Alternative pathways for removal of nitrogen from the sea

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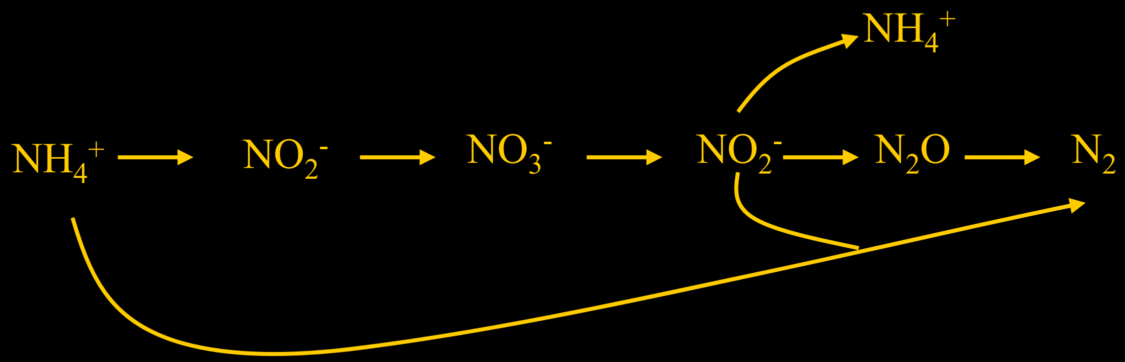
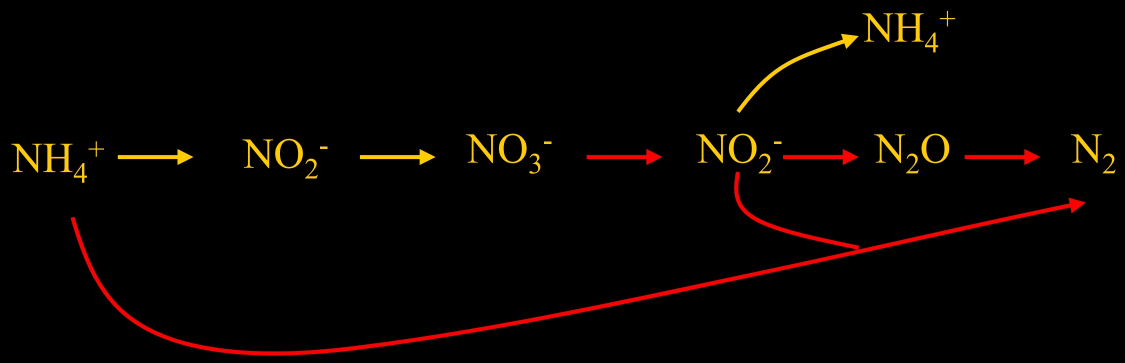
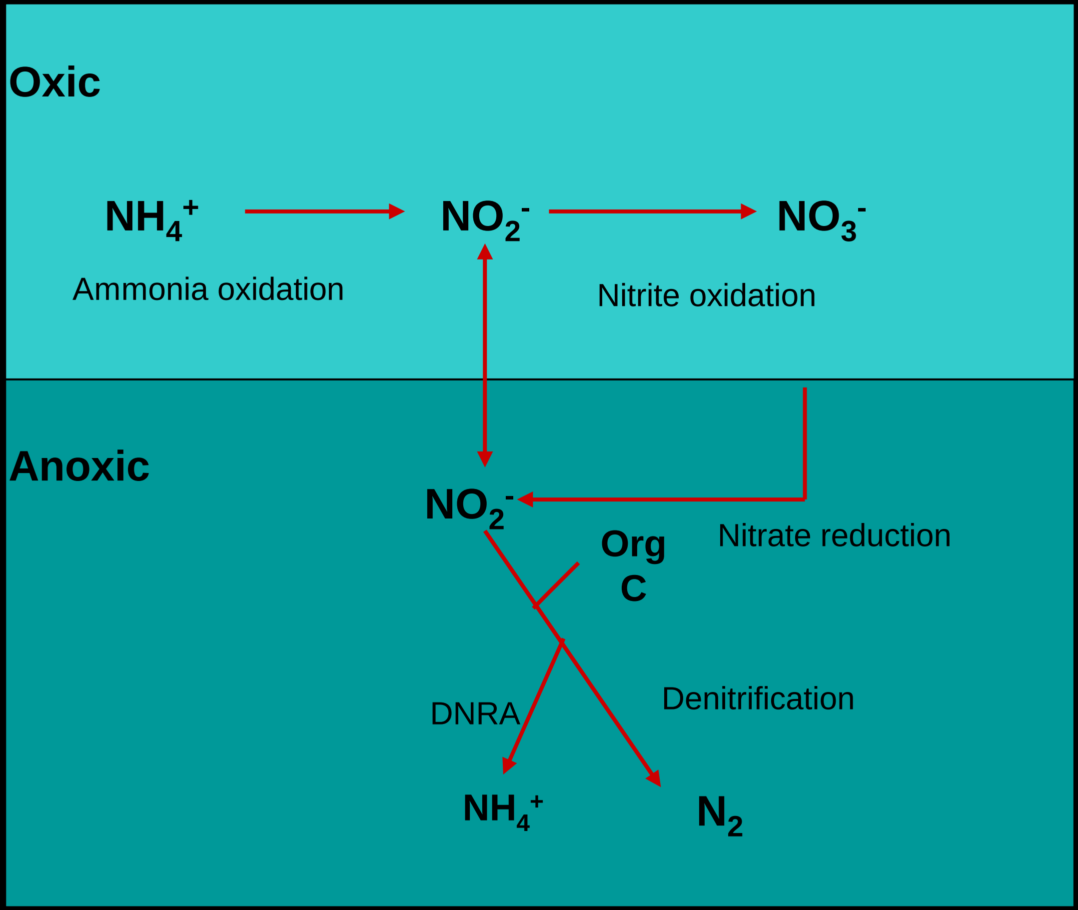


NH4+
NO2-
NO3-
NO2-
N2O
N2
NH4+


NH4+
NH4+
NO2-
NO3-
NO2-
N2O
N2

The classical benthic nitrogen cycle



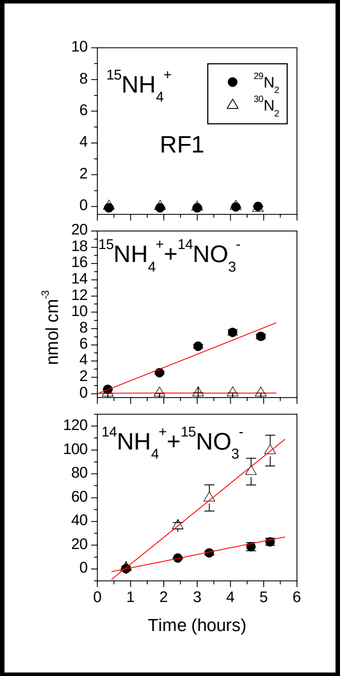
The Anammox process:

$$NH_4^+ + NO_2^- \rightarrow N_2 + 2\ H_2 0$$

Historic:

- Process suggested :Hamm & Thomoson 1941
- NH_4^+ deficit in oxygen minimum zones $\Rightarrow$ anaerobic oxidation of NH4+: Richards 1965
- Disappearance of NH_4^+ from fluidized bed reactor: Mulder 1995
- Reaction identified in wastewater sluged: Van de Graff 1997
- Bacteria responsible for the reaction identified: Schmid 2000
- First direct evidence for existence of the process in marine sediments: Thamdrup and Dalsgaard 2002.

Experimental evidence for anammox: Incubations of sediment slurries with ^{15}N-isotopes



Nothing happens!

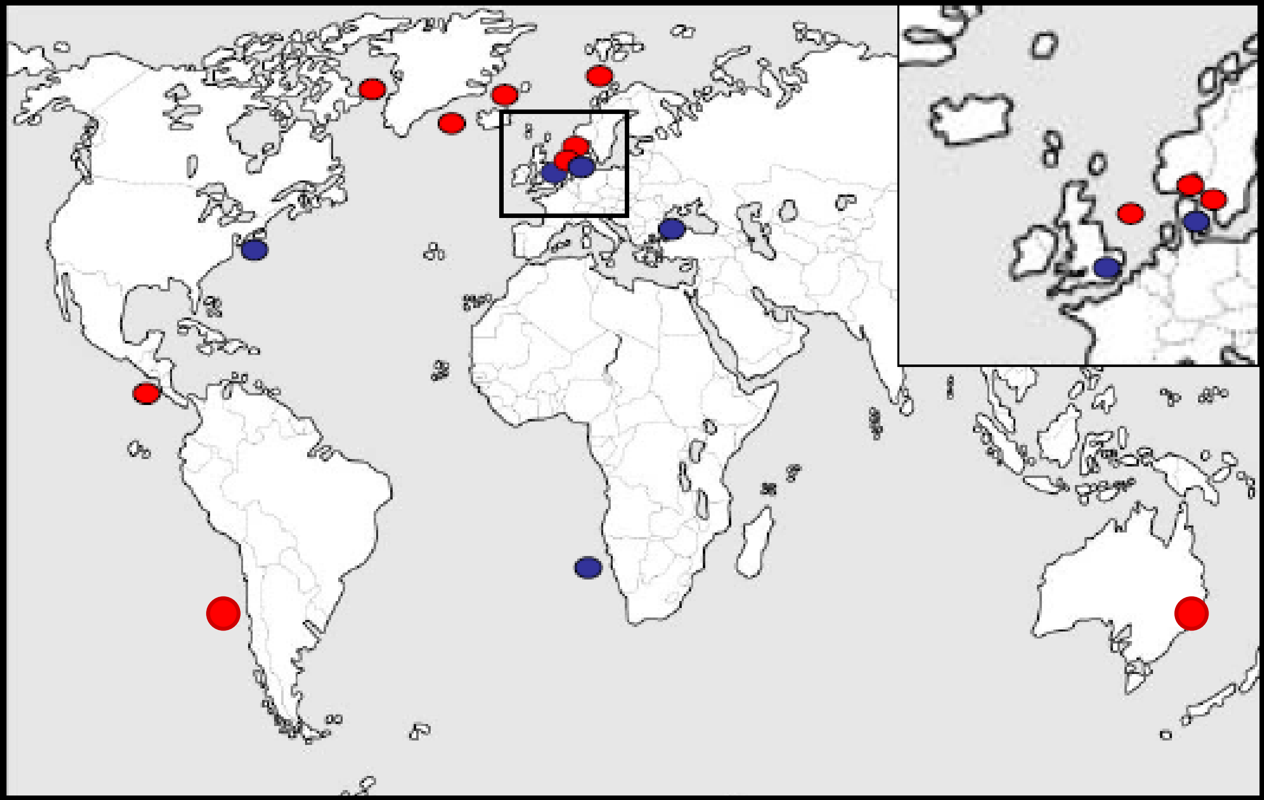
$^{15}NH_4^+ + ^{14}NO_2^- \rightarrow ^{29}N_2 + 2*H_20$ (anammox)

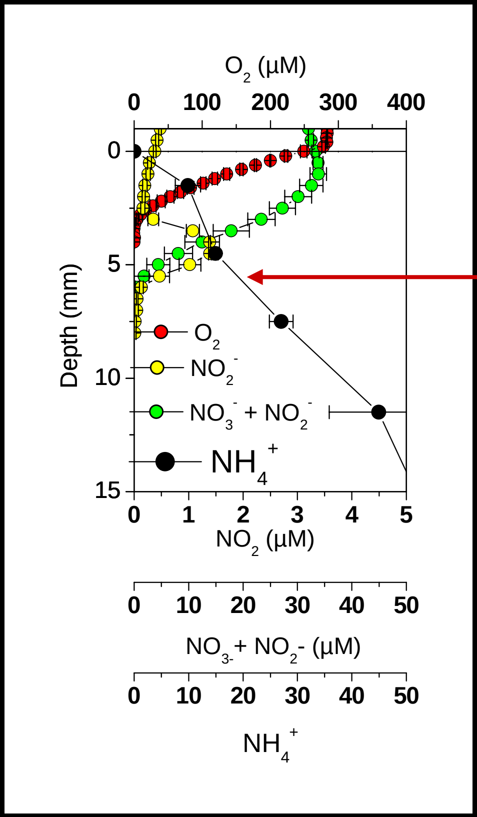
$^{15}NH_4^+ + ^{14}NO_2^- \rightarrow ^{29}N_2$ (anammox)

$^{15}NO_3^- + ^{15}NO_3^- \rightarrow ^{30}N_2$ (denitrification)

Data from Randers Fjord, DK

Anammox is ubiquitous in the marine environment

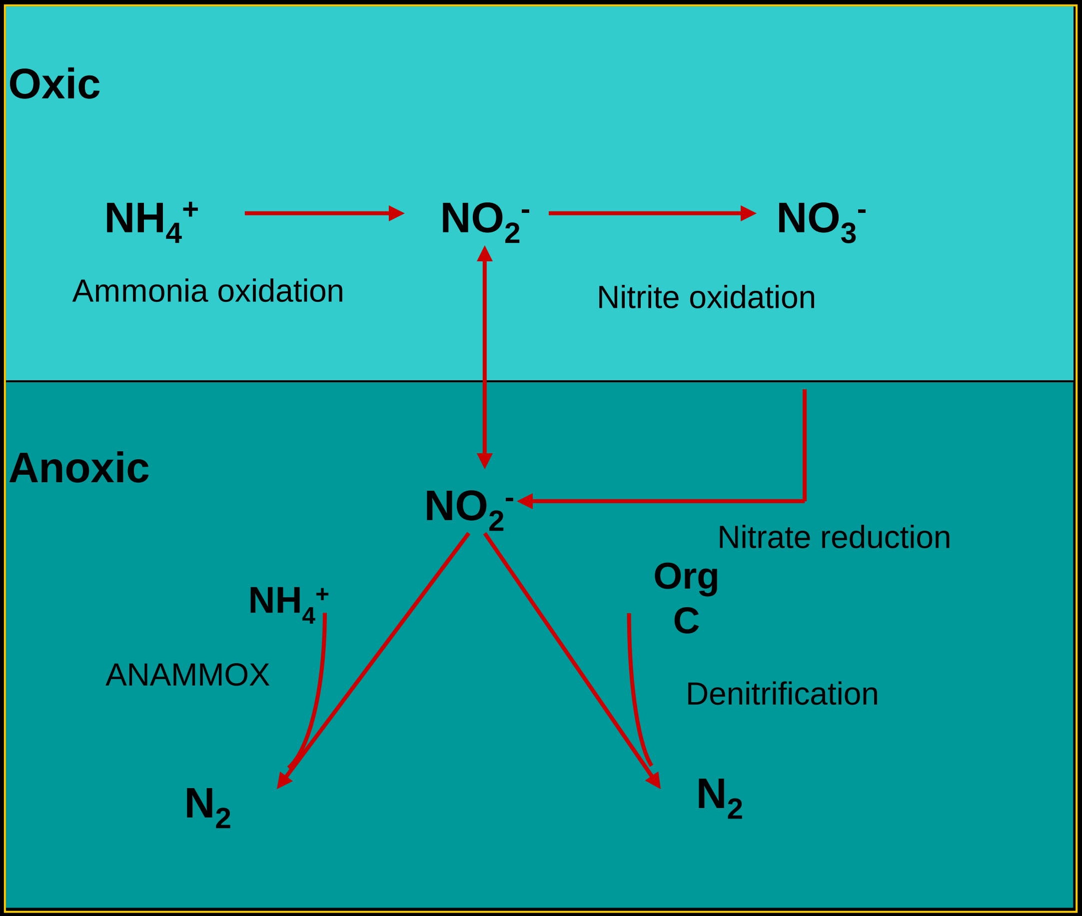




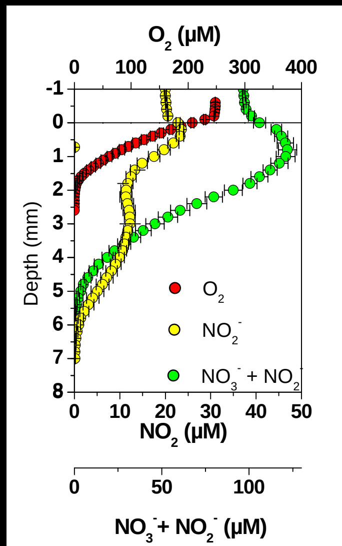
Randers Fjord

In sediments Anammox occurs below the oxic/anoxic interface

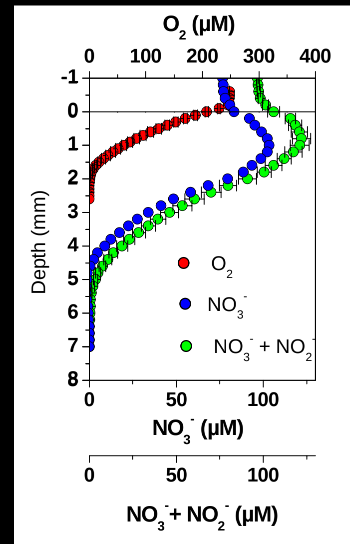
Which processes are responsible for the supply of NO_2^- to the ANAMMOX reaction?



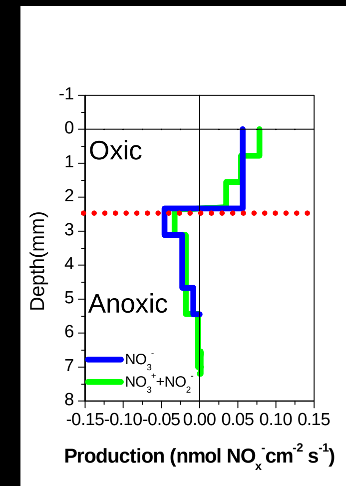
Inference of process rates from microprofiles

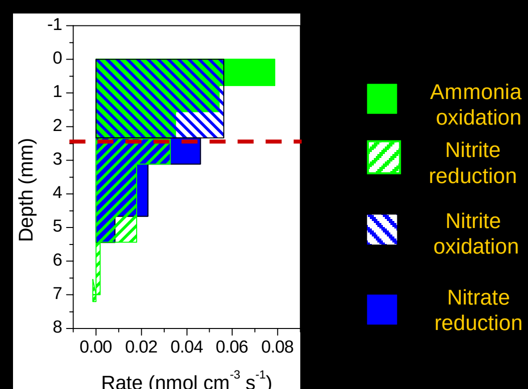


calculation of Nitrate profile



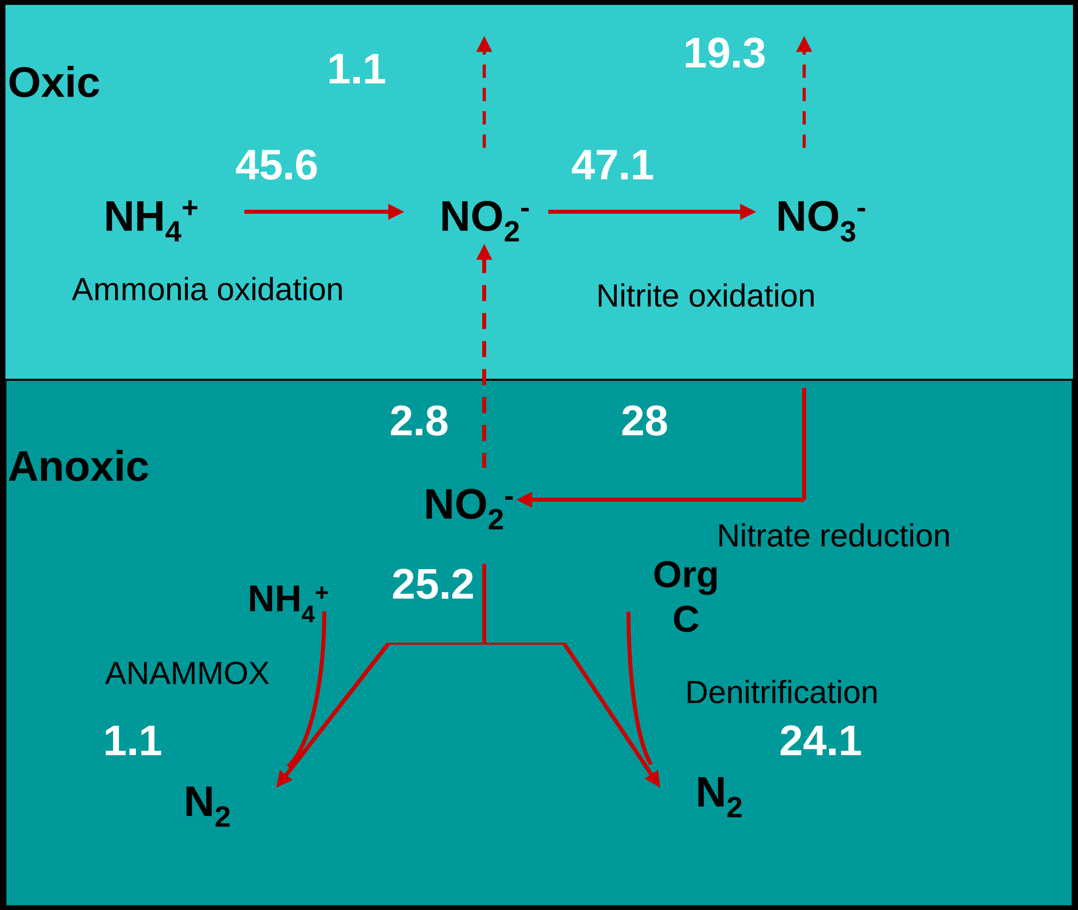
modeling



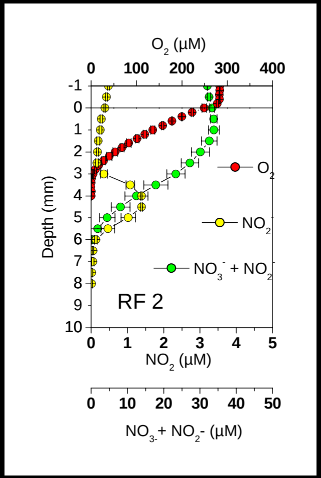


Meyer et al 2005

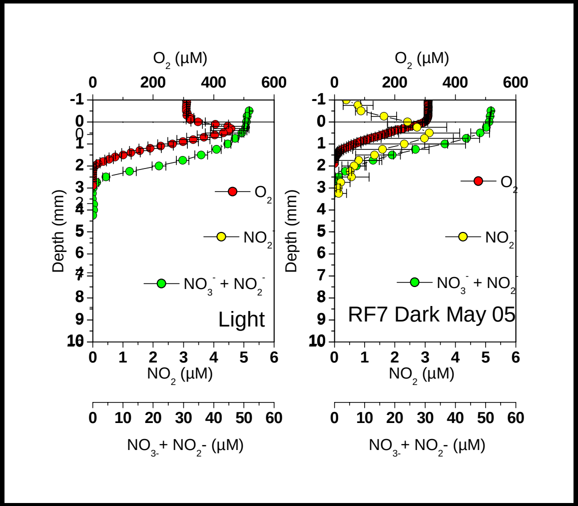
The principal Nitrite source for anammox is Anaerobic Nitrate Reduction
Example from Logan River Australia. Units: nmol cm^{-2} h^{-1}



Anammox Station



“NO anammox” station

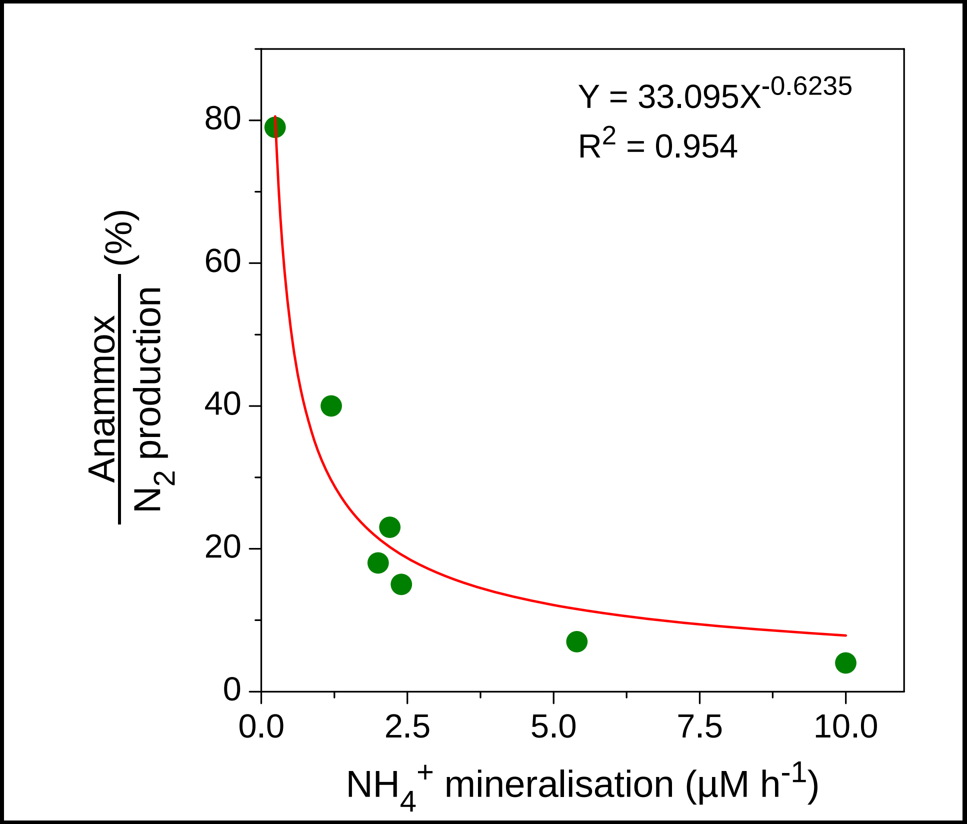


Deep profiles of NOx
NO2 present in anoxic zone most of the year
Relative low Denitrification capacity
Relative low O2 consumption
Relative low C-mineralization

Shallow profiles of NOx
Relative High Denitrification capacity
Relative High O2 consumption
Relative High C-mineralization

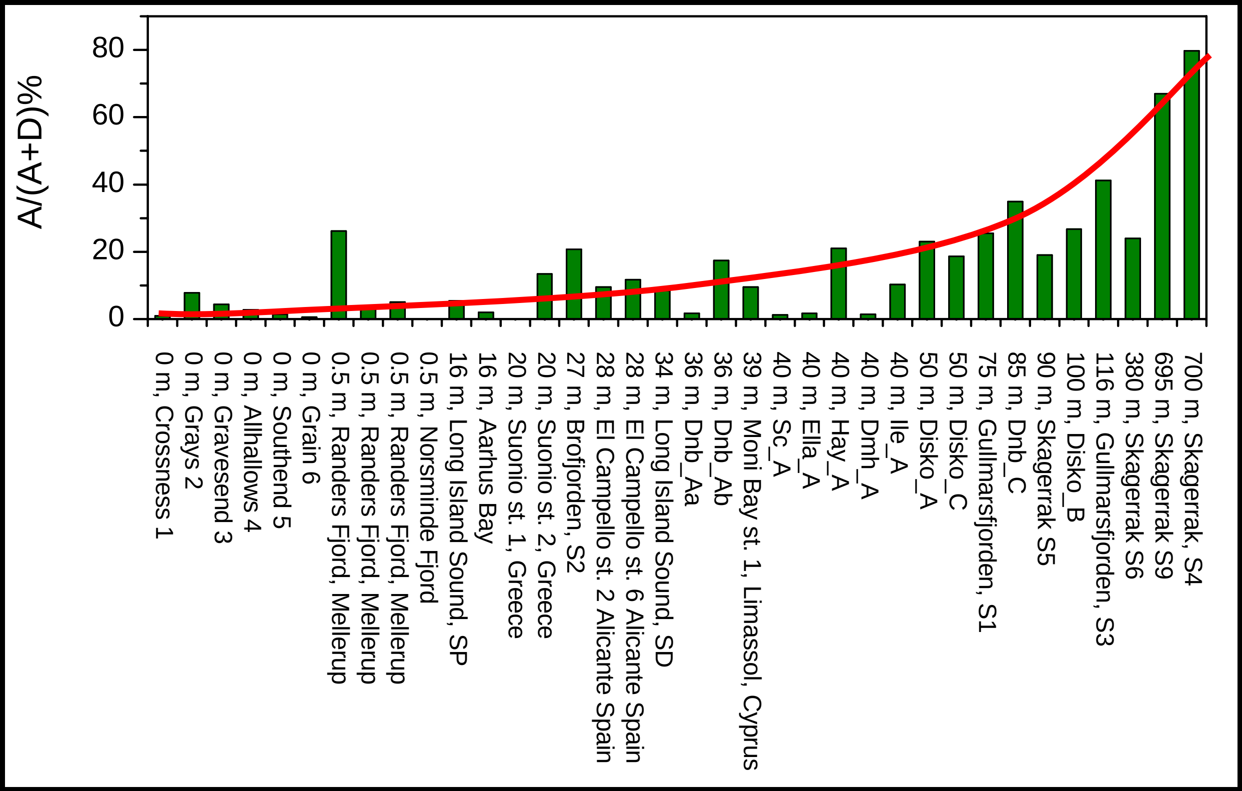
Ho: High Org C load favours hetrotropic denitrification on the expense of Anammox.

The contribution of anammox to benthic N_2 production decreases with increasing sediment reactivity, because heterotrophic denitrifies do better in sediments with high organic loadings.



Data from Engström et al. 2005

The contribution of anammox to benthic N removal increases with water depth

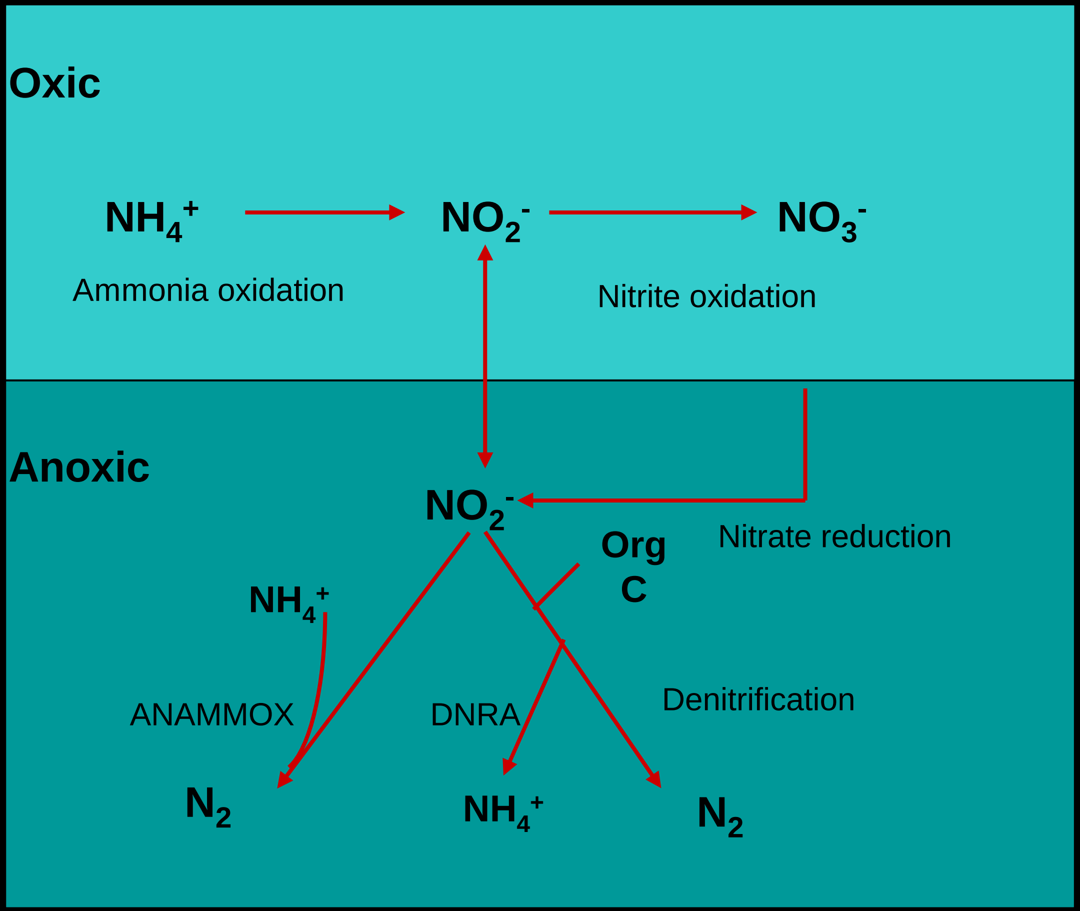


Dalsgaard et al 2005

The average depth of the ocean is 3800 m.

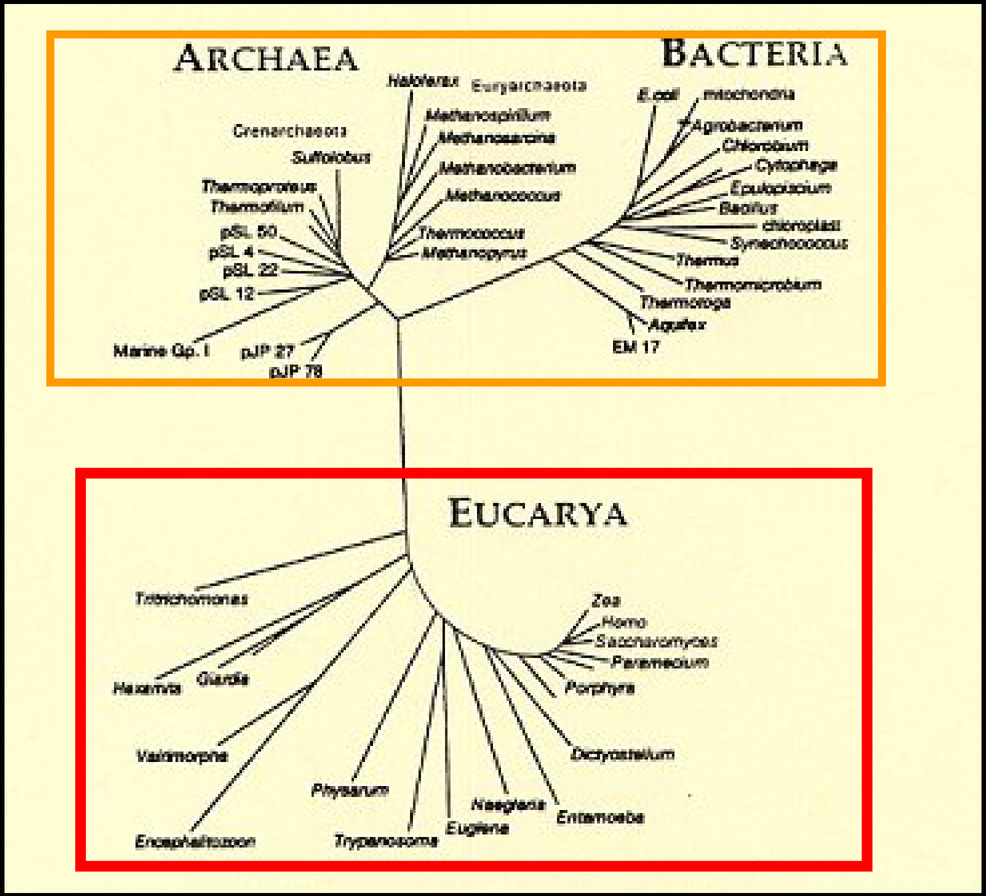
Anammox might be the dominant process for removal of N

The updated benthic nitrogen cycle

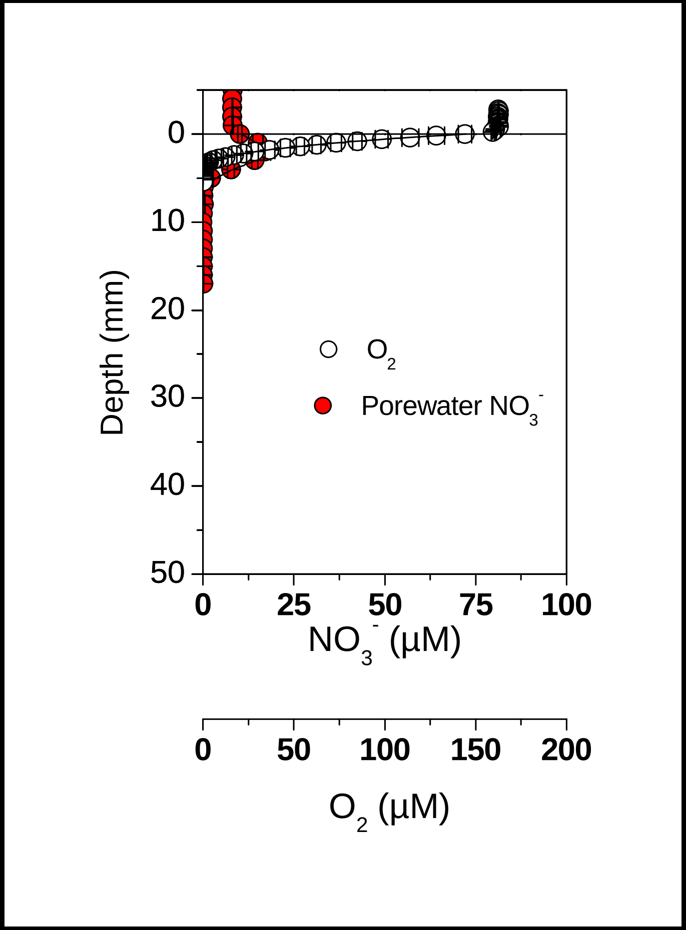


According to the present conceptual view removal of fixed N the oceans is mediated by prokaryotes

But is it true?



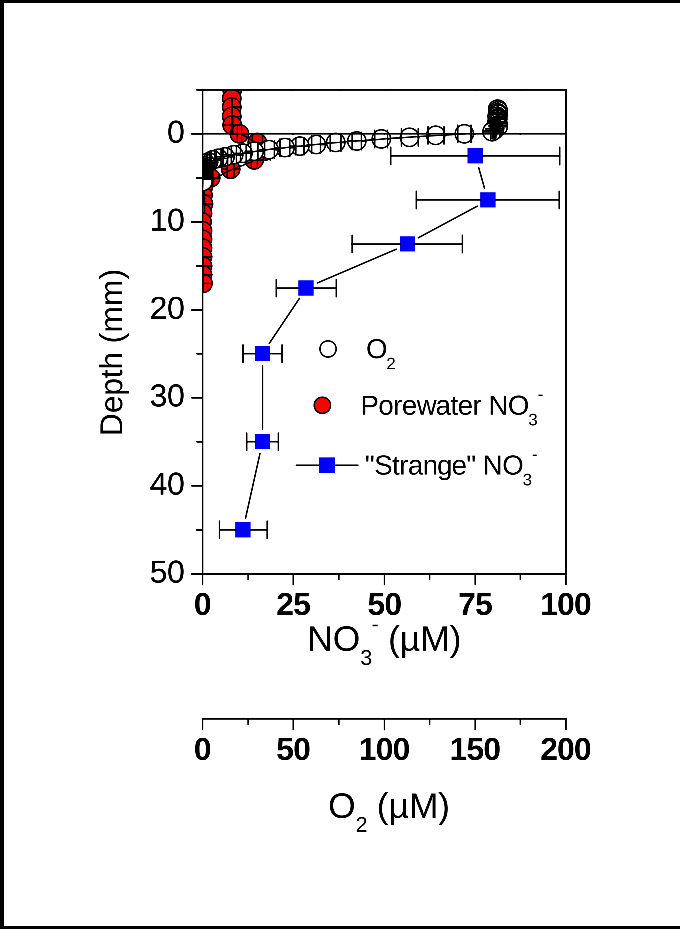
Nitrate in Gullmar Fjord (S) Sediment



Water depth: 114 m
O_2: 25-100% sat
NH_4^+ in water <0.05 µM
NO_3^- in water 9-17 µM
Temp: 6 C
Salinity 34 psu

Risgaard-Petersen et al. 2006

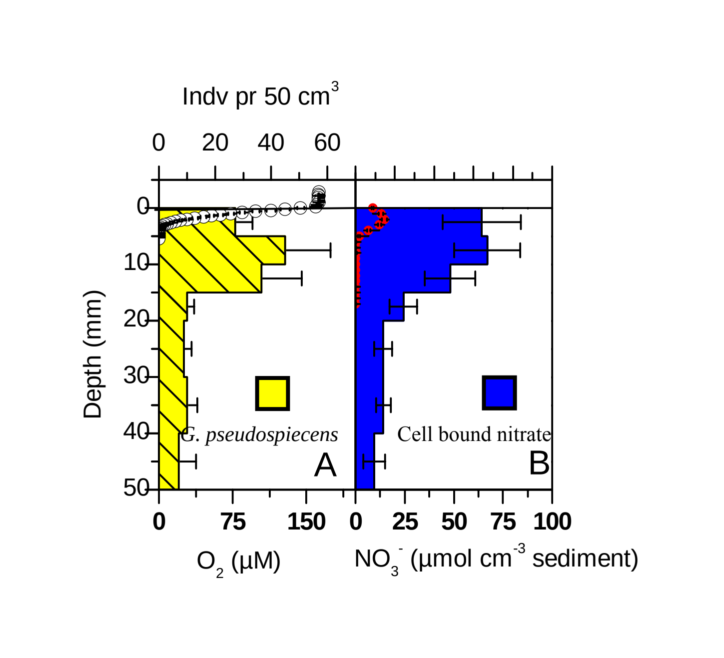
Nitrate in Gullmar Fjord (S) Sediment

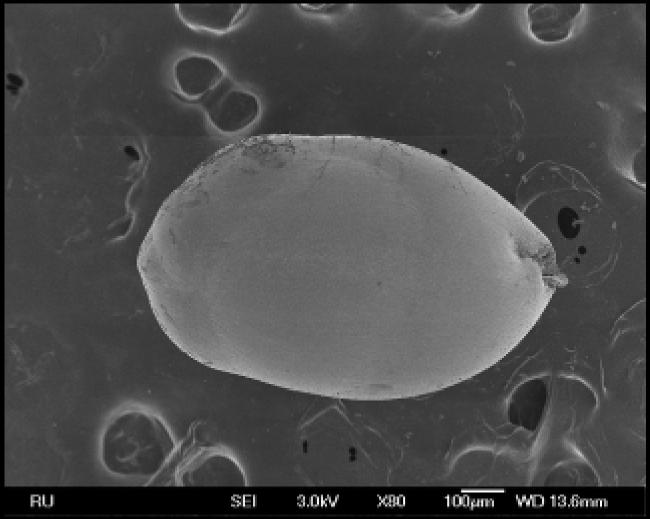


Nitrate is not only present in the porewater.
There are cell bound pools in sediments

Risgaard-Petersen et al. 2006

Nitrate and distribution of foraminifers (*Globobulimina pseudospiecens*)



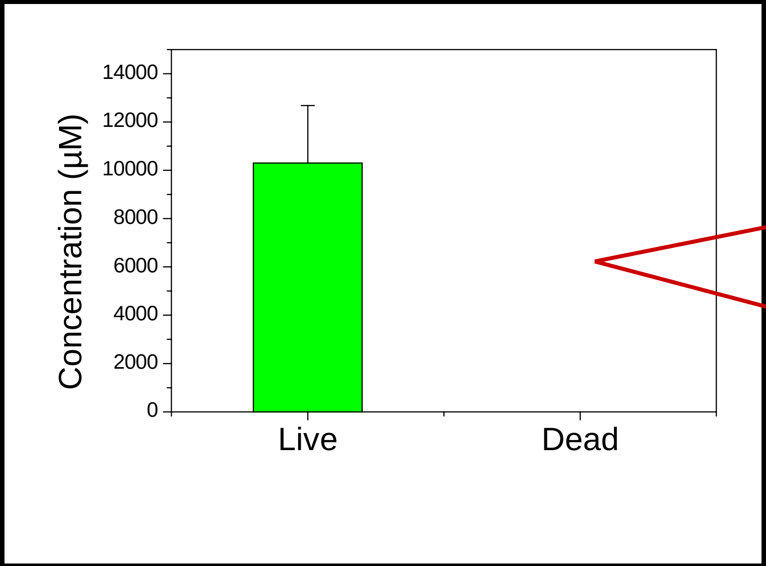


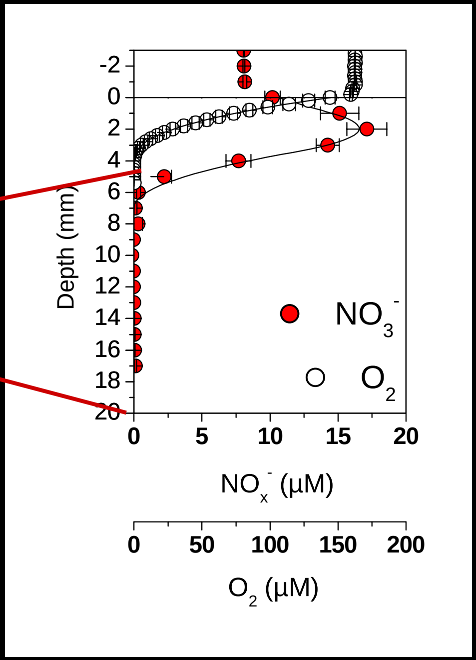
Cell bound nitrate correlate with foraminiferal abundance (Pearson, $r=0.95$; $p<0.001$)

Risgaard-Petersen et al. 2006

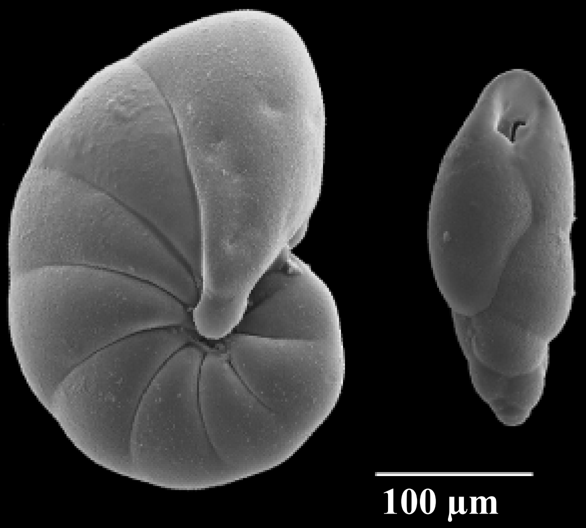
Nitrate in live and dead foraminifers

(Globobulimina pseudospiecens)





Nonionella cf. *stella* and *Stainforthia* sp from OMZ off Chile



Maximum NO_3^- concentration in porewater (µM)	Species	Intracellular NO_3^- content (pmol per individual)		Intracellular NO_3^- concentration (µM)
		Mean	Range	
12	*Nonionella* cf. *stella*	186 (25, n=43)	8-794	35000
12	*Stainforthia* sp.	60 (9, n=26)	0- 172	180000

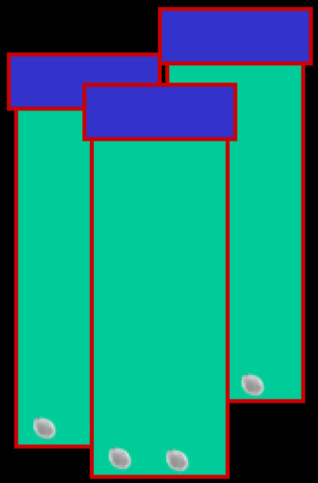
Risgaard-Petersen et al. 2006

Why do benthic foraminifers accumulate nitrate?

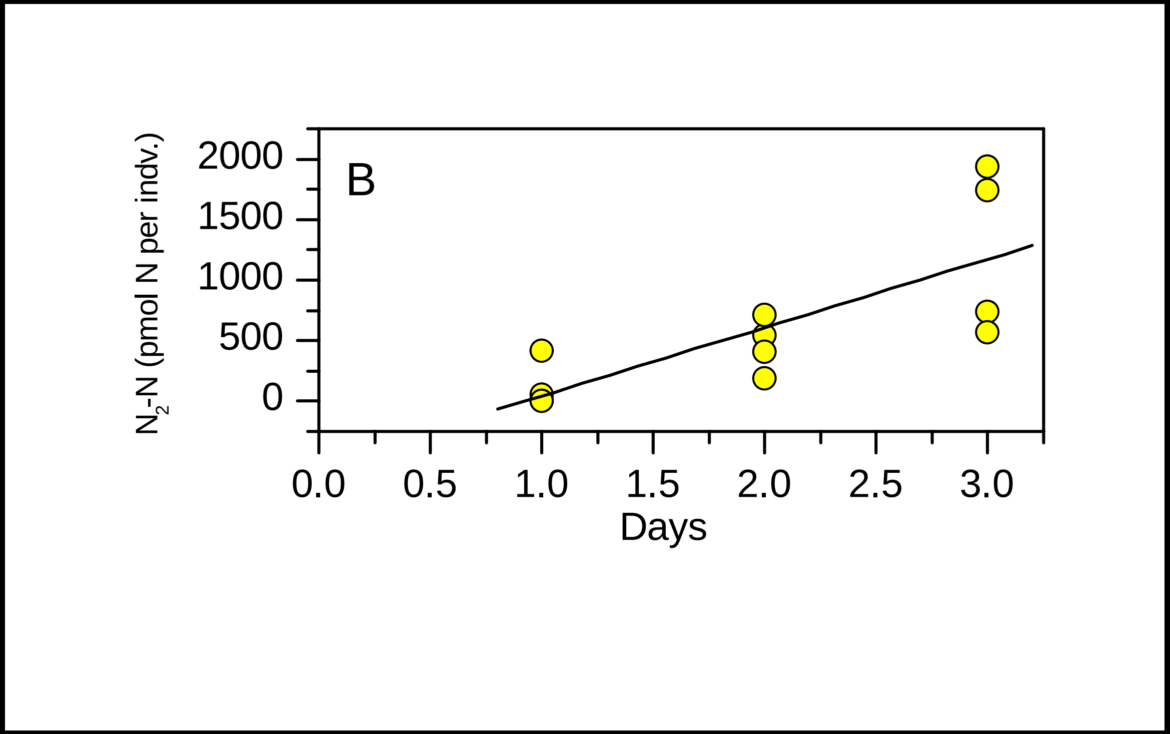
$$8NO_3^- + 5CH_3COO^- + 13H^+ \rightarrow 4N_2 + 10CO_2 + 14H_20$$

$\Delta G = -545$ kJ per mol NO_3^-

Denitrification by foraminifers (*Globoubulimina pseudospinences*)



Anoxic incubations of foraminifers with a ^{15}N-labelled intracellular nitrate pool



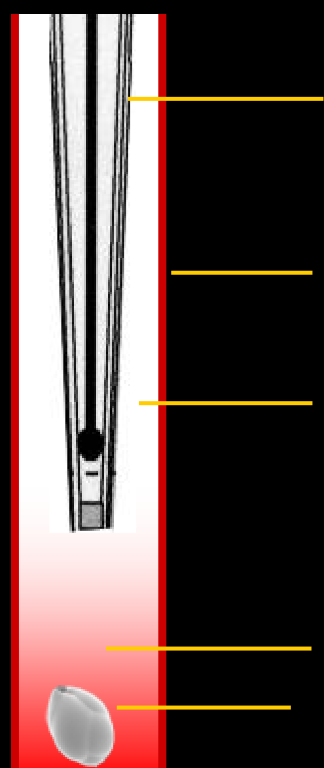
Denitrification rate =565±151 pmol N $cell^{-1}$ day^{-1}

Risgaard-Petersen et al. 2006

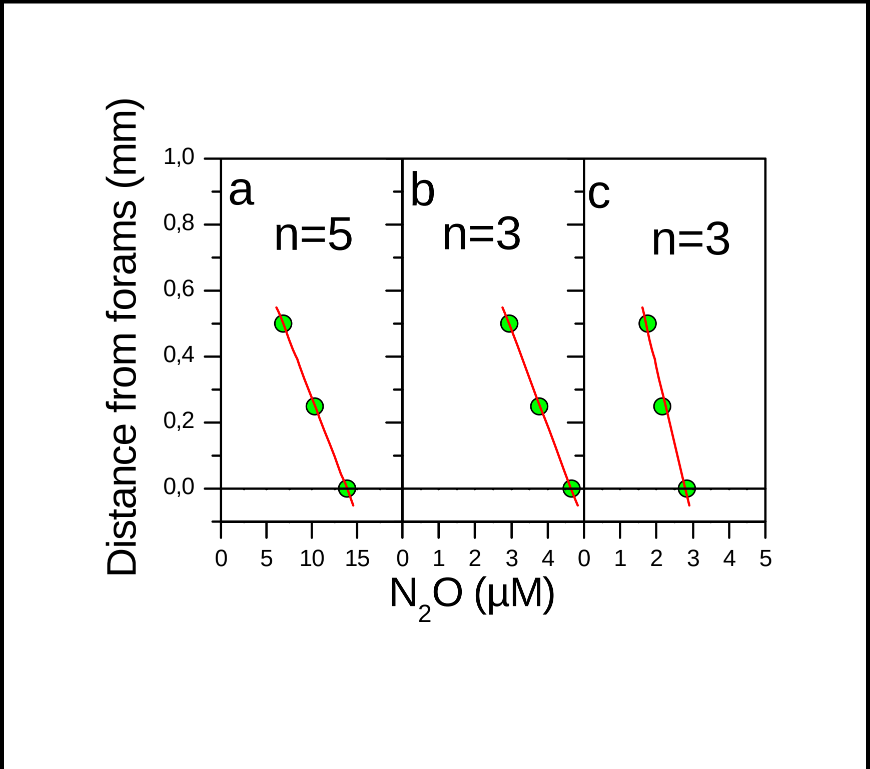
Denitrification by foraminifers
(*Nonionella cf. Stella*)

Acetylene block: $NO_3^- \rightarrow NO_2^- \rightarrow NO \rightarrow N_2O \nrightarrow N_2$

Setup

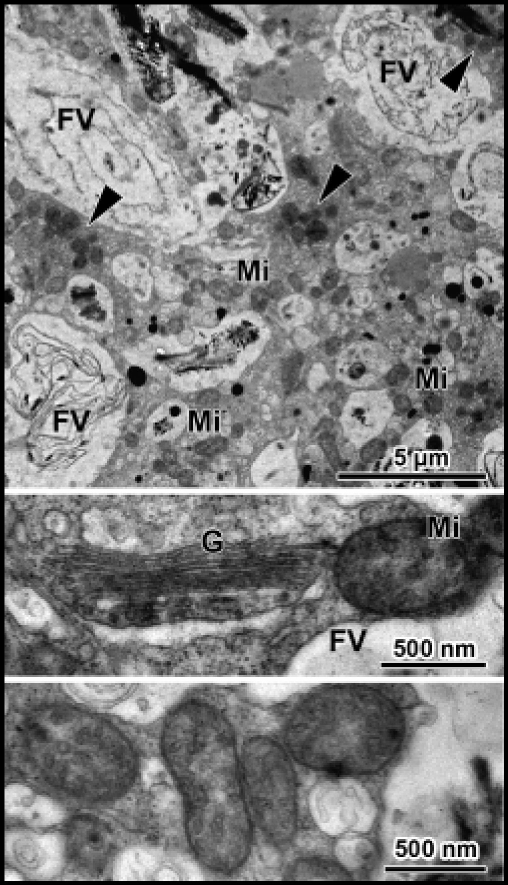


Denitrification by foraminifers
(*Nonionella cf. Stella*)

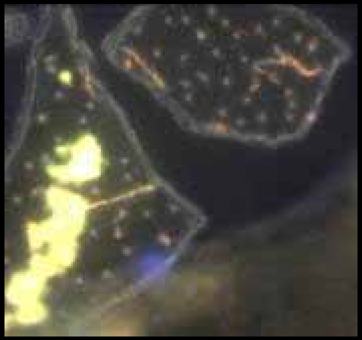


Denirification =
D_{N_20}*dC/dX *surface area
=84±33 pmol N cell^{-1} d^{-1}

Who is responsible for denitrification of the intracellular nitrate??



TEM micrograph of G. pseudospinencens



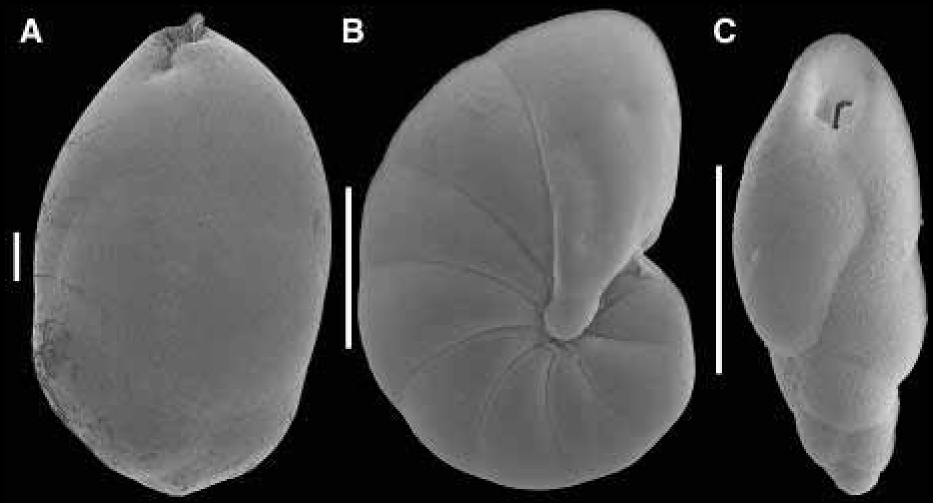
■ GS2
■ EUB
■ DAPI
■ Autofluorescence

FISH applied on *G. pseudospinencens*

FISH analysis and TEM micrographs shows that endosymbiontic bacteria are absent

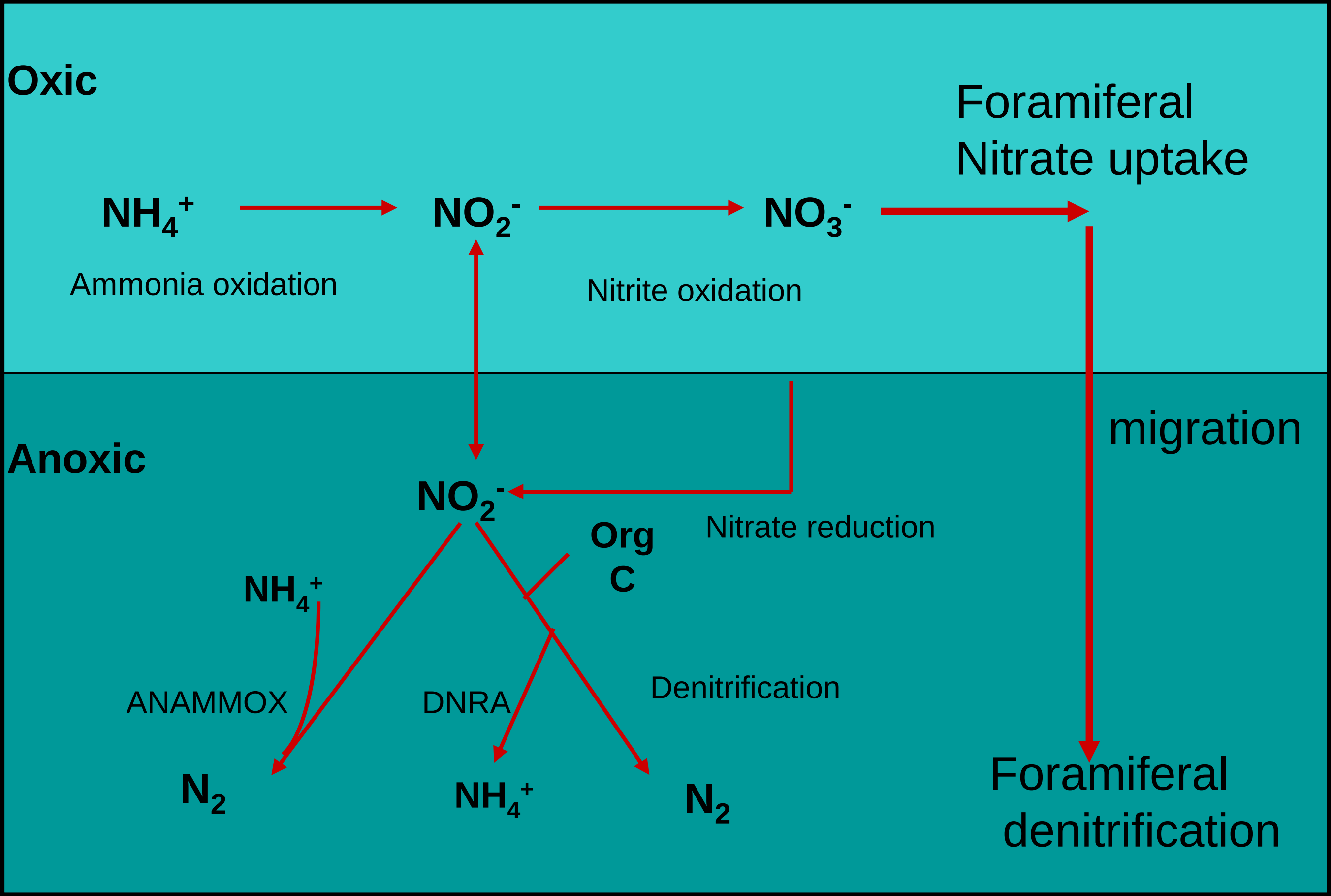
Risgaard-Petersen et al. 2006

This implies that denitrification is performed by the foraminifers



Benthic foraminifers forms a hitherto unknown pathway for removal of fixed N from the sea

The updated benthic nitrogen cycle
Version 2.0



Thanks to:

Tage Dalsgaard, National Environmental Research Institute (DK)
Langezaal, A. M., Utrecht University, (NL)
Ingvardsen, S, University of Aarhus, (DK)
Schmid, M.C., Radboud University Nijmegen, (NL)
Revsbech, N. P., University of Aarhus, (DK)
Nielsen, L.P., University of Aarhus, (DK)
Andreas Schramm, University of Aarhus, (DK)
Mike S.M. Jetten Radboud University Nijmegen, (NL)
Huub J.M. Op den Camp Radboud University Nijmegen, (NL)
Jan W.M. Derksen Radboud, University Nijmegen, (NL)
Elisa Piña-Ochoa, Centre of Environmental Sciences, (E)
Susanne P. Eriksson, Göteborg University, (S)
Tomas Cedhagen ,University of Aarhus (DK)
Gijsbert J. van der Zwaan, Utrecht University, (NL)
Britta Poulsen, University of Aarhus (DK)
Preben Sørensen, University of Aarhus (DK)
Kitte Gerlich Lauritsen, National Environmental Research Institute (DK)
Marlene Venø Skjærbæk, National Environmental Research Institute (DK)
Tanja Quotrup, National Environmental Research Institute (DK)
The Carlsberg Foundation (DK)
The Danish Natural Science Research Council (DK)