IFM-GEOMAR

Leibniz-Institut für Meereswissenschaften
an der Universität Kiel

IFM-GEOMAR Report 2002-2004

From the Seafloor to the Atmosphere

- Marine Sciences at IFM-GEOMAR Kiel -

INSTITUT FÜR MEERESKUNDE KIEL

GEOMAR

PAX OPTIMA RERUM ACADEMIA HOLSATORUM CHILONIENSIS

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Preface

For the first time, the Leibniz Institute of Marine Sciences (IFM-GEOMAR) presents a joint report of its research activities and developments in the years 2002-2004. In January 2004 the institute was founded through a merger of the former Institute for Marine Research (IfM) and the GEOMAR Research Center for Marine Geosciences. This report addresses friends and partners in science, politics and private enterprises. It gives an insight into the scientific achievements of IFM-GEOMAR and its predecessor institutes during the last three years.

3.6 Interaction of Oxygen and Marine Productivity

New data show that the modern ocean is loosing dissolved oxygen at high rates. Significant oxygen losses occur in many coastal areas and also in the open ocean at intermediate water depths. These changes may be driven by enhanced nutrient inputs causing higher rates of export production and microbial respiration and/or by global warming reducing the rates of ocean ventilation. They may be harmful to many marine biota depending on dissolved oxygen.

On geological time scales, the productivity of the global ocean is regulated by the size of the nutrient inventory residing in the vast deep water masses of the large ocean basins; the major nutrients dissolved in seawater being nitrate and phosphate. Nitrate is delivered to the oceans by rivers and by nitrogen-fixing microorganisms. It is removed from seawater by the burial of particulate organic matter in marine sediments and by microbial denitrification. The latter process occurs only in the absence of dissolved molecular oxygen. Reducing (oxygen-poor) environments serving as habitat for nitrate-consuming microorganisms can be found in poorly ventilated intermediate waters and marine sediments. Phosphate is released into the oceans via rivers and is removed by burial of phosphorus-bearing compounds in marine sediments. Oxygen-bearing (oxic) surface sediments are often rich in ferric iron and manganese phases which take up large amounts of phosphate by adsorption and mineral formation while anoxic (oxygen-free) sediments are depleted in these phases so that phosphate can only be bound in rather soluble calcium minerals formed during early diagenesis. Burial of organic phosphorus bound in the remains of marine plankton depends also on sedimentary redox conditions (abundance of oxidizing and reducing chemicals). Under reducing conditions the C/P ratio of sedimentary organic matter may be as high as 5000 while the composition of particulate organic matter in oxic deposits approaches the Redfield ratio (C/P = 106). Hence, phosphorus is buried very efficiently in oxic sediments while anoxic deposits have a diminished retaining capacity.

Positive and negative feedback loops are established by the coupling between pelagic processes (export production, ventilation of deep and intermediate water masses) and benthic turnover (Fig. 1). Under phosphate limitation, marine productivity, nutrient inventories and redox conditions may change dramatically. Thus, reducing conditions in bottom waters inhibit phosphorus burial and expand the inventory of dissolved phosphate. In response to the enhanced nutrient availability, eutrophic conditions prevail inducing oxygen consumption in the water column and underlying marine sediments. The resulting spread of anoxic environments in sediments and bottom waters induces further benthic phosphate release and eutrophication in a positive feedback loop (Fig. 1). A different picture emerges under nitrogen limitation (Fig. 1). Anoxic conditions favour the removal of dissolved nitrate via denitrification so that nutrient inventory, export production, and oxygen respiration are diminished and oxic conditions are restored in a negative feedback loop. Nitrogen limitation occurs when the rate of nitrogen-fixation is too small to compensate for denitrification and burial. Cyanobacteria, responsible for most of the nitrogen-fixation in modern and ancient oceans, are limited by iron and phosphate. They live in warm surface waters of the tropical oceans receiving iron either from dust deposition or up-welling. Anoxic sediments supply iron to up-welling bottom waters so that the rate of nitrogen-fixation may also be enhanced by the spread of anoxia. Hence, under favourable climatic conditions, the marine biogeochemical system may be unstable and subject to positive feedback amplifying external perturbations.

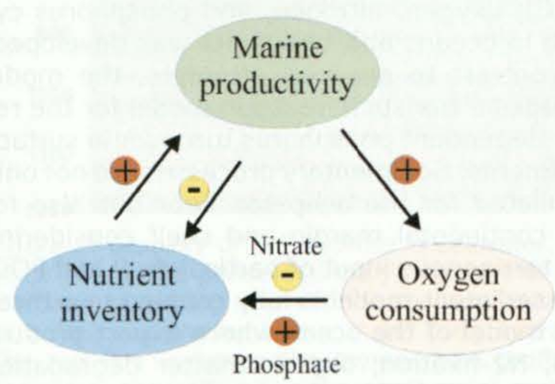

Figure 1: Feedbacks between marine productivity, oxygen consumption and nutrient inventory.

The geological record suggests that marine productivity and redox conditions changed dramatically on different time scales. Global scale anoxic events where enormous amounts of organic matter accumulated at the seafloor are documented for the mid-Cretaceous, the late Jurassic and other periods of the Earth's history. More gradual changes in the ocean's productivity occurred during late Quaternary glacial/interglacial cycles. In many productive areas of the ocean (equatorial Pacific and Atlantic, southern Arabian Sea, Subantarctic Ocean), marine surface sediments received more organic carbon and were more reducing under glacial conditions.

Field studies and sedimentary data clearly show that marginal seas dominated by anoxic bottom waters are highly productive. Usually, the anoxic conditions are ascribed to the high productivity whereas the source of nutrients is not identified even though additional phosphate supply from anoxic sediments could easily sustain and enhance eutrophic conditions in the overlying water. The role of phosphate recycling is clearly seen in the Black Sea and the Baltic Sea which are the most prominent examples of marginal seas with anoxic bottom waters. Here, the C/P ratios are high in sediments deposited after the onset of anoxia so that the enhanced productivity may be supported and maintained by benthic phosphate release from surface sediments. Moreover, the analysis of Mediterranean sapropels showed that phases of enhanced productivity were accompanied and supported by anoxic conditions in bottom waters favoring the release of benthic phosphate.

To further investigate the feedbacks between marine productivity and redox conditions, a new model for the particulate organic carbon (POC), oxygen, nitrogen, and phosphorus cycling in oceans and sediments was developed. In contrast to previous attempts, the model includes a transport-reaction model for the redox-dependent phosphorus turnover in surface sediments. Sedimentary processes are not only simulated for the deep-sea floor but also for the continental margin and shelf considering the terrigenous input of particulate P and POC. The sediment model is fully coupled to a three box model of the ocean where export production, N2-fixation, organic matter degradation and denitrification are the major processes. The coupled model reveals that the positive feedback embedded in the marine phosphorus cycle can induce large changes in the ocean's productivity and nutrient inventory. It also shows that the dissolved phosphate inventory of the ocean may have changed drastically during the Quaternary glacial/interglacial cycles.

Recent data show that eutrophication of coastal waters has been increased in many areas leading to the spread of anoxia in bottom waters, enhanced denitrification and changes in the functional groups dominating the phytoplankton community. Moreover, the stratification of the upper water column in the equatorial Pacific has been enhanced over the last decades inducing a decrease in the ventilation of intermediate waters. Finally, it has been proposed to fertilize the Southern Ocean and other areas of the ocean with iron to increase the biological CO_2 uptake and to remove anthropogenic CO_2 from the atmosphere. All of these anthropogenic perturbations are amplified by the release of dissolved phosphate from anoxic sediments and may thus ultimately push significant areas of the global ocean towards anoxia. Thus, the positive feedback rooted in the benthic phosphorus cycle has to be considered and should be more closely investigated in high-resolution models of the ocean to predict the consequences of iron-fertilization and other human impacts on the marine biogeochemical system.

IFM-GEOMAR Contributions

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Wallmann, K., 2003: Feedbacks between oceanic redox states and marine productivity: A model perspective focused on benthic phosphorus cycling. *Global Biogeochemical Cycles*, **17**, 1084, doi: 10.1029GB001968.

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