

Present and past contribution of anaerobic ammonium oxidation to nitrogen cycling in the marine environment

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Anaerobic ammonium-oxidizing (anammox) bacteria have been found to be key players in the marine nitrogen cycle, converting fixed nitrogen to dinitrogen gas under anoxic conditions. Sediments from the Irish Sea provided us with evidence that anammox is an important process for the biogeochemical cycling of nitrogen in sediments deposited on continental margins, and especially in continental slope sediments. Based on the presence of fossil ladderane lipids, which are specific for anammox bacteria, we found for the first time evidence for past anammox in the Arabian Sea at least over the last 140,000 years, constituting a sink for fixed nitrogen in the ocean.

Anammox, the oxidation of ammonium to dinitrogen gas with nitrite under low oxygen conditions, constitutes a novel route to convert biologically available (fixed) nitrogen to gaseous dinitrogen gas (Fig. 1). This process is mediated by specific bacteria belonging to the Planctomycetes that were initially discovered in waste water treatment systems. Within the nine years after their discovery, anammox bacteria have been identified as key players in the global nitrogen cycle. They have been found in different suboxic to anoxic environments, including oxygen minimum zones (OMZs), marine and freshwater sediments, tropical lakes and even in sea ice. Anammox bacteria contain unusual membrane lipids composed of either three or five cyclobutane rings, called ladderane lipids (Fig. 2). Since these lipids are unique to anammox bacteria, they form suitable tracers (or biomarkers) for the anammox process in the environment.

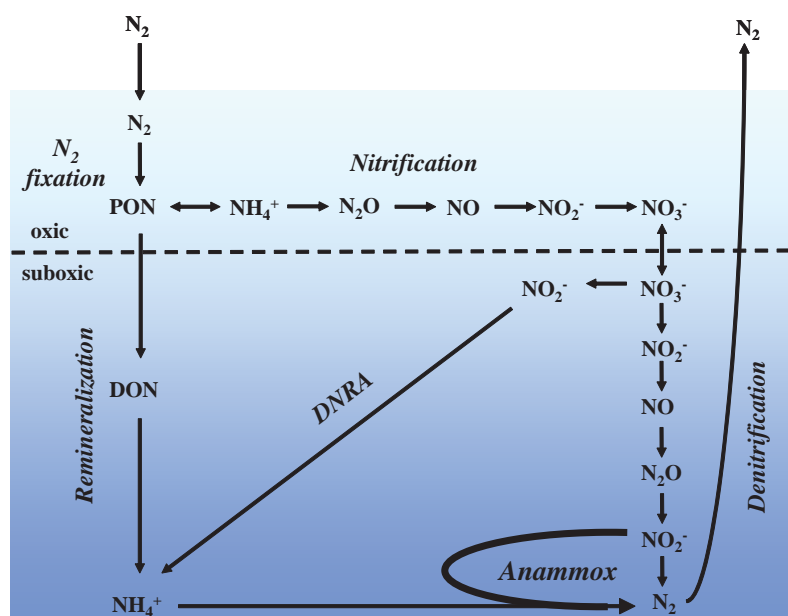


Fig. 1. Simplified version of the marine nitrogen cycle including anammox. DNRA = dissimilatory nitrate reduction to ammonium

Anammox in continental shelf and slope sediments

During a R/V Pelagia cruise in 2006, sediment cores from six sites along the continental shelf (50 m) and deeper slope (2000 m) in the Irish Sea and North Atlantic were investigated for the occurrence of anammox using ladderane biomarker lipids and ¹⁵N-labelling techniques (Fig. 3).

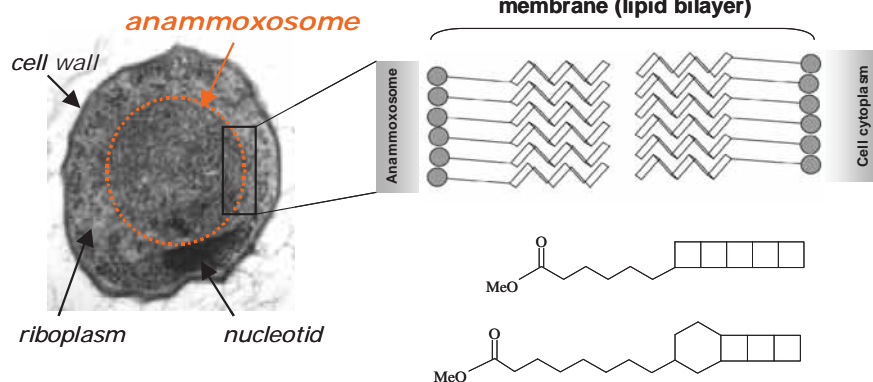


Fig. 2. Anammox cell with anammoxosome, an organelle-like compartment where the anammox reaction takes place. Ladderane lipids are the main building blocks of a dense and impermeable membrane surrounding the anammoxosome.

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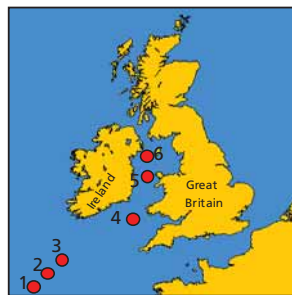
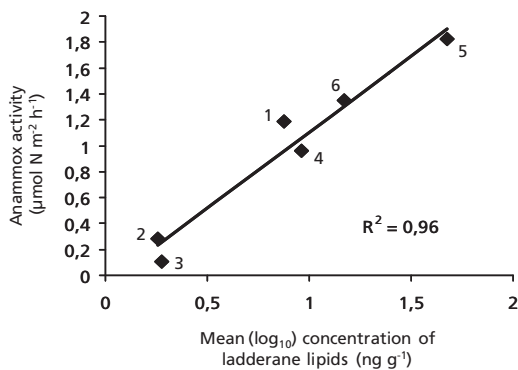


Fig. 3. Relation between dinitrogen gas production via anammox and concentration of ladderane lipids in intact sediment cores from six sampling sites on the continental shelf and slope in the North Atlantic investigated during the R/V Pelagia 2006 cruise.

As shown in figure 3, the abundance of ladderane lipids at each site is directly related to dinitrogen gas production rates via the anammox reaction over the whole depth transect. These data provide evidence that anammox is an important process removing fixed nitrogen from shelf and slope sediments, and probably also constituting a significant sink for fixed nitrogen compounds in the deep ocean.

Past anammox in the Arabian Sea OMZ

The Arabian Sea comprises one of the largest OMZs presently found in the oceans, and ca. 20% of the global nitrogen removal from the ocean is estimated to take place here. The Arabian Sea, therefore, is believed to have a substantial influence on the global marine nitrogen cycle. A sediment core from the Murray Ridge in the northern Arabian Sea was chosen to investigate the occurrence of past anammox activity (Fig. 4).

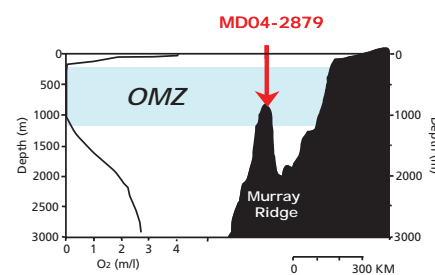
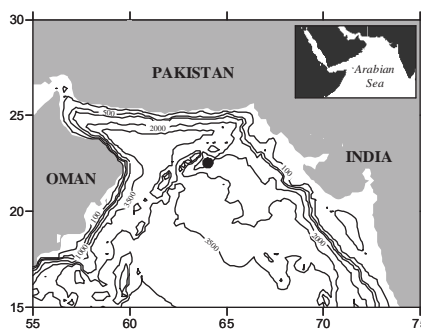


Fig. 4. Location of a sediment core in the oxygen minimum zone (OMZ) of the Arabian Sea retrieved during the R/V Marion Dufresne 2004 cruise.

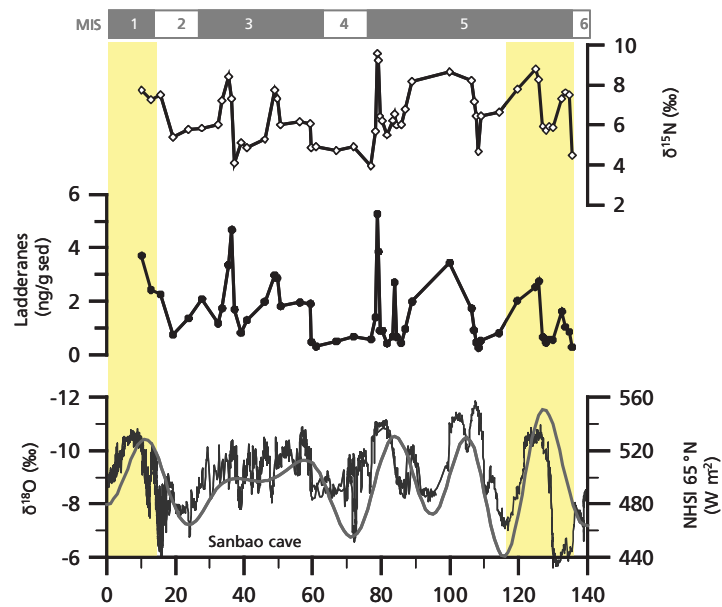


Fig. 5. Nitrogen stable isotope ratio ($\delta^{15}\text{N}$), total ladderane lipid concentrations for sediment core MD04-2879, $\delta^{18}\text{O}$ records from speleothems and NHSI (Northern Hemisphere summer insolation, 21 July) at 65°N . MIS=Marine Isotope



Sampling using a boxcorer on board of R/V Pelagia, and subsampling for lipid analysis and incubation experiments