Evidence of Significant Destratification of the Subantarctic Pacific During the Past 3.3-2.4 Million Years

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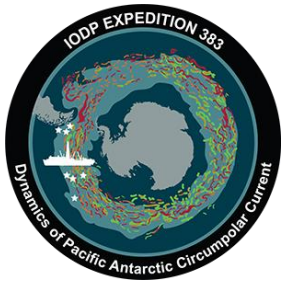
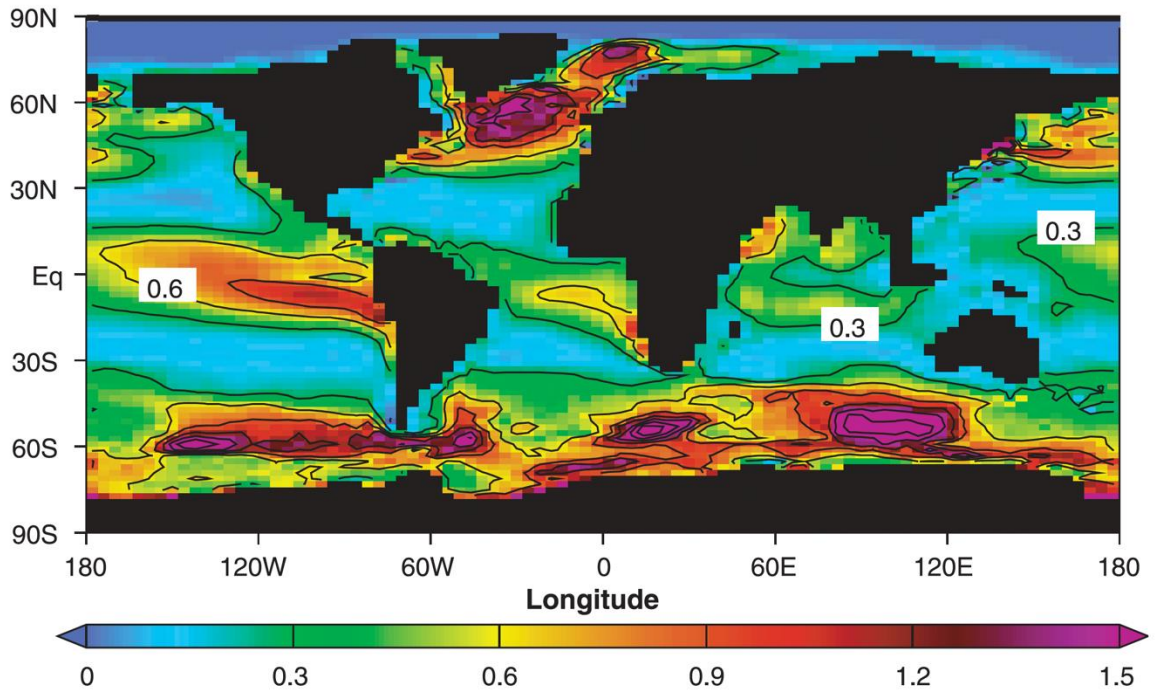


Introduction

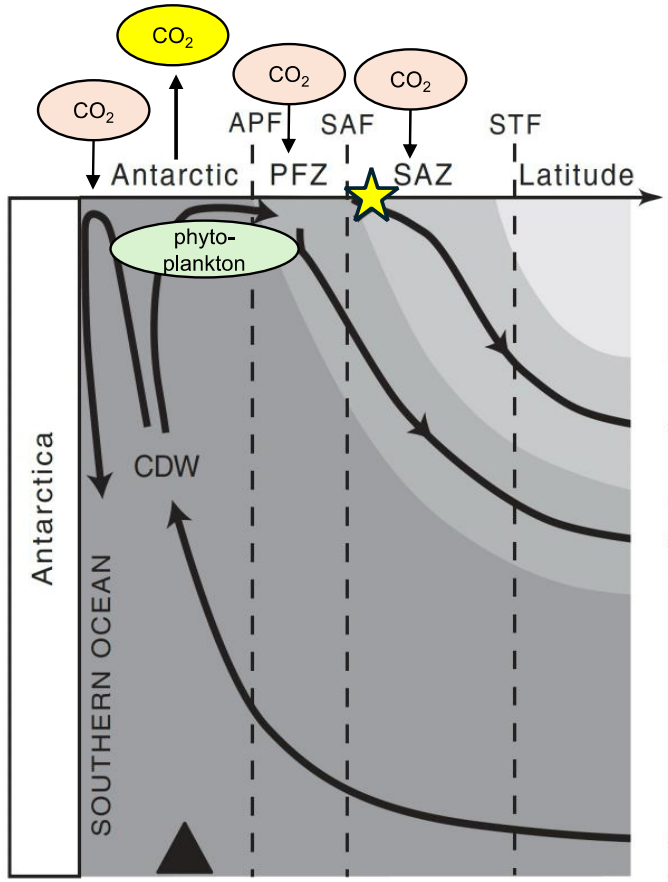
The Southern Ocean (SO) upwelling system plays a key role in the uptake and release of CO_2 and greatly influences the climate system.

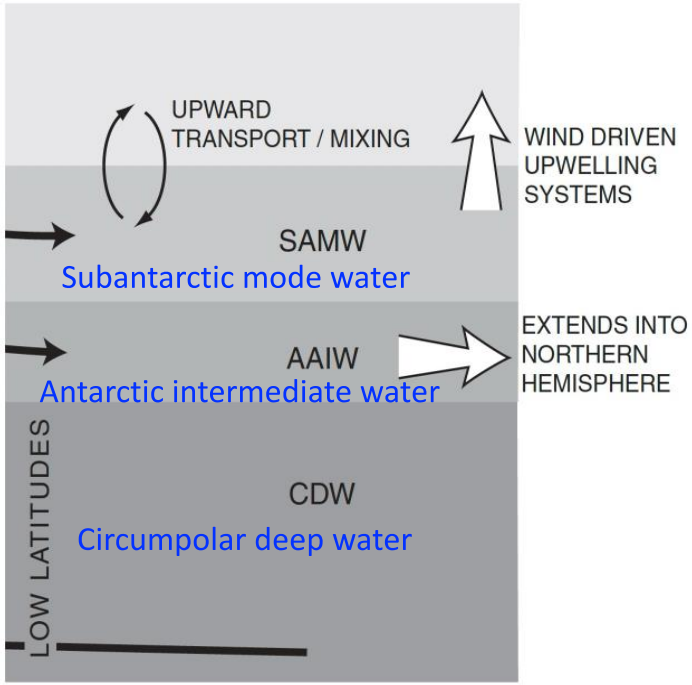
The upwelling CDW carries the regenerated nutrient and alkalinity to the SO surface, therefore influencing surface productivity and the ability to capture CO_2.

STF: Subtropical Front
SAF: Subantartic Front
APF: Antarctic Polar Front
SAZ: Subantarctic Zone
PFZ: Polar Frontal Zone
SH: Southern Hemisphere



(Caldeira and Duffy, 2000)





research site

Modified from Anderson et al. (2009)

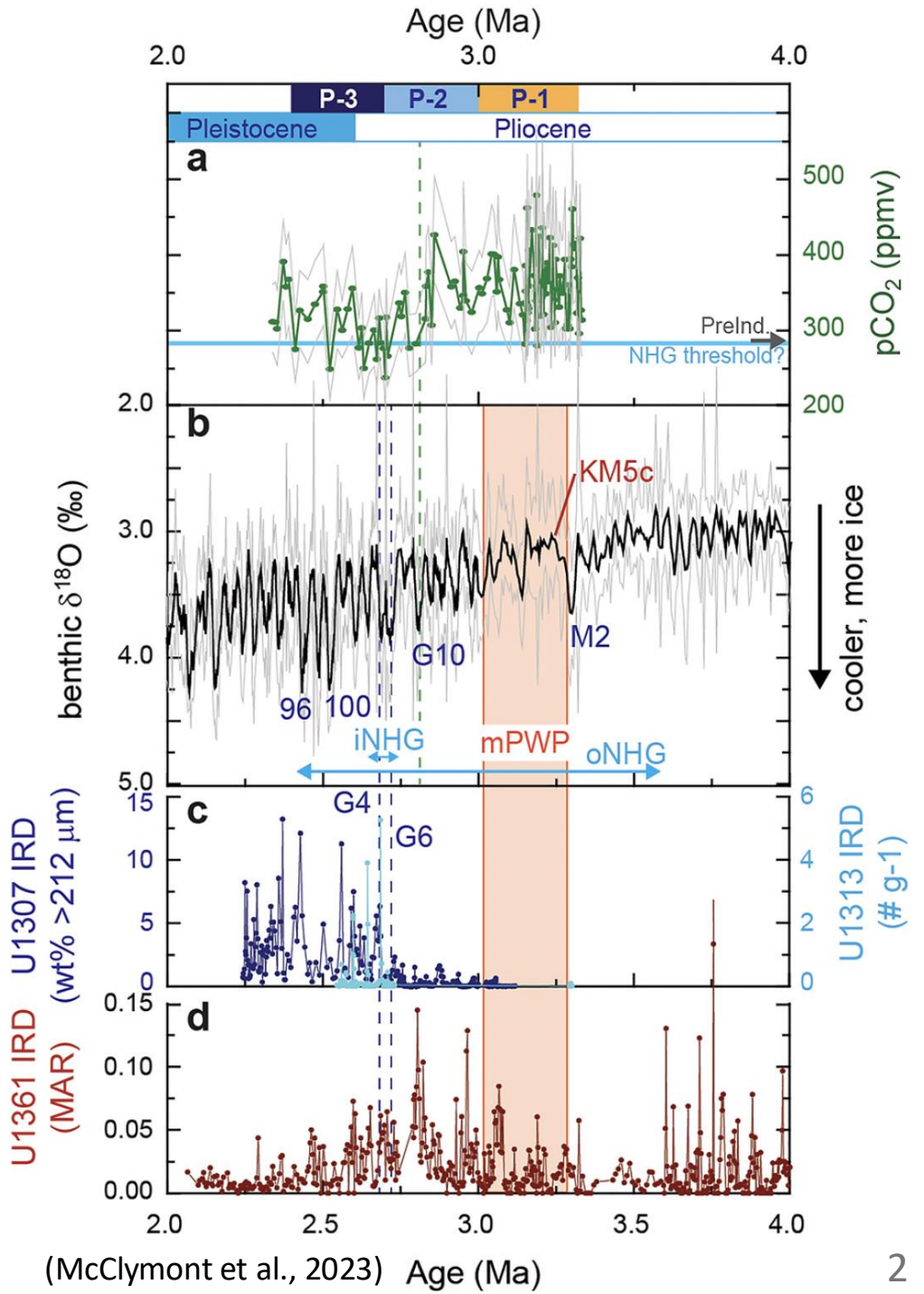
Introduction

Late Pliocene cooling

mid-Piacenzian warm period (mPWP)

- characterized by the **intensification of Northern Hemisphere Glaciation** (iNHG)
- growth of ice sheets and sea ice
- lowered atmospheric CO_2
- increased ice-rafted debris (IRD) fluxes

- **high atmospheric CO_2 levels** (reaching 400 ppm)
- higher sea level and temperature
- similar to pre-industrial climate



(McClymont et al., 2023)

Aims of this Study

1. variations in the **vertical structure of the upper Southern Ocean (SO)** during the **Northern Hemisphere Glaciation (NHG)** using multiple planktonic foraminiferal species

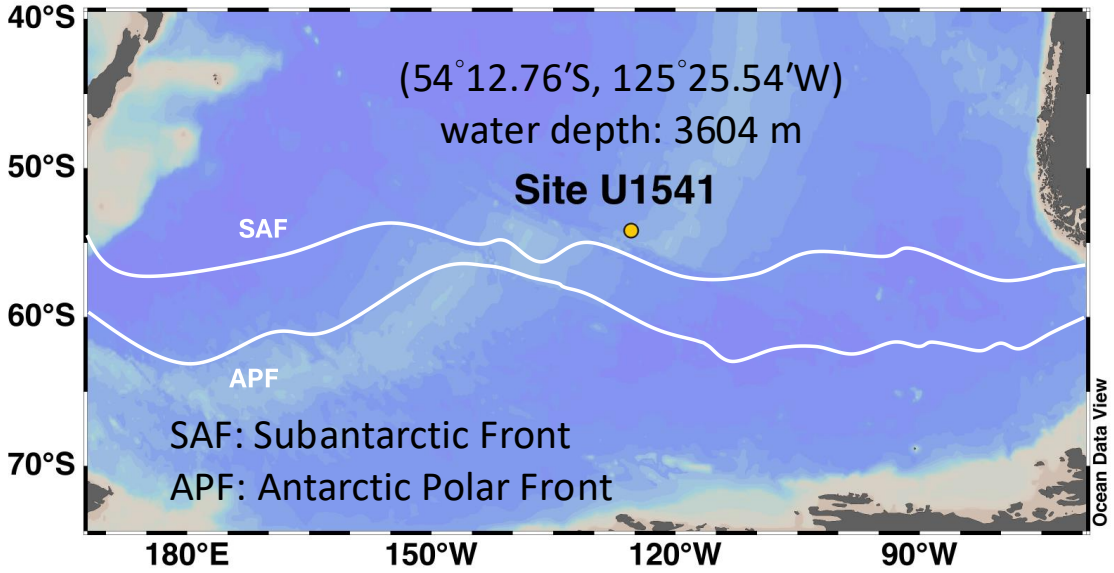
2. evolution of the **SO frontal system** and the associated changes in the **paleoenvironment** within the Pacific sector during the climate transition of the NHG

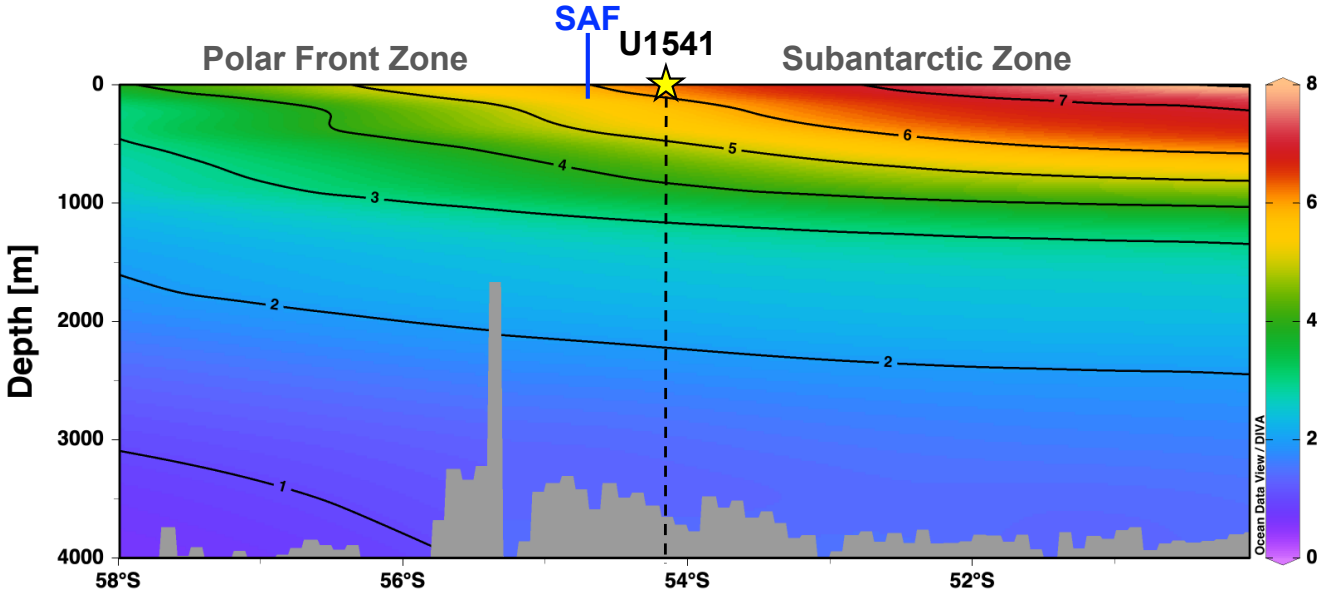
3. fluctuations in the **SO carbon sequestration capacity** during the climate transition

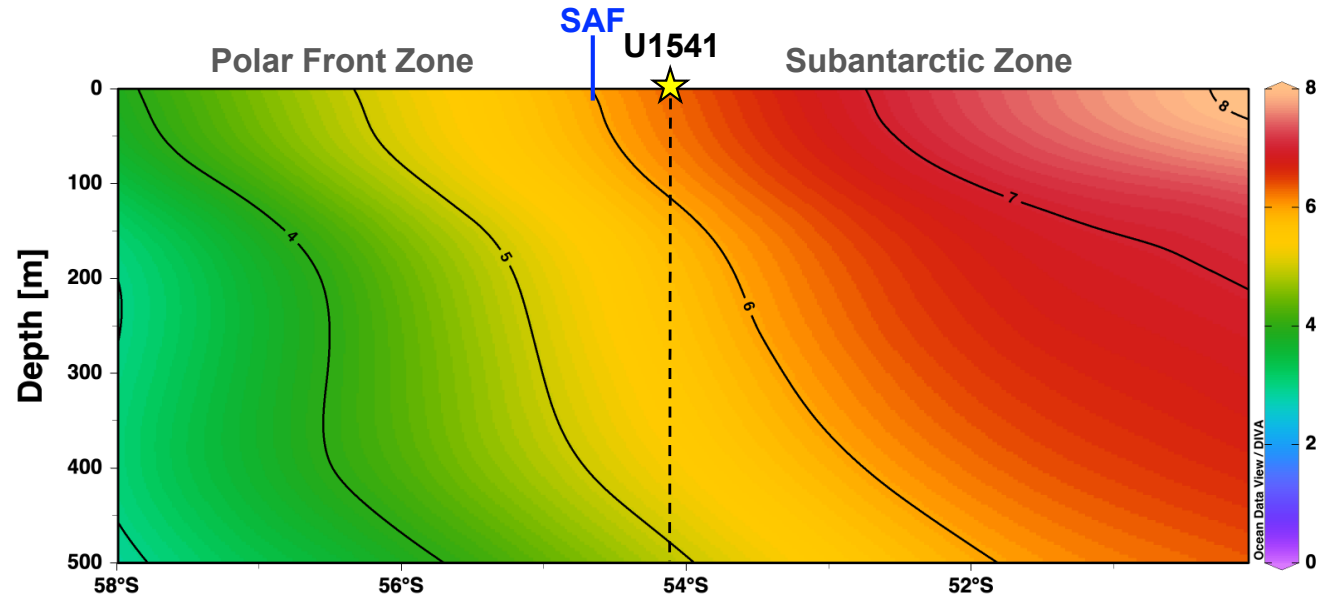
Materials and Methods

The research materials are the marine sediment from the study site U1541 of IODP Expedition 383.

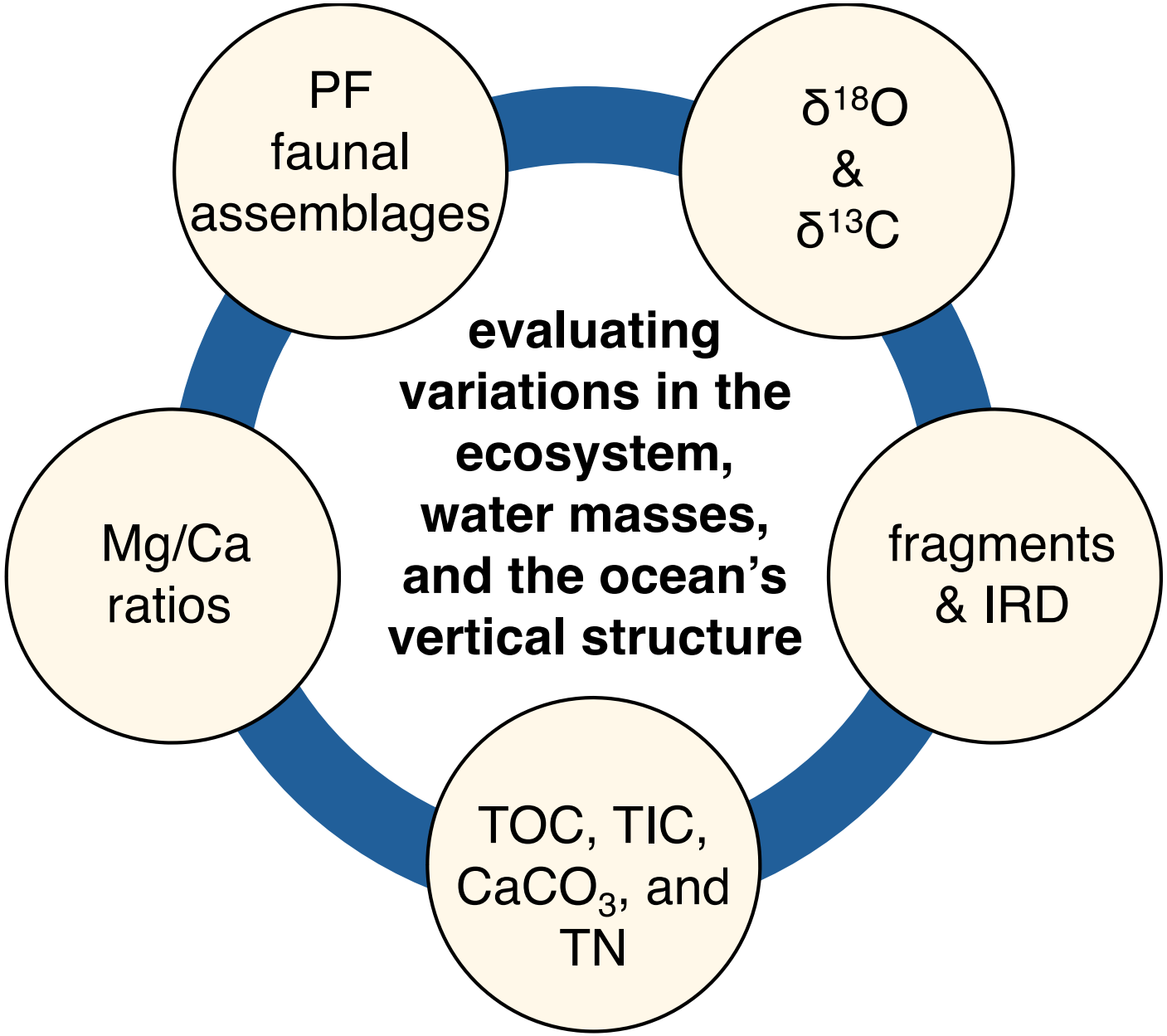
The planktonic foraminiferal research in this study mainly focuses on the upper 500 meters.



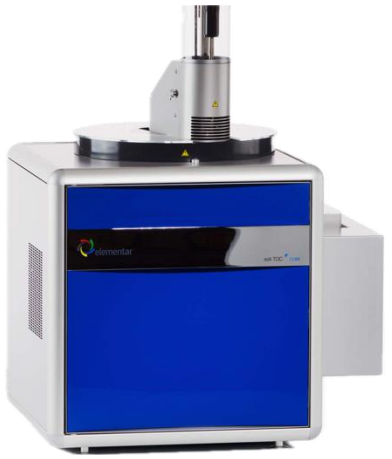




Materials and Methods



High-Resolution ICP-MS (Element 2)



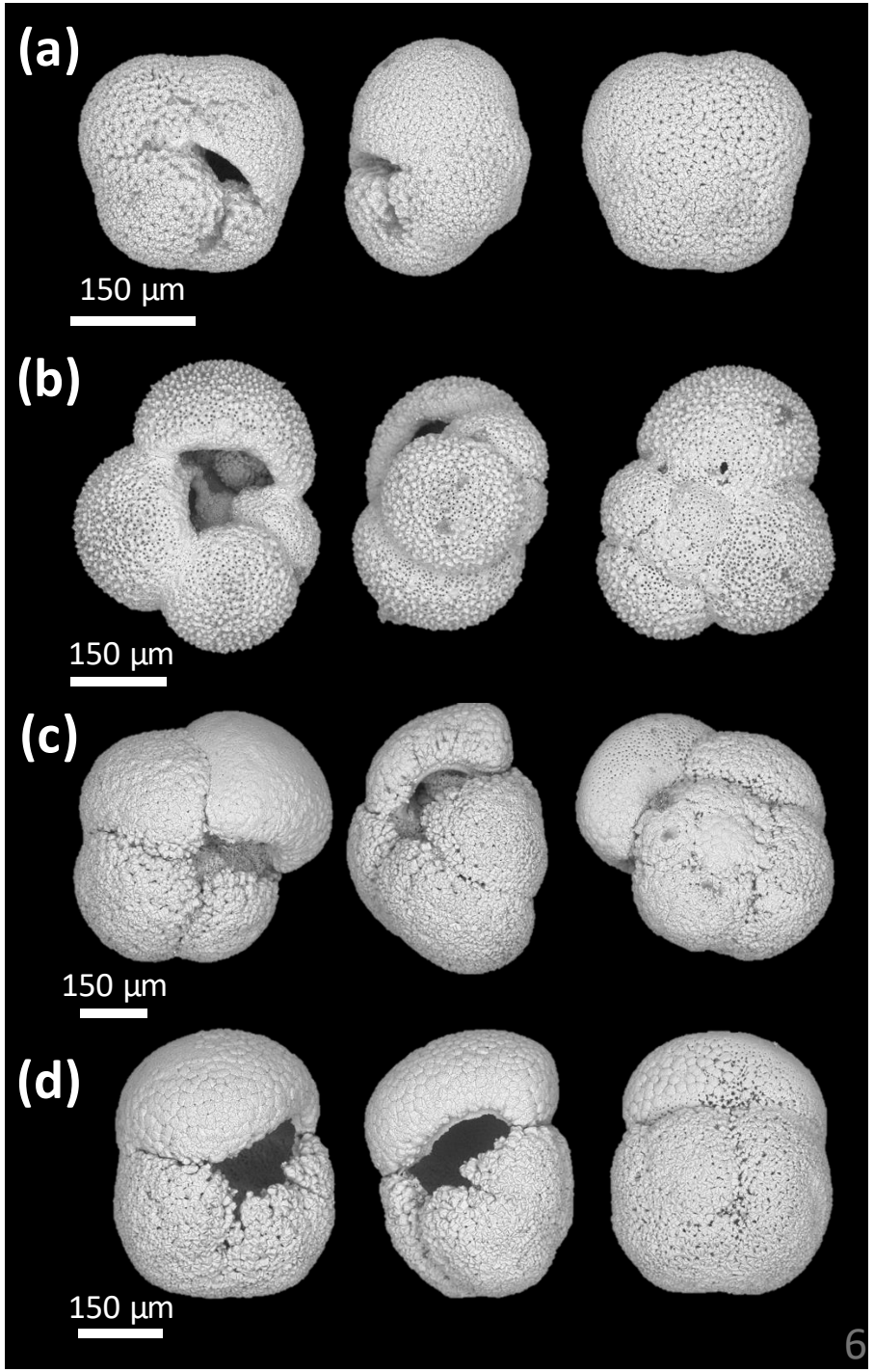
TOC analyzer (soli TOC® cube)

Isoprime stable isotope ratio mass spectrometer (IRMS)

Main Planktonic Foraminifera Species

Each main planktonic foraminiferal species represents a different environment and can be separated into groups according to different habitat depths.

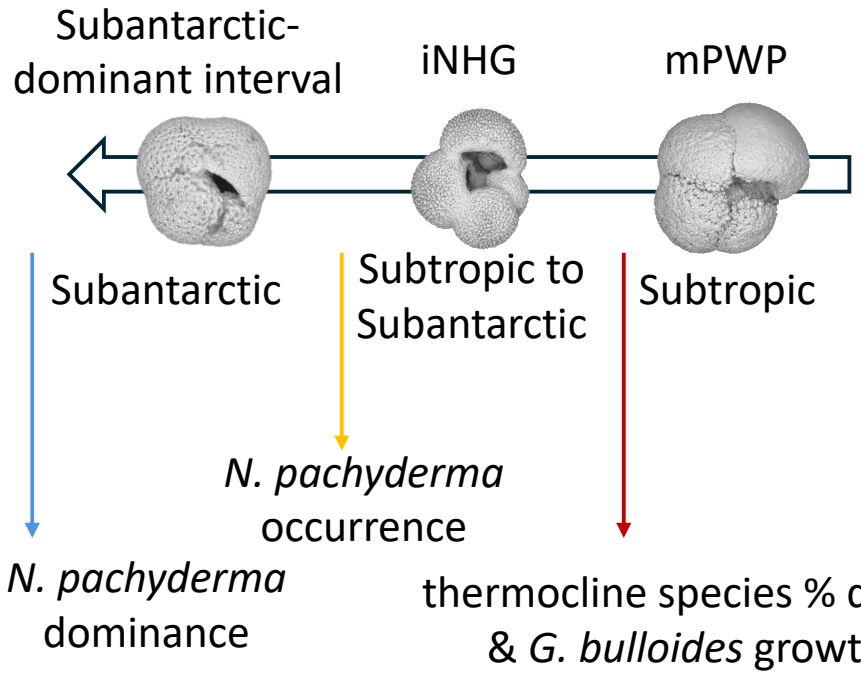
	Species Name	Representative	Habitat Depth	
(a)	*Neogloboquadrina pachyderma*	cold water	Upper 100-200 m	Surface
(b)	*Globigerina bulloides*	nutrient-rich/ upwelling	Upper 100-200 m	
(c)	*Globoconella puncticulata*	thermocline	400-450 m	Sub-surface
(d)	*Globoconella inflata*	thermocline	400-450 m	

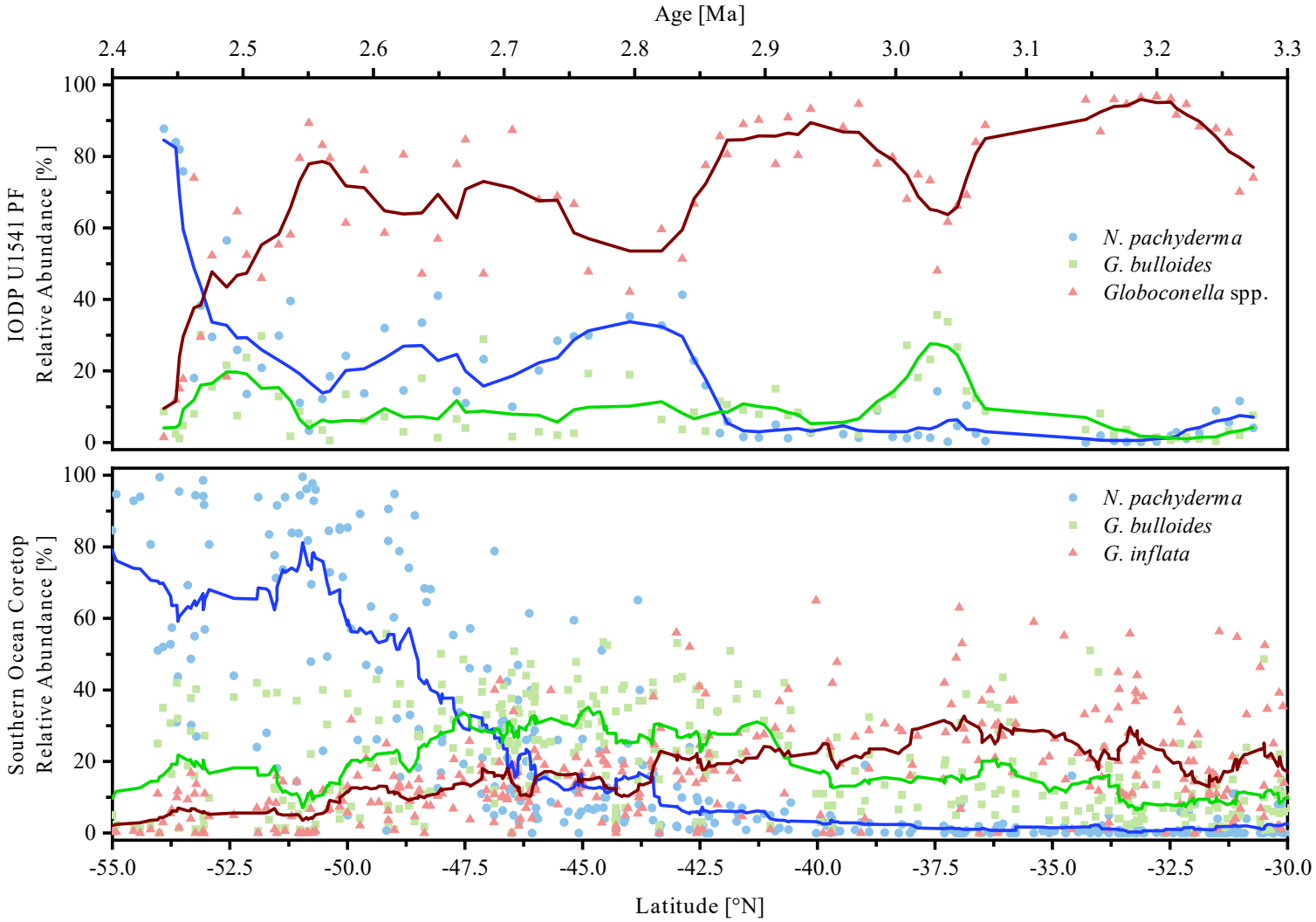


Results and Discussions

PF Faunal Assemblages

The temporal changes of planktonic faunal assemblage at Site U1541 match the latitudinal changes in the modern Southern Ocean faunal group, providing evidence of the SO northward frontal shifting.





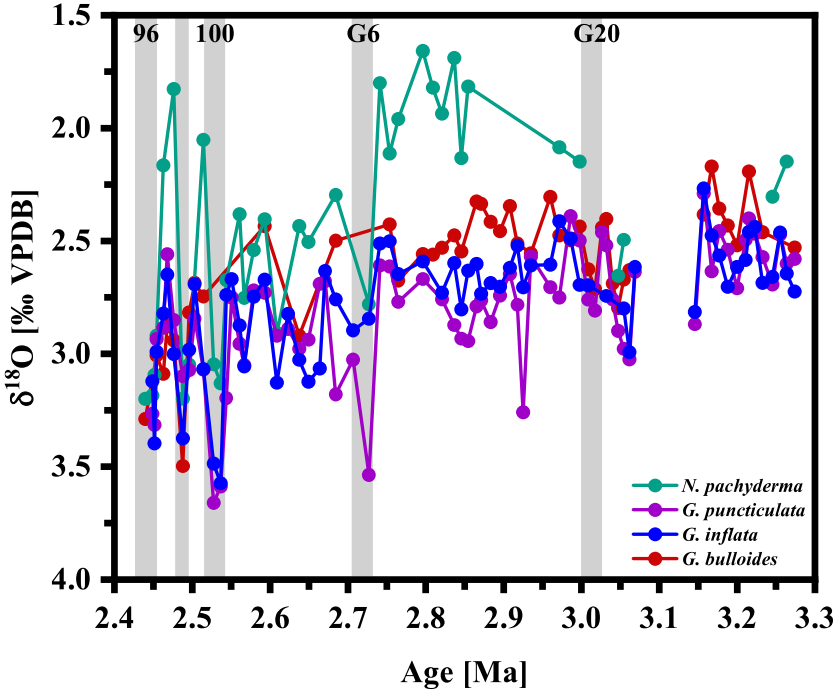
Temporal changes in PF abundances of U1541 (upper panel) and the spatial changes in PF abundance of the Southern Ocean across latitudes (lower panel) from Haddam et al. (2016).

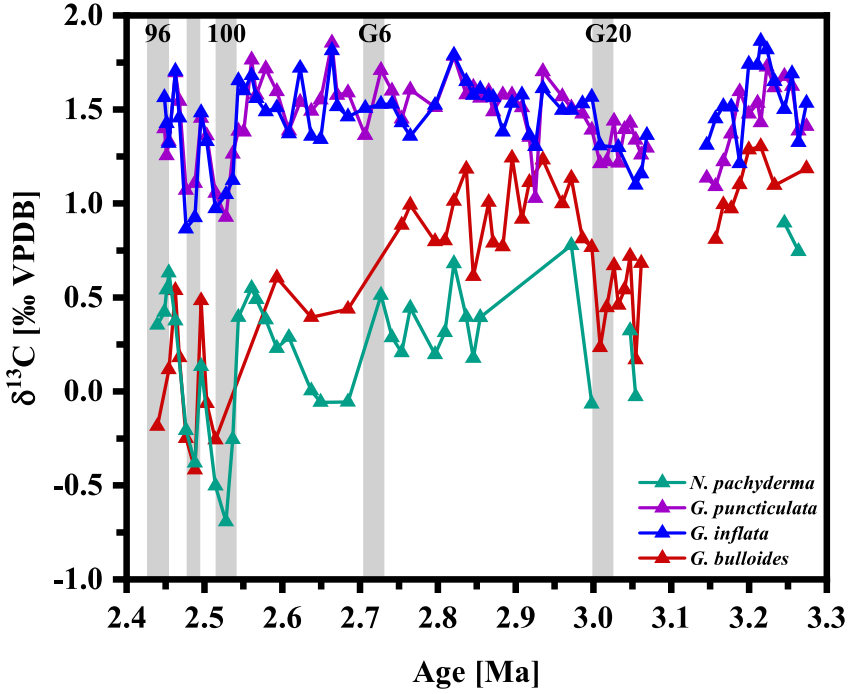
Results and Discussions

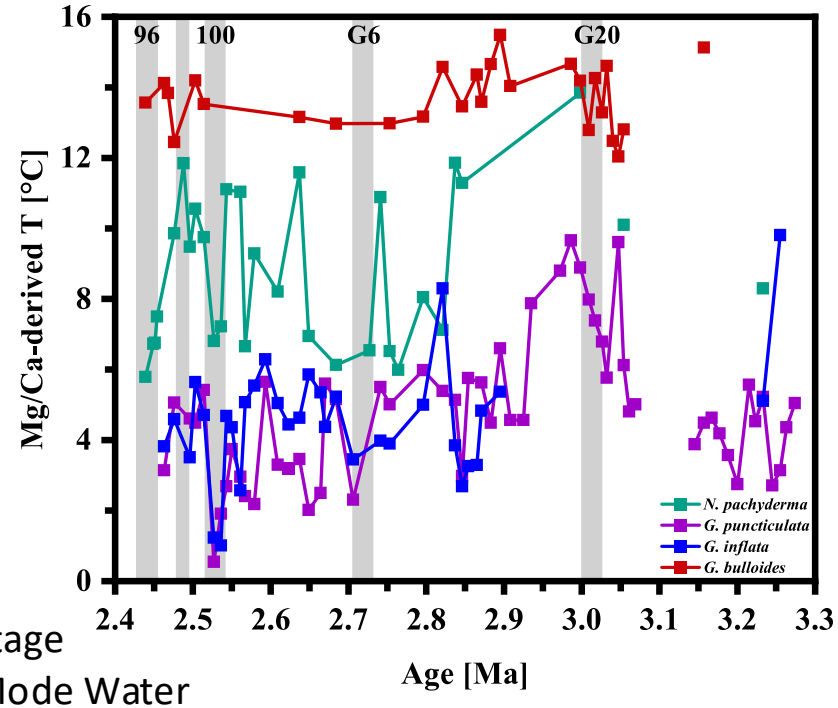
Geochemical records

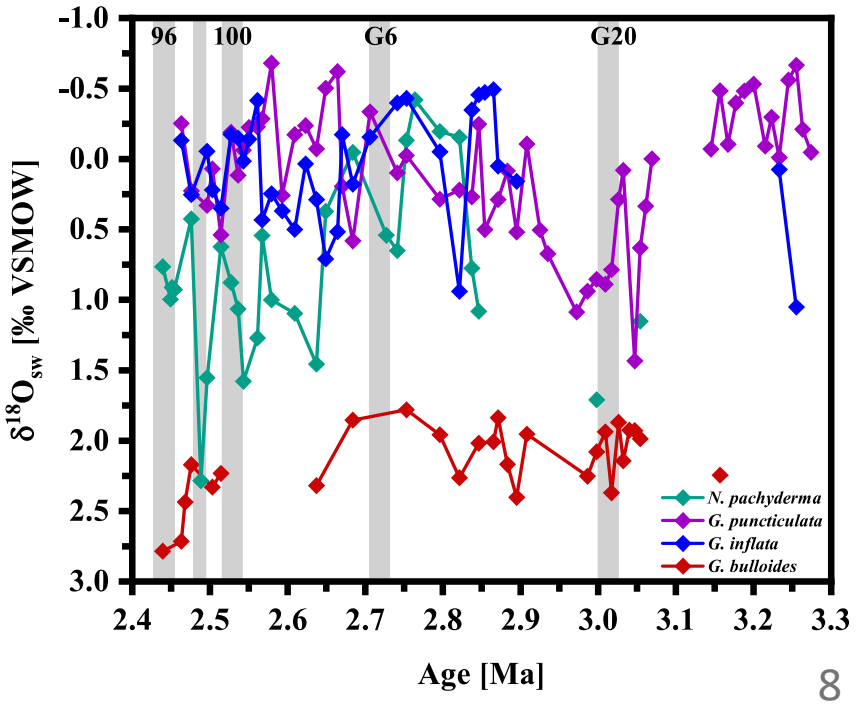
Geochemical records reveal strong **glacial-interglacial dominance after 2.7 Ma**, especially during MIS 100-98.

Temperature-dependent proxies exhibit long-term cooling trends during our research interval.
Mg/Ca records of the thermocline species reveal the **enhanced formation of the cold SAMW**.









MIS: Marine Isotope Stage
SAMW: Subantarctic Mode Water

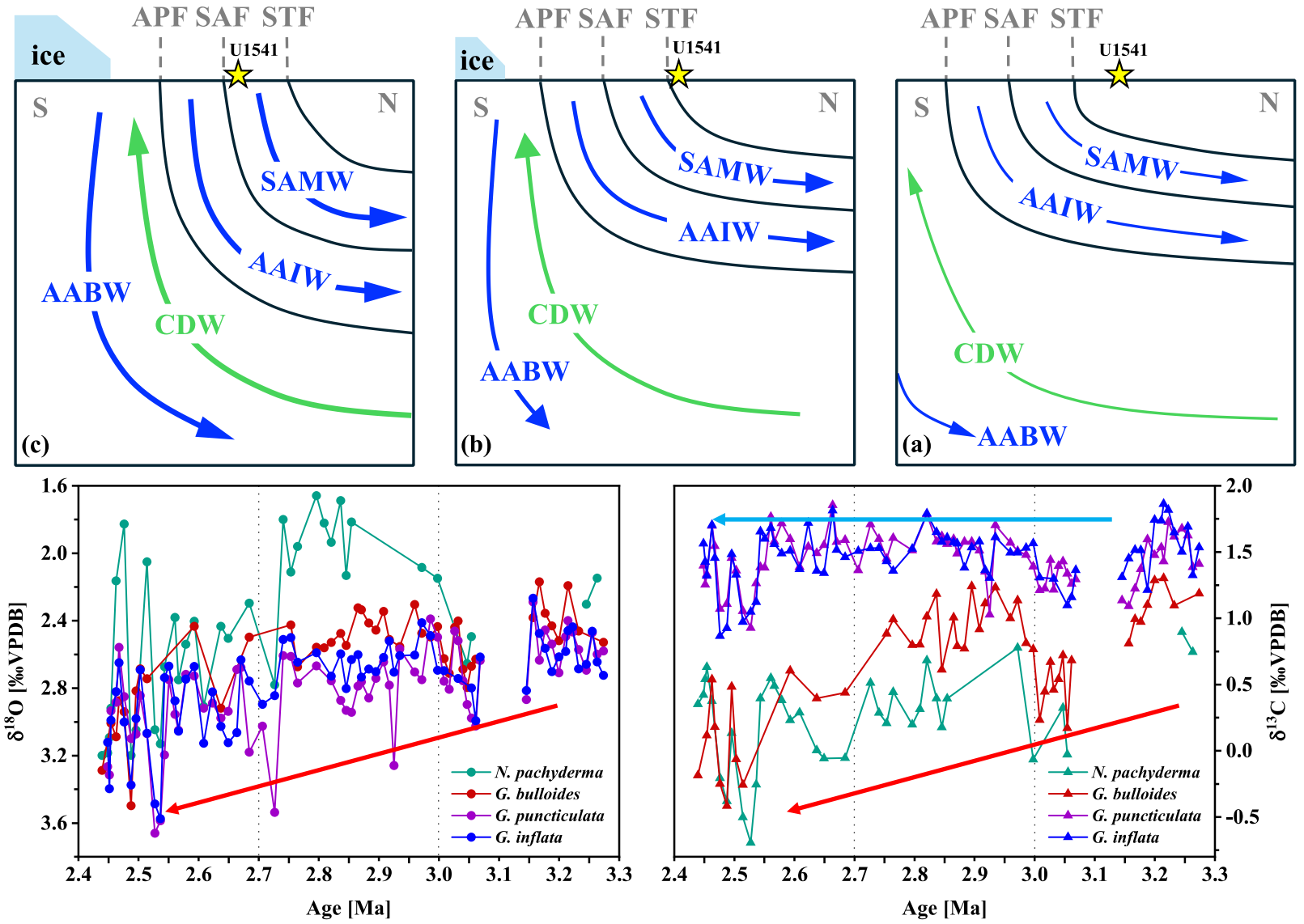
Results and Discussions

Stable isotopes

The increasing trend of the planktonic $\delta^{18}O$ indicates the effect of the sea ice extension and the enhanced formation of the cold sinking SAMW.

The enhanced upwelling CDW carries the respired ^{12}C from the deep ocean and increases the deviations between $\delta^{13}C$ of the surface and sub-surface species by lowering the surface ocean $\delta^{13}C_{DIC}$.

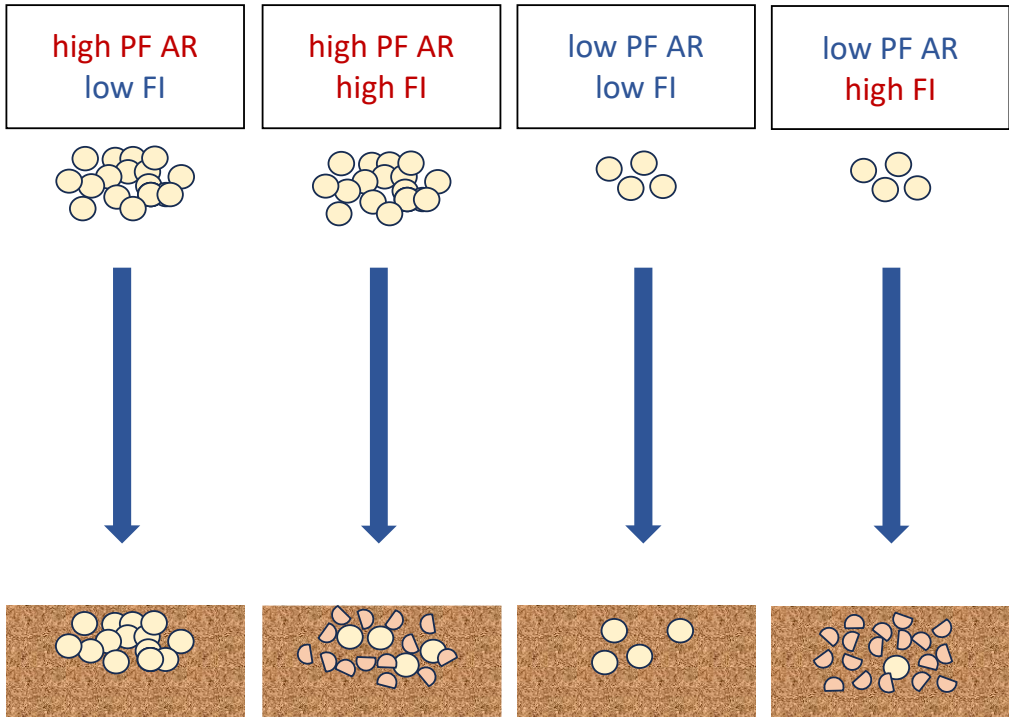
Subantarctic-dominant iNHG mPWP



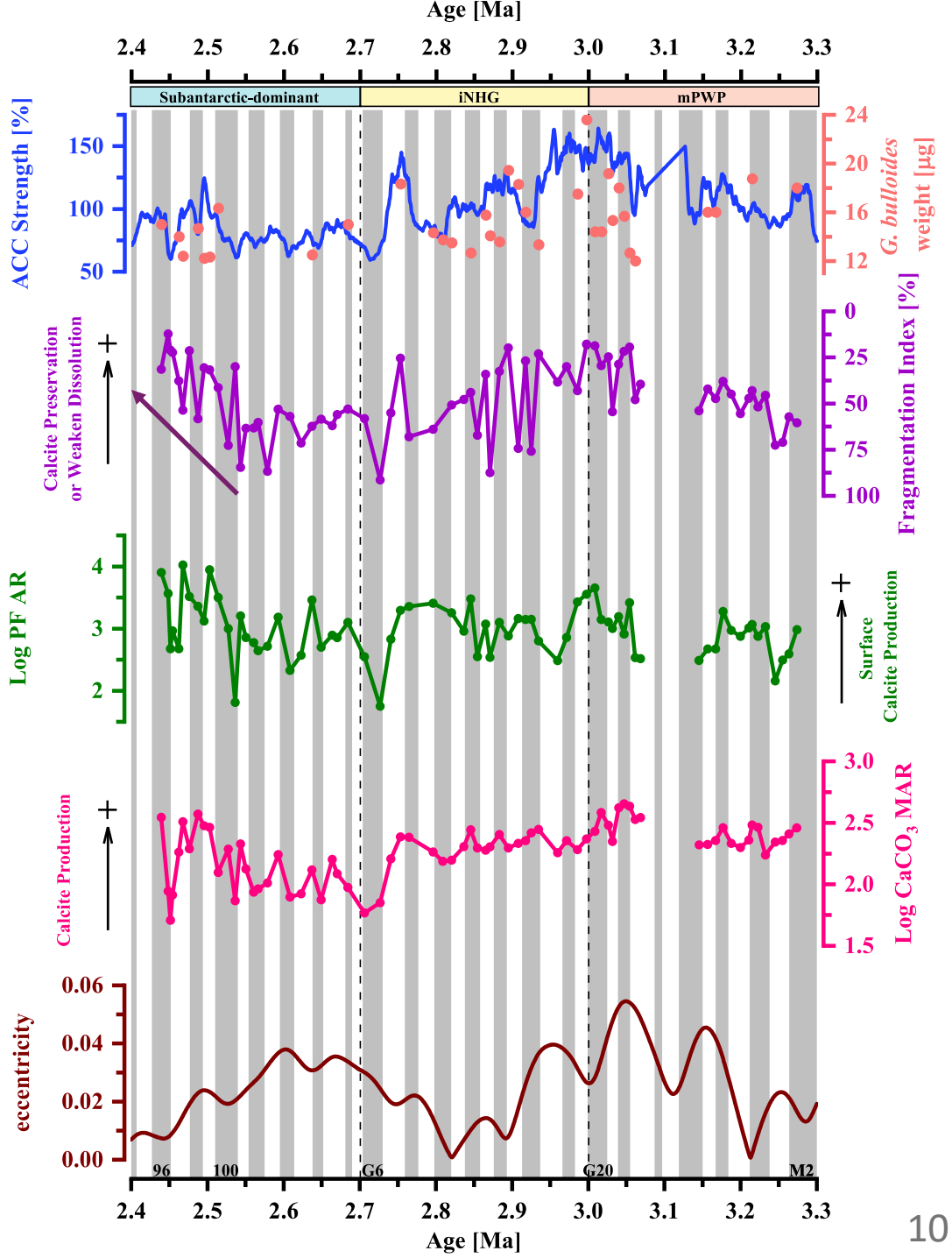
SAMW: Subantarctic Mode Water
AAIW: Antarctic Intermediate Water
AABW: Antarctic Bottom Water
CDW: Circumpolar Deep Water
STF: Subtropical Front
SAF: Subantarctic Front
APF: Antarctic Polar Front

Results and Discussions

Subantarctic Calcite Preservation



Changes in the Southern Ocean	Changes in the Fragmentation Index	Calcite Preservation Evalutaion
Warm and saturated upper ocean	↓	↑
Increased cold and unsaturated AABW production	↑	↓
Increased foraminiferal fluxes	↓	↑



Take Home Messages

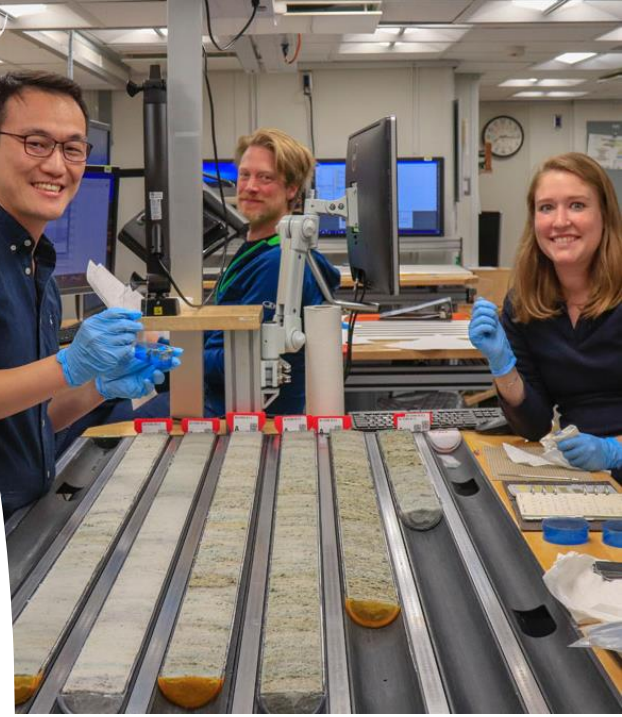
1. Site U1541 experiences **a shift from a warm, stratified subtropical regime to a cold, destratified Subantarctic regime** during the mid-Piacenzian to early Pleistocene transition, driven by the **northward migration** of the Southern Ocean frontal system.

2. The enhanced calcite sink during the Subantarctic-dominant interval likely improves calcite preservation, thereby **increasing the efficiency of deep-ocean CO_2 sequestration**.

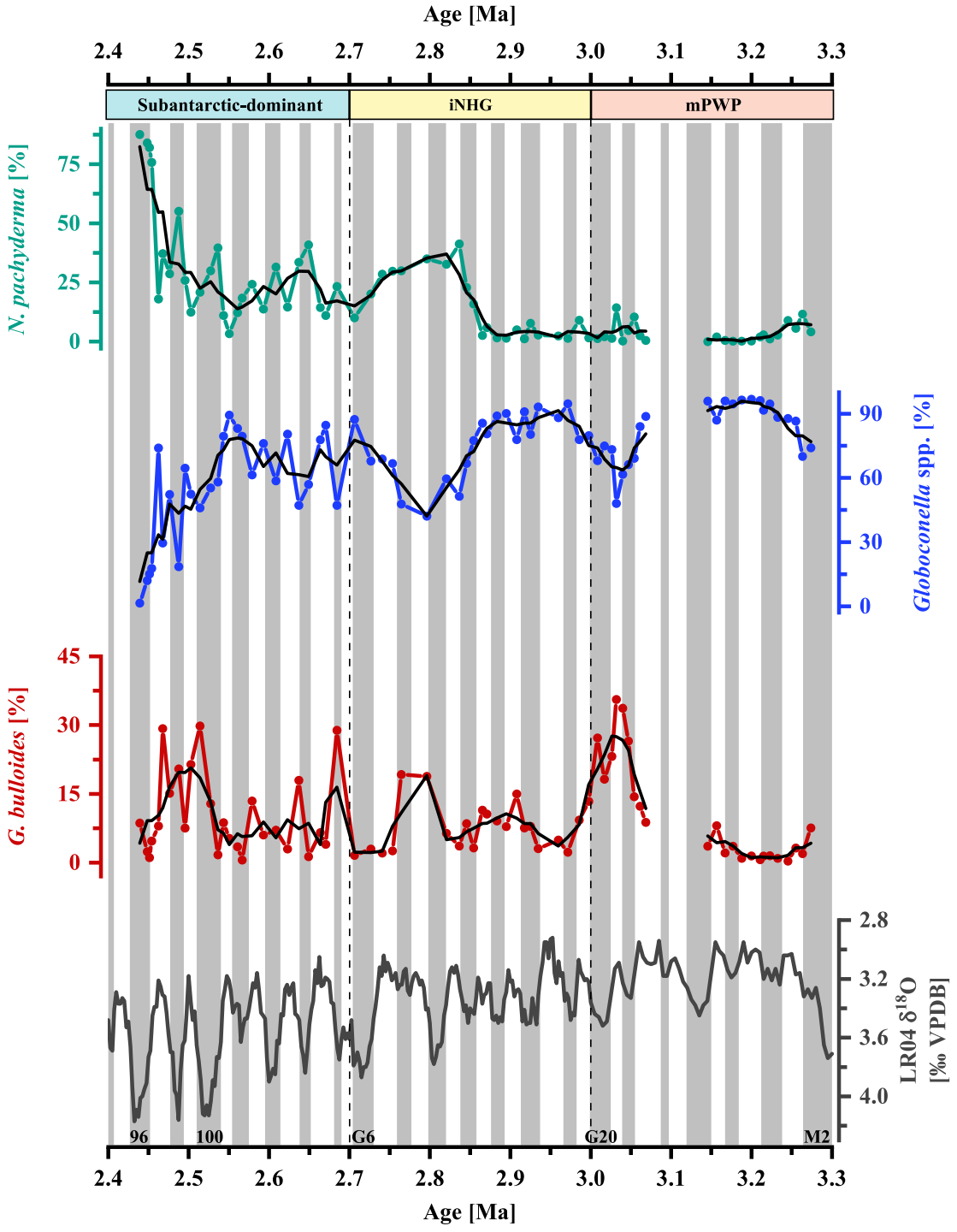
1. Strengthened **production of sinking water masses** further facilitates the transport of CO_2 into the ocean interior, amplifying the Southern Ocean's role in long-term carbon storage.

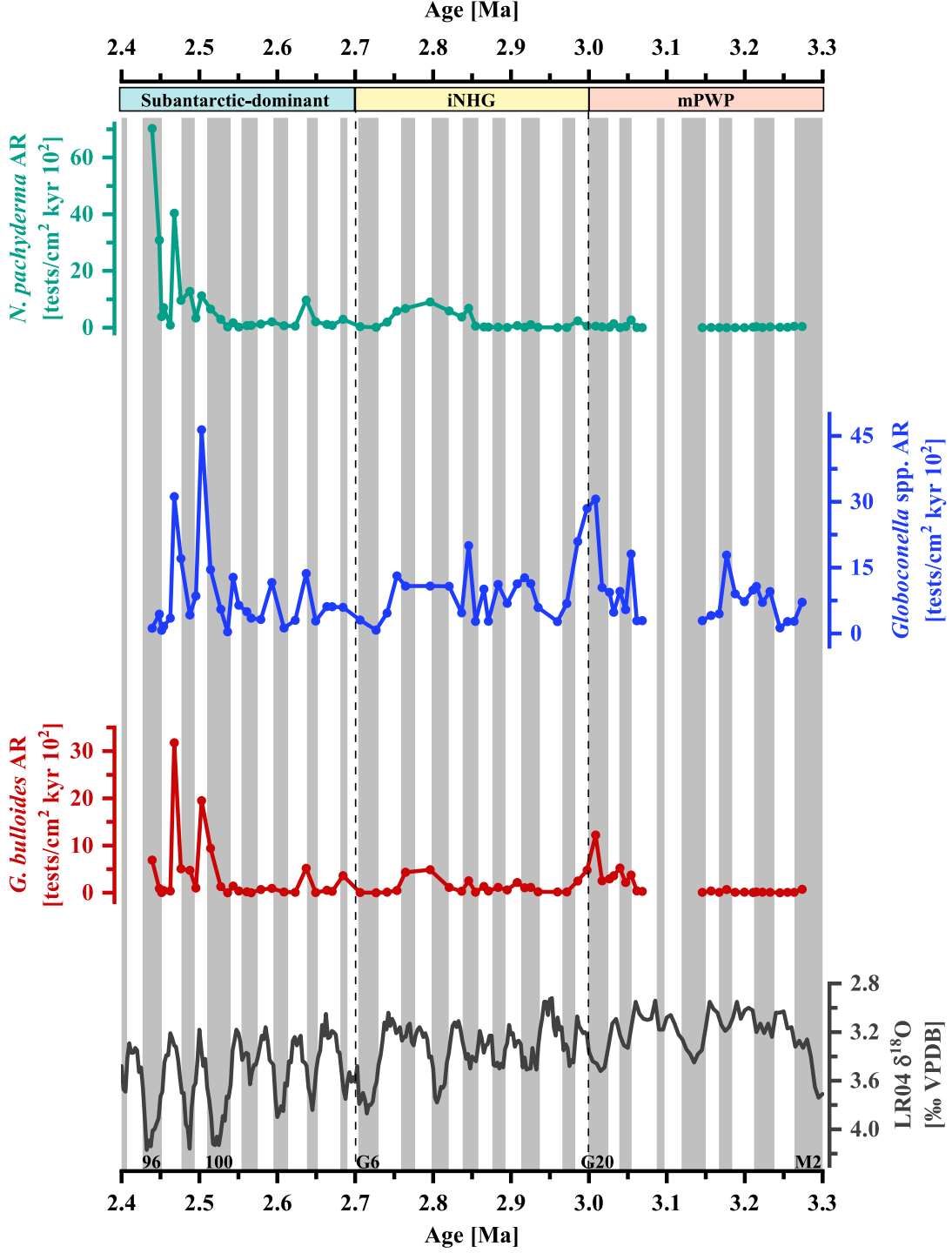
Thank you for your attention.

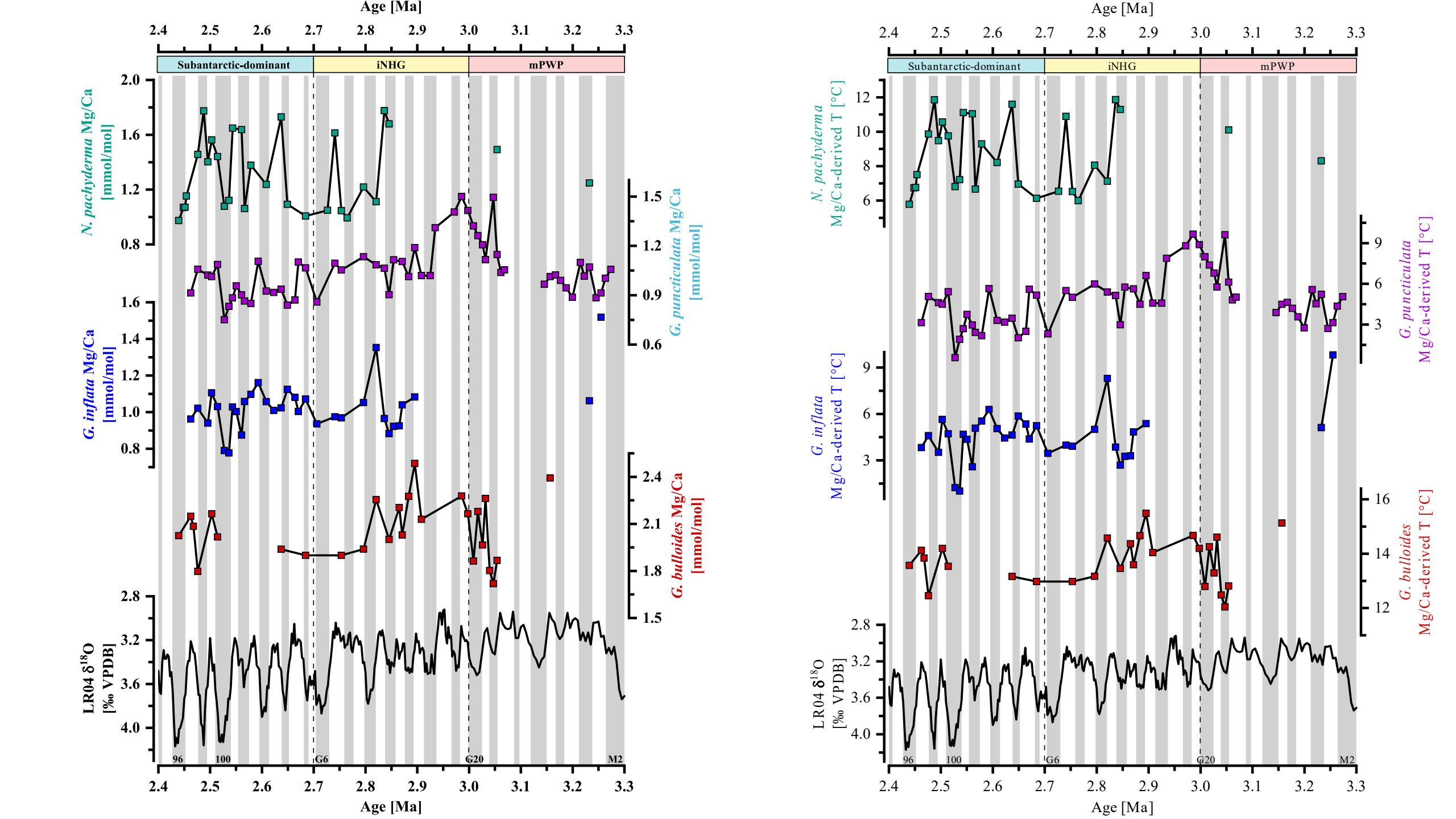
We express our sincere gratitude to the IODP Exp. 383 scientists for their invaluable contributions.



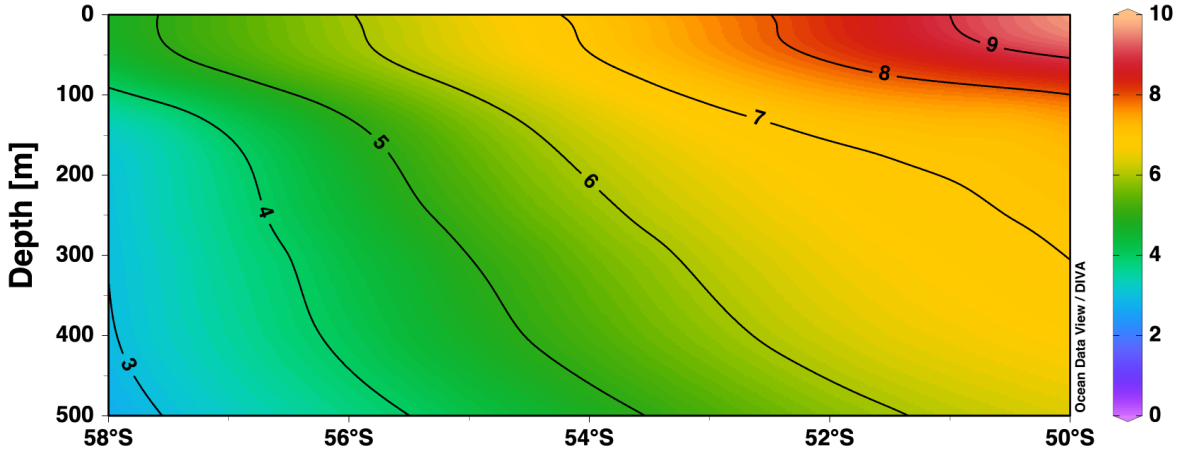
source: IODP


Age [Ma]
2.4 2.5 2.6 2.7 2.8 2.9 3.0 3.1 3.2 3.3
Subantarctic-dominant
iNHG
mPWP
N. pachyderma [%]
75
50
25
0
Globoconella spp. [%]
90
60
30
0
G. bulloides [%]
45
30
15
0
LR04 δ18O [‰ VPDB]
2.8
3.2
3.6
4.0
96
100
G6
G20
M2

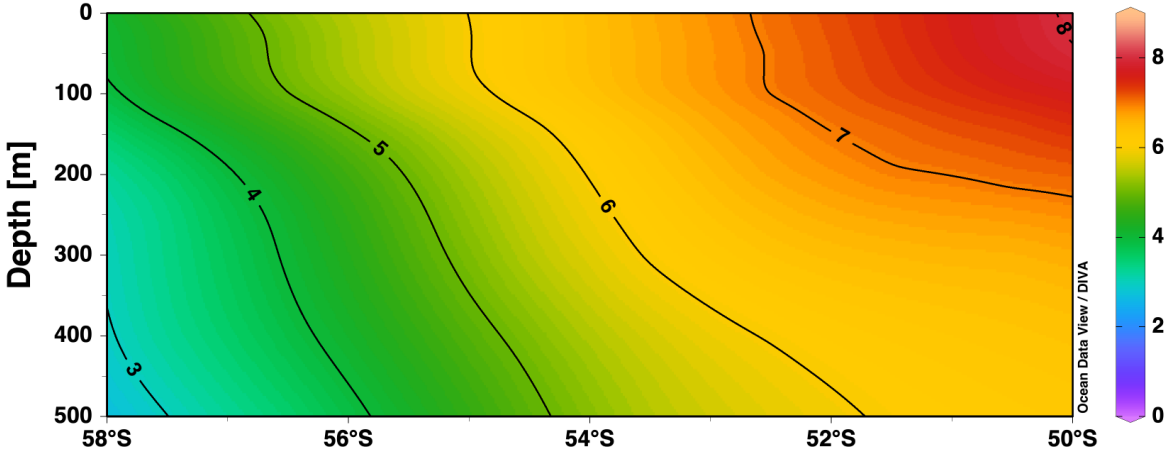

Age [Ma]
2.4 2.5 2.6 2.7 2.8 2.9 3.0 3.1 3.2 3.3
Subantarctic-dominant
iNHG
mPWP
N. pachyderma AR [tests/cm2 kyr 102]
60
40
20
0
Globoconella spp. AR [tests/cm2 kyr 102]
45
30
15
0
G. bulloides AR [tests/cm2 kyr 102]
30
20
10
0
LR04 δ18O [‰ VPDB]
2.8
3.2
3.6
4.0
96
100
G6
G20
M2


Age [Ma]
Subantarctic-dominant
iNHG
mPWP
N. pachyderma Mg/Ca [mmol/mol]
G. inflata Mg/Ca [mmol/mol]
G. puncticulata Mg/Ca [mmol/mol]
G. bulloides Mg/Ca [mmol/mol]
LR04 δ18O [‰ VPDB]
96
100
G6
G20
M2
N. pachyderma Mg/Ca-derived T [°C]
G. inflata Mg/Ca-derived T [°C]
G. puncticulata Mg/Ca-derived T [°C]
G. bulloides Mg/Ca-derived T [°C]

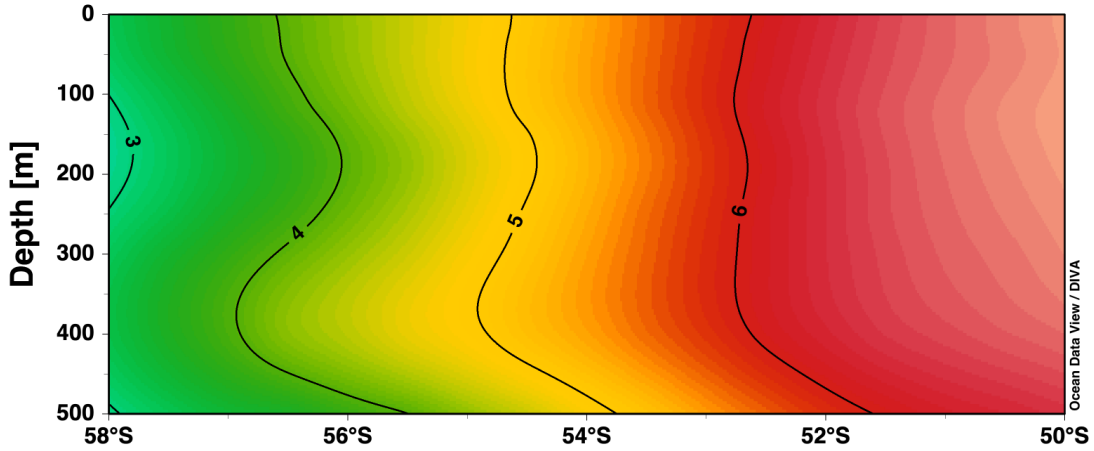
(a) January-March



(b) April-June



(c) July-September



(d) October-December