Nitrogen dynamics during the Cenomanian-Turonian oceanic Anoxic Event 2: A model study for the proto-North Atlantic

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1. Introduction

Evidence from sediment core records and model studies suggest that increased nutrient supply played a key role in the initiation of the Cenomanian-Turonian oceanic anoxic event 2 (OAE2; 94 Ma). The relative roles of nitrogen (N) and phosphorus (P) availability in controlling primary productivity during the event are not fully understood, however. Low $\delta^{15}N$ of OAE2 sediments in the proto-North Atlantic has been interpreted to reflect high cyanobacterial N_2-fixation in N-depleted surface waters [1]. Based on nitrogen-isotope ratios of porphyrins it has been proposed that upwelling of ammonium (NH_4^+) was also critical to new production during OAE2 [2]. The interpretations of $\delta^{15}N$ signals are still under development.

2. Aim

1) Provide a first attempt to quantify the N processes during OAE2.
2) Analyze their responds to low oxygen conditions and ocean circulation during OAE2.
3) Asses the role of NH^+_4 in upwelled anoxic waters and its influence on primary productivity.
4) Study the spatial coupling between denitrification and N_2-fixation.

3. Model

We expand an existing multi-box model of the coupled cycles of P, carbon and oxygen in the proto-North Atlantic [3] with the marine N cycle. The model includes both the coastal and open ocean and thus, is adequate to study regional differences. The key processes for the N cycle are:

1) N uptake for phytoplankton growth
2) degradation of PON
3) Conversion of NH^+_4 to nitrate (nitrification);
4) PON export and burial of PON
5) Ddenitrification and N_2-fixation

4. Numerical experiments

NPSTANDARD:
- Enhanced P supply by weathering (0.03 Tmol y^{-1})
- P (1.4 Tmol y^{-1}) and oxygen input ($[O_2]$=10 µmol L^{-1}) from the Pacific Ocean
- Meridional ocean overturning of 12 Sv (70% the original)

Experiment 1: Change in P input from the Pacific bottom waters (from 0.6 to 1.9 Tmol y^{-1}).

Experiment 2: Change in oxygen concentrations from the Pacific bottom waters (from 0 to 200 µmol L^{-1}).

Experiment 3: Change in ocean circulation (from 100 to 30% of the original model)

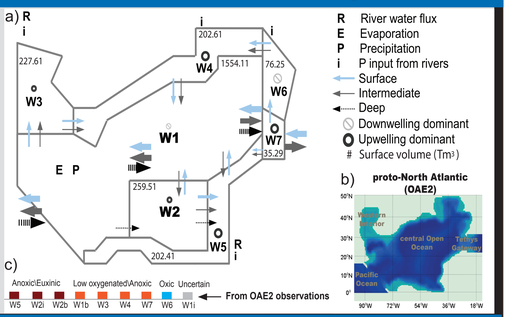


Fig. 1: During OAE2, the continental shelves were flooded and the ocean circulation might have been rather vigorous in the proto-North Atlantic [e.g. 4].

a) Water cycle in the model: The proto-North Atlantic is divided into 7 boxes mainly based on the location of upwelling/downwelling regions and bathymetric features [4].
b) Bathymetry of the proto-North Atlantic during OAE2 [4].
c) Simplified regional oxygen regional trend as deduced from geological records and as captured by the original box-model.

5. Results and Discussion

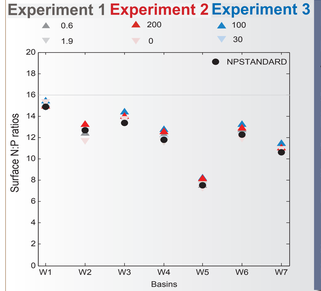


Fig. 2: While in pre-OAE2 conditions all regional N:P ratios in the model are constrained to be close to Redfield ratios (N:P=16:1), during OAE2, **the ratios are spatially variable due to local conditions affecting nutrient transport, sources (N_2-fixation) and sinks (denitrification).** In all experiments, N:P ratios are lower than Redfield ratios, making N the limiting nutrient for priamry productivity. In most of the proto-North Atlantic surface area (e.g. W1), the N:P ratios are close to Redfield. The lower N:P ratios are found in the southern coast (W5) where euxinia can develop.

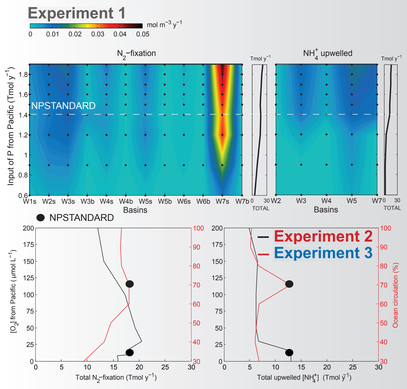


Fig. 3: The abrupt increase of P supply during OAE2 leads to N-deficit bottom waters and greatly favours N_2-fixation. The low oxygen conditions allow high rates of NH^+_4 upwelling. **Both processes are significantly affected by P and oxygen input from the Pacific Ocean and ocean circulation, which can further increase/decrease the total NPSTANDARD rates** (~7-15 Tmol y^{-1}).

A spatial variablity in both N_2-fixation and NH^+_4 upwelling can be obsereved, where maximum rates are mostly related to *NPSANDARD*.

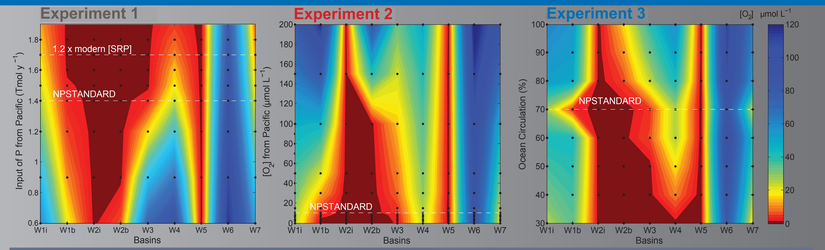


Fig. 4: The spatial distribution of oxygen in the proto-North Atlantic is sensitive to changes in P and oxygen input from the Pacific Ocean and ocean circulation. The bottom waters of the central open ocean (W1b), which affect the intermediate and coastal waters, are especially sensitive to changes in Pacific Ocean conditions. The southern proto-North Atlantic (W2 and W5), where anoxia existed before OAE2, is less affected by the changes performed in the 3 experiments. **This suggests that the key parameter to further strengthening anoxia in the south is mainly due to enhanced P supply from weathering.** Anoxia in the central open bottom waters (W1b) as expected from observations can be obtain only when further increasing (reducing) the P (O_2) supply from the Pacific Ocean relative to *NPSTANDARD*.

Fig. 5: From geological records, at least a doubling in relative burial increase of particulate organic carbon (POC) is expected from pre-OAE2 to OAE2 conditions (dashed black line). This is obtained when all variables are kept as in *NPSTANDARD*, except the P supply from the Pacific Ocean, which needs to increase to at least 1.7 Tmol P y^{-1}. **This suggests that P supply was a major forcing for anoxia in the prtoto-North Atlantic during OAW2.** In our model, high burial of POC is mainly possible due to high N_2-fixation rates, that compensate for N-losses due to denitrification.

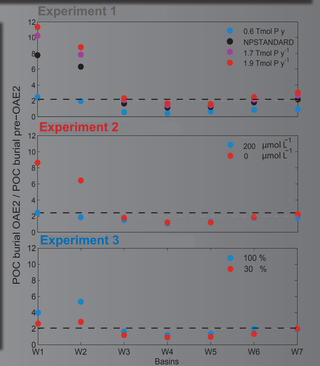
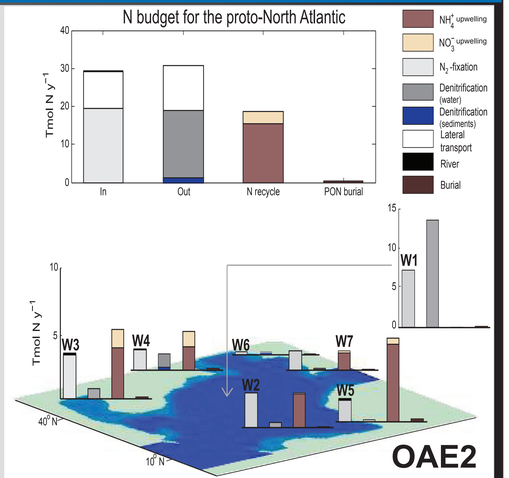


Fig. 6: During OAE2, large **P inputs enhanced** not only primary productivity, but also **N_2-fixation**. Total N_2-fixation in the proto-North Atlantic could have been as high as global modern rates (10-24 Tmol y^{-1}). The N cycle was likely close to balance. **The contribution of the N sources and sinks, as well as NH^+_4 upwelling to the N budget are similar, but their rates are not homogenously distributed in the basin.** NH^+_4 upwelling does not influence the surface N:P ratios. **N_2-fixation constitutes a positive feedback to primary productivity**, re-equilibrating the N:P ratios in surface waters.



6. Conclusions

Even though primary productivity in most of the proto-North Atlantic is N limited, the spatial trends in carbon dynamics are similar to those of observations. Our model confirms that upwelling of NH+ is important in supplying N to surface waters with rates that are of the same order of magnitude as N_2-fixation. N dynamics in the proto-Atlantic are highly sensitive to changes in the strength of the circulation and changes in oxygen and P supply from bottom waters of the Pacific Ocean. More nitrogen-isotope data are needed to further constrain the N dynamics in the proto-North Atlantic.

References:

[1] Kuypers, M. M., van Breugel, Y., Schouten, S., Erba, E., and Sinninghe Damsté, J. S.: N_2-fixing cyanobacteria supplied nutrient N for Cretaceous oceanic anoxic events, Geology, 32, 853–856, 2004.
[2] Higgins, M. B., Wolfe-Simon, F., Robinson, R. S., Qin, Y., Saito, M. A., and Pearson, A.: Paleoenvironmental implications of taxonomic variation among ^{15}N values of cyanobacterial Geochimica et Cosmochimica Acta, 75, 7361–7363, 2011.
[3] Ruvalcaba-Baroni, I. and Topper, R. P. M. and van Helmond, N. A. G. M. and Brinkhuis, H. and Slomp, C. P.: Was the North Atlantic Ocean well-ventilated during Oceanic Anoxic Event 2 in the mid-Cretaceous?, Biogeosciences Discussions, 10, 13 231–13 276
[4] Topper, R. P. M., Trabucho Alexandre, J., Tuenter, E., and Meijer, P. Th.: A regional ocean circulation model for the mid-Cretaceous North Atlantic Basin: implications for black shale formation, Climate of the past, 7, 277–297, 2011.