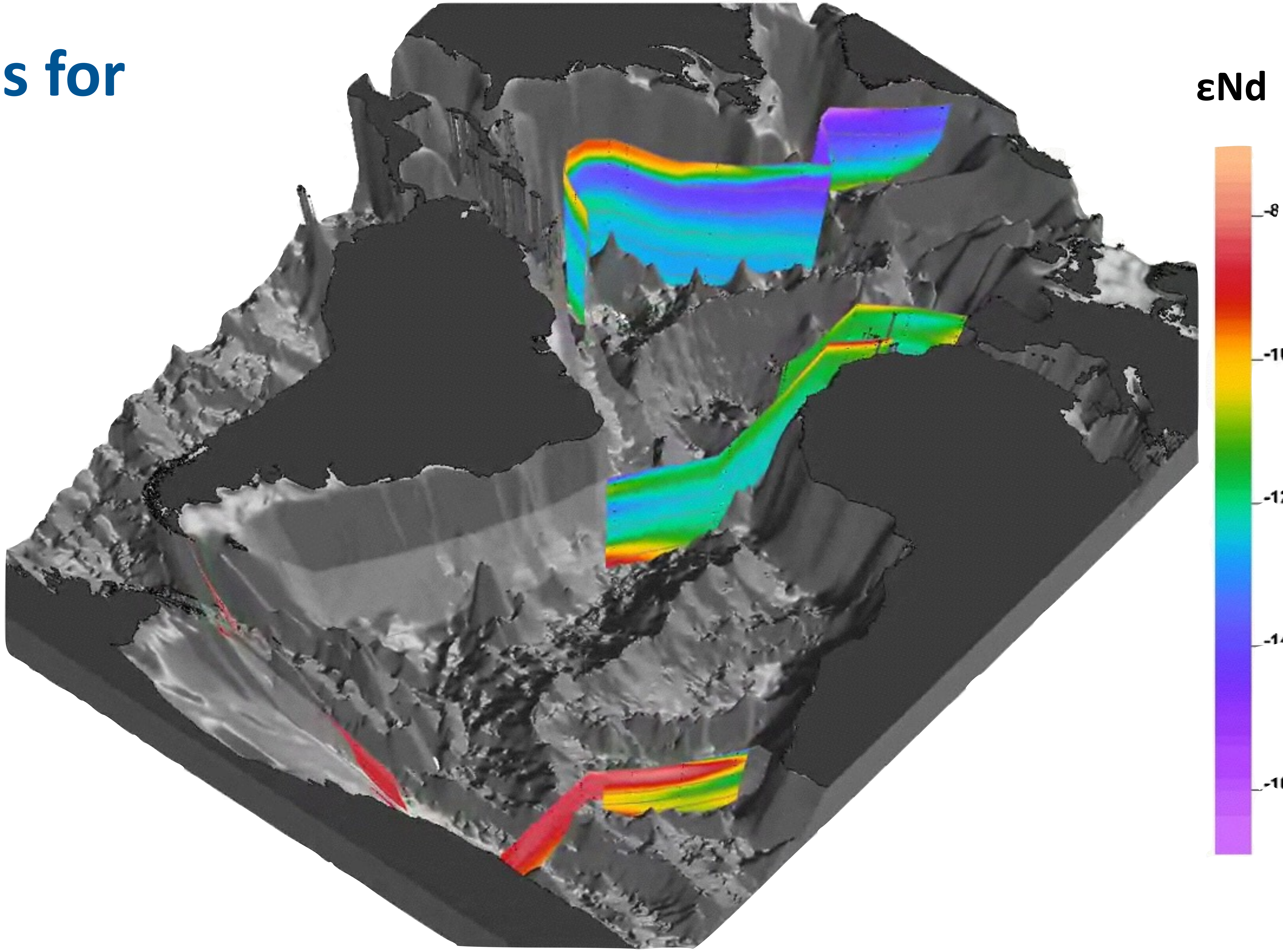
Neodymium Isotopes as Proxies for Past Ocean Circulation

Progress & Challenges



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GEOTRACES

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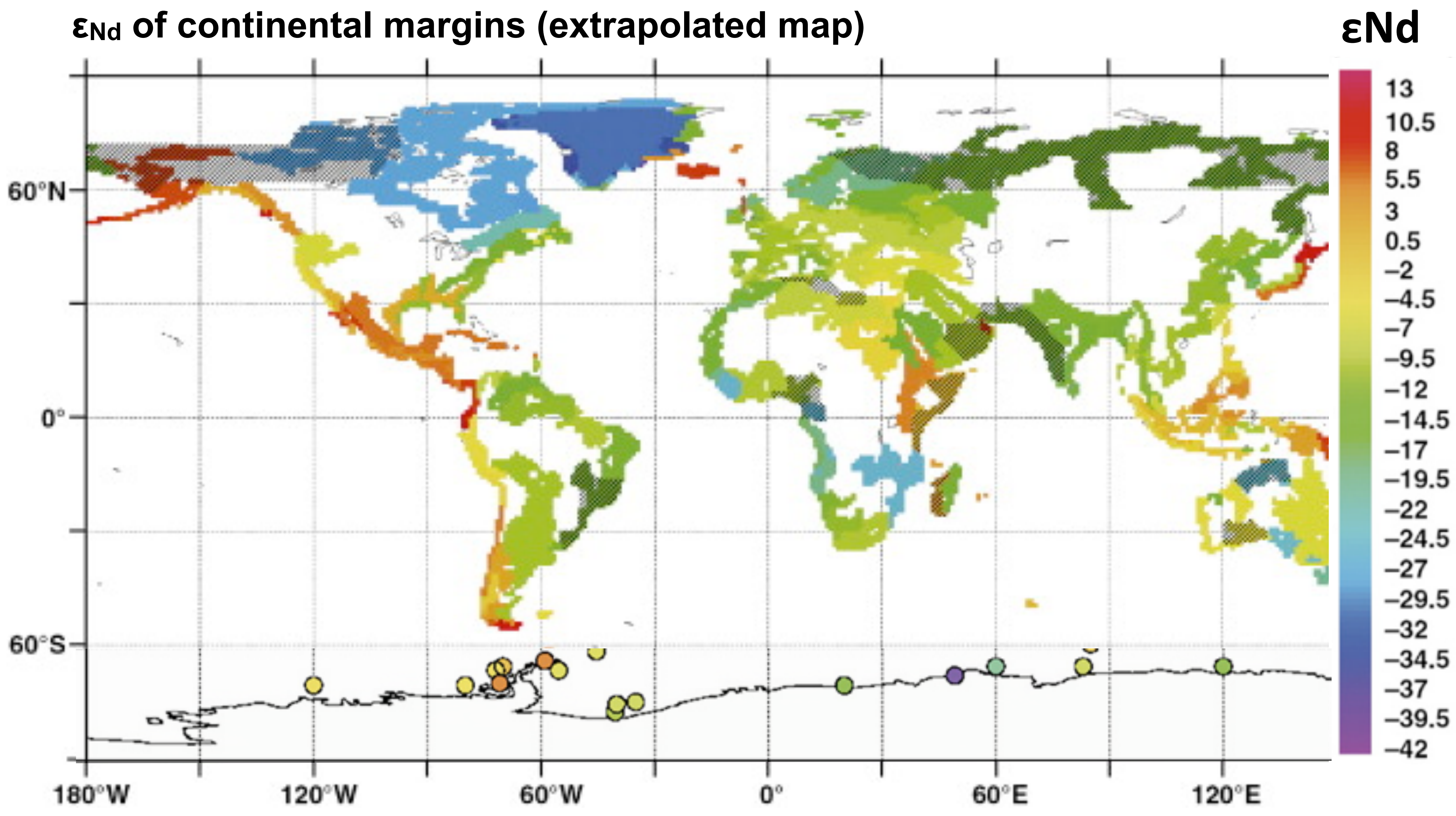
& Max Planck Institute for Marine Microbiology, Bremen

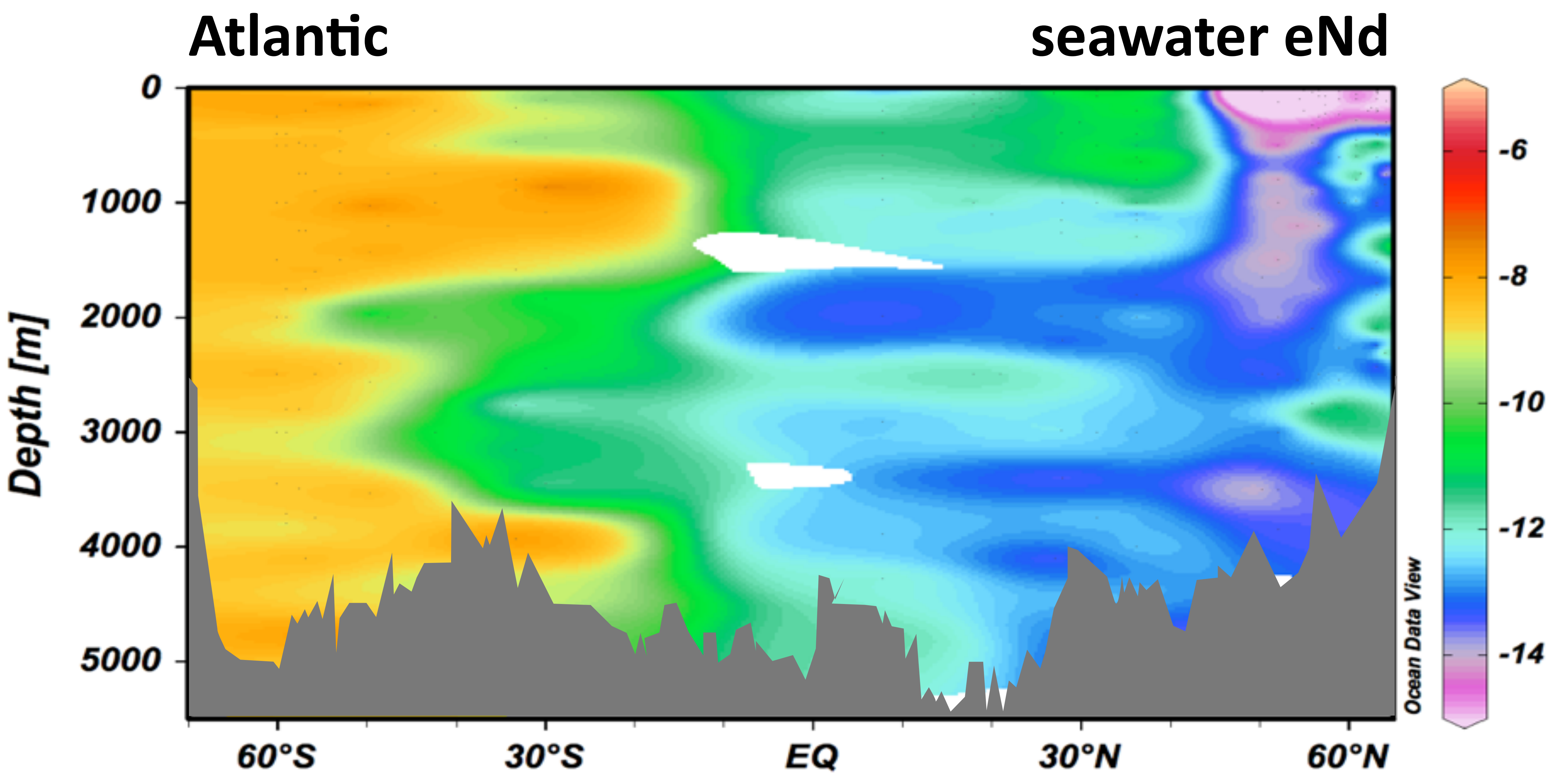
Outline

1. State of the Art
    - Archives & extraction methods
    - Recent scientific advances from Nd isotope records & GEOTRACES studies
2. Challenges & Open Questions
    - Overprints of original provenance signal of water masses
    - Local, regional, and/or global overprints?
3. Perspectives
    - How can future GEOTRACES studies address challenges & open questions?

εNd as tracer for water mass source and circulation pathway:

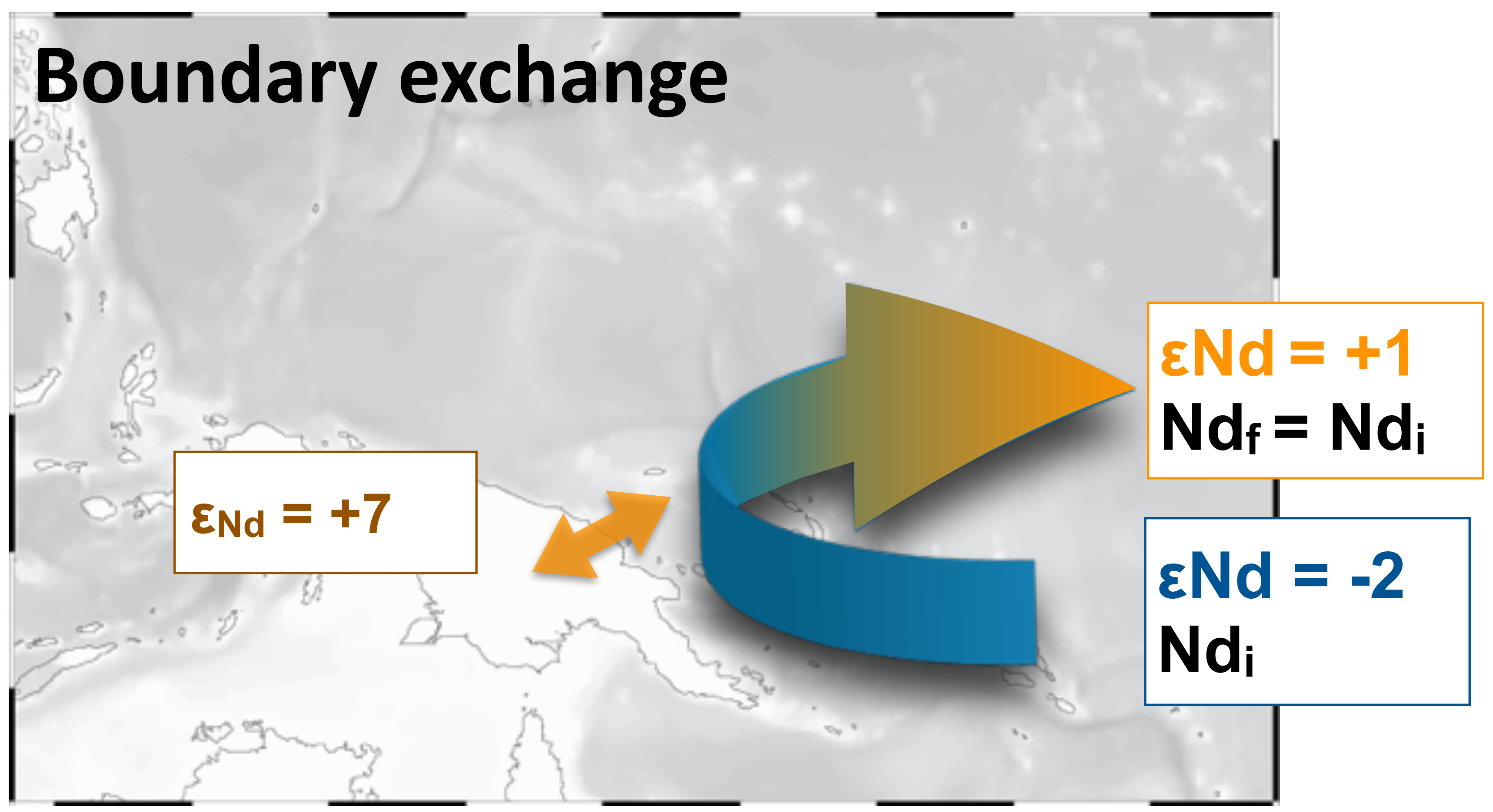
- seawater εNd carries source information of water mass
- spatial distribution suggests residence time ≤ ocean overturning
- no isotope fractionation during incorporation into archives
- reliable archives & extraction methods available



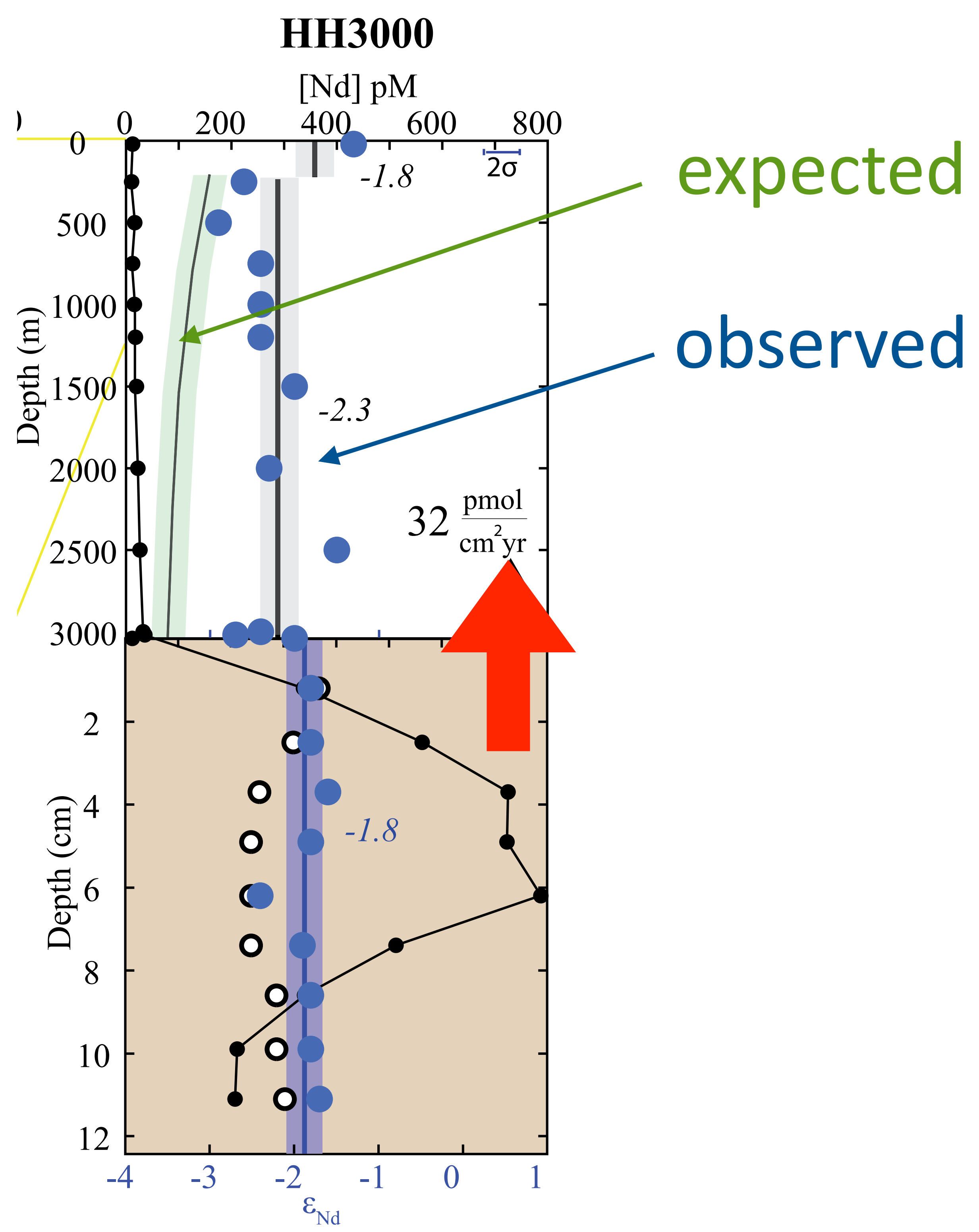


Challenges for εNd as conservative water mass tracer:

- Overprints from local/regional sources
    - **boundary exchange** at continental/island margins & seafloor (εNd)
    - **particle-seawater interactions** in the water column (εNd, [Nd])
    - **benthic flux of REE** (εNd, [Nd])



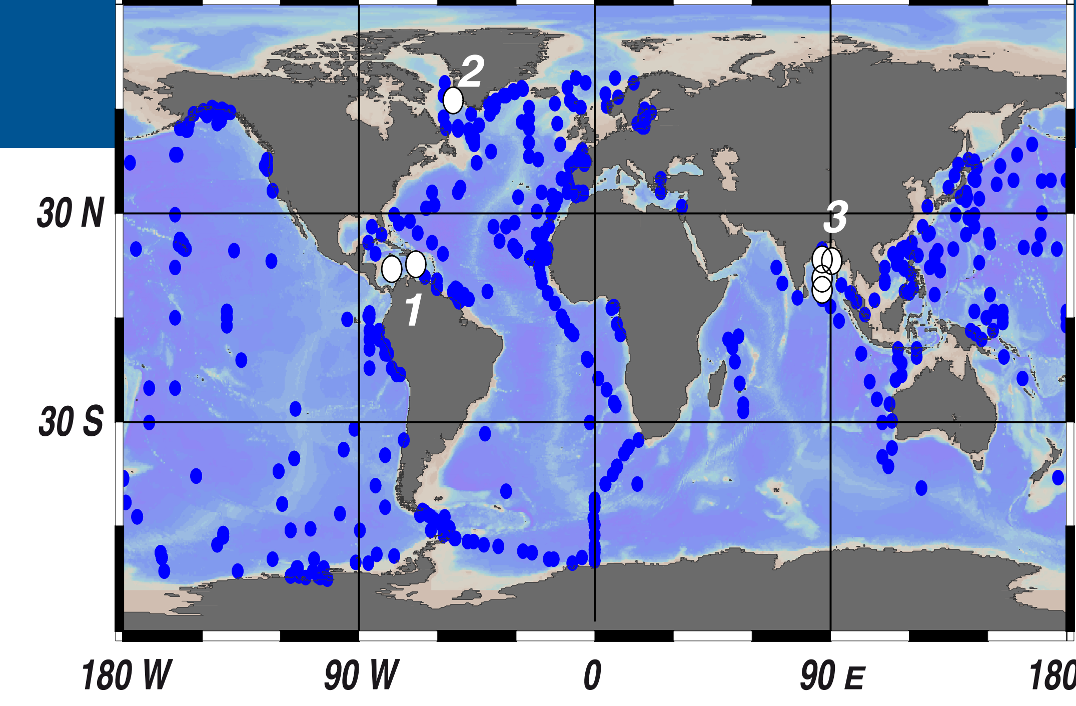
Benthic flux

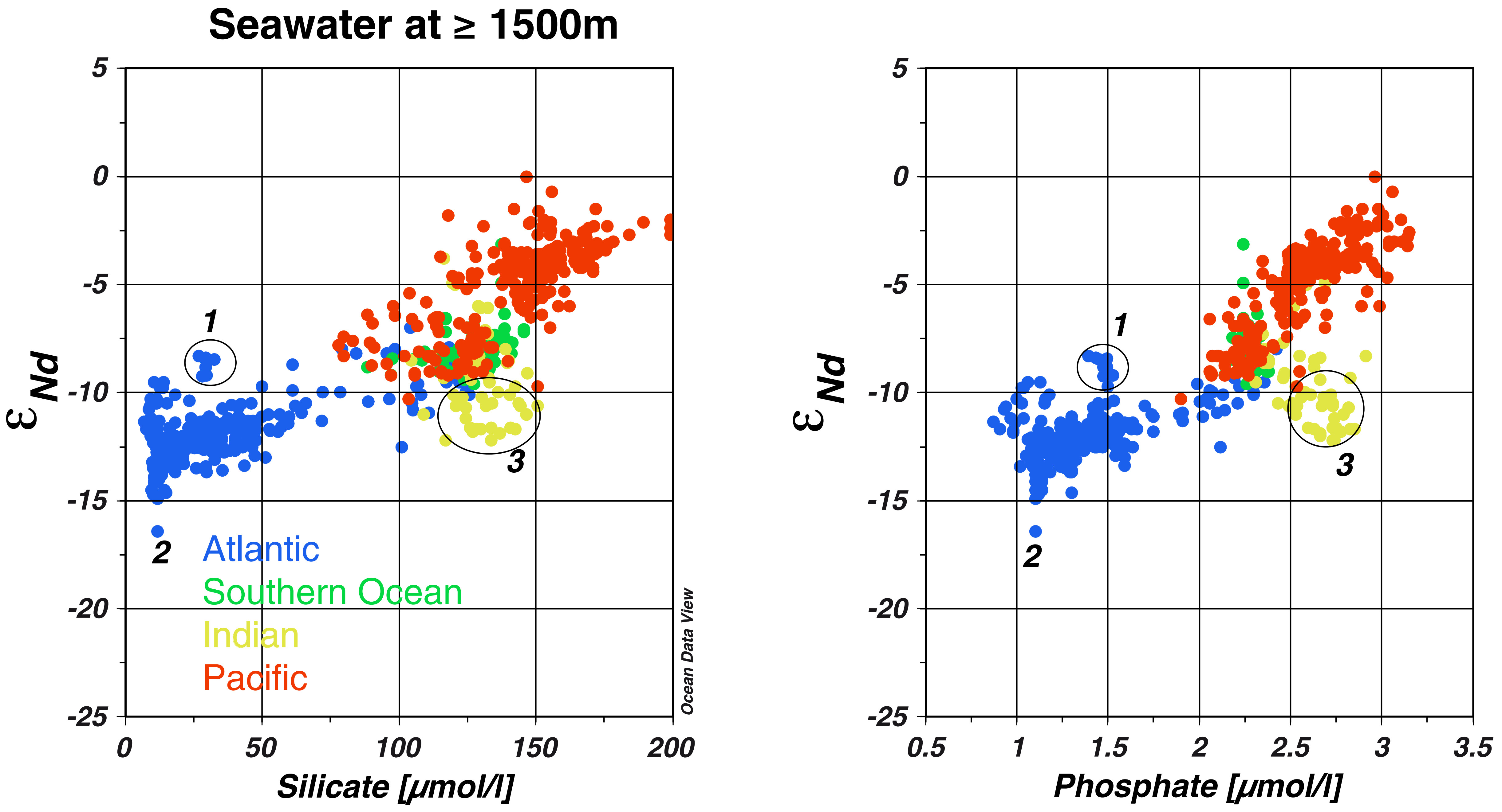


Proven εNd archives of paleo-seawater:

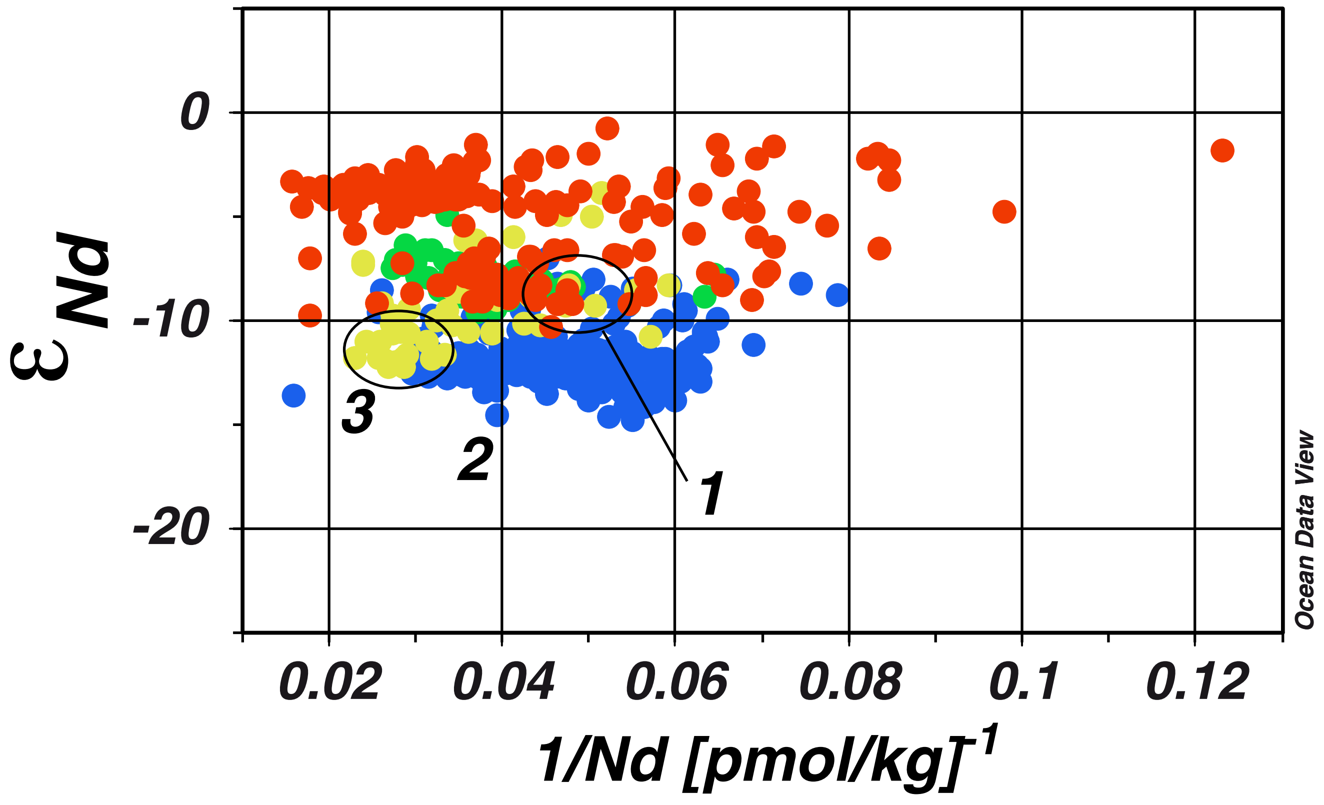
Archive:	**Extraction method:**	**Application comment:**
foraminifera Fe-Mn-oxide coatings  	manual (without cleaning) or weak leach of bulk sed.	high temporal resolution in carbonate-rich sediments
fish teeth / debris 	manual	medium to low temporal resolution, no $CaCO_3$ required, not ubiquitous
deep sea corals 	manual (with chemical cleaning)	absolute U-Th dating, shallow depths, very high temporal resolution, no continuous records, can change habitat

Global observations (from GEOTRACES):



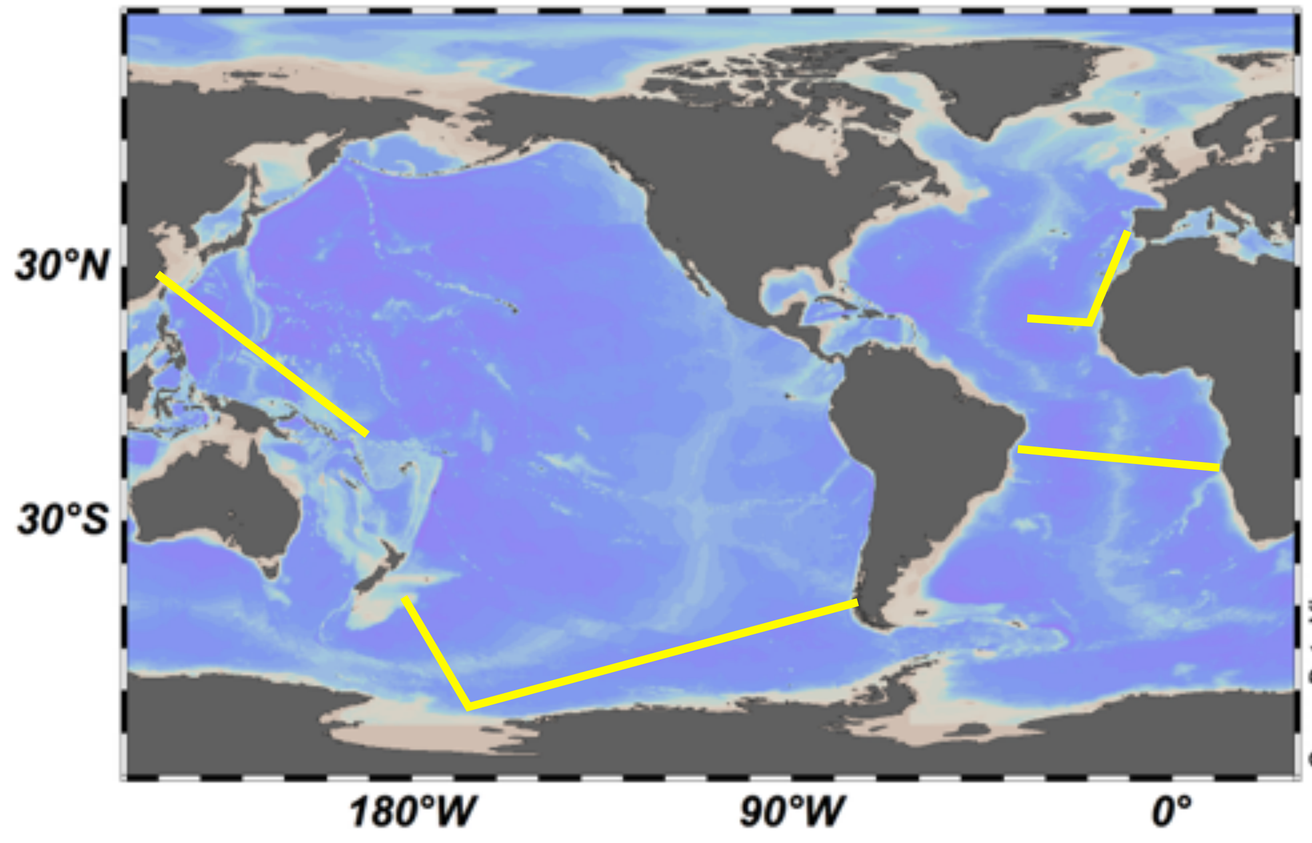


- At ≥1500 m: εNd dominantly affected by water mass mixing
- Continental influence mainly within 1000 km of margin



- no correlation of εNd and 1/[Nd]
  ➔ [Nd] non-conservative

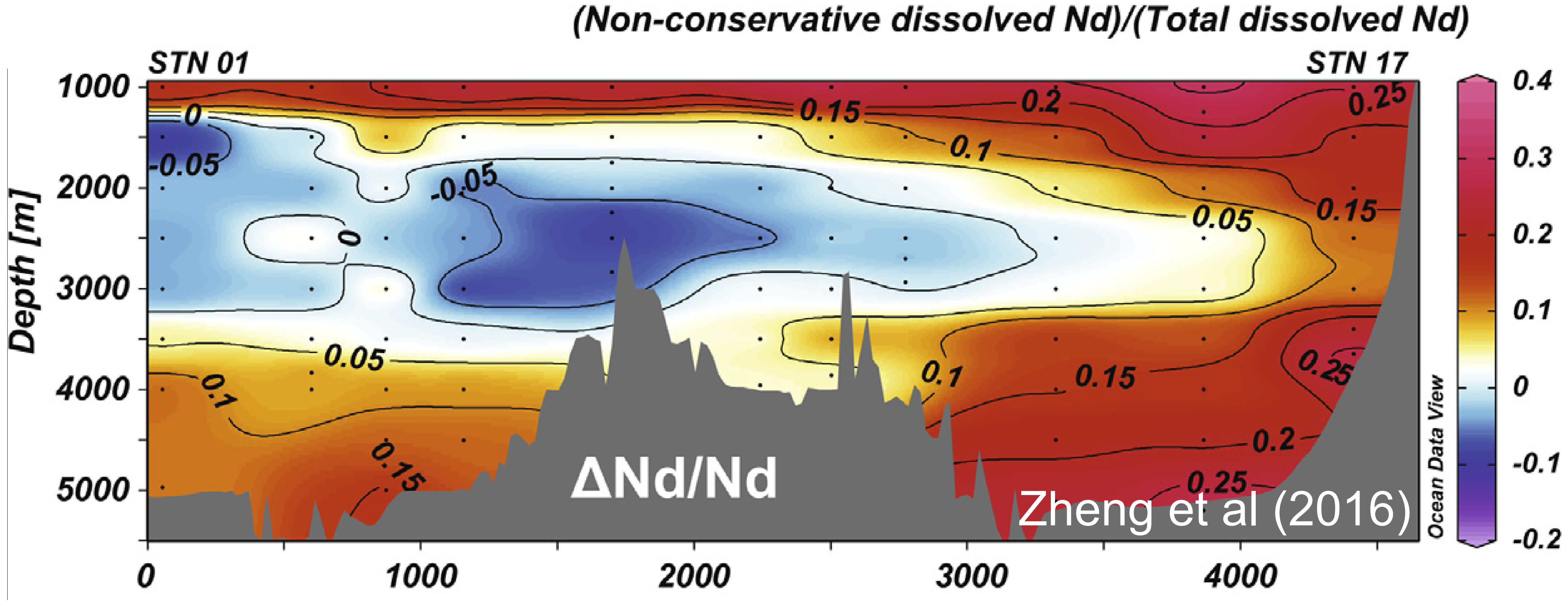
Tachikawa et al., Chem.Geol. (2017)



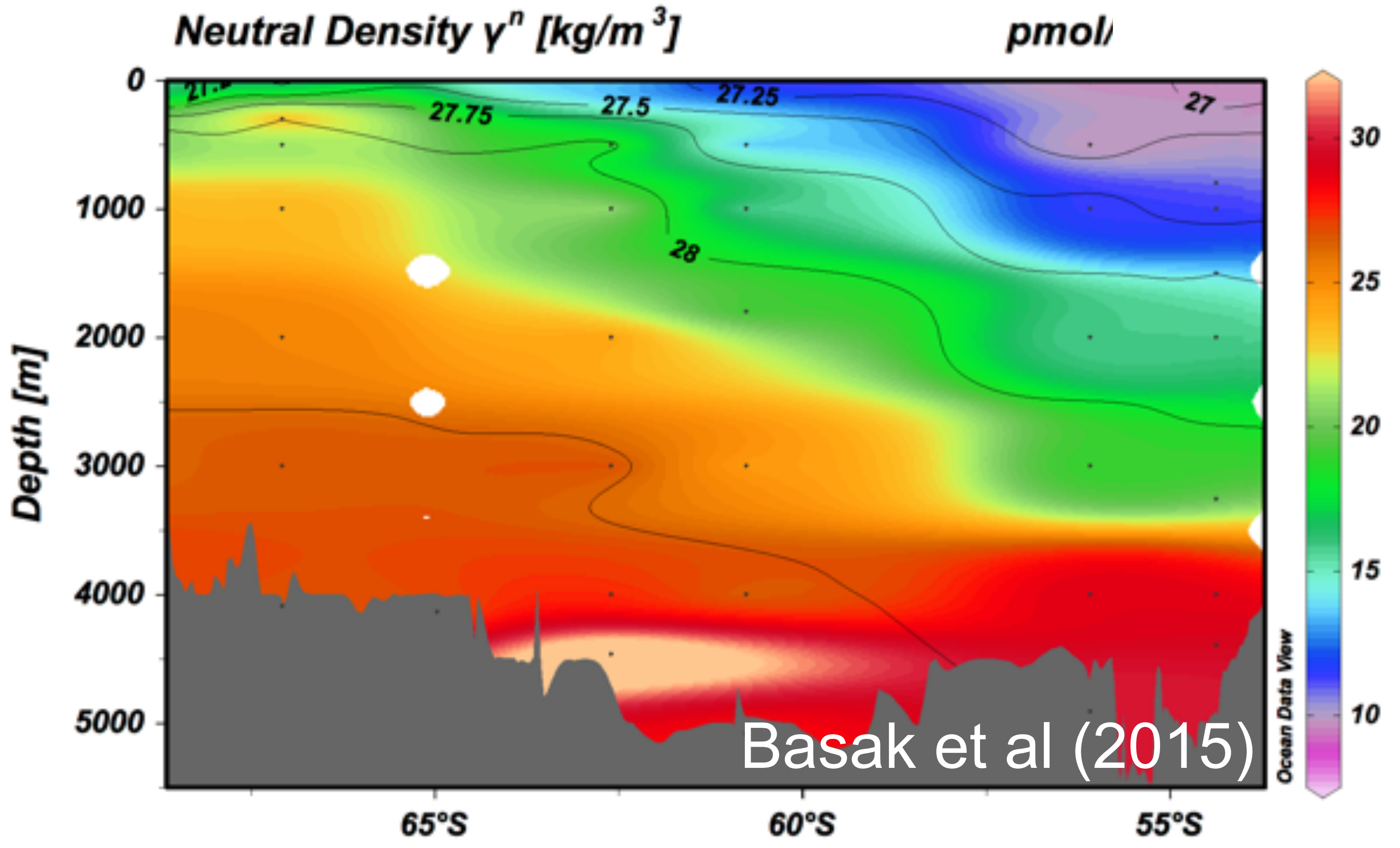
Global GEOTRACES Observations:

- ≥75 % conservative behavior of Nd

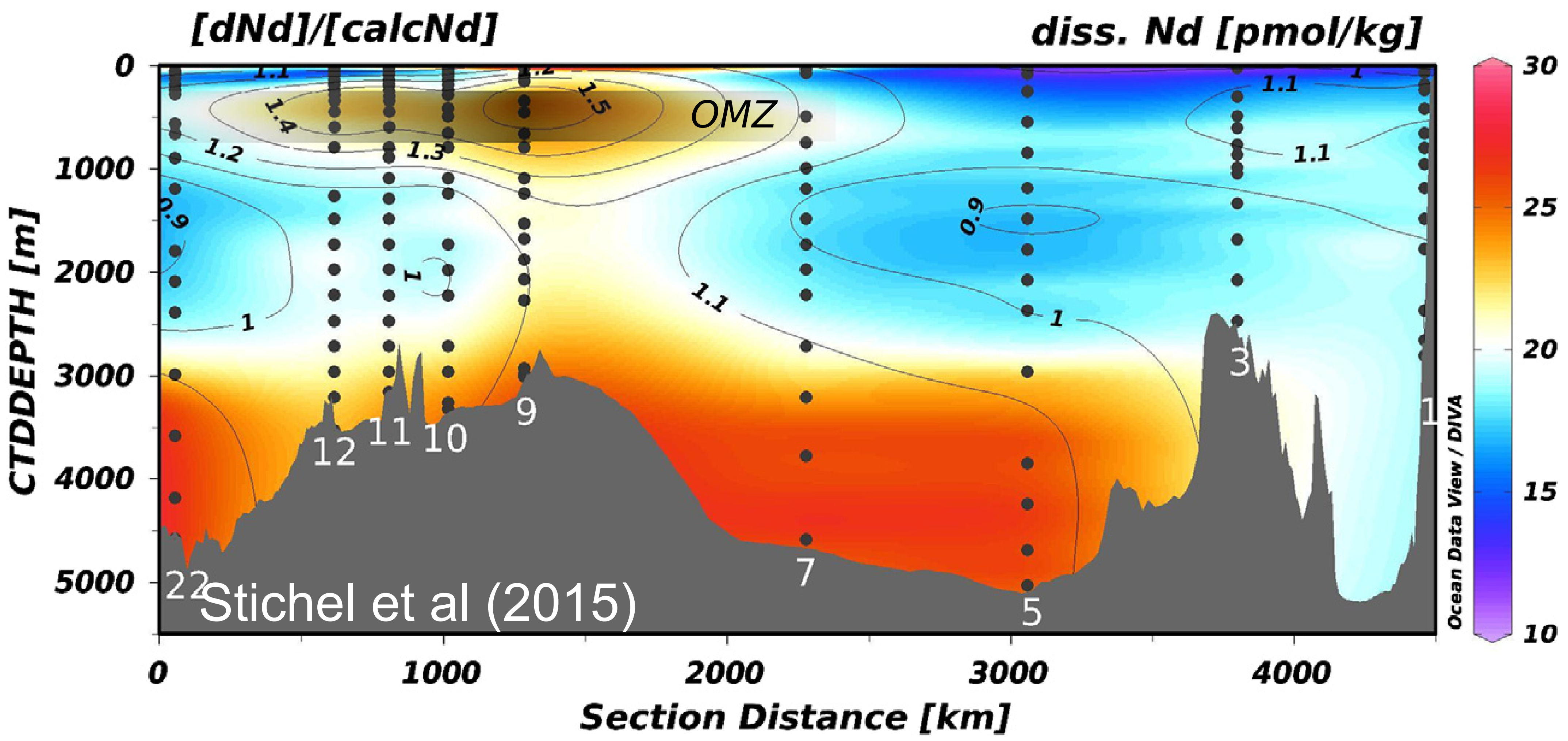
South Atlantic >1000m



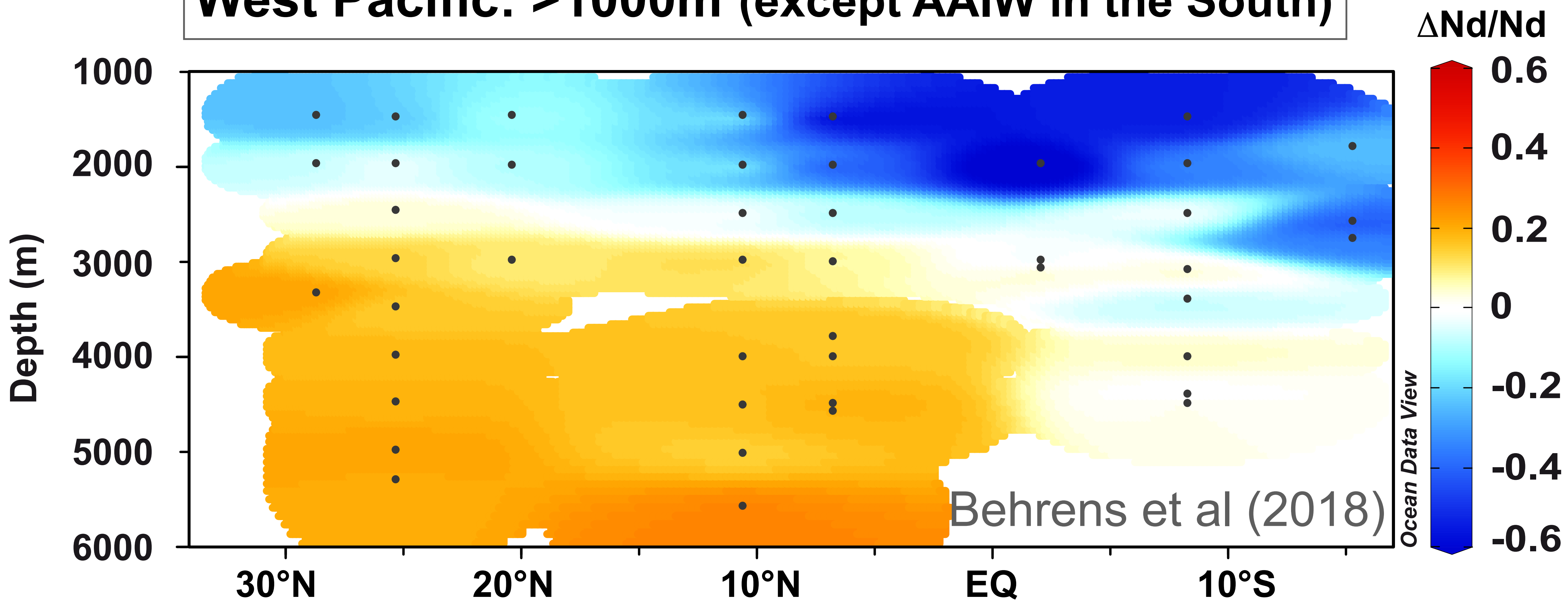
South Pacific: >1000m



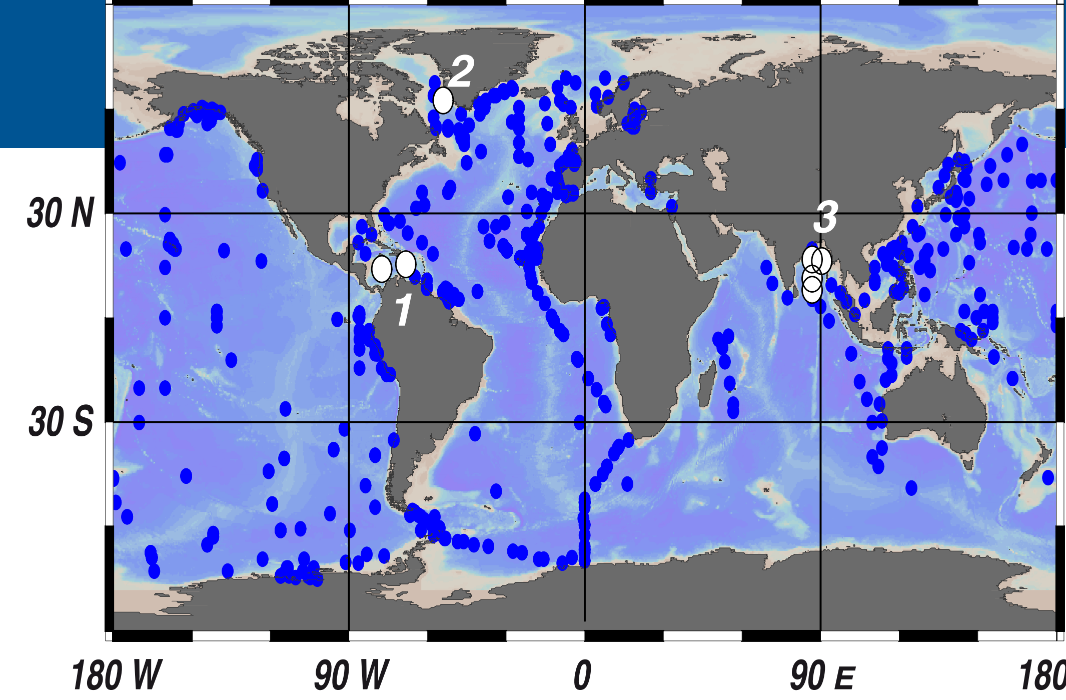
NE Atlantic: NADW-depth



West Pacific: >1000m (except AAIW in the South)

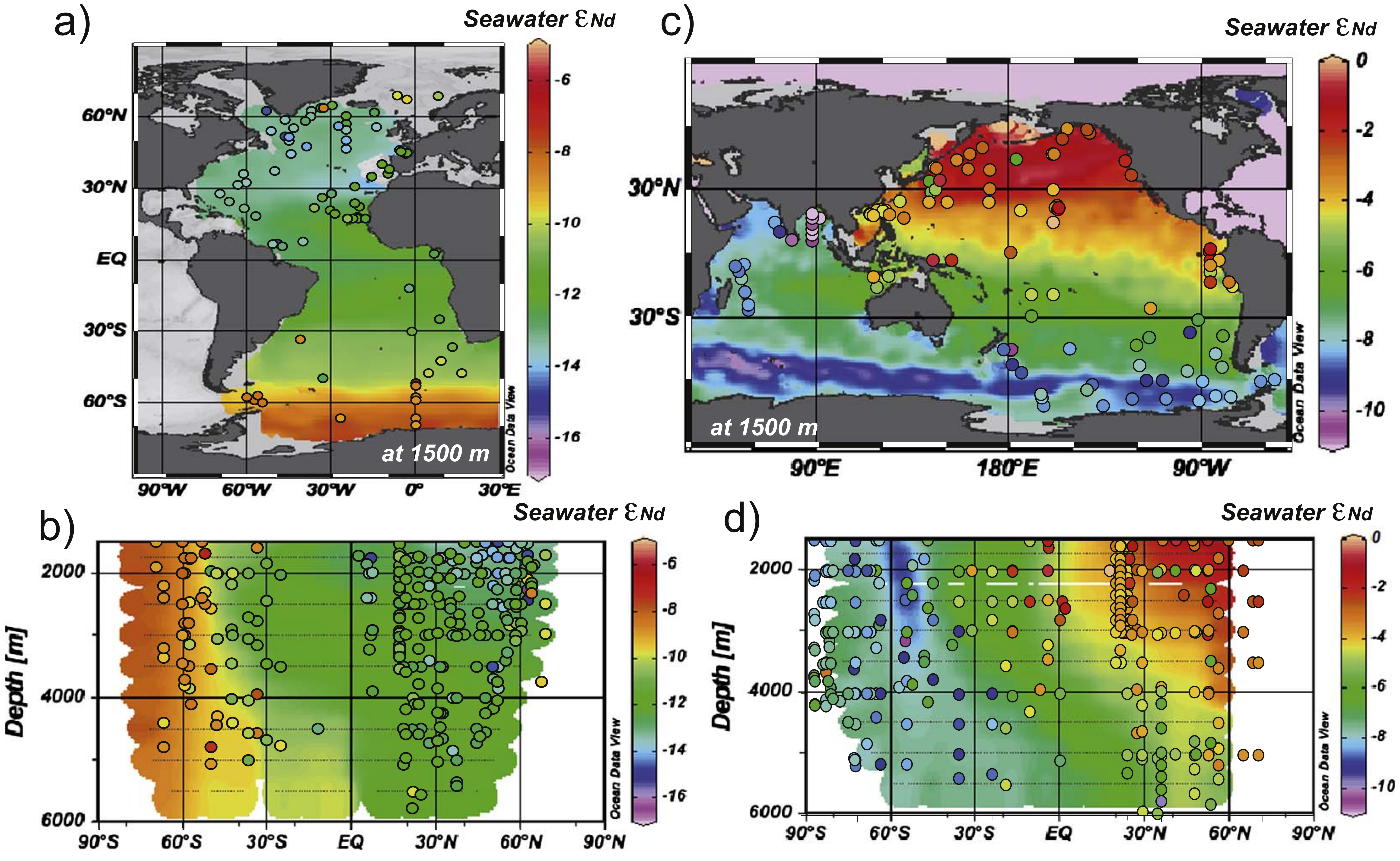


1. State of the Art - scientific advances from εNd

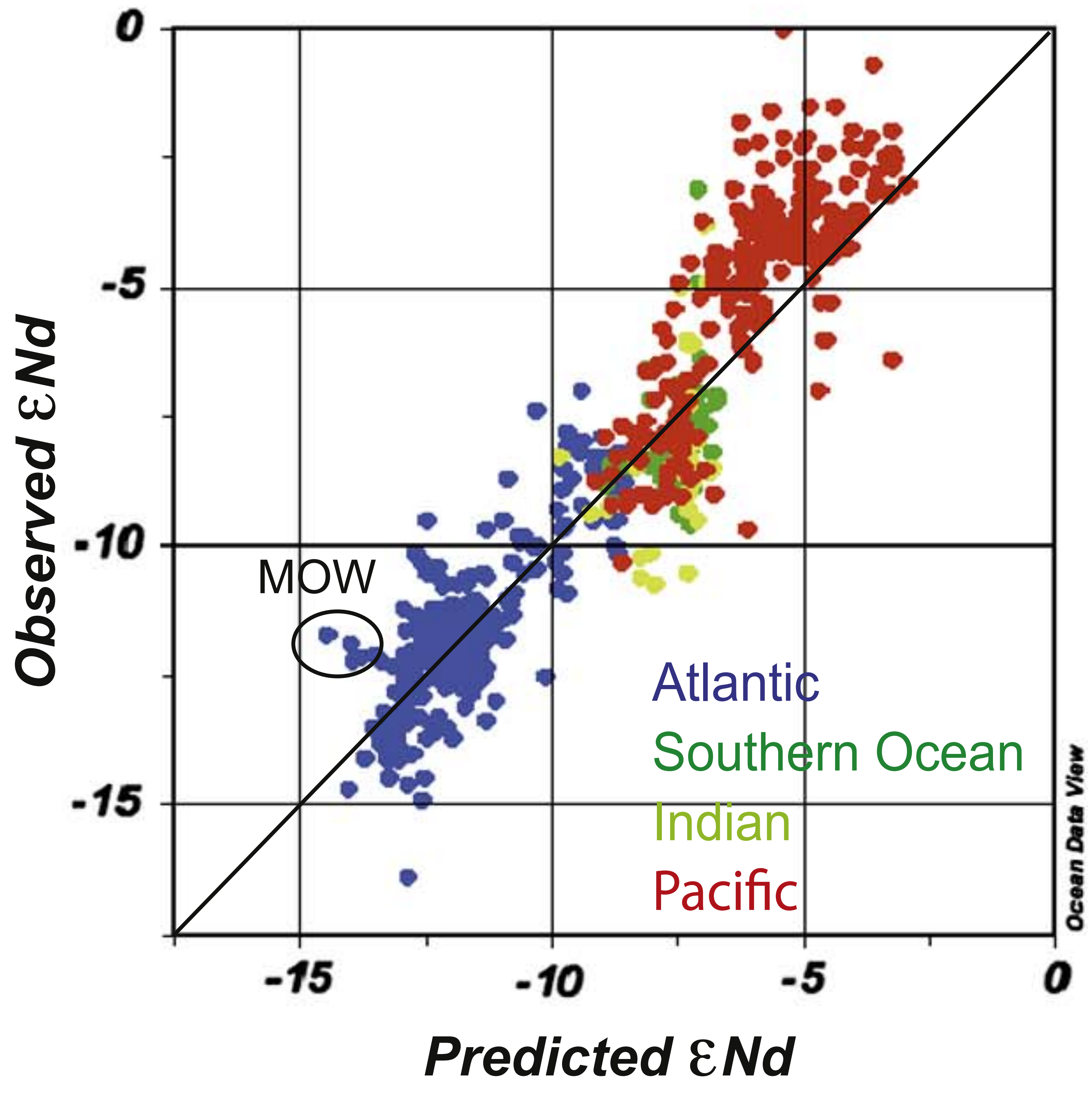


Global observations (from GEOTRACES):

Predicted vs. observed seawater εNd:



- offsets: equ. W & E Pacific



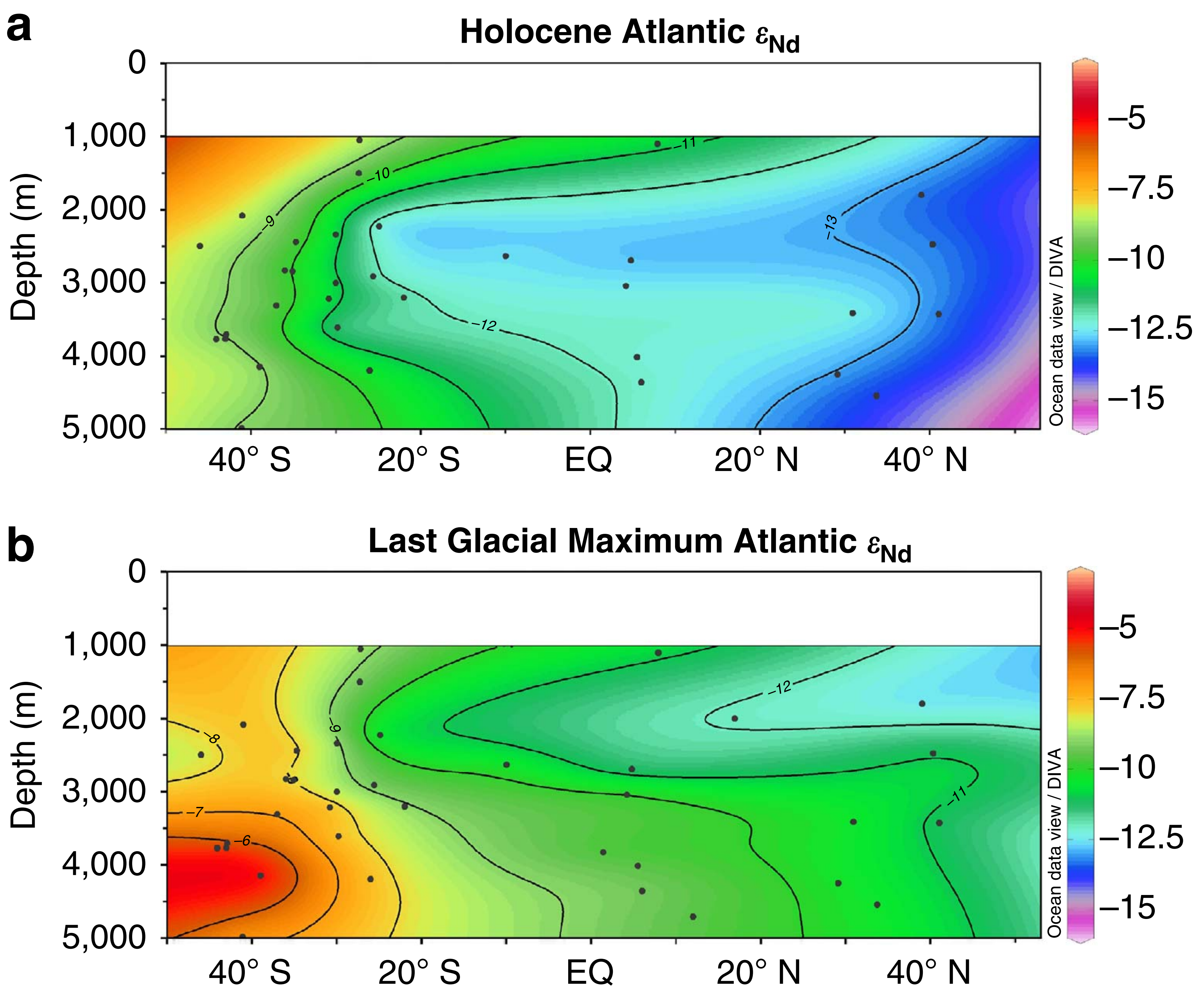
color shading = predicted εNd

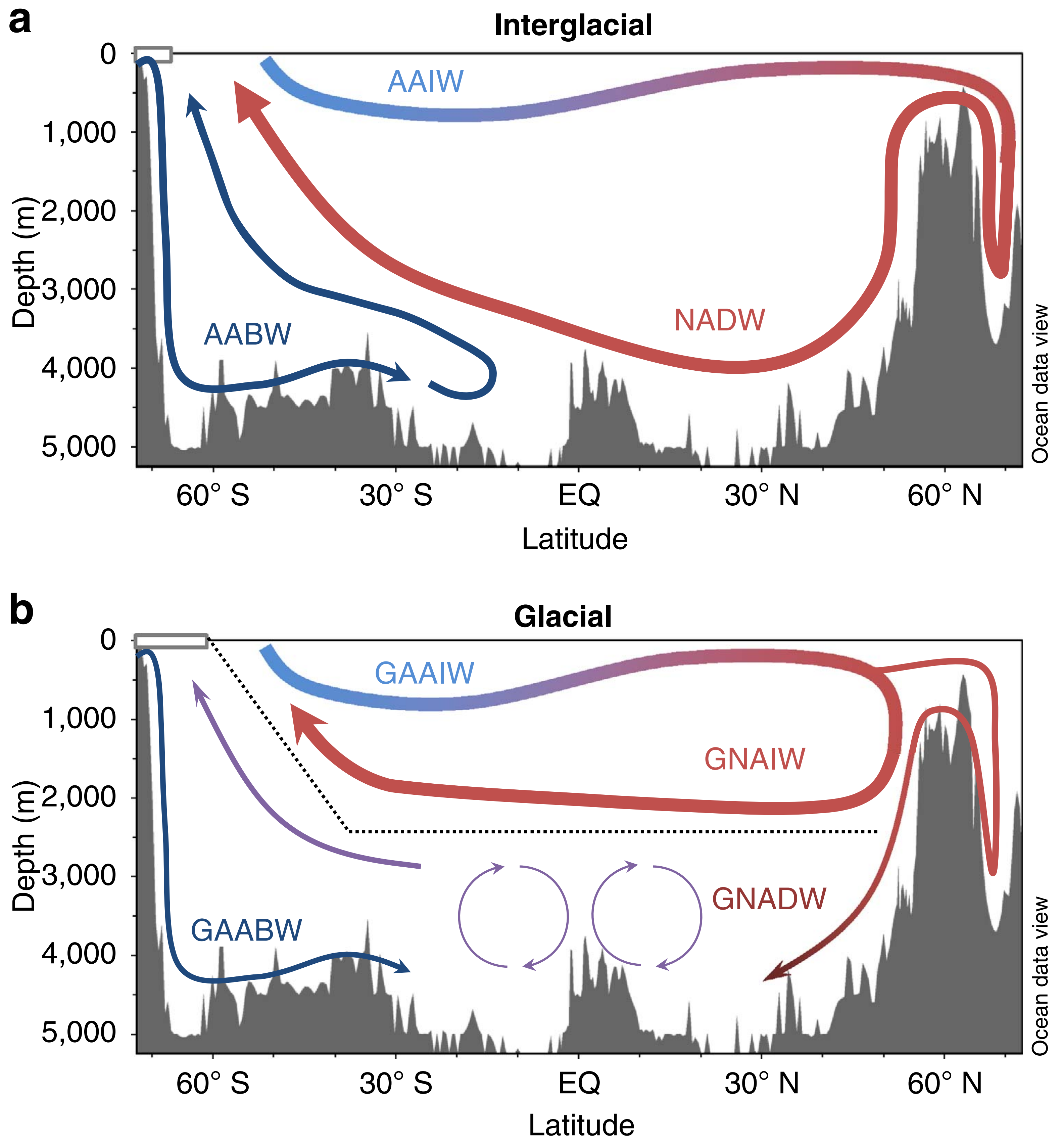
colored dots = observed εNd

Tachikawa et al., Chem.Geol. (2017)

Atlantic:

NADW Production during LGM





GNADW also suggested by:

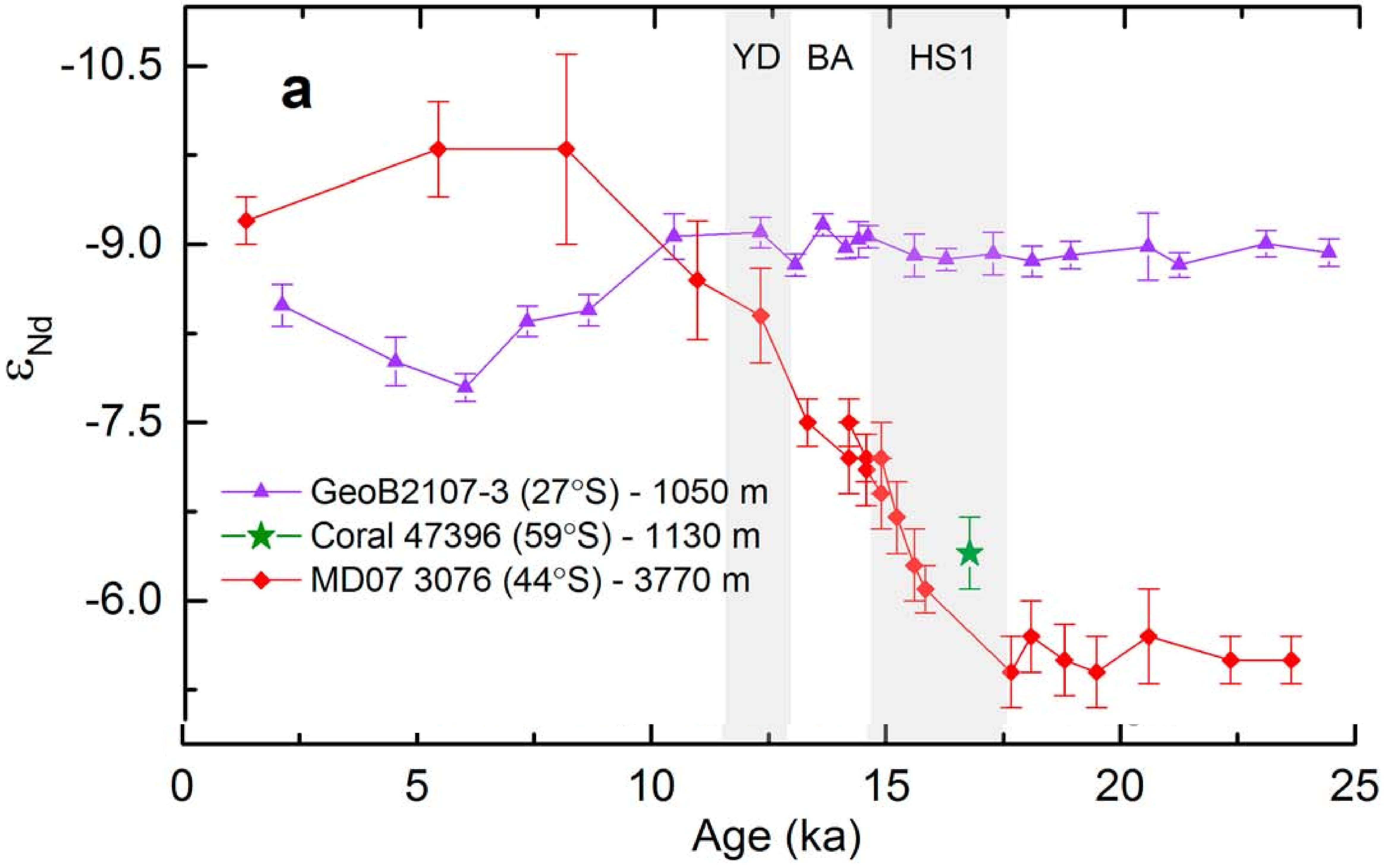
Bradtmiller et al., Nat. Comm. (2014) using Th/Pa isotopes

Keigwin & Swift, PNAS (2017) using d13C

Pöppelmann et. al., Paleoc. (2016) using eNd

Howe et al., Nat. Comm. (2016)

Atlantic:



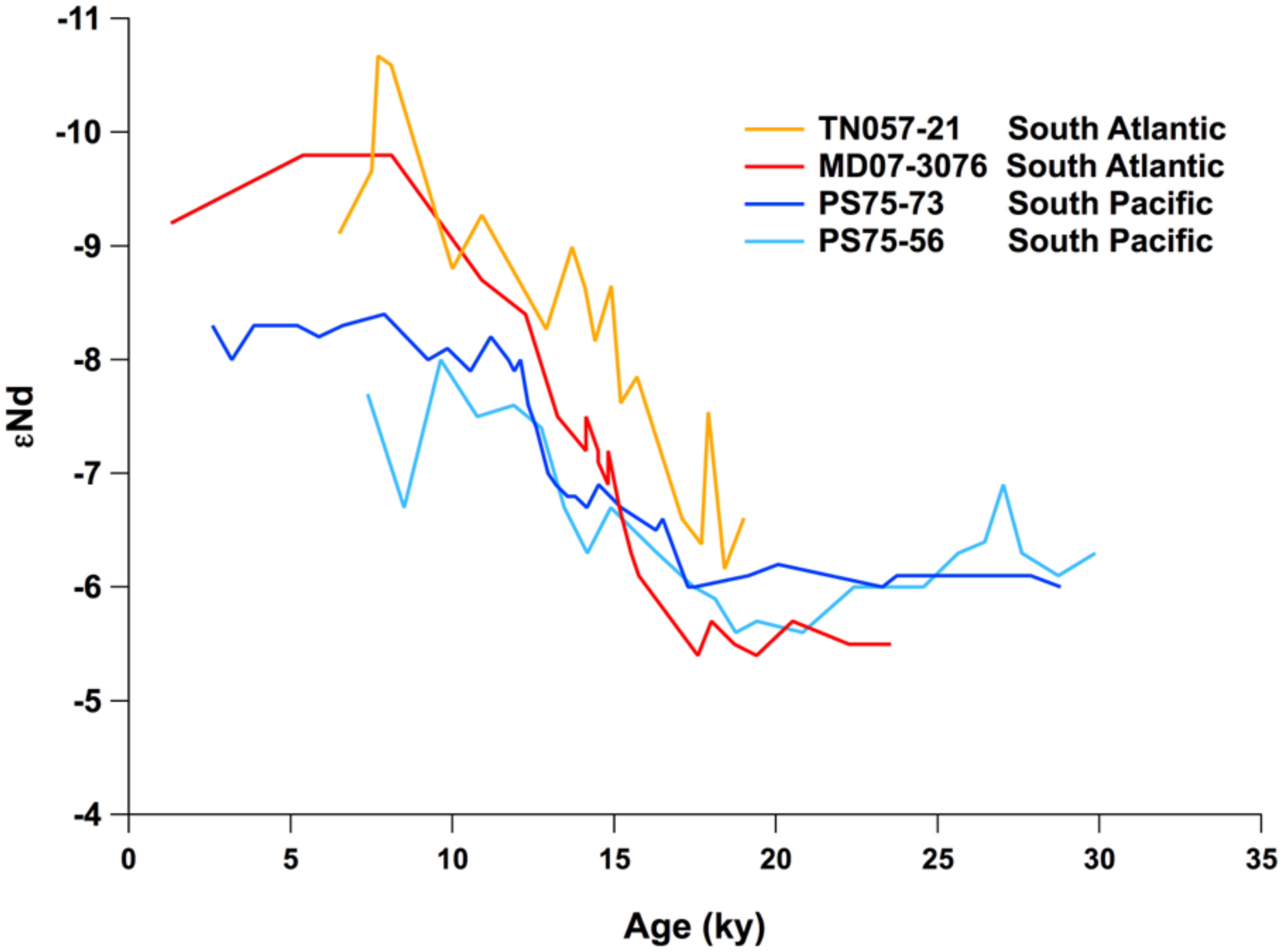
South Atlantic:

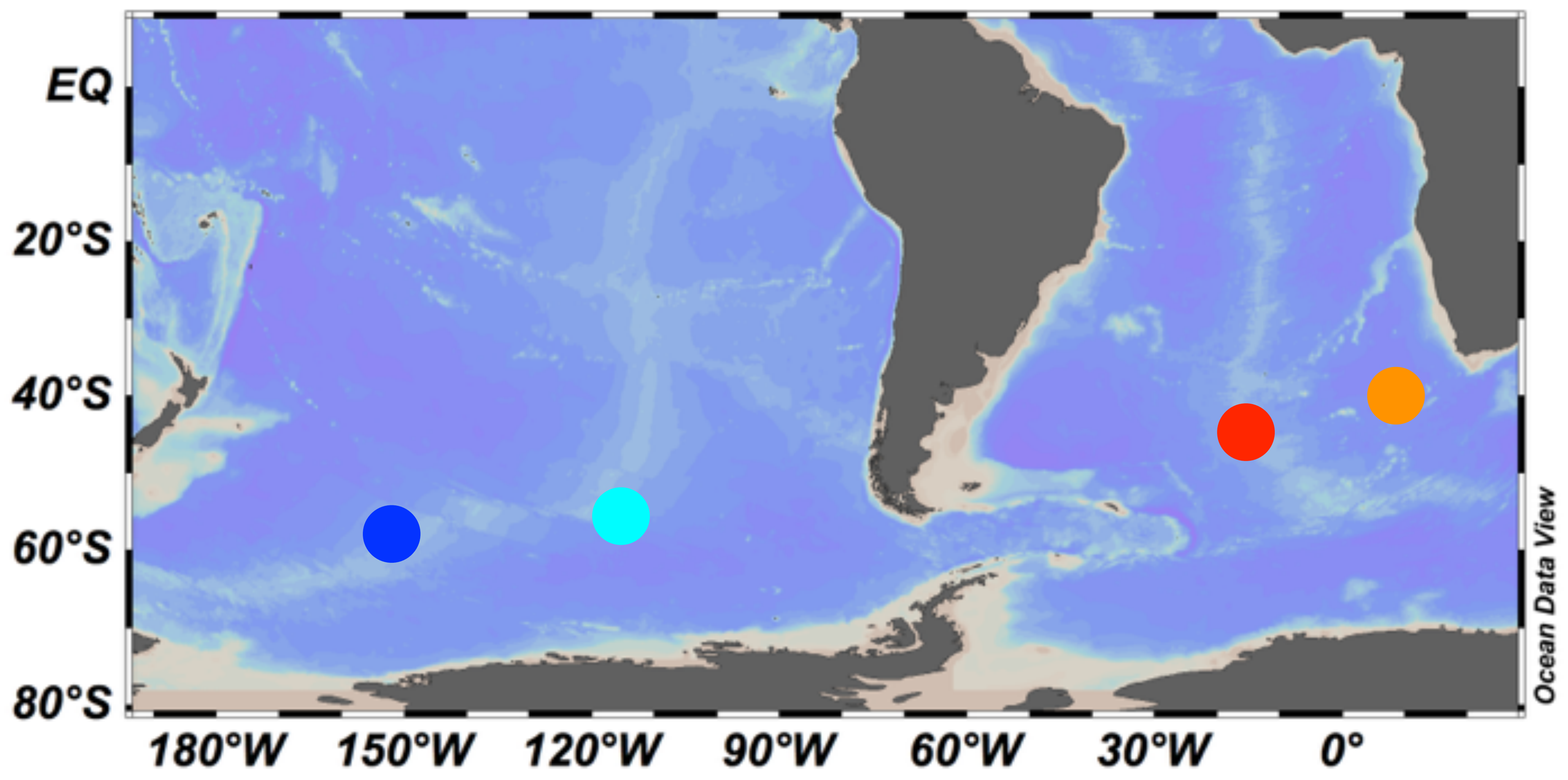
- AAIW: εNd +/- <u>stable</u> from LGM to Holocene (except for change in early Holocene)
- Deep Water: εNd more <u>radiogenic</u> during LGM

- No increased Pacific contribution to AAIW?

Howe et al., Paleoc. (2016)

Deep Southern Ocean:

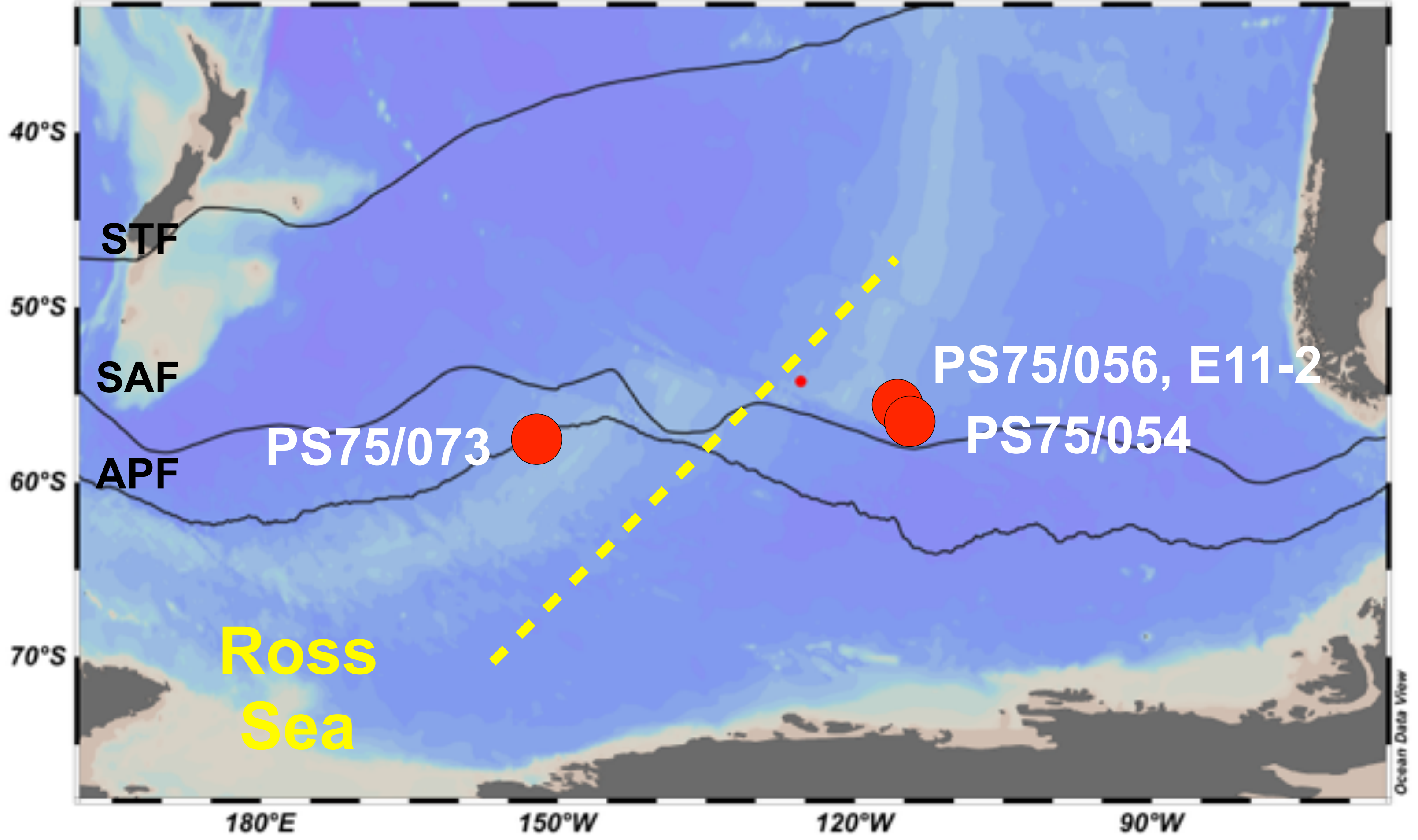




Deep Southern Ocean past 20 ky:

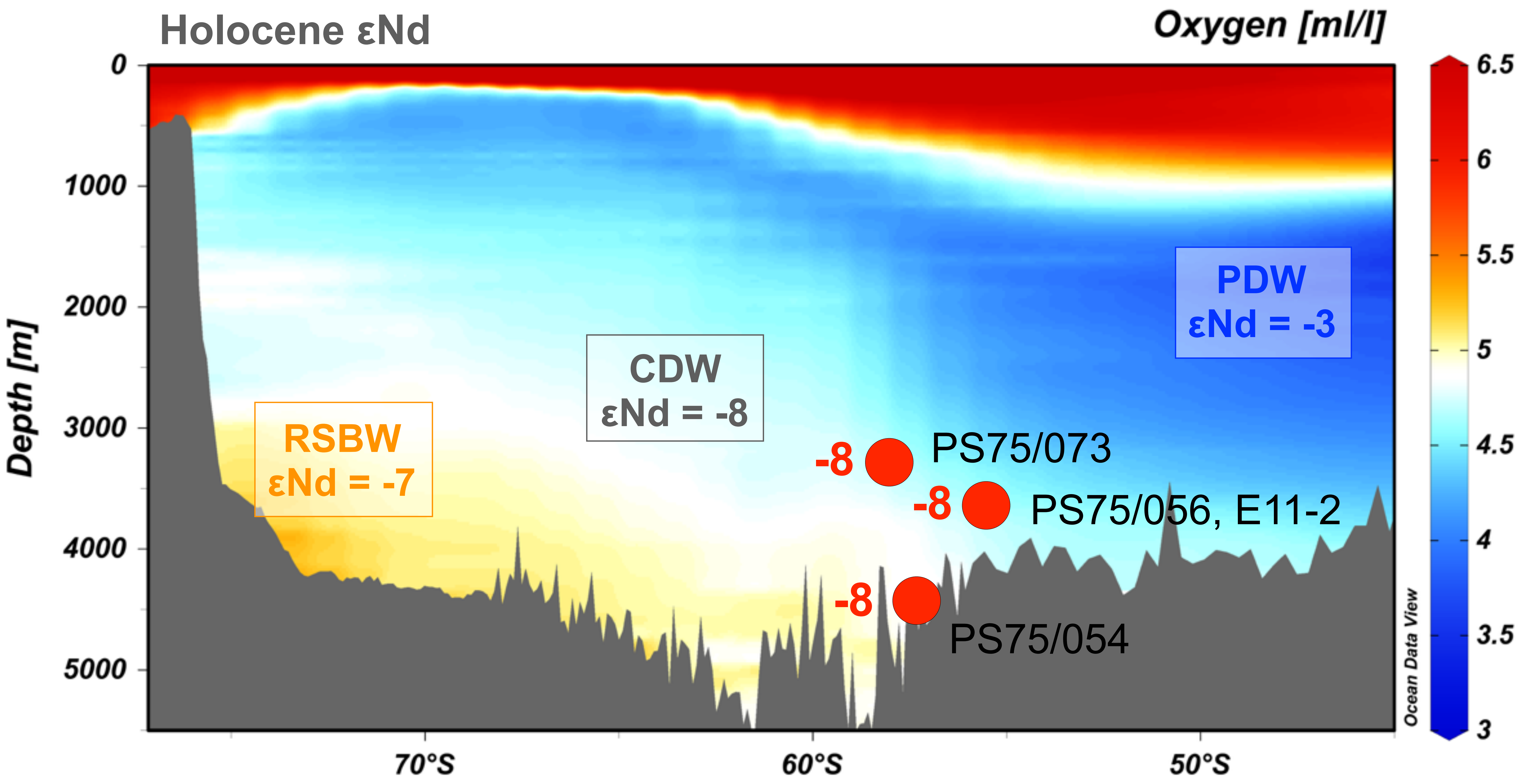
- consistent timing and direction of εNd changes

Basak et al., Science (2018);
Skinner et al., Geol. (2013);
Piotrowski et al., EPSL (2012)



Deep South Pacific:

Zonal section through the South Pacific

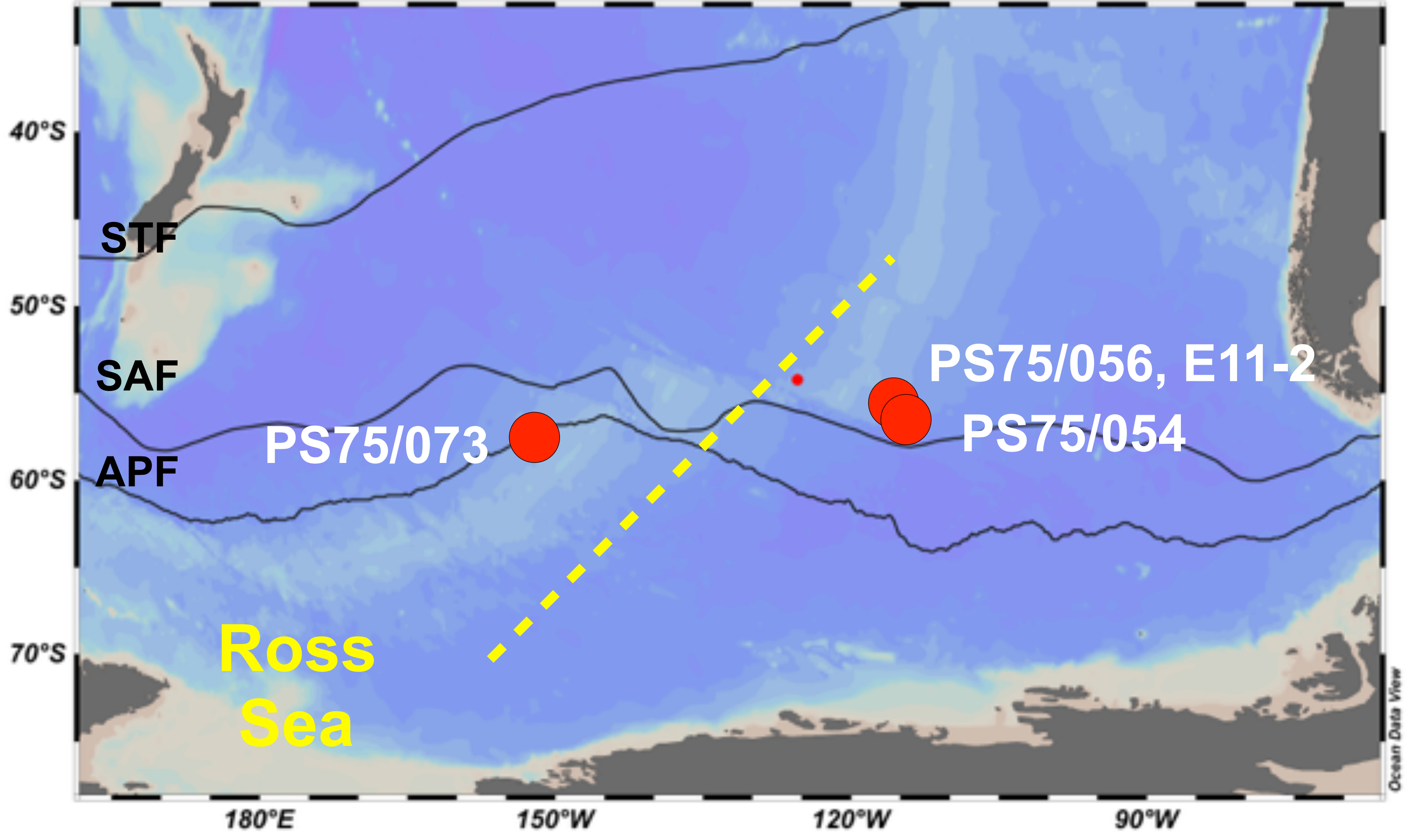


RSBW: Ross Sea Bottom Water; PDW: Pacific Deep Water
CDW: Circumpolar Deep Water

Homogeneous εNd of -8:

- well-mixed deep waters

Basak et al., Science (2018)



Deep South Pacific:

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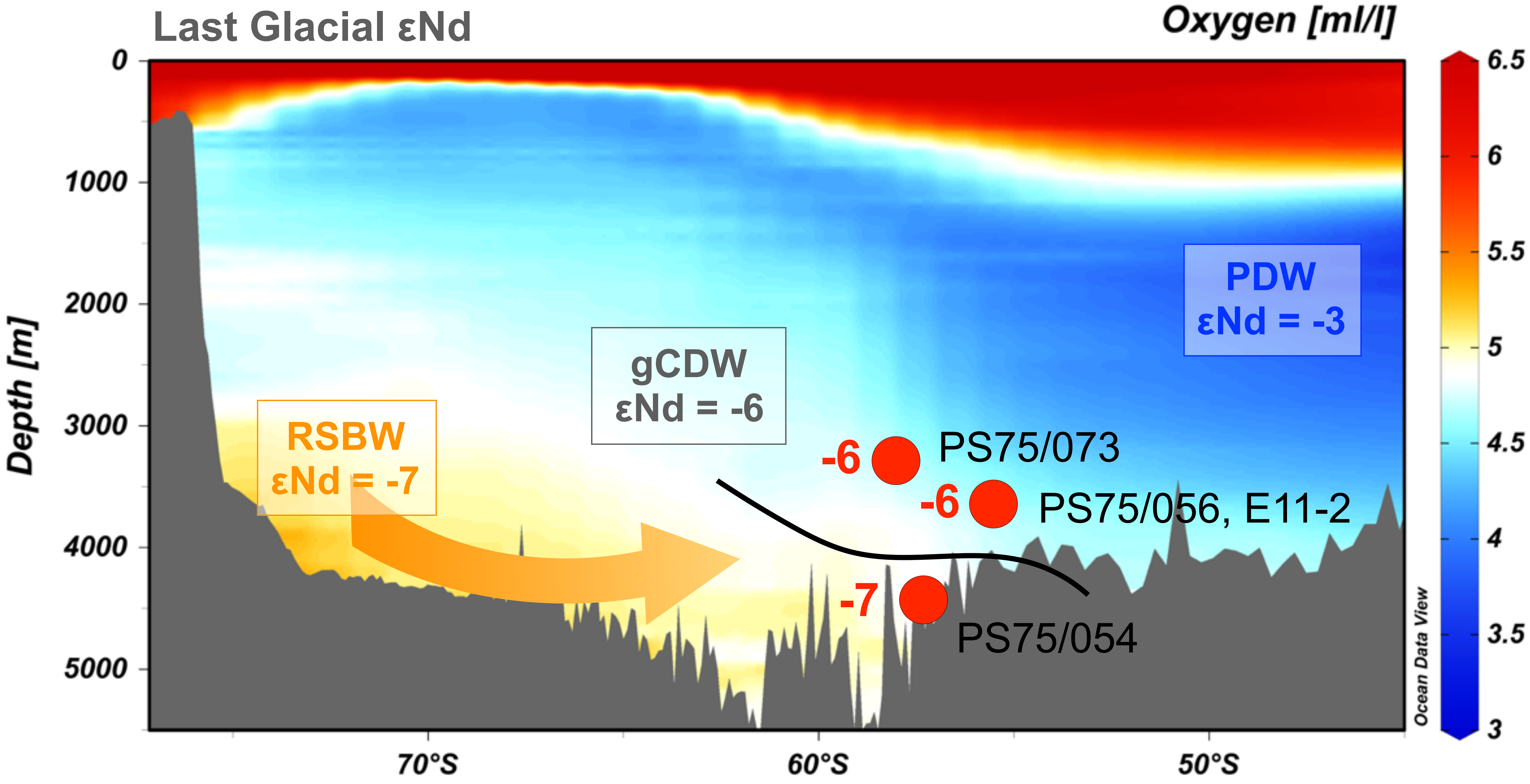


RSBW: Ross Sea Bottom Water; PDW: Pacific Deep Water
CDW: Circumpolar Deep Water

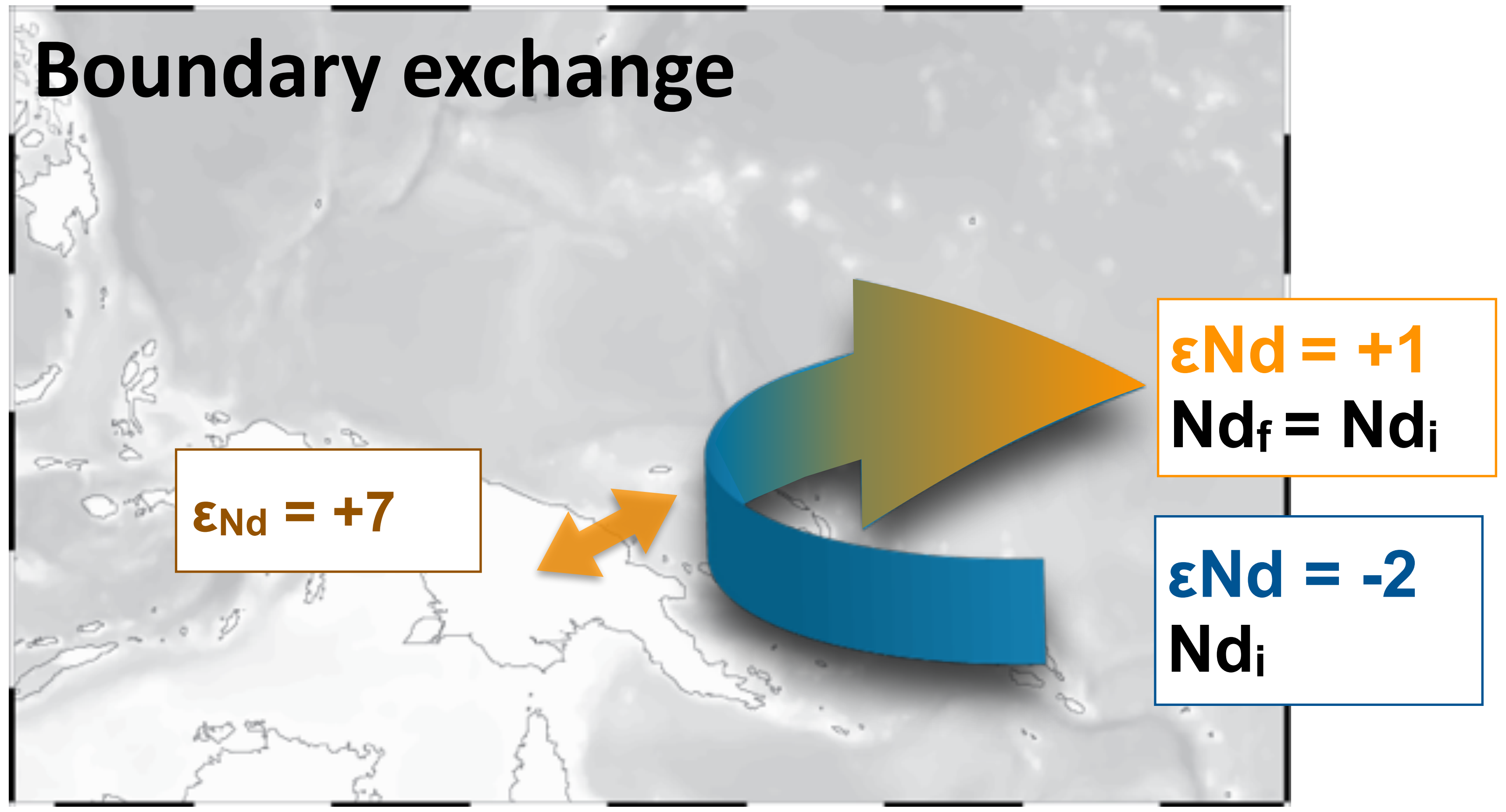
Different εNd above/below 4000 m:

- increased northward extent of RSBW
- stable deep-abyssal water column

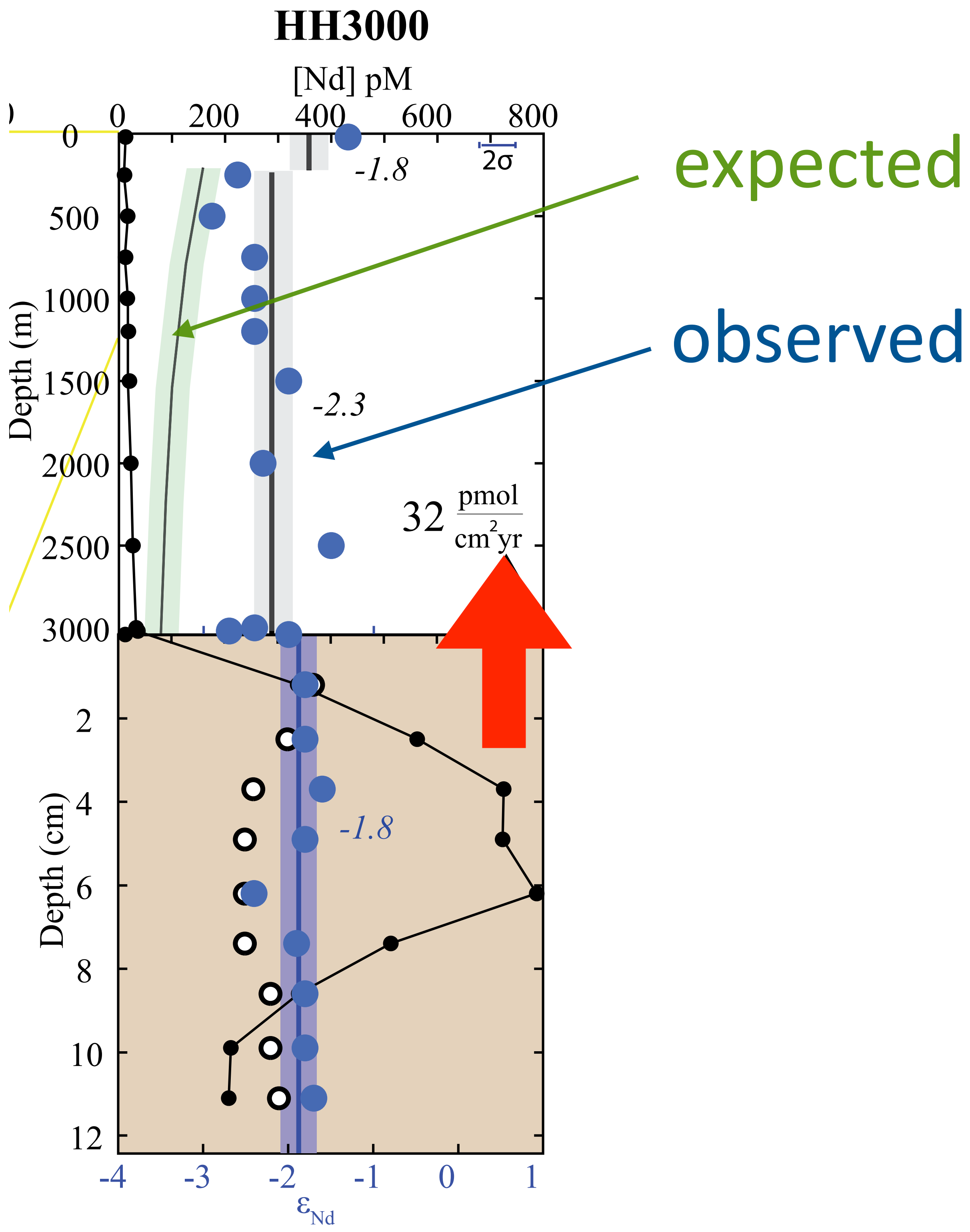
Basak et al., Science (2018)

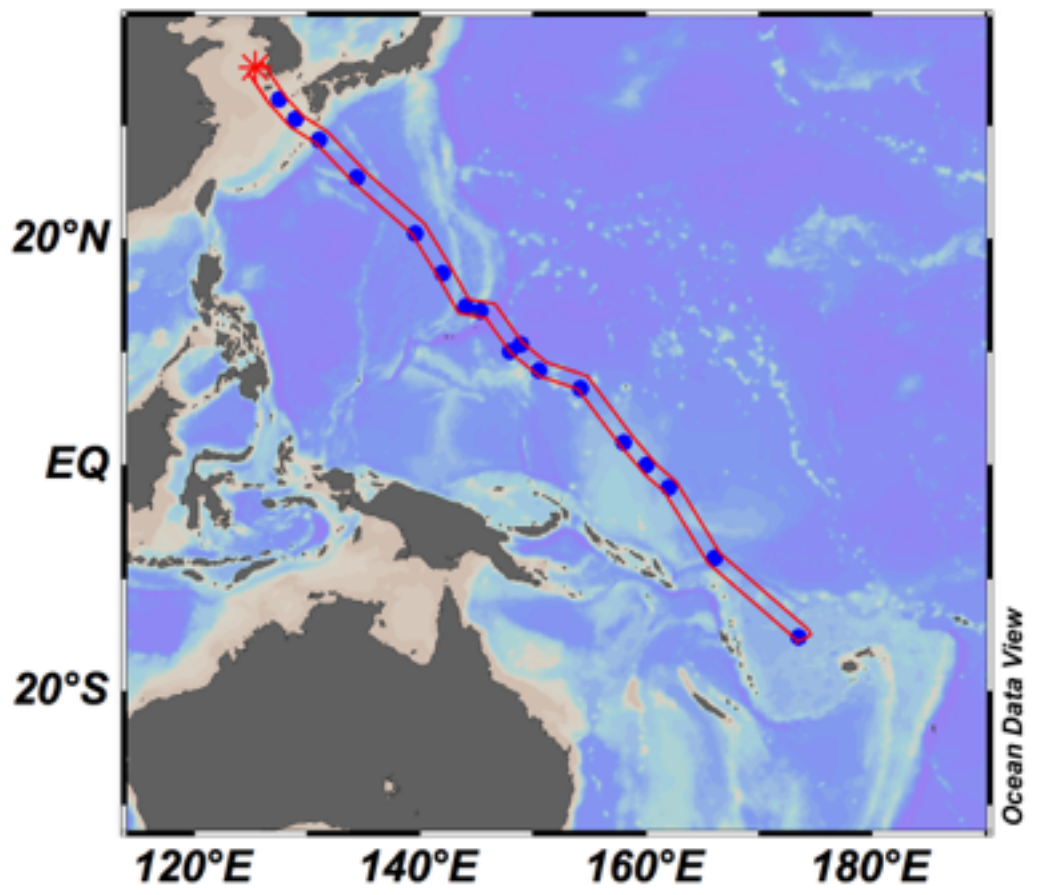
Challenges for εNd as conservative water mass tracer:

- Overprints from local/regional sources
  - **boundary exchange** at continental/island margins & seafloor (εNd)
  - **particle-seawater interactions** in the water column (εNd, [Nd])
  - **benthic flux of REE** (εNd, [Nd])



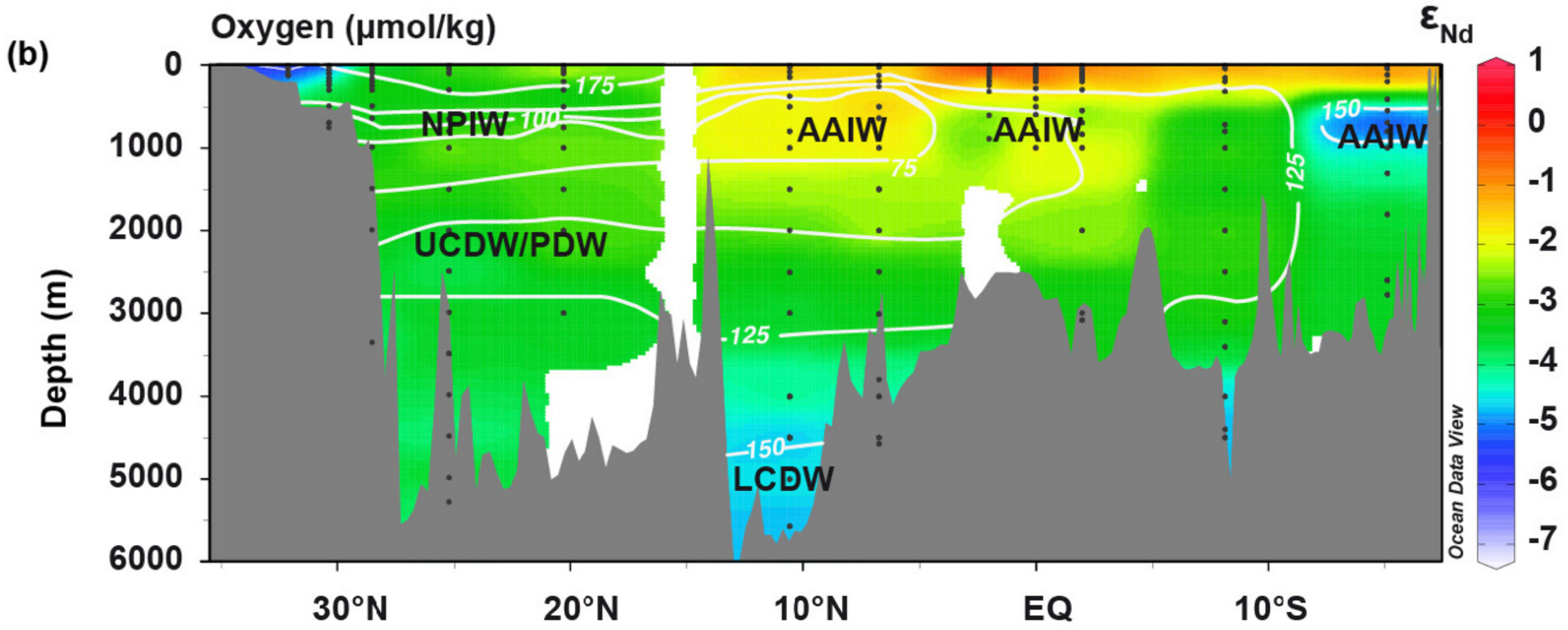
Benthic flux



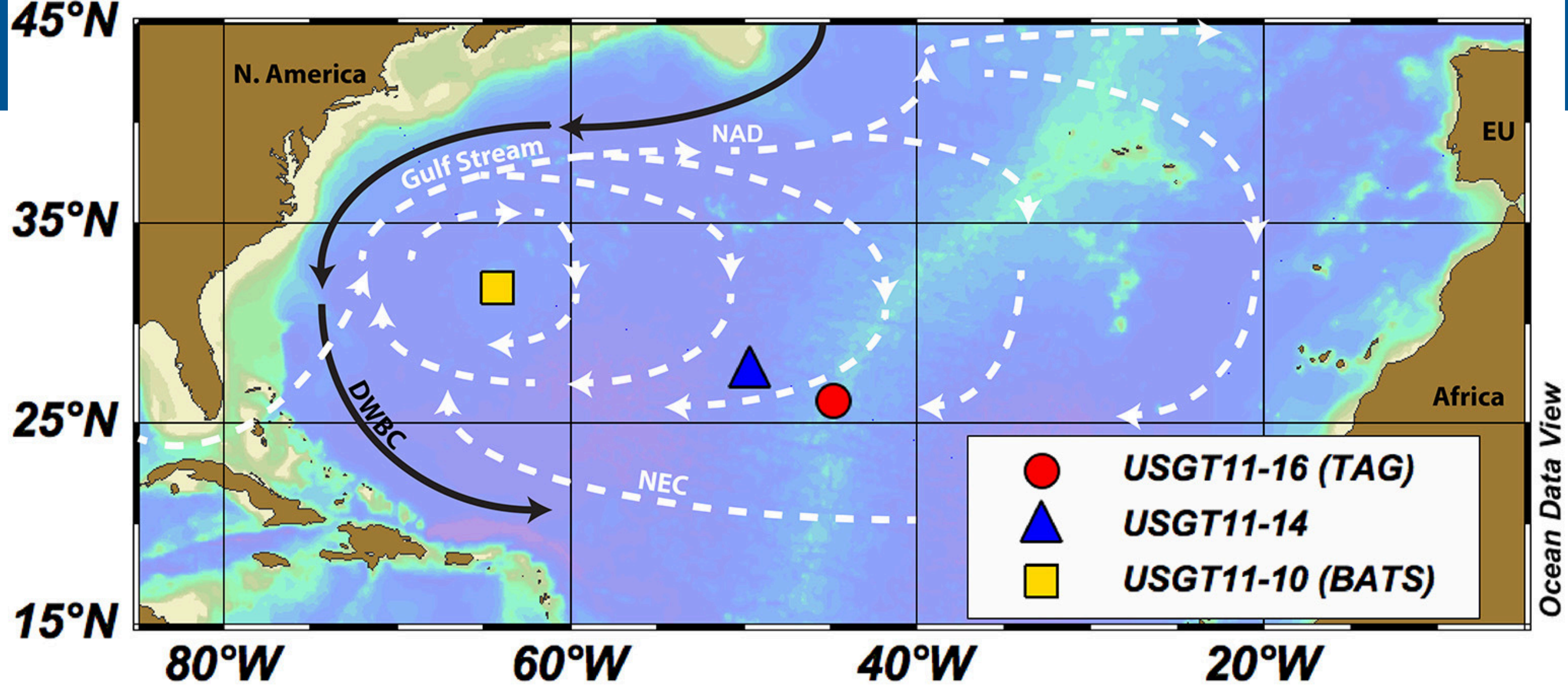


Pacific: **substantial εNd modification:**

- **surface/subsurface**: volcanic islands, boundary exchange & input
- **LCDW**: Samoan Passage (+4 εNd), Philippine Sea/Mariana Basin (+ 1 εNd)
- **AAIW**: volcanic islands, hydrothermal particle exchange?



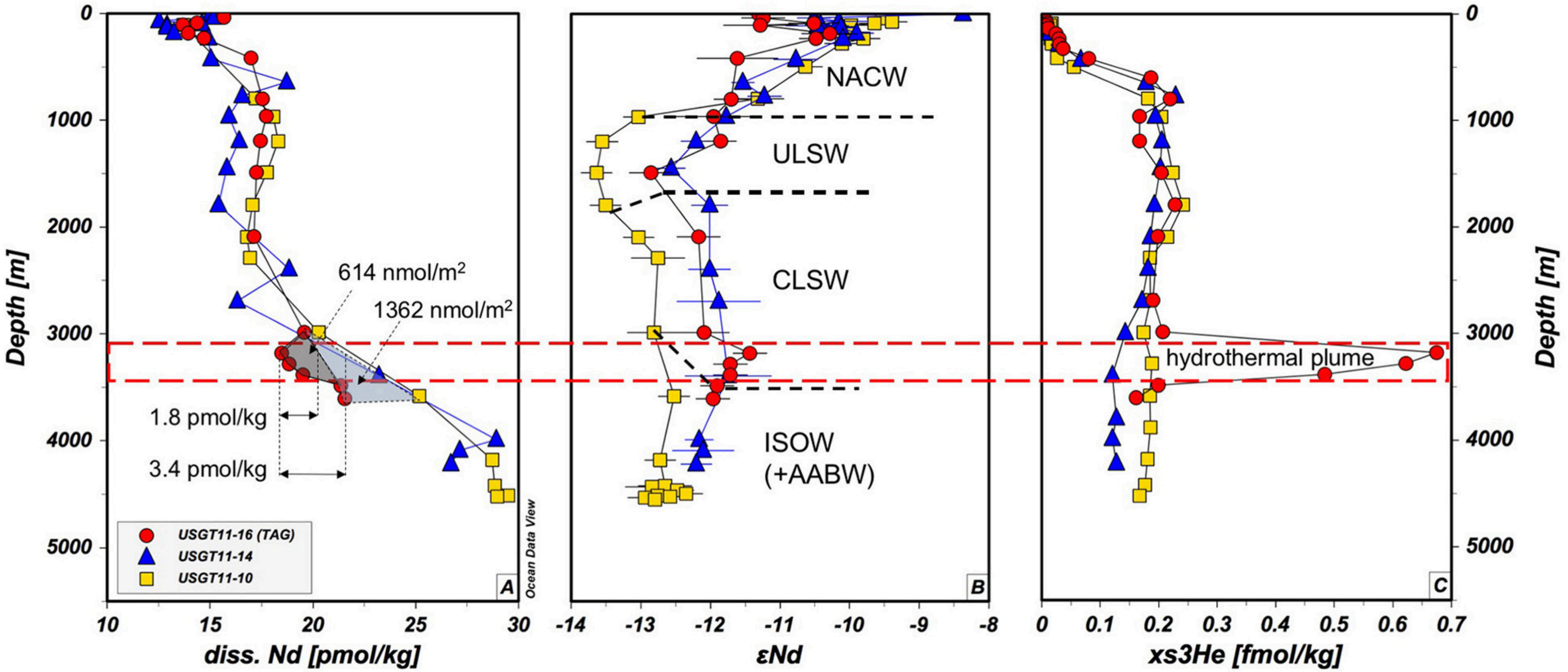
Behrens et al., GCA (2018)



Atlantic GA03

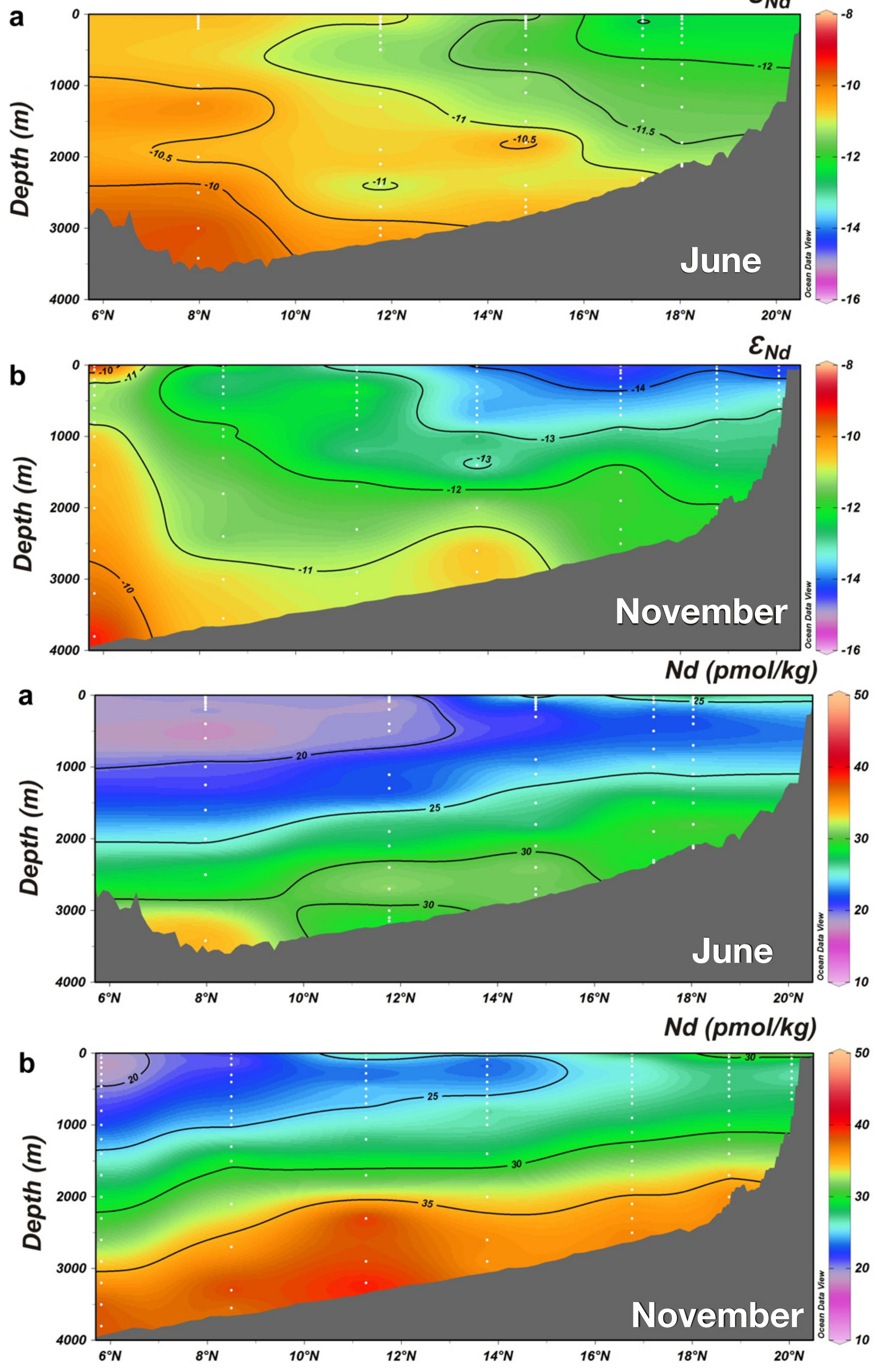
North Atlantic TAG hydrothermal plume:

- Nd removal
- εNd modification towards radiogenic values



Stichel et al., Frontiers (2018)

Indian Ocean

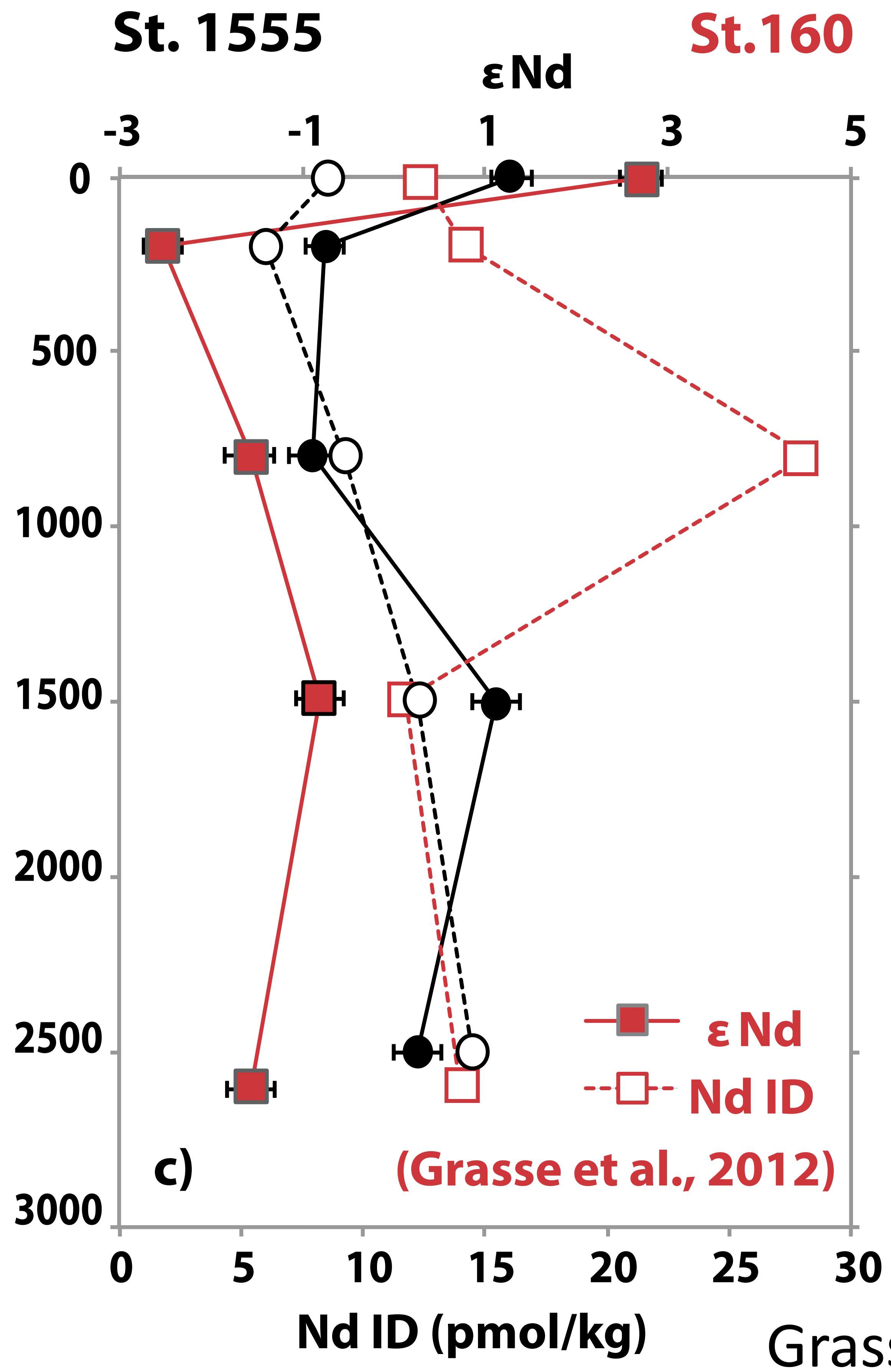


Yu et al., EPSL (2017)

Short-term dissolved eNd and [Nd] changes down to 3000 m water depth due to surface particle input

Also during H-events in North Atlantic (Roberts & Piotrowski, 2015)

Panama Basin



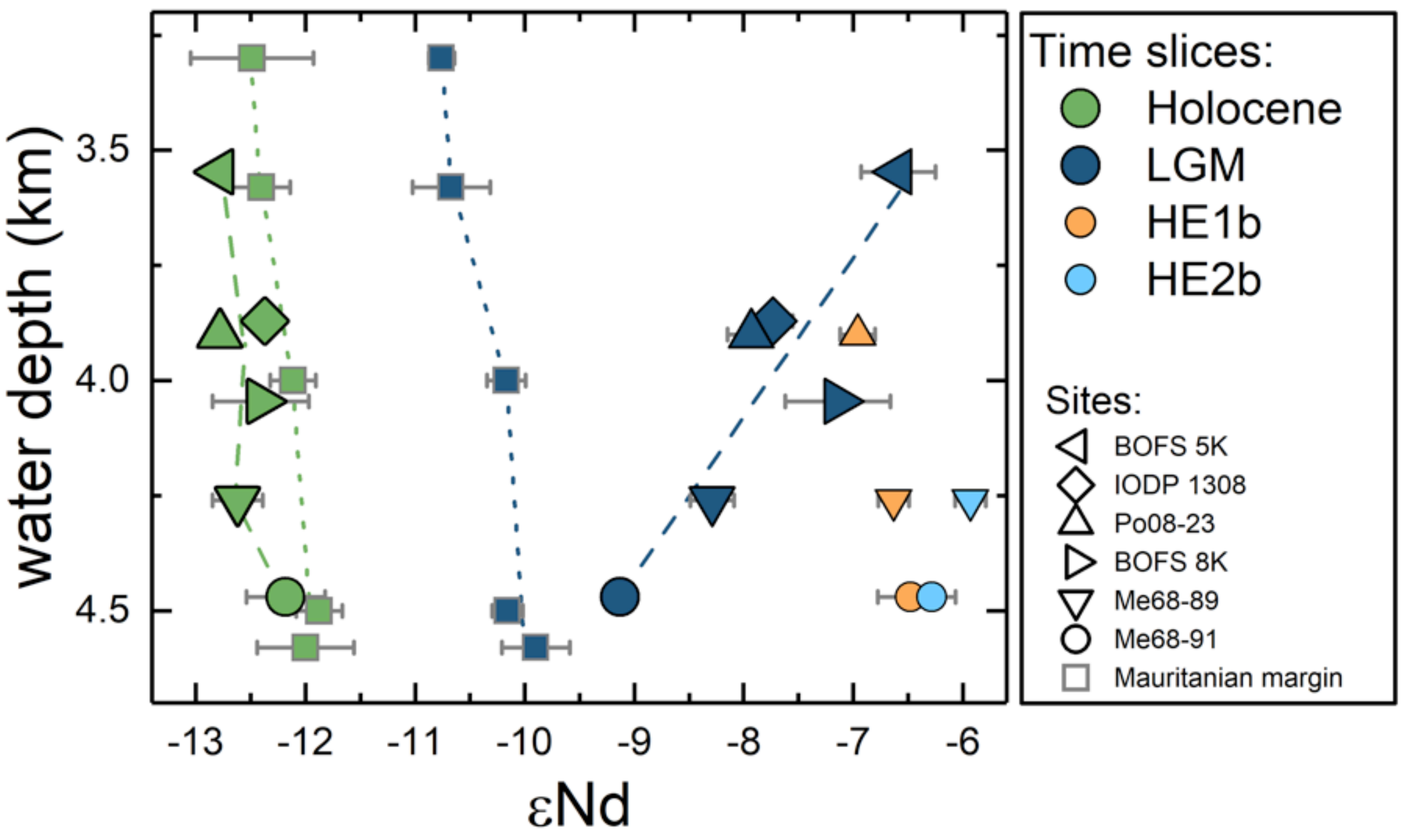
filled symbols: eNd
open symbols: [Nd]

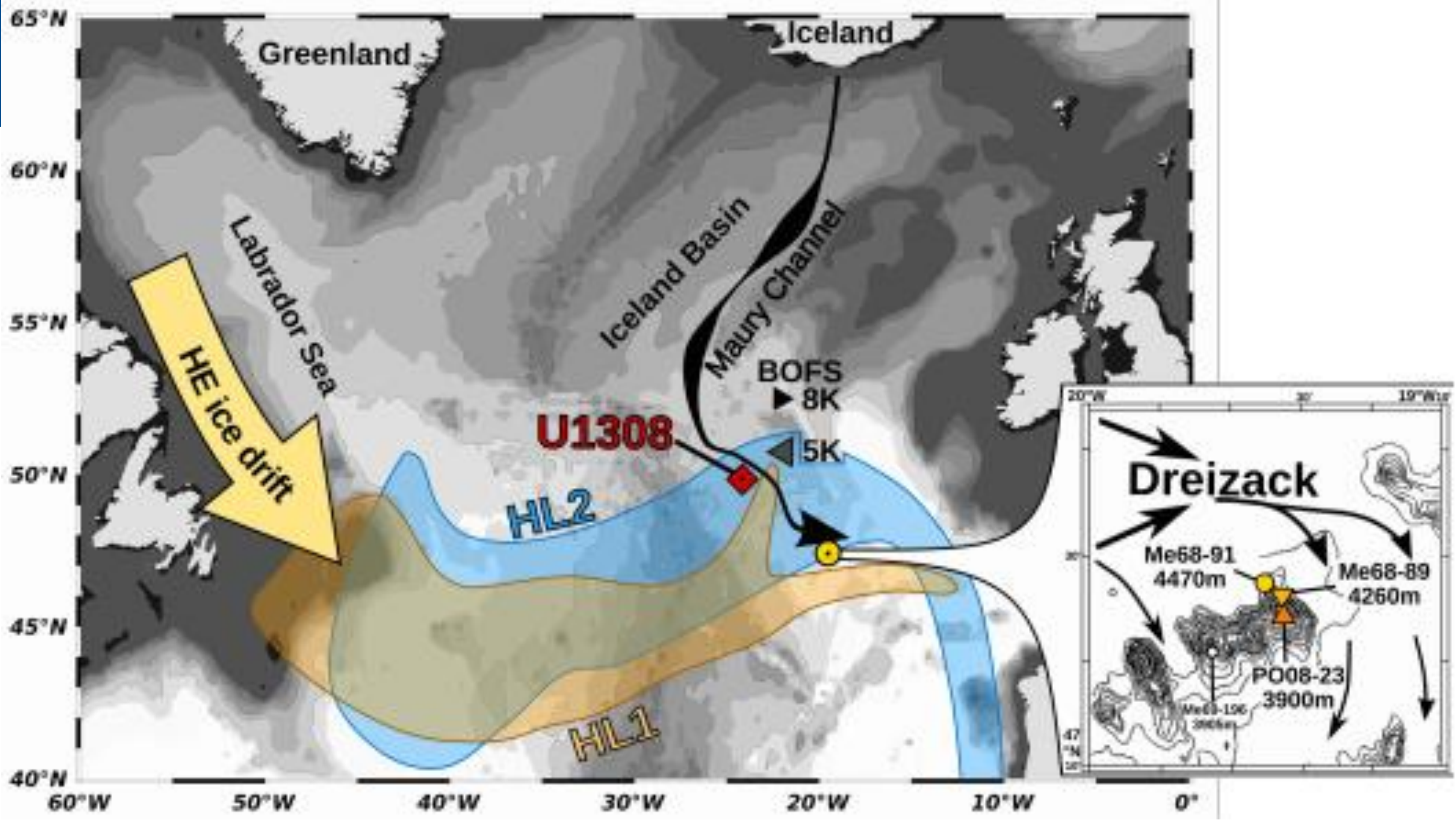
Grasse et al., EPSL (2017)

2. Challenges & Open Questions - Particle-Seawater Exchange

Benthic flux:

NE Atlantic >47°N (north of Dreizack)



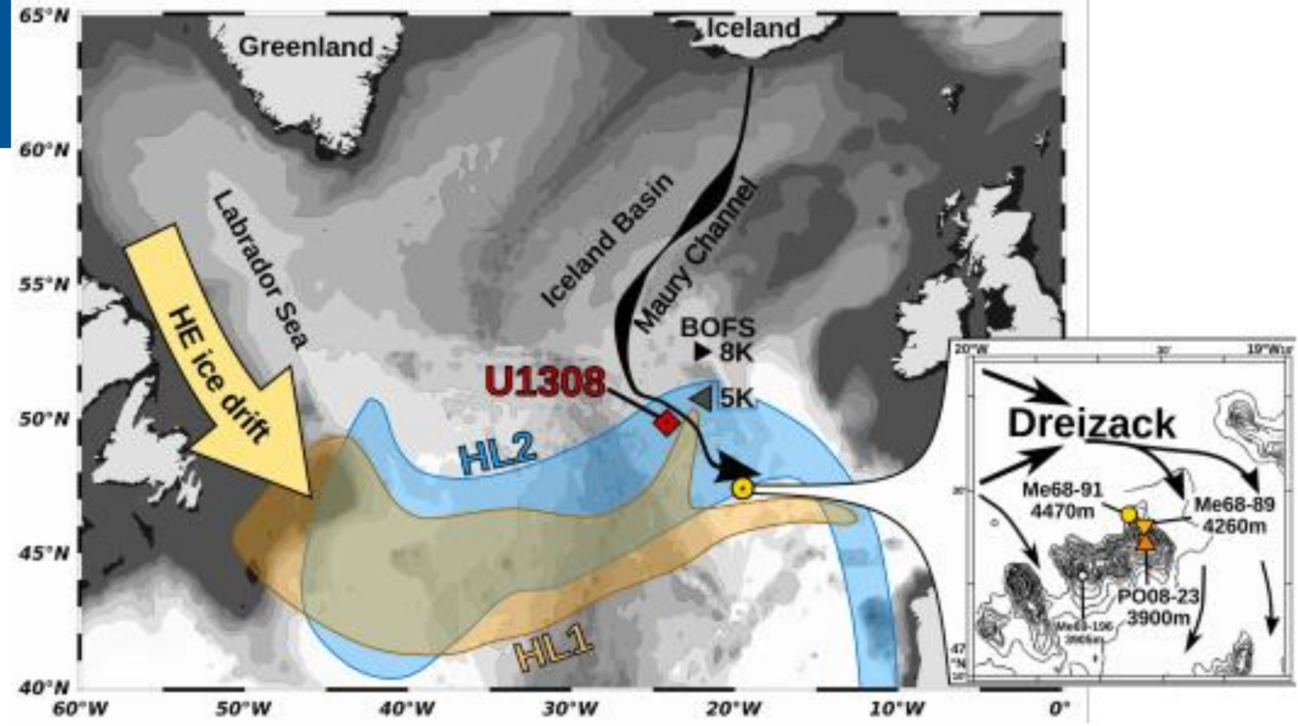


Deep NE Atlantic >47°N:

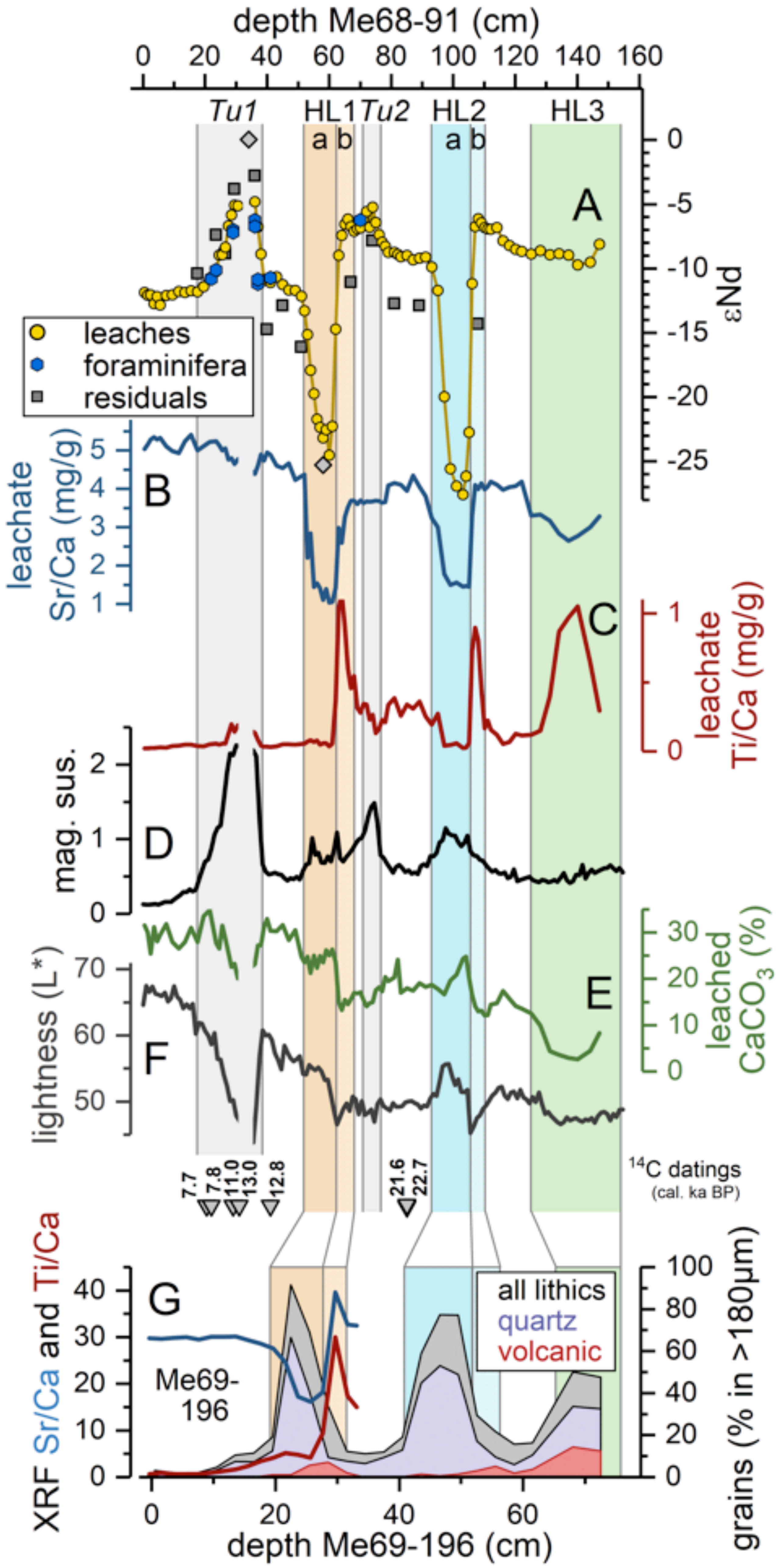
- relabelling across different water masses
- stronger relabelling and greater southward extent during HE1 and HE2 (sluggish AMOC)

Data: Blaser et al., GCA (accepted), Roberts & Piotrowski, EPSL (2015). Howe et al., EPSL (2016)

Blaser et al., GCA (accepted)



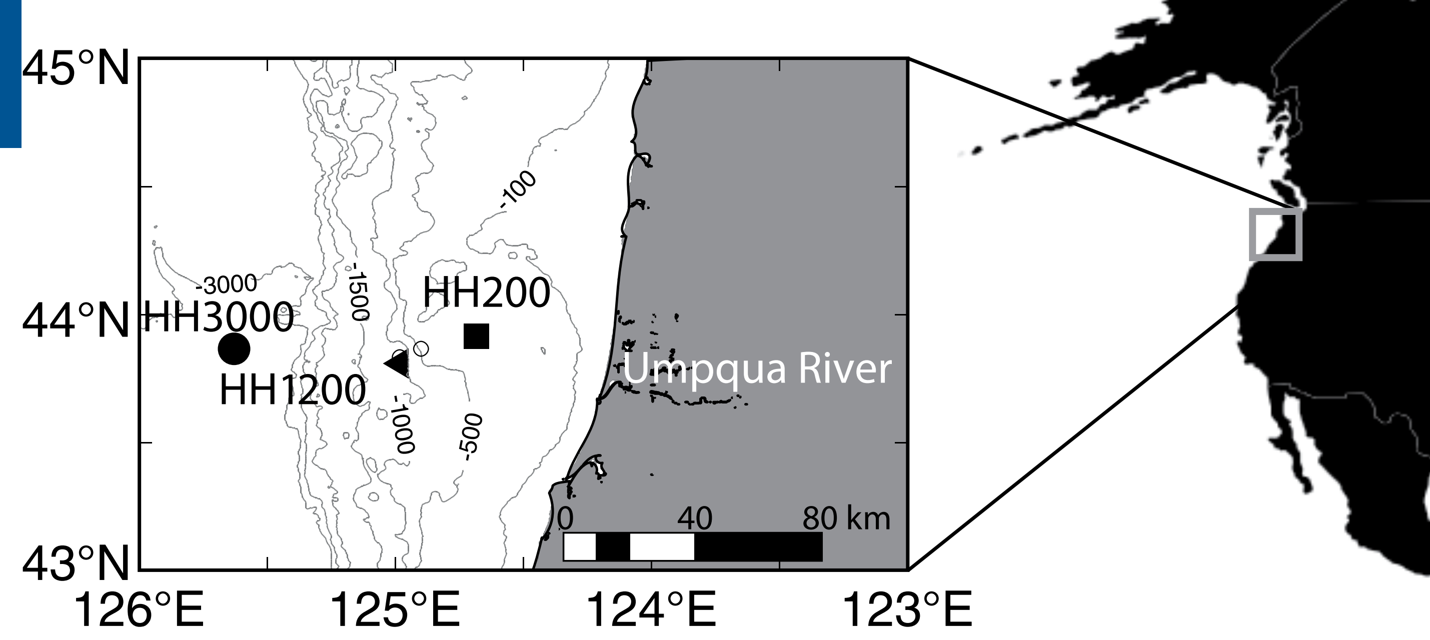
Dreizack Seamount:



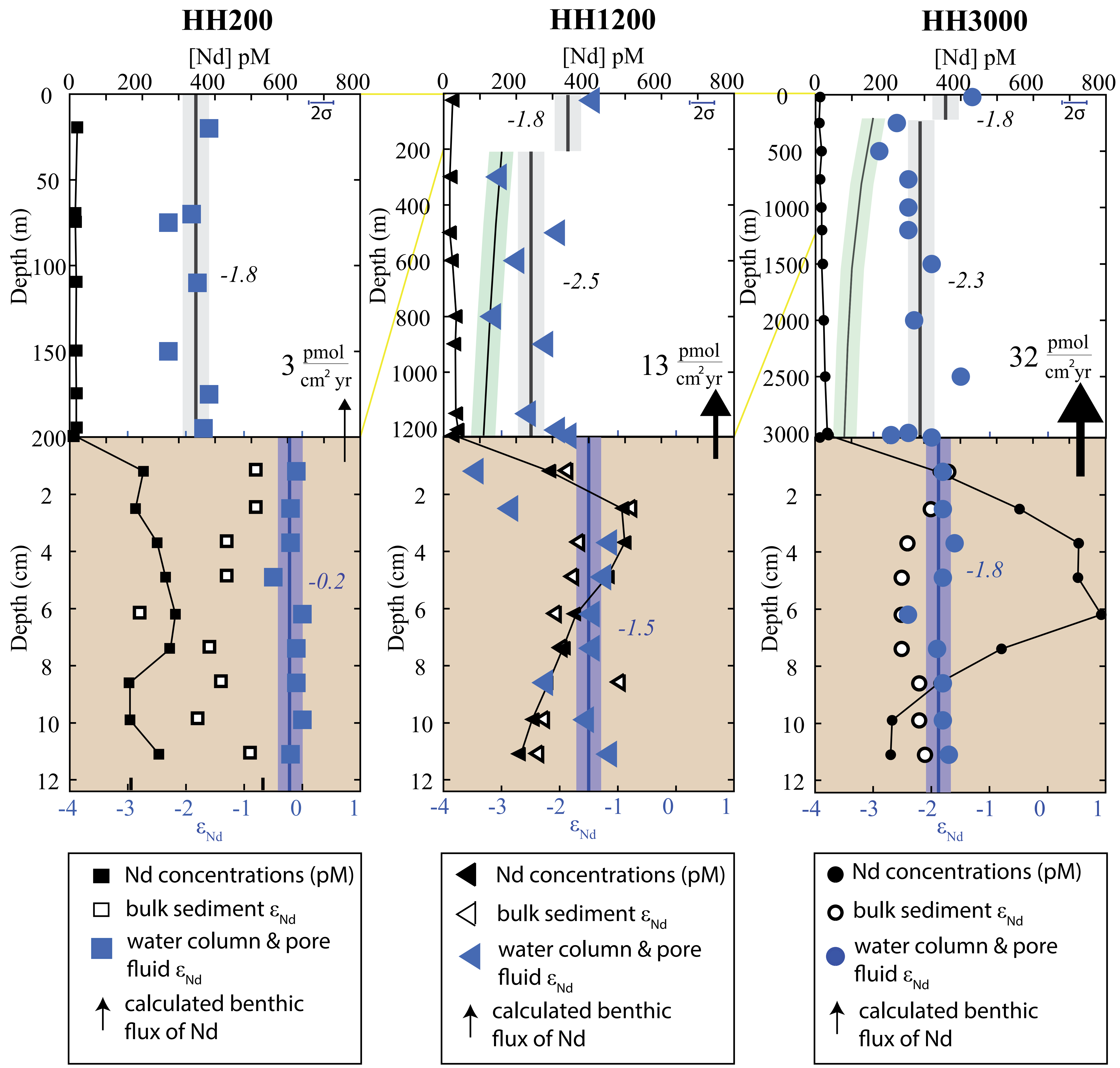
Deep NE Atlantic, Dreizack seamount:

- Extreme εNd range of bulk weak leachates and forams (εNd = -28 to -5)
- no indication for migration of signal up or down (sharp boundaries to over-/underlying sediments)
- no indication for benthic flux into bottom waters at Dreizack seamount

Blaser et al., GCA (accepted)



Oregon margin:



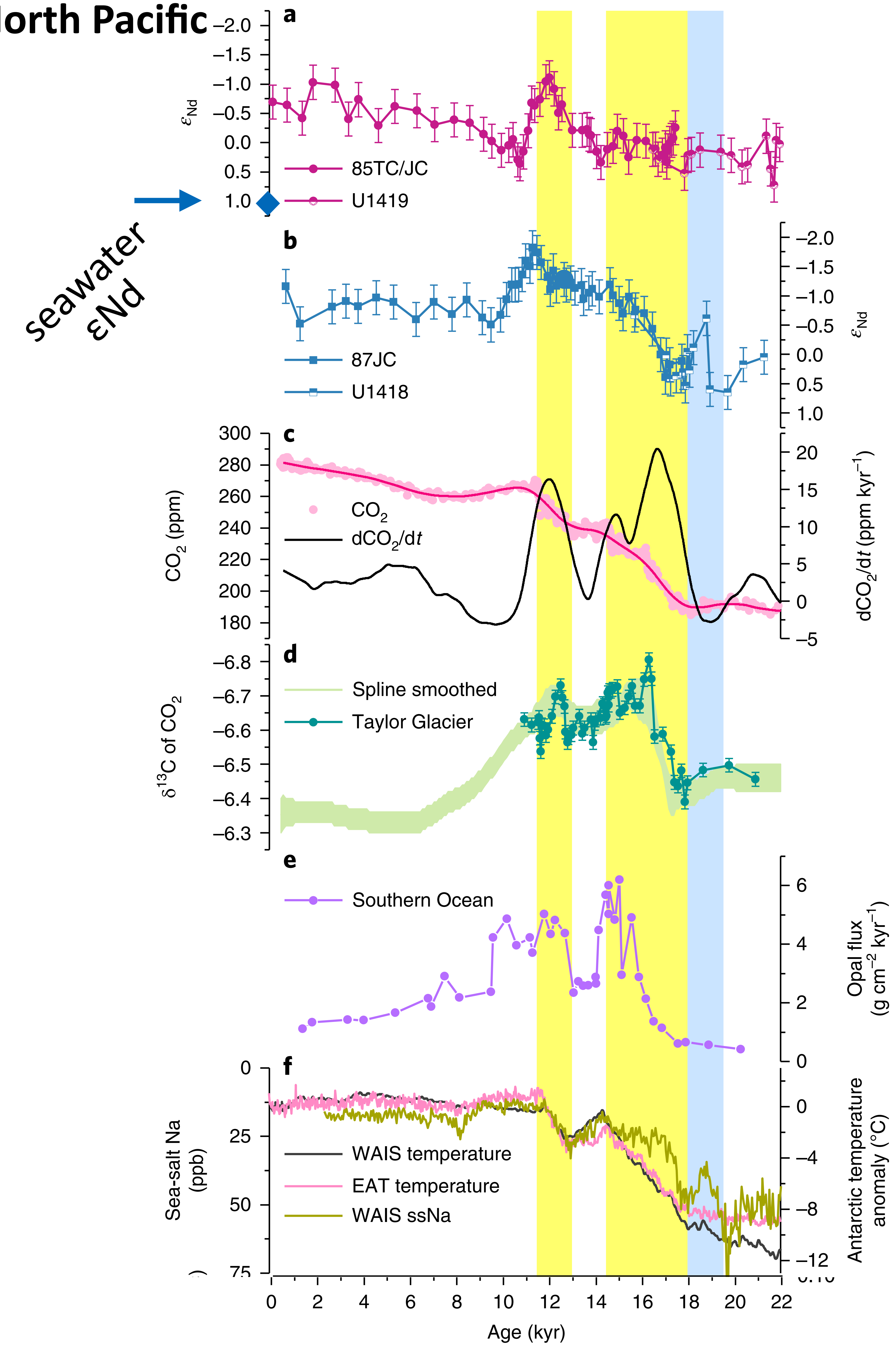
NE Pacific, Oregon Margin:

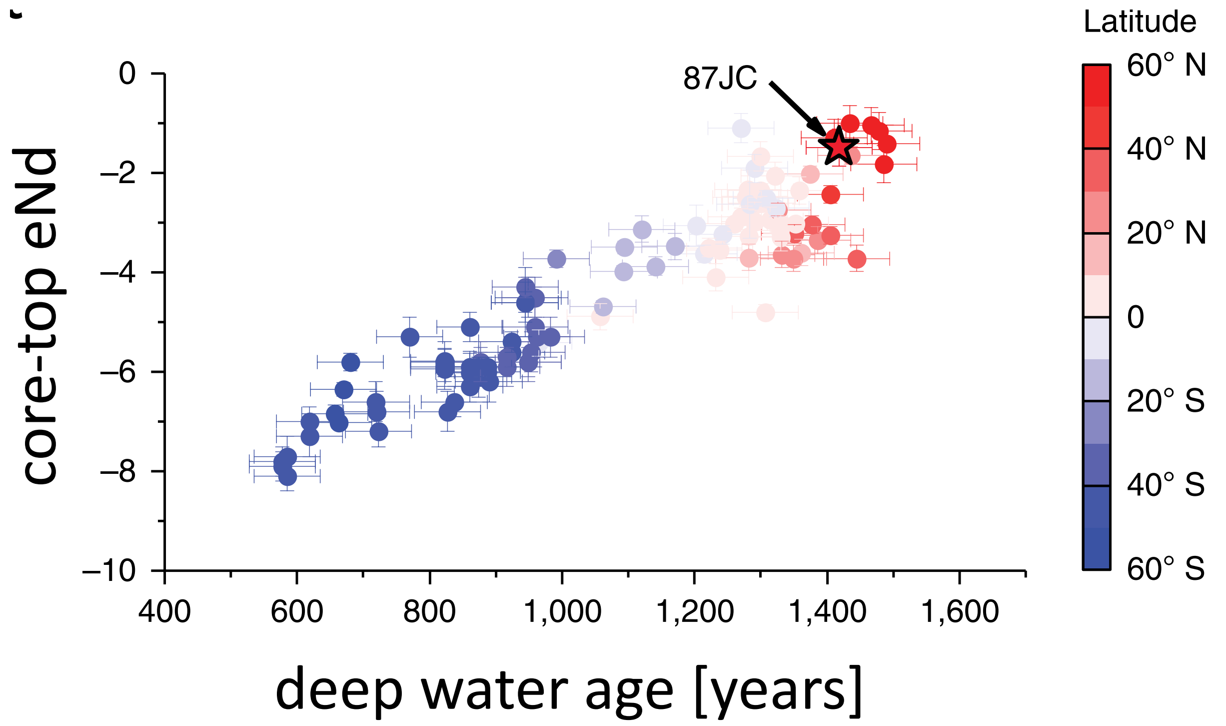
- porewaters are **major source of REEs** to the ocean
- if extrapolated to global ocean, it can account for missing Nd flux
- affects bottom water εNd (>2000 m upwards)
- magnitude of the benthic flux is a result of the development of reactive authigenic phases during diagenesis & depends on circulation strength

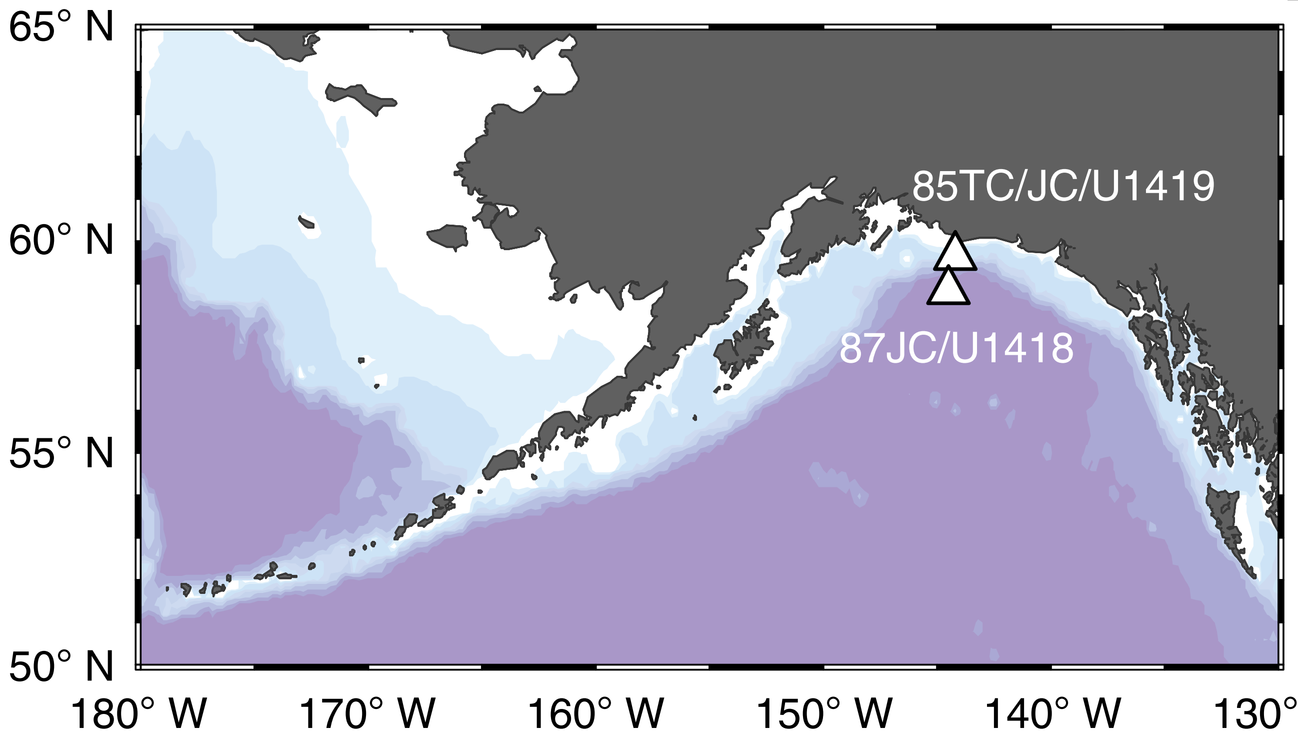
Abbott et al., GCA (2015);
Abbott et al., Geology (2015);
Abbot et al., EPSL (2016)

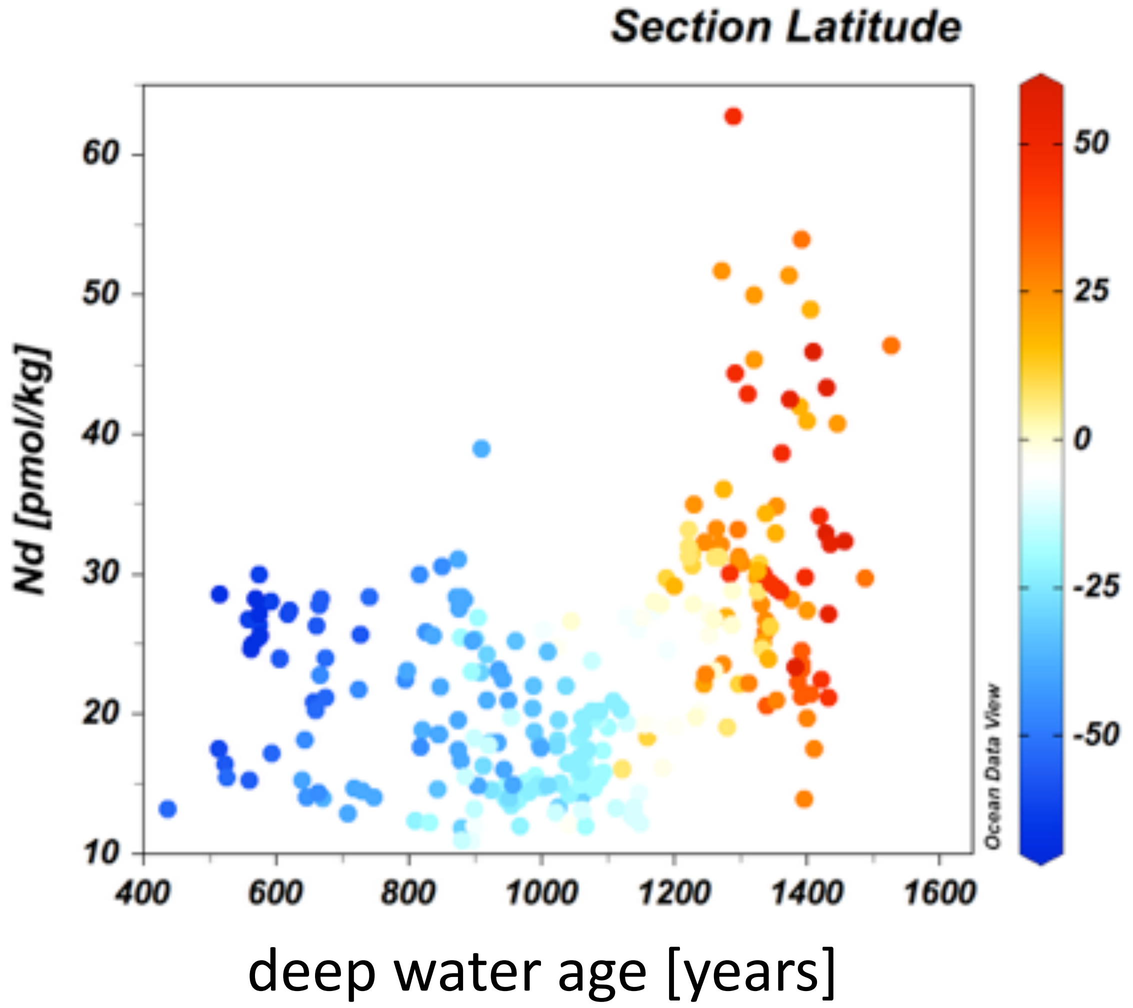
2. Challenges & Open Questions - Benthic Flux

North Pacific







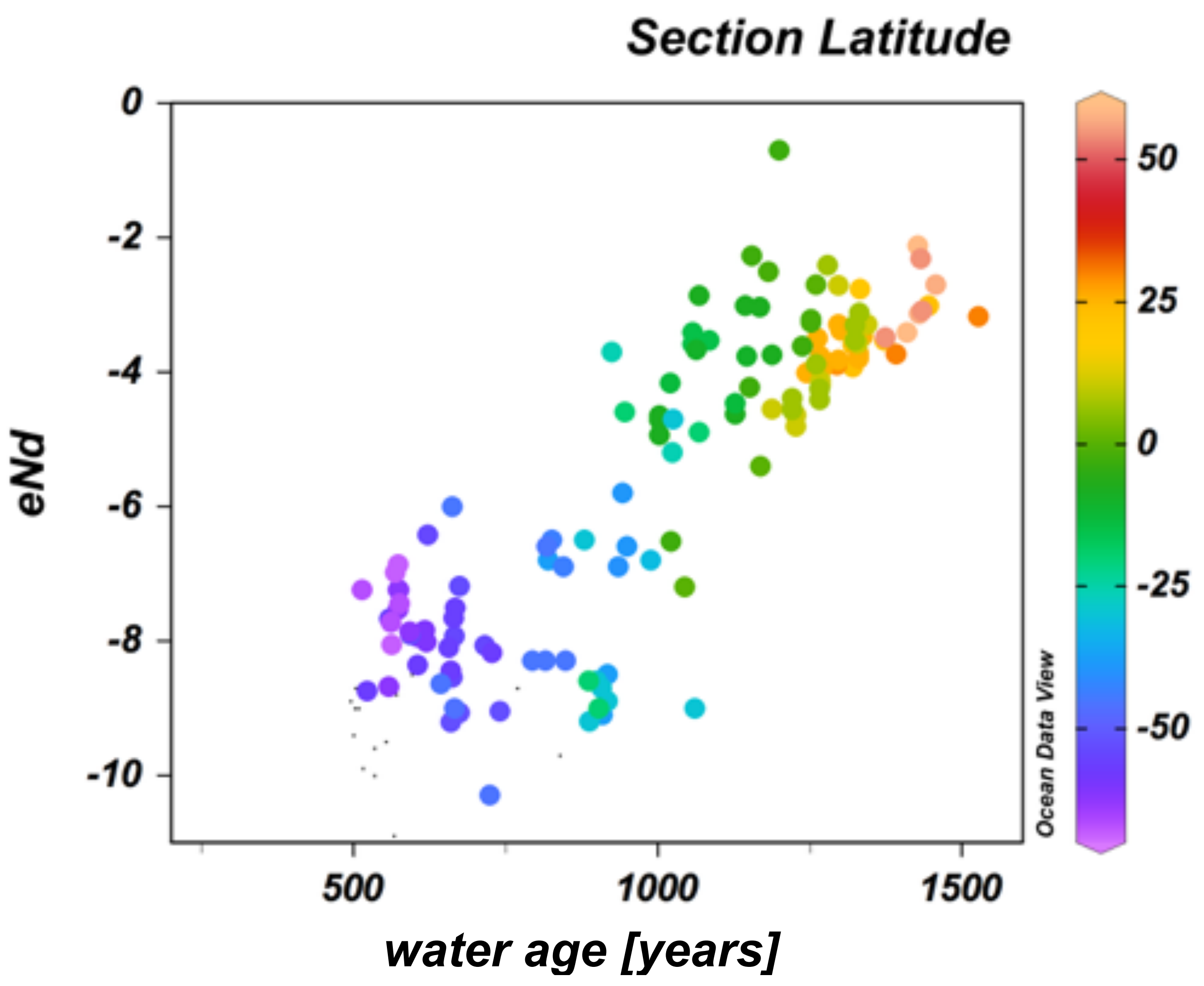


N Pacific:

- deep water εNd = function of exposure time to benthic flux (i.e., circulation speed)
- downcore εNd reflects circulation rate (more positive εNd = slow circulation)
- no correlation of deep water [Nd] with age

Du et al., Nat.Geo. (2018);
Compilation (Pahnke); Gebbie & Huybers (2012)

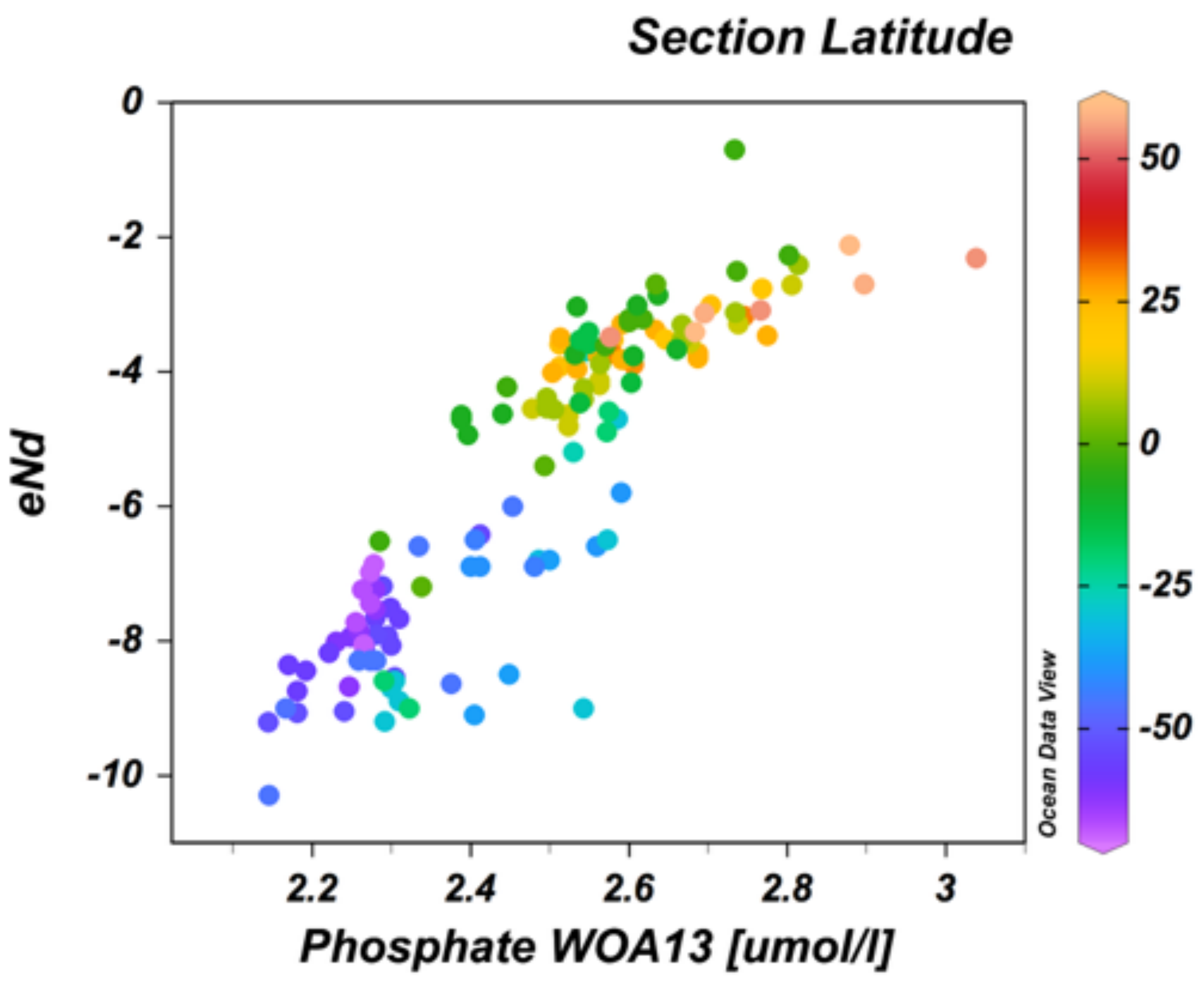
Benthic flux?

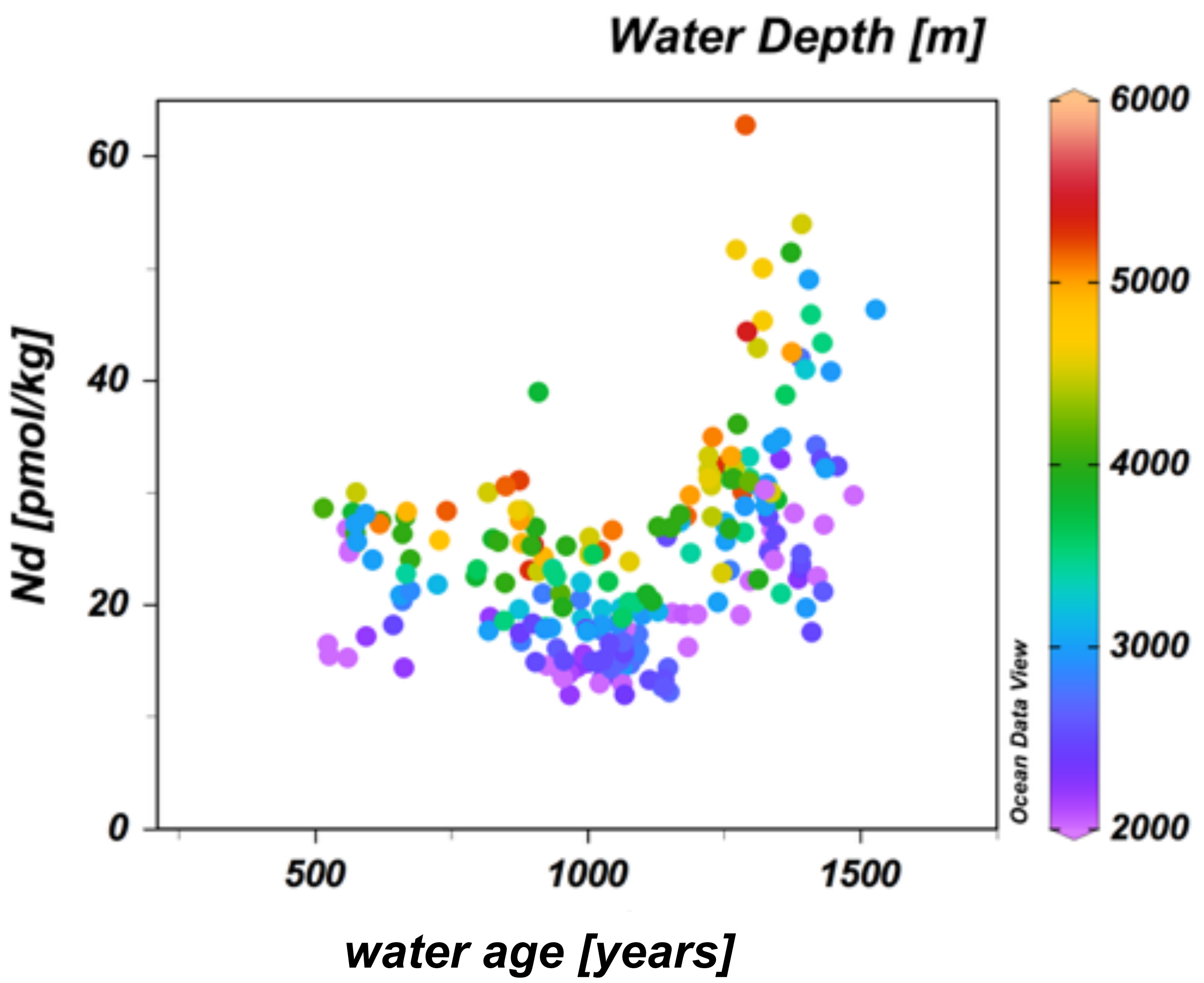


Pacific >2000 m:

- εNd correlates with deep water age & phosphate
- [Nd] does not correlate with deep water age

➔ no indication for benthic flux on a global scale



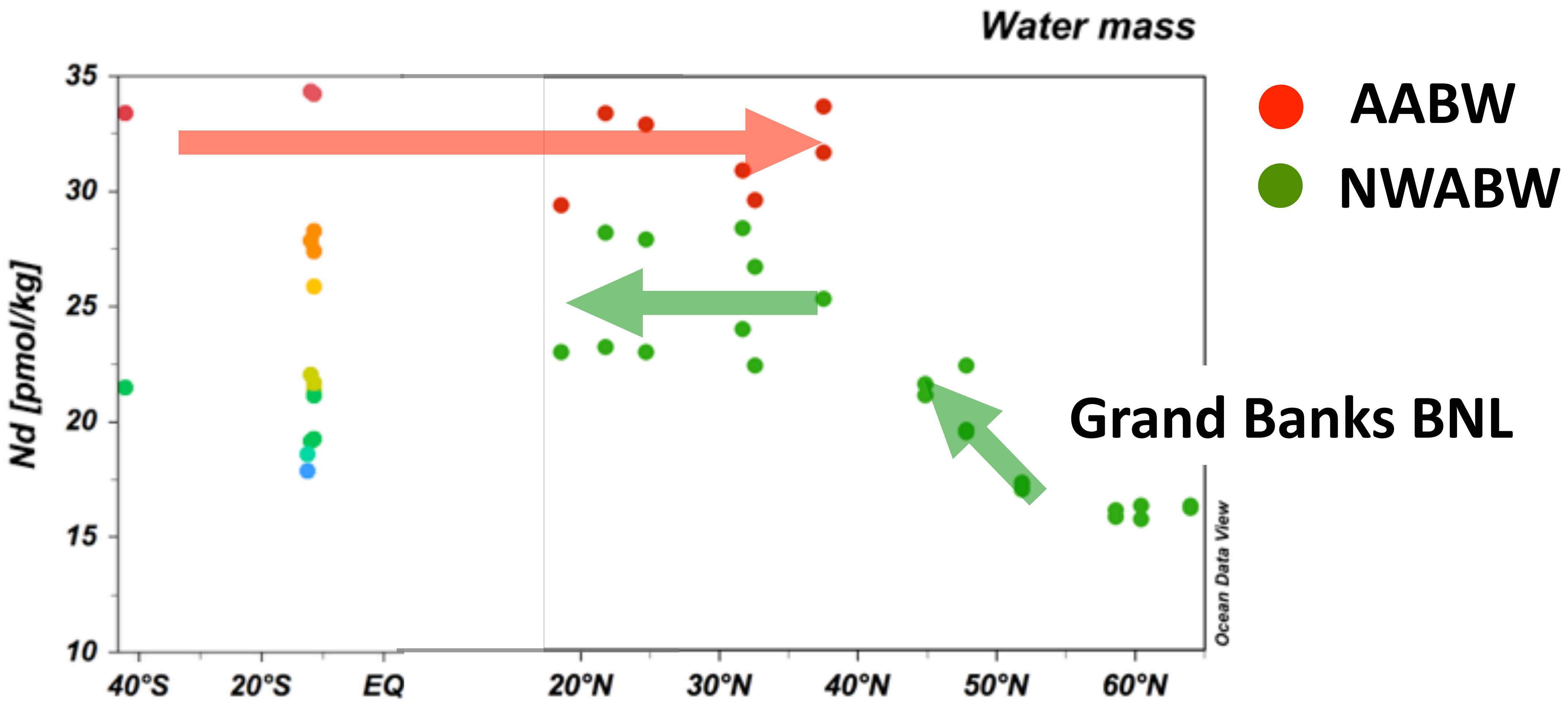


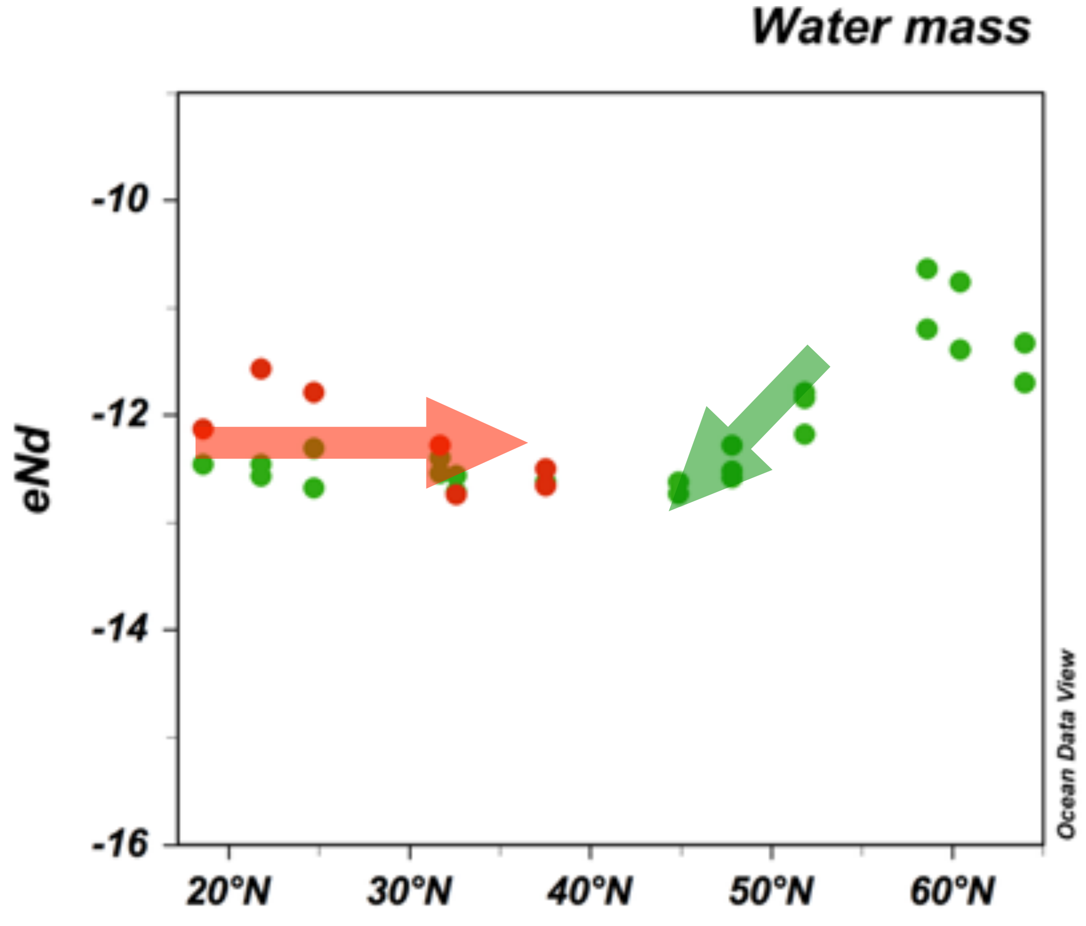
Compilation (Pahnke)
Gebbie & Huybers (2012)

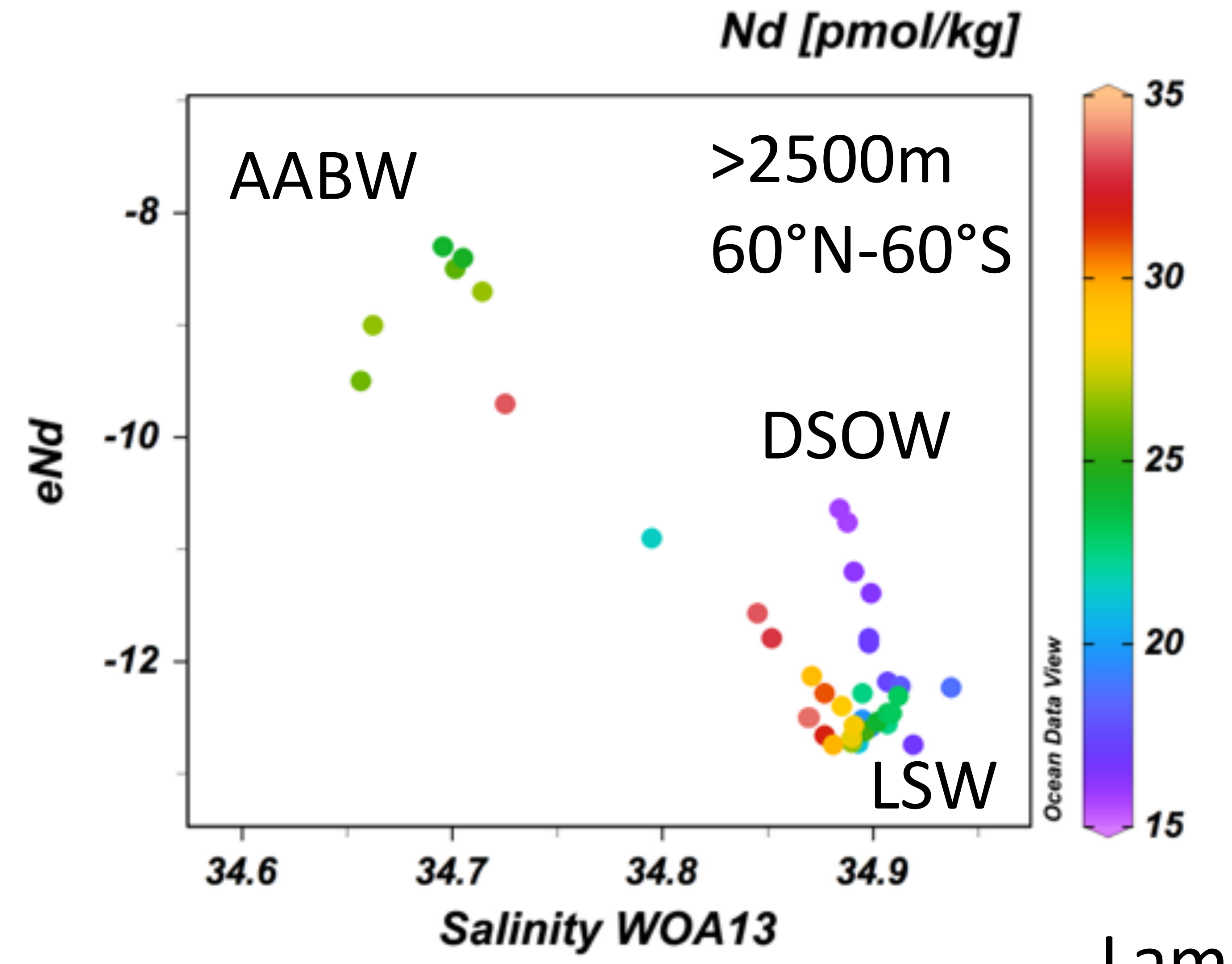
2. Challenges & Open Questions - Benthic Flux

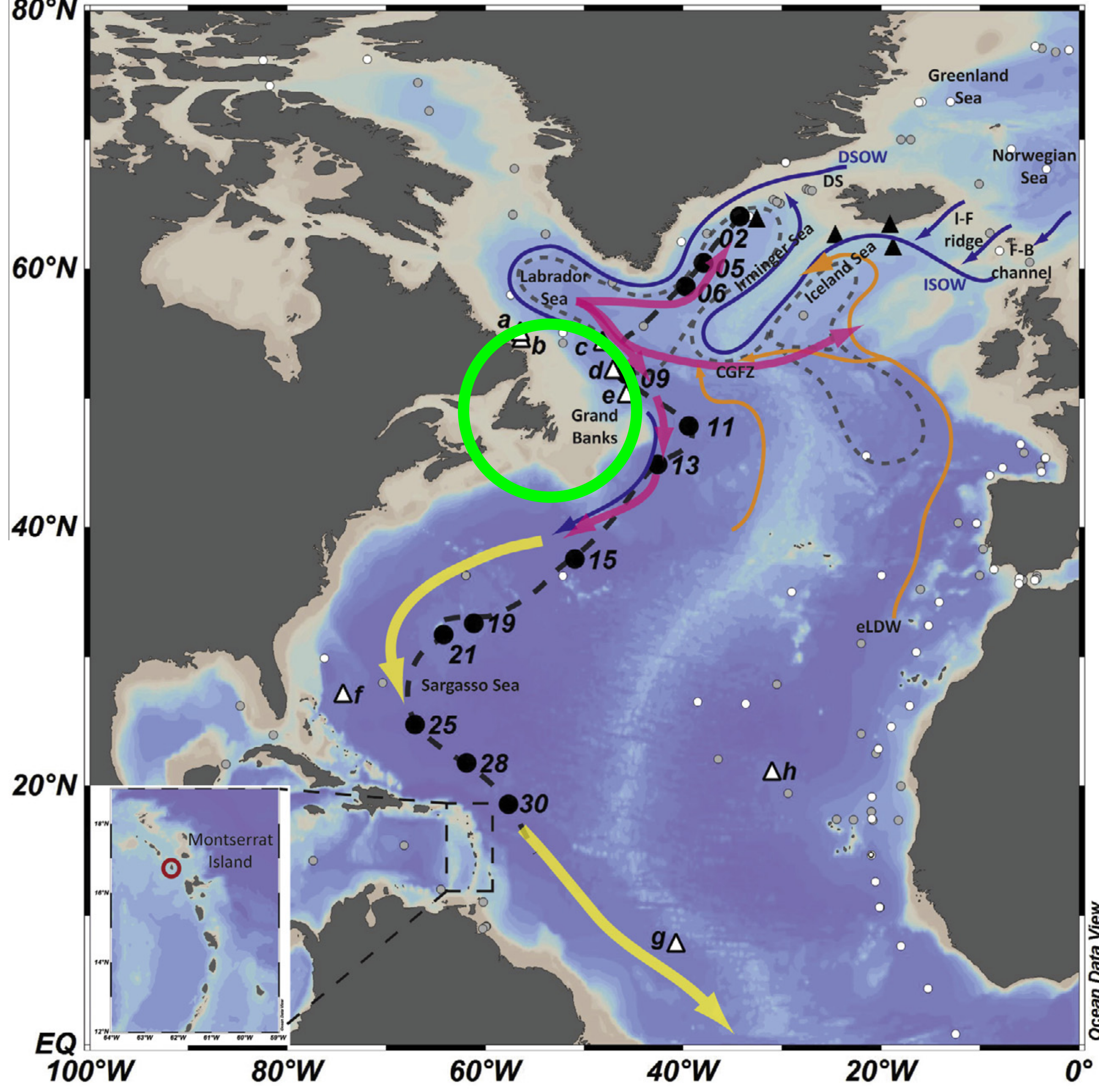
West Atlantic

Local Nd input and εNd modification from benthic nepheloid layer



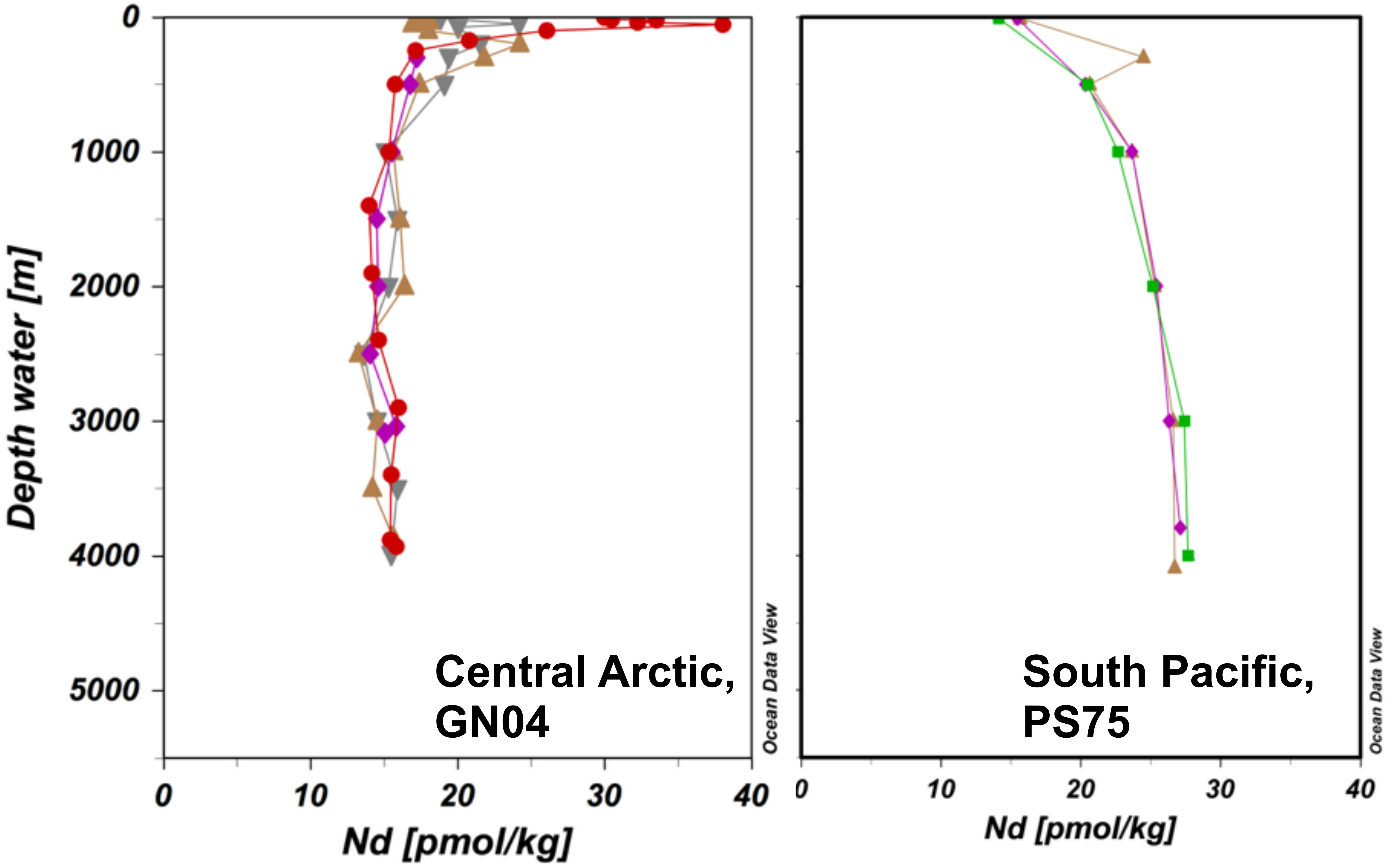






Lambelet et al., GCA (2016);
Zheng et al., EPSL (2016);
Hathorne et al., Marine Chem. (2015)

Benthic flux?



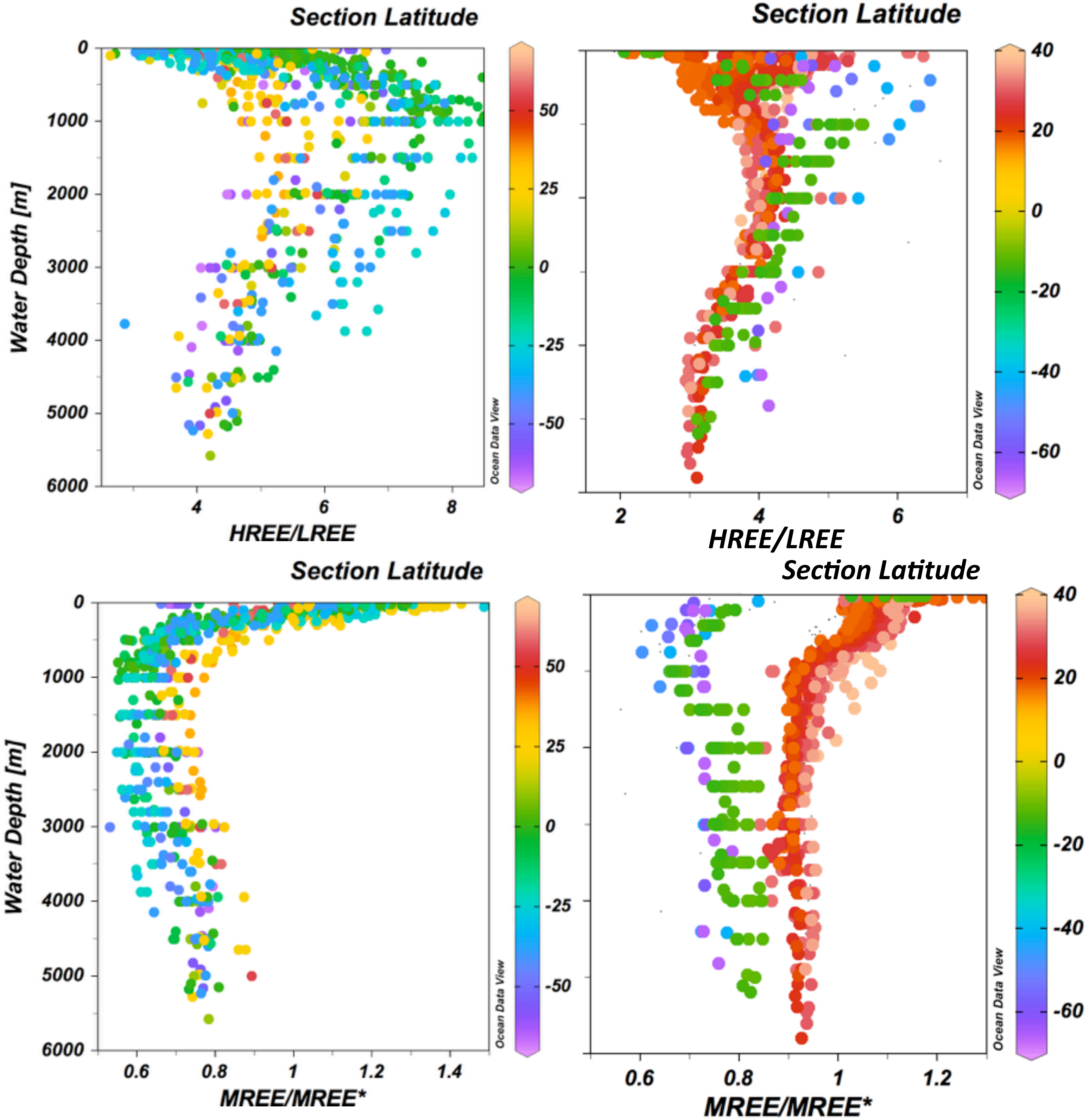
Global GEOTRACES Observations:

- no indication for benthic REE flux in Arctic and Southern Ocean?

Basak et al., EPSL (2015);
Paffrath & Pahnke, unpubl. data

Benthic flux?

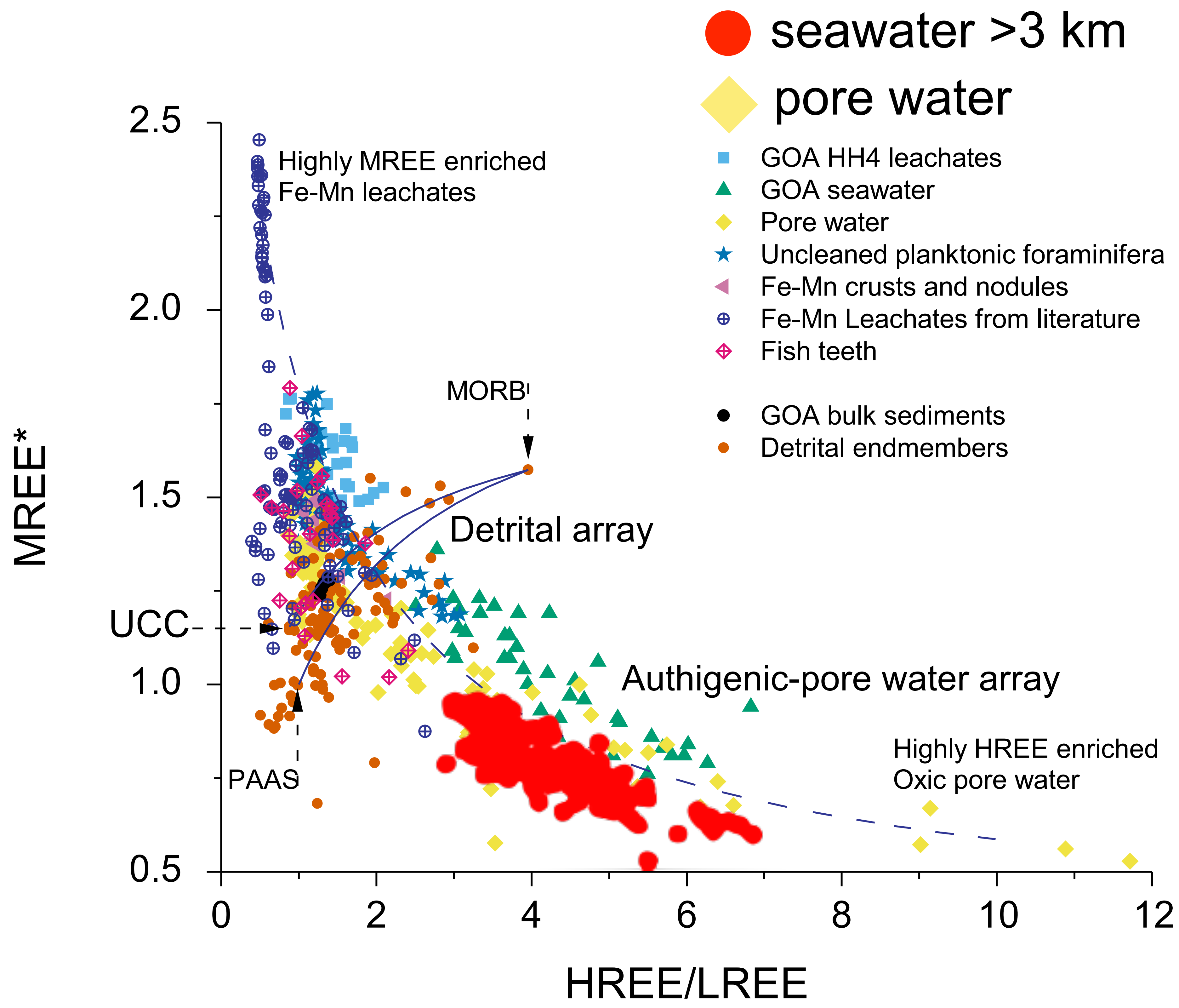
Pacific **Atlantic**



Global GEOTRACES Observations:

HREE/LREE and MREE/MREE*

- pore water: highly variable (e.g., Abbot et al., 2015; Du et al., 2016)
- bottom water: much less variable

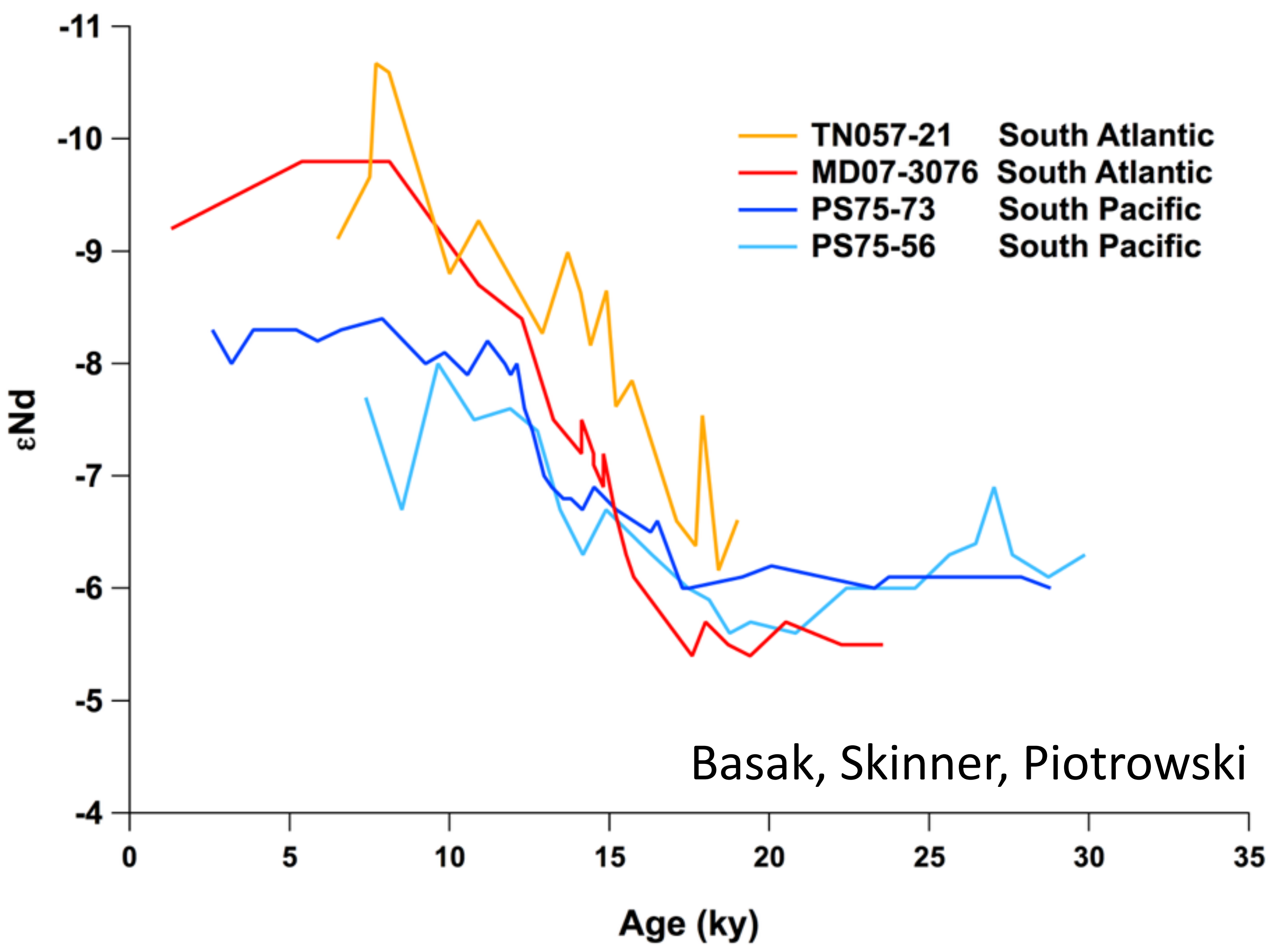


Du et al., GCA (2016)

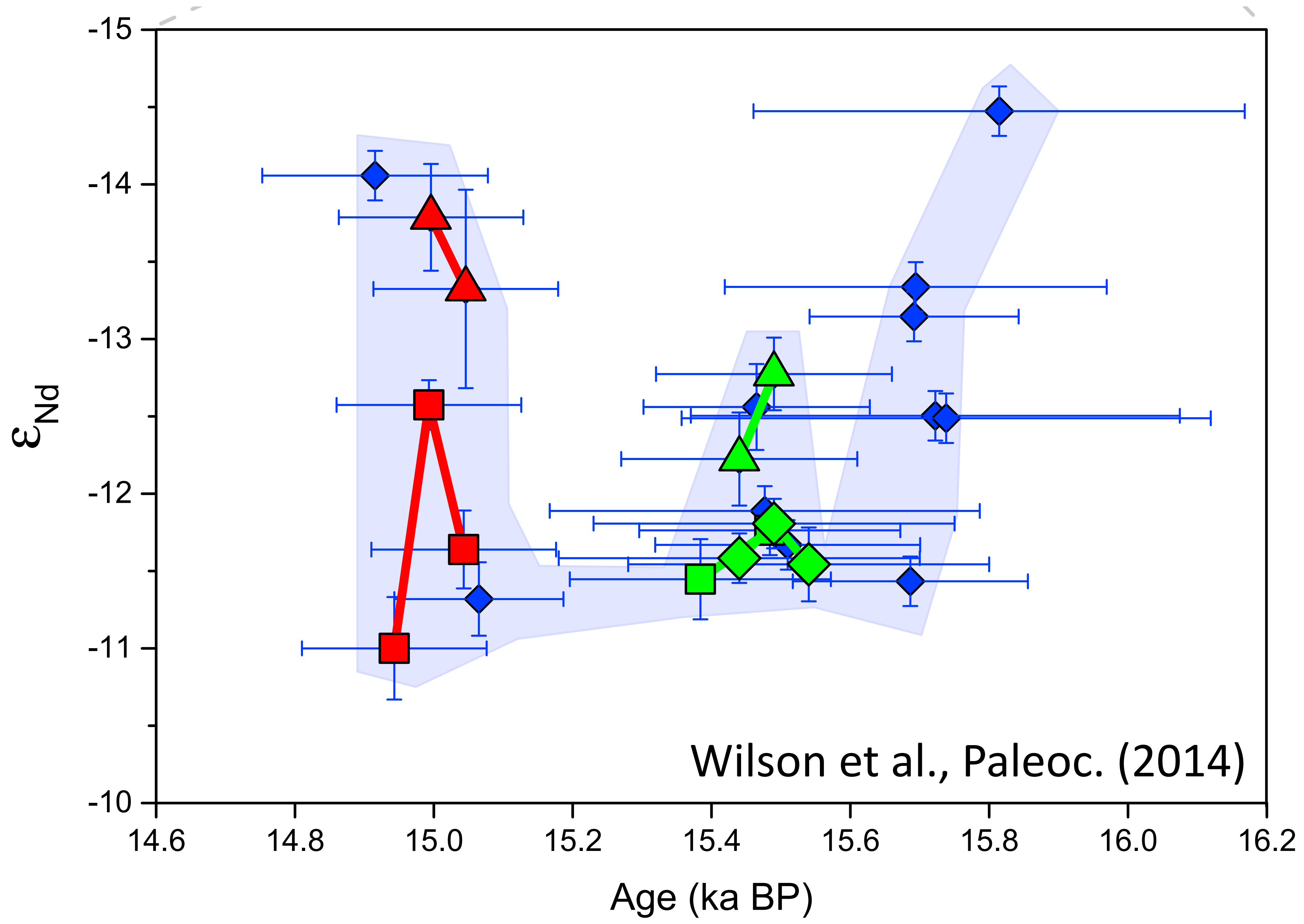
Basak et al., EPSL (2015);
Behrens et al., EPSL (2018)

Benthic flux? **Are paleo-records consistent with benthic flux hypothesis?**

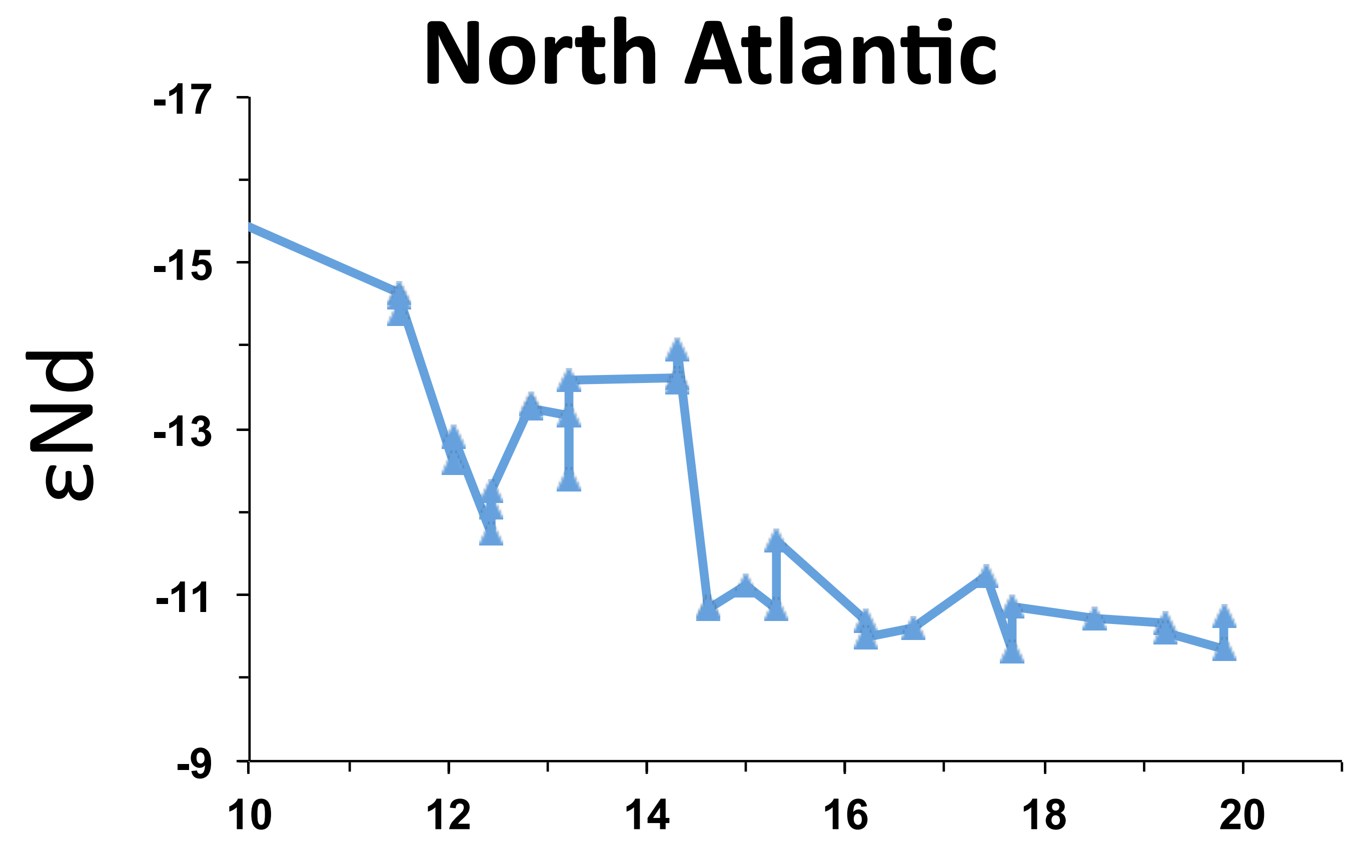
Southern Ocean-wide consistency of deep water εNd changes:

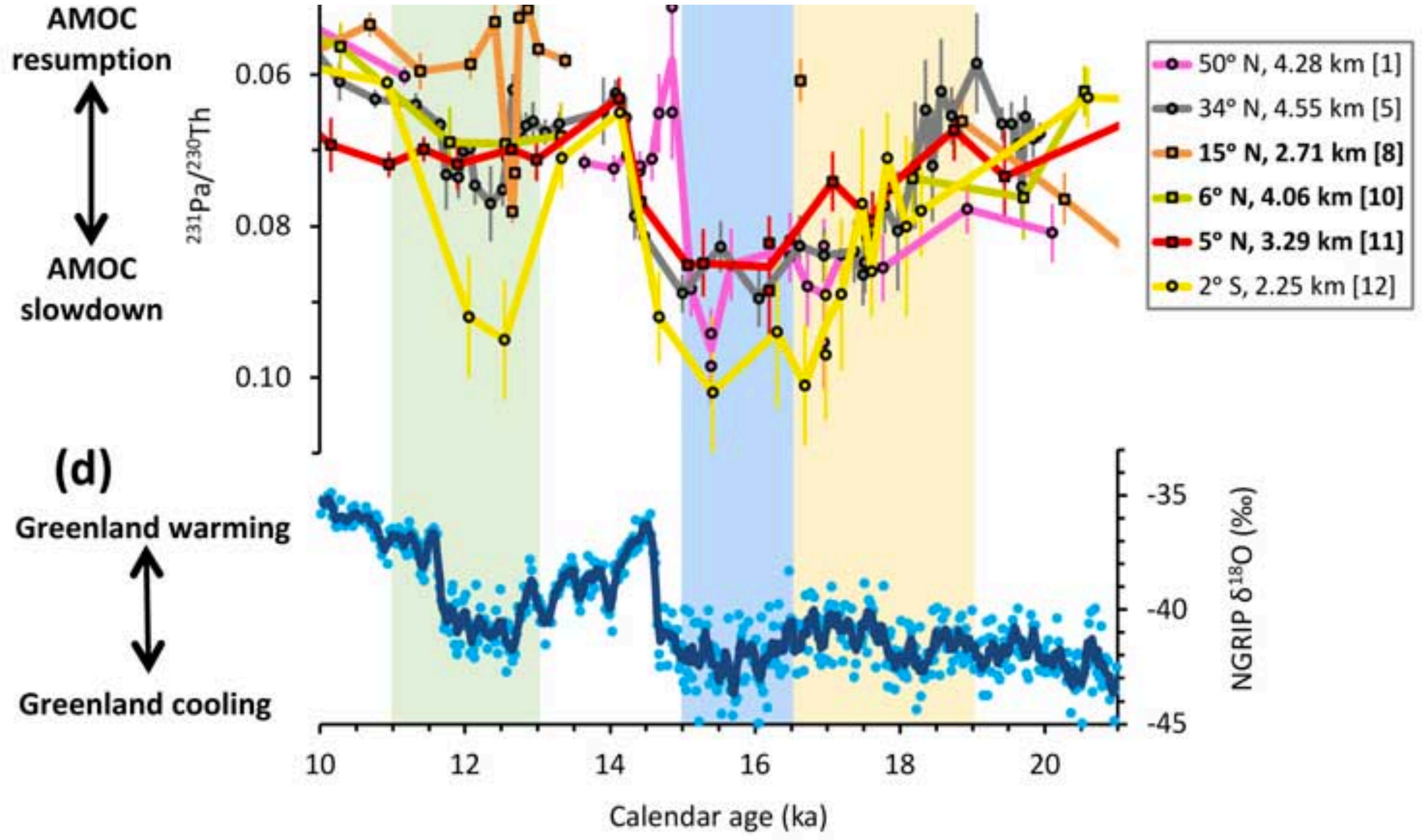


Abrupt εNd changes (corals):



eNd *versus* Pa/Th - Are we closer to understanding the differences?





- if eNd reflects deep water source and Th/Pa circulation speed, the records are not at odds
- lack of change from LGM through H1 calls benthic flux hypothesis into question

GEOTRACES Science Plan (2003);
Ng et al., Nat.Comm. (2018);
Roberts et al., Science (2010)

How to precede?

- Water mass circulation and mixing play important role in εNd distributions

  εNd will remain useful (qualitative) tracer for water mass provenance and circulation pathways

  non-conservative processes are increasingly used to explain inconsistencies/strong anomalies in paleo-records
- How can non-conservative processes be identified / quantified in paleo applications?
- Is benthic flux a global phenomenon and the main source of Nd to the ocean?
- Should eNd rather be used as a dynamic tracer (circulation speed/deep water exposure time to benthic flux)?

What is needed?

- Improved global coverage of observations in the **water column** (e.g., in Pacific, Southern Ocean) and **sediment**
- Observations at **interfaces** (land/margin-ocean (rivers, SGD), seafloor-seawater)
- Direct **benthic flux measurements** (benthic chambers)
- Modeling studies

Thank you!