The NW Indian Ocean’s Biogeochemistry in Relation to a Changing Planet and Changing Concepts

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Nomenclature

Canonical Denitrification: $\text{NO}_3^- \rightarrow \text{NO}_2^- \rightarrow \text{NO} \rightarrow \text{N}_2\text{O} \rightarrow \text{N}_2$

Denitrification: the ensemble of biological processes that convert fixed-N to $\text{N}_2$

This nomenclatural detour is made necessary because of the recent explosion of knowledge *vis a vis* biological pathways that produce $\text{N}_2$. 
Multiple Pathways to N$_2$

What happens to NH$_4^+$ flux from sediments to suboxic water?

--- Nitrifying Bacteria ---

\[
\begin{align*}
\text{NH}_4^+ & \xrightarrow{\text{Anammox}} \text{N}_2 \\
\text{NH}_4^+ & \rightarrow \text{N}_2 \\
\text{NH}_4^+ \text{ and } \text{R-NH}_2 & \rightarrow \text{N}_2 \\
\text{NH}_4^+ \text{ and Organic Matter Oxidation}\;\text{Using IO}_3^-, \text{NO}_3^-, \text{Mn (III & IV)} & \text{ and Fe (III)}
\end{align*}
\]

Denitrifiers & Dissimil. Nitrate Reducers

Oxidation State
Data from 6 US JGOFS Cruises that attempted to resolve the seasonal cycle

Station N9 in quasi-permanent secondary nitrite max (shaded region)
Low oxygens extend considerably deeper (several hundred db) than nitrite maximum.

Existing denitrification estimates assume that denitrification is confined to the nitrite max layer. Is this so?

We need a better understanding of the distribution of N-transformations in the 0-10 micromolar range.
$N_{\text{Deficit}}$ VS. $NTO_{\text{Deficit}}$

Produced locally, elsewhere or some combination? Anammox in particles?
Excess $N_2 + N_{\text{Deficit}}$ vs. Depth
North-South Arabian Sea Sections for NO based and N/P Based Deficits

Distance (km) from most southerly station at 8.0° N

8°N  22-23°N
Do the Ras al Hadd Jet, and Associated Eddies and biology, help to “feed” the suboxic layer?

In any event, this region and Gulf of Oman “light up” in some satellite color images.

This Figure is From John Morrison’s SIBER PPT that I can make available.
Certainly, the RAH jet and eddies are in the right neighborhood.
Does Si regeneration over the shelf, make the shelf a site of enhanced diatom production? Is this phytoplankton community advected northward in a coastal jet, and then swept seaward over the suboxic zone in the RAH jet?

Local nutrient trap

Fig. 29. Anomalously high reactive silicate (μM) values at station S-1 during cruise TN049, suggesting enhanced retention and regeneration of silicate over the shelf during coastal upwelling.
Shaded regions = DO concentrations $<\sim 20\mu M$ (from Deuser). Suboxic regions (DO $< 3 \mu M$) within the shaded areas are major denitrification sites.
With respect to sedimentary P deposition or loss, I think that there is a major difference between suboxic and anoxic conditions.
Bacteria that Oxidize Sulfide With Nitrate

“The More We Look, The More We Find!!!”
Denitrification Sites Not Yet Dreamt of in Our Philosophy?

1. Estimates for denitrification in deep sediments are on the increase.
2. Vents, seeps, & brines, MOR flanks.
3. Transient suboxia [W. Indian Shelf, Bay of Bengal]
4. Denitrification deep within sediments at sediment base-rock boundaries.
5. Denitrification in oxygenated water.
7. Brine pockets in ice.

Asimetrías introducidas por la operación del la energía external en sequencias de sdeimentos y de poblaciones

Ramon Margalef

“..... of a bias introduced by the very structure of the world. It records and tells only one side of the story.”
Suboxic conditions apply in only ~0.1-0.2% of the oceanic water column’s volume. Thus, minor changes in the ocean can cause large % changes in the suboxic volume. It is important to realize that we are undersampling a time variable system and that different types of estimates have different time scales!!!! Portions of the Bay of Bengal are on the verge of suboxia.
My experience and reading leads me to believe that undersampling, sampling problems and incubation problems lead to underestimates of PP.
Have we paid enough attention to PP during the NE Monsoon? Does the widespread nutrient enrichment over the secondary nitrite max. during TN 043 suggest another process that feeds the suboxic zone?

Fig. 9. Average inorganic nitrogen concentrations ($NO_3^- + NO_2^- + NH_4^+$) in the 0–25 db layer during cruises TN043, TN045, TN049, TN050, TN053, and TN054. Concentrations are in µM.
Adaptive and Integrated Monitoring System (AIMS)

Deployment Platform

- Battery Box
- ISCO
- ESM Logger
- Phosphate
- Ammonium
- Power
- Power&Comm.

AIMS Website
www.hpl.umces.edu/aims

HPL Public WEB Server

Shore Station PC

Spread Spectrum or Cellular

YSI 6600

N + N

ISCO or urea

Spread Spectrum or Cellular

Communications
Conclusion

• Thus if we are to understand the productivity of this region, it is essential to resolve the dynamics at scales of less than 10 km.
Fig. 7. Mixed layer depths cruises TN043, TN045, TN049, TN050, TN053, and TN054.
Fig. 12. Inorganic nitrogen (NO$_3^-$ + NO$_2^-$ + NH$_4^+$) to phosphate ratios from all data collected during the US JGOFS Arabian Sea Process Study in the Arabian Sea. Phosphate concentrations have been reduced by 0.05 μM to account for arsenate interference.
Inorganic N / SiO$_4^{4-}$ ratios for the upper 25m along the US JGOFS Southern Line

Fig. 28. Temporal and spatial distribution of average inorganic nitrogen (NO$_3^-$ + NO$_2^-$ + NH$_4^+$) to silicate ratios in the 0–25 db layer along the southern line (stations S-1–S-11).
Comparing $N_{\text{Deficit}}$ for two Arabian Sea cruises

Note that N deficits based on N/P ratios extend much deeper in water column than NO based deficits.