Seeing the Past Through JGOFS Spectacles

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The Original JGOFS Mission:

“To investigate the time-varying fluxes of carbon in the ocean”
AII54-25PC
Central Panama Basin

500 kyr record of organic carbon abundance

Pedersen et al., 1991
4 glacial cycles recorded in the Vostok ice core

AI54-25PC
Central Panama Basin

500 kyr of Organic Carbon Abundance
Nitrogen Isotopes As Paleotracers

- **Relative Nutrient Utilization**
  Phytoplankton discriminate against $^{15}$N ($\varepsilon = \sim 5 \, \%$) when $\text{NO}_3^-$ is abundant.
  As $\text{NO}_3^-$ utilization proceeds with distance from the nitrate source, the product becomes isotopically heavier.
  Discrimination has little effect on $\delta^{15}$N when $\text{NO}_3^-$ is scarce.

- **Denitrification**
  Reduction of $\text{NO}_3^-$ by denitrifying bacteria strongly fractionates the product $\text{N}_2$ (which is depleted in $^{15}$N) from the substrate.
  The residual $\text{NO}_3^-$ becomes progressively enriched as denitrification proceeds and $\text{N}_2$ and $\text{N}_2\text{O}$ are lost to the atmosphere.
Nitrogen Isotopes in Surface Sediments

Nitrate Climatology (Levitus)

Farrell et al., 1995
Transect Across the Eastern Equatorial Pacific at ~90° W:

“Lighter” 15N during the LGM in conjunction with higher C$_{org}$ % implies dominance of upwelling.

*Farrell et al., 1995*
Global $\Delta pCO_2$, µatm

Takahashi et al.,
PNAS, 1997
But, when we moved from the open equatorial regions to the continental margins, a different picture emerged...
Paleoproductivity Indices, NW Mexican Margin, off Mazatlan

Ganeshram et al., 2000
Nitrogen Isotopes As Paleotracers

- **Relative Nutrient Utilization**
  Phytoplankton discriminate against $^{15}$N ($\varepsilon \approx -5 \%$) when NO$_3^-$ is abundant. As NO$_3^-$ utilization proceeds with distance from the nitrate source, the product becomes isotopically heavier.
  Discrimination has little effect on $\delta^{15}\text{N}$ when NO$_3^-$ is scarce.

- **Denitrification**
  Reduction of NO$_3^-$ by denitrifying bacteria strongly fractionates the product N$_2$ (which is depleted in $^{15}\text{N}$) from the substrate. The residual NO$_3^-$ becomes progressively enriched as denitrification proceeds and N$_2$ and N$_2$O are lost to the atmosphere.
Nitrogen Species and Isotopic Composition in the Eastern Tropical North Pacific

$\delta^{15}N$ of NO$_3^-$

$\delta^{15}N$ of N$_2$

Nitrate (µM)

Nitrate deficit (µM)

Brandes et al., 1998, GBC
Proxy Denitrification History, NW Mexican Margin

Ganeshram et al., 2000
Dissolved Oxygen Concentration on the
\( \sim 27.8 \sigma_T \) Surface

Illustration by Ingrid Hendy
Nitrate $\delta^{15}N$ in the California Undercurrent, ~250 m depth

S. Kienast et al., 2002, Paleoceanography
Core of the California Undercurrent

Kienast et al. 2002
Stadial/Interstadial Transitions in the Santa Barbara Basin

Behl and Kennet (1996)
*Nature*, 379, 243-246.
Greenland-Baja Comparison

CORE MD02-2508   Cruise MONA-IMAGES VIII (June 2002)
Location : Western Margin of Baja California

MONA Shipboard Party, unpublished
Key Coring Sites and Surface Currents, Southern Californian Margin

~ 1 km water depth, below O₂ minimum
ODP Hole 1017E, S. California Margin
1 km water depth

Temperature proxies
- Cool
- Warm

Opal flux proxy

Upwelling and denitrification proxy

Hendy and Pedersen, in prep
Dissolved Oxygen Concentration on the 
~27.8 $\sigma_T$ Surface

Illustration by Ingrid Hendy
Silver and Cadmium

Productivity
(Ag enrichment = hard part nutrient [silica]
Cd enrichment = soft part nutrient [biomass]
Sr enrichment = carbonate [coccoliths, forams])

Ag (unless depleted) & Cd

Ag & Cd

Degradation of organic material

Cd

Oxygen Minimum Zone

Ag & Cd precipitated only if traces of dissolved sulphide present

Redox reactions

Suboxic & dysoxic conditions

Poorly ventilated water

The Ag/Cd ratio is thought to represent increases/decreases in diatom production relative to coccolithophorids
ODP Hole 1017E, S. California Margin
1 km water depth

Hendy and Pedersen, in prep
Summary 1:

- Abrupt climate and hydrographic changes were common and possibly (probably?) synchronous in the North Atlantic and the NE Pacific during the Last Glacial.

- Off California, climate variations were accompanied by biological responses in surface waters and changes in oxygenation at 1 km water depth.

- The time-varying vertical flux of carbon (JGOFS!) was a (critical?) factor in modulating intensity of denitrification in the northeast subtropical Pacific.
A final question:

Are there implications for global climate bound up in variations in the intensity of denitrification in the NE tropical Pacific (and elsewhere)?
Oxygen at 300 m Water Depth

DISSOLVED OXYGEN (ML/L)
**Modern N cycle background:**

Fixed N supply to oceans is ~100-120 Tg yr\(^{-1}\), but the loss is roughly 200 Tg yr\(^{-1}\). **Deficit:** <100 Tg yr\(^{-1}\).

Imbalance is partly compensated by N\(_2\) fixation, but the integrated contribution from this source is not well known.

**Implication:**
*The modern ocean is losing nitrogen. But if NO\(_3^-\) reduction was to be switched off, there would be a net gain of N, allowing “excess” P to be utilized and CO\(_2\) to be drawn down.*
Unpublished data, courtesy Jacqueline Flueckiger, University of Bern
Oman Margin, Arabian Sea

Altabet et al., 2002
Nature

Chlorins

\[ \delta^{15}N \]

\[ \delta^{18}O_{\text{ice}} \]
High-frequency variability of denitrification intensity in the Arabian Sea

Altabet et al., 2002

NB: the timescale for the Arabian Sea cores is not independent, but was derived by correlation to GRIP. It is thus assumption dependent.

Altabet et al., 2002
Summary 2:

• The coupling of upwelling, export production and consequent denitrification in key oxygen minima may have had significant implications for climate but indirectly, through the nutrient-abundance loop.

• Emerging pN₂O records support this inference.

• With respect to the impact of the time-varying fluxes of carbon on pCO₂, both quantification and attribution remain compelling problems.
Continuing Challenges or Needs: (PaleoJGOFS II?)

• More high-resolution paleogeochemical records from underexplored areas (e.g. the western coast of South America, the western Canadian margin, the Guatemalan margin).

• Continued refinement of interpretations based on empirical data with inferences from modelling (and vice versa). Integration and interdisciplinarity remain key.