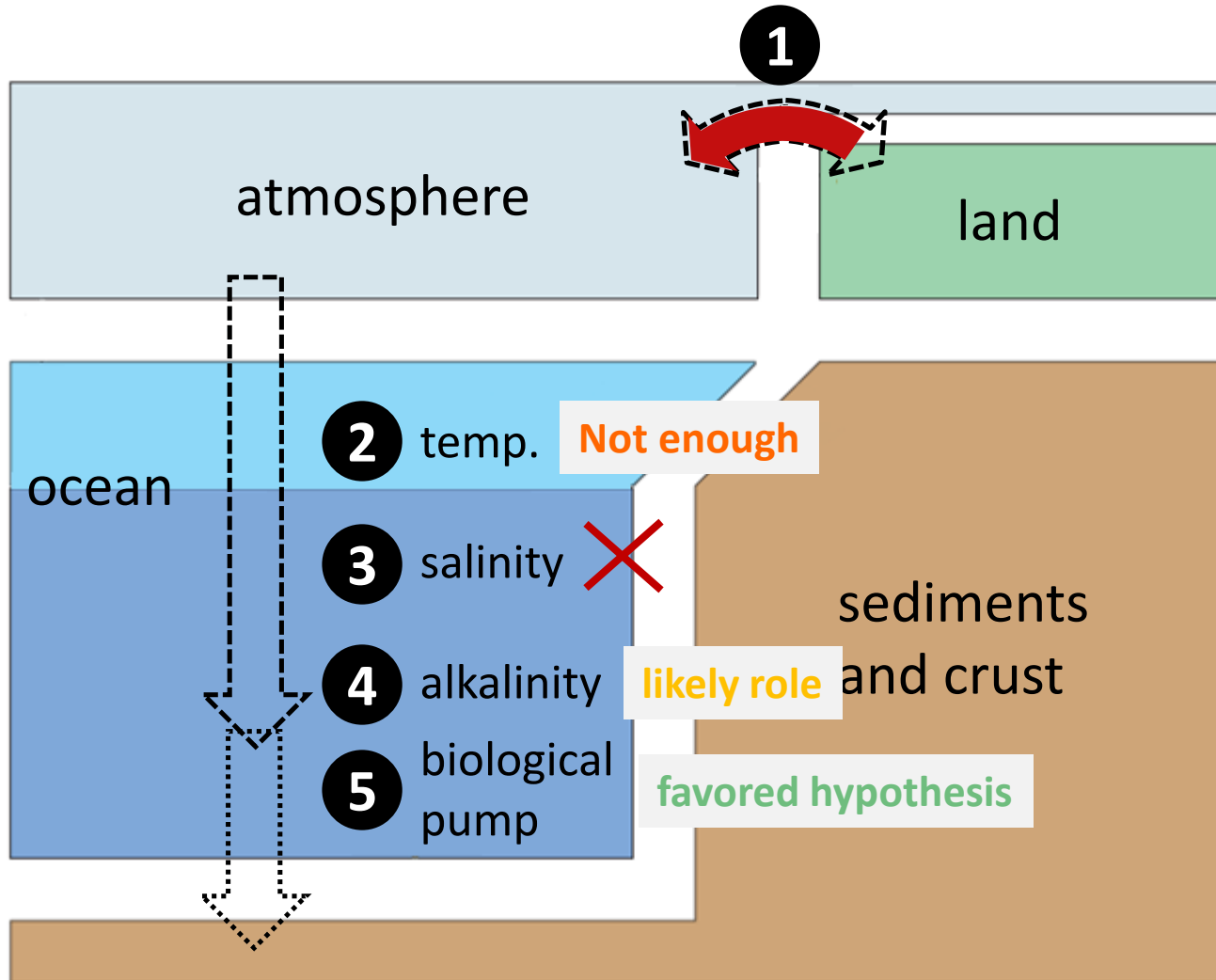


2 Biologically pumped to the ocean interior?

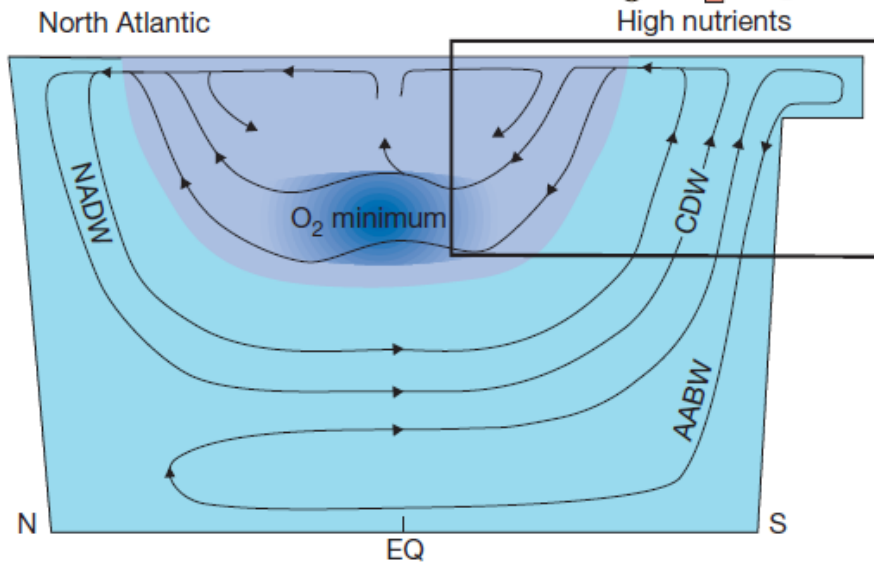
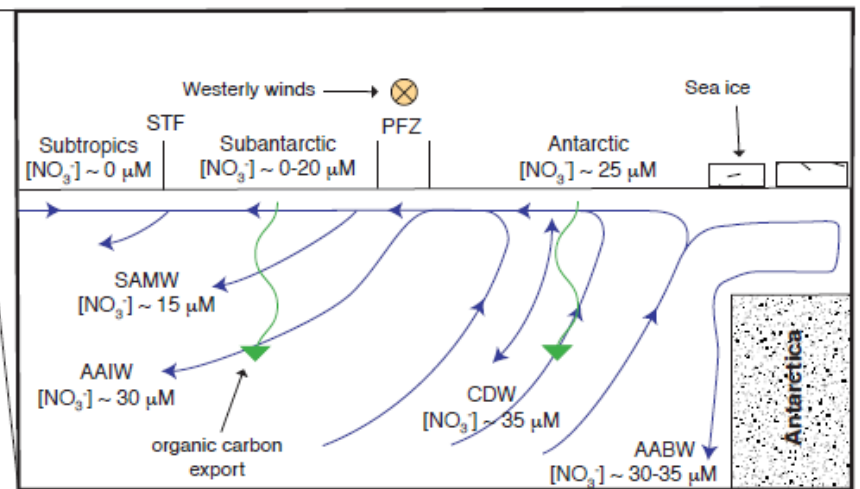
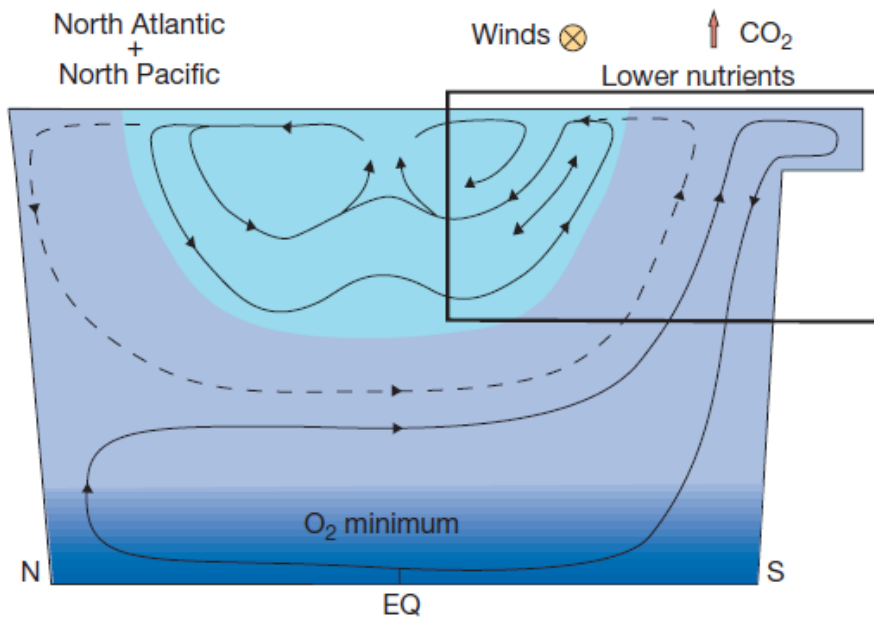
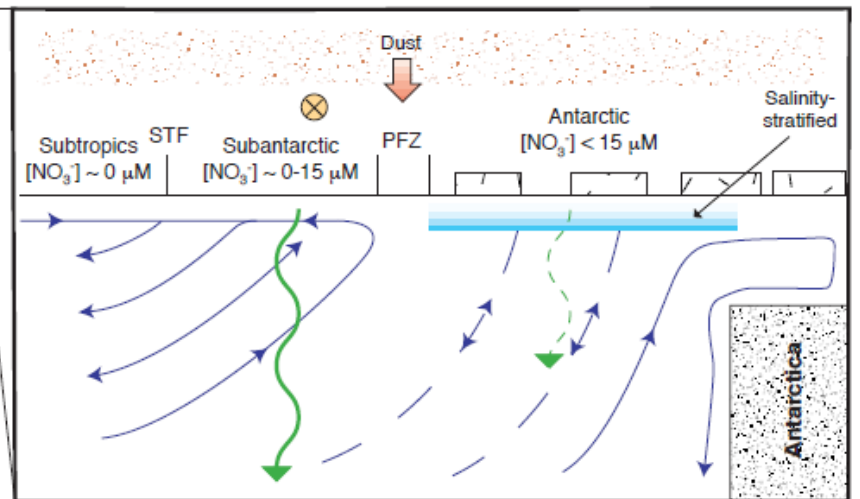
low lat. nutrient reservoir:
↓ atm. CO₂ by 15-80 ppmv

high latitude nutrient utilization:
[additive] 25-40% higher nitrate util.
↓ atm. CO₂ by full 100 ppmv

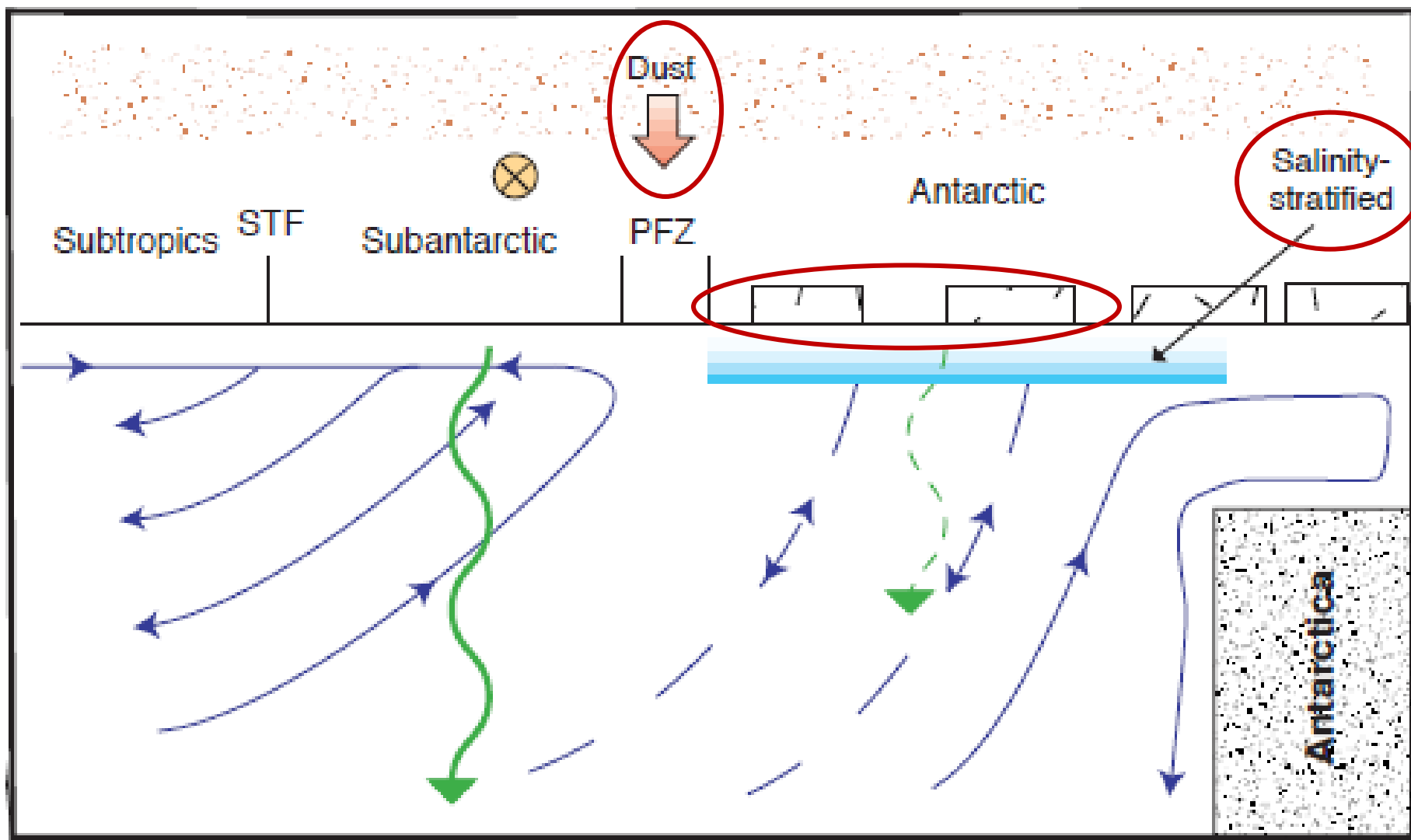
Q: Where does atmospheric carbon go during glacial maxima?



SIGMAN & BOYLE HYPOTHESIS

a Today**b Modern Southern Ocean****c Last Ice Age (hypothesis)****d Ice Age Southern Ocean (hypothesis)**

d Ice Age Southern Ocean (hypothesis)



Sigman, D. M. and Bolye, E. A. (2000)
Glacial/interglacial variations in atmospheric carbon
dioxide. Nature 407, 859-869



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