Neodymium Isotopes as Proxies for Past Ocean Circulation

Progress & Challenges

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1. State of the Art - current use of Nd isotopes as paleocirculation proxy

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 $\epsilon$Nd as conservative water mass tracer:

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

![Boundary exchange](image)
### 1. State of the Art - current use of Nd isotopes as paleocirculation proxy

#### Proven εNd archives of paleo-seawater:

<table>
<thead>
<tr>
<th>Archive:</th>
<th>Extraction method:</th>
<th>Application comment:</th>
</tr>
</thead>
<tbody>
<tr>
<td>foraminifera Fe-Mn-oxide coatings</td>
<td>manual (without cleaning) or weak leach of bulk sed.</td>
<td>high temporal resolution in carbonate-rich sediments</td>
</tr>
<tr>
<td>fish teeth / debris</td>
<td>manual</td>
<td>medium to low temporal resolution, no CaCO$_3$ required, not ubiquitous</td>
</tr>
<tr>
<td>deep sea corals</td>
<td>manual (with chemical cleaning)</td>
<td>absolute U-Th dating, shallow depths, very high temporal resolution, no continuous records, can change habitat</td>
</tr>
</tbody>
</table>
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
1. State of the Art - scientific advances from $\varepsilon$Nd

Global GEOTRACES Observations:

- $\geq 75\%$ conservative behavior of Nd

**South Atlantic >1000m**

**NE Atlantic: NADW-depth**

**South Pacific: >1000m**

**West Pacific: >1000m (except AAIW in the South)**
Global observations (from GEOTRACES):

Predicted vs. observed seawater $\varepsilon$Nd:

- offsets: equ. W & E Pacific

color shading = predicted $\varepsilon$Nd
colored dots = observed $\varepsilon$Nd

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

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

Atlantic: 

South Atlantic: 

- AAIW: εNd +/- stable from LGM to Holocene (except for change in early Holocene)
- Deep Water: εNd more radiogenic during LGM
- No increased Pacific contribution to AAIW?
Deep Southern Ocean:

Deep Southern Ocean past 20 ky:

- consistent timing and direction of $\varepsilon$Nd 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

Homogeneous $\varepsilon$Nd of -8:
- well-mixed deep waters

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

Basak et al., Science (2018)
1. State of the Art - scientific advances from $\varepsilon$Nd

Deep South Pacific:

Zonal section through the South Pacific

Different $\varepsilon$Nd above/below 4000 m:

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

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

Basak et al., Science (2018)
Challenges for $\varepsilon$Nd as conservative water mass tracer:

- Overprints from local/regional sources
  - **boundary exchange** at continental/island margins & seafloor ($\varepsilon$Nd)
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  - **benthic flux** of REE ($\varepsilon$Nd, [Nd])
2. Challenges & Open Questions - Boundary Exchange

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?
2. Challenges & Open Questions - Particle-Seawater Exchange

Atlantic GA03

North Atlantic TAG hydrothermal plume:
- Nd removal
- εNd modification towards radiogenic values
2. Challenges & Open Questions - Particle-Seawater Exchange

Indian Ocean

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

Yu et al., EPSL (2017)
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)
Deep NE Atlantic, Dreizack seamount:

- Extreme $\varepsilon$Nd range of bulk weak leachates and forams ($\varepsilon$Nd = -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 $\varepsilon$Nd (>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:

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

Du et al., Nat.Geol. (2018);
Compilation (Pahnke); Gebbie & Huybers (2012)
Benthic flux?

Pacific >2000 m:

- $\varepsilon$Nd correlates with deep water age & phosphate
- [Nd] does not correlate with deep water age

$\Rightarrow$ no indication for benthic flux on a global scale

Compilation (Pahnke) Gebbie & Huybers (2012)
Local Nd input and εNd modification from benthic nepheloid layer

**West Atlantic**

![Map of the North Atlantic Ocean indicating the location of seawater profiles and surface samples from this study and the literature.](image)

**Fig. 1.** Map of the North Atlantic Ocean indicating the location of seawater profiles (black dots with numbers) and surface samples (black triangles) from this study and the literature (white and grey symbols). White triangles with letters refer to stations from the literature, the data from which are used for comparison in this study. (a) Signature station 5 (Lacan and Jeandel, 2005a); (b) Hudson 83-036 LC (Piepgras and Wasserburg, 1987); (c) Thalahassa station 15 (Rickli et al., 2009); (d) Hudson 83-036 station 11 (Piepgras and Wasserburg, 1987); (e) Signature station 6 (Lacan and Jeandel, 2005a); (f) OCE 63 station 3 (Piepgras and Wasserburg, 1987); (g) TTO/TAS station 63 (Piepgras and Wasserburg, 1987); (h) NE Atl. E3 O (Tachikawa et al., 1999).

Light grey dots represent literature data where at least three depths were sampled for Nd isotopic compositions, and the white dots mark stations with less than three published depths results. Pink (thicker) arrows represent schematically the spreading of Labrador Sea Water (LSW). Blue (thinner) arrows symbolise overflow of waters from the Greenland and Norwegian Seas (DSOW: Denmark Strait Overflow Water; ISOW: Iceland–Scotland Overflow Water). Yellow (thicker) arrows represent the spreading of North Atlantic Deep Water (NADW) once exported from the subpolar gyre. Orange (thinner) arrows mark the northward flow of southern-derived water masses (w-LDW and e-LDW: western and eastern Lower Deep Water, respectively). Dotted grey lines represent deep recirculation cells. DS: Denmark Strait; I-F ridge: Iceland Faroe ridge; F-B channel: Faroe Bank channel; CGFZ: Charlie Gibbs Fracture Zone. Stippled black line marks the path of the section view shown in Fig. 2. The map was created using ODV software, available at [http://odv.awi.de/](http://odv.awi.de/) (Schlitzer, 2012).

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2. Challenges & Open Questions - Benthic Flux

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
2. Challenges & Open Questions - Benthic Flux

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

![Graph showing Benthic flux and Global GEOTRACES Observations: HREE/LREE and MREE/MREE*](image)

Basak et al., EPSL (2015); Behrens et al., EPSL (2018)
Southern Ocean-wide consistency of deep water $\varepsilon$Nd changes:

![Graph showing Southern Ocean-wide consistency of deep water $\varepsilon$Nd changes.](image1)

Abrupt $\varepsilon$Nd changes (corals):

![Graph showing abrupt $\varepsilon$Nd changes in corals.](image2)
3. Summary & Perspectives

**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

- Reichs isotopes, where $\varepsilon_{Nd}$ 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

- Fig. 6: Distribution of advection budg and flow of ocean at the warmer TEI (2004)
- TEIs in the warmer ocean are discussed
3. Summary & Perspectives

How to precede?

- Water mass circulation and mixing play important role in $\varepsilon$Nd distributions
  
  $\varepsilon$Nd 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 $\varepsilon$Nd 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!