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The effects of *Phaeocystis globosa* bloom on the dynamics of the mineralization processes in intertidal permeable sediment in the Eastern English Channel (Wimereux, France)

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ABSTRACT

In the Eastern part of the English Channel, high biomasses of the phytoplankton prymnesiophyceae *Phaeocystis globosa* (reaching biomasses over 20 μg Chla l^{-1}) are a recurrent spring event (March–June). A significant part of the pelagic *Phaeocystis*-derived organic matter can be broken down in the sandy permeable sediment that makes up most of the intertidal zone in this part of the Channel. Sediment characteristics, macrofaunal distribution, bacterial biomass, organic carbon content, sediment oxygen demand (SOD), and the sediment–water flux of dissolved inorganic nitrogen and silicates were calculated for an exposed sandy beach (Wimereux, France) over a two-year period (2004–2006). According to the data collected, the SOD remains relatively low throughout the whole survey (64–306 μmol m^{-2} h^{-1}), indicating limited mineralization. However, the same data reveals a temporal variability in the flux, with a sharp increase in the SOD and ammonium released in spring when *Phaeocystis*-derived phytodetritus was deposited. The organic carbon content and bacterial biomass values indicate similar patterns of increase in response to the phytodetritus deposit. The nitrogen cycle also appears to be modified during the *Phaeocystis* bloom, with a clear stimulation of nitrification. The influence of various factors (e.g., temperature, nutrient concentrations, and bacterial activity) on the temporal fluctuations of the exchanges is discussed, as are the direct effects of spring bloom. A synthesis of the annual cycle of the mineralization dynamics in this permeable sediment type is also presented.

1. Introduction

About 30% of oceanic primary production occurs in shelf and coastal environments, constituting less than 10% of the total area of the ocean (Janhke et al., 2005). In many coastal systems, phytoplankton blooms are common events; a significant amount of this phytoplanktonic biomass can then filter through the water column, settling on the bottom and remineralizing in the superficial sediments (Boon et al., 1998; Grenz et al., 2000; Denis et al., 2001). Field observations and experimental studies commonly point to significant changes in benthic nutrient regeneration and dissolved nutrient releases in coastal ecosystems affected by bloom events (Dollars et al., 1991). These studies generally report a rapid response (within a few weeks) of the benthic systems to the input of organic matter following post-bloom sedimentation (Boon et al., 1998). However, the links between eutrophication, algae production/deposition and nutrient cycling in superficial sediment remain rather poorly documented and should not be generalized (Grenz et al., 2000).

Most of the published data on benthic flux involve muddy environments. Although permeable sandy sediments are estimated to represent almost 70% of the continental shelves worldwide, they remain largely unstudied (Emery, 1968). This paradox is mainly due to technical limitations (Viollier et al., 2003), but also to the low levels of organic matter and other reactive substances in permeable sediment. Many authors believe that significant mineralization reactions require a large stock of organic matter and result in the accumulation of dissolved substances, and therefore, sandy sediments have largely been neglected (Boudreau et al., 2001).

Fortunately, recent research is bringing about a change in this misguided view. Studies of nutrient profiles and sediment–water exchange rates in permeable shelf sediments have revealed that organic-poor sands can still have relatively high mineralization rates (Janhke et al., 2005), and experimental studies have confirmed that nutrient regeneration in such sandy environments may be similar to the regeneration taking place in cohesive fine sediments (Rauch and Denis, in press). Several recent studies have demonstrated that the common perception of coastal sands as

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biogeochemical deserts must be completely reworked (Boudreau et al., 2001; Janhke et al., 2005). In fact, numerous studies about sedimentary biogeochemical processes have had a relatively limited scope, with none involving repetitive sampling over entire annual cycles (Dollars et al., 1991). Consequently, it is often difficult to determine the integrated impact of environmental parameters on benthic flux.

In the eastern English Channel and the southern Bight of the North Sea, intense pelagic spring blooms are recurrent events (Gentilhomme and Lizon, 1998; Seuront and Souissi, 2002). Such phytoplankton outbursts are dominated by the prymnesiophyceae algae *Phaeocystis globosa* (Lancelot et al., 1987), a species characterized by a phase alternation between free-living solitary cells and gelatinous colonies (Rousseau et al., 1994). *P. globosa* have become a population of silica-controlled diatoms that dominate the spring phytoplankton community at levels of more than 95% (Rousseau et al., 1994). These *Phaeocystis* colonies increase rapidly in size and in number during the exponential phase of the bloom. Proposed hypotheses to explain the *Phaeocystis*/diatom succession include differential competition for light and/or nutrients (Peperzak et al., 1998), but specific causes remain uncertain. The end of the *Phaeocystis* bloom in the North Sea is typically followed by the cells' release from the colonies and massive cell lysis (Cadée, 1996). Recently, the intensity and the duration of this spring bloom have been linked to coastal eutrophication (Gypens et al., 2007).

At the end of the bloom, colony disruption results in the accumulation of mucilaginous aggregates on the sea surface, in quantities that depend on wind conditions (Seuront and Souissi, 2002). Consequently, beaches are often covered with an impressive layer of foam. The impact of this foam has mainly been studied on phyto- and zooplankton pelagic populations (Becquevort et al., 1998). For the intertidal benthic area, Cadée (1996) demonstrated that the foam is incorporated into the food web. However, Desroy and Denis (2004) have more recently shown the mortality of macrobenthic fauna in estuarine zones is affected by the foam accumulation. Due to their impact on the marine ecosystem, *Phaeocystis* colony blooms are generally reported as undesirable and have been defined as non-toxic Harmful Algal Blooms (HAB) (Veldhuis and Wassman, 2005).

Few studies have dealt with the impact of foam deposition on the biogeochemistry of intertidal sediment (Hubas et al., 2007; Rauch and Denis, in press). The objective of the present study is to describe the temporal variability of benthic flux and interstitial pore water composition on a sandy beach (Wimereux, France) throughout the year. This beach is representative of the exposed permeable sandy sediments along the French coast of the eastern part of the English Channel and is regularly affected by spring foam deposition (Spilmont et al., 2005; Rauch and Denis, in press).

2. Methodology

2.1. Study site and sampling strategy

A two-year survey of intertidal benthic mineralization processes was conducted from March 2004 to March 2006 in the eastern part of the English Channel in Wimereux, France (Fig. 1). During this two-year period, a total of 30 sampling campaigns were performed in order to measure benthic flux, with a reduced lag time between sampling during the spring *Phaeocystis* bloom. Pore water analyses were also performed monthly during the first year of the survey. The study area was a typical hydrodynamically exposed (western exposition) sandy beach subjected to a semi-diurnal megatidal regime (spring tidal range >8 m). The sampling point (50°45′905 N, 1°36′397 E) was located on the higher part of the beach, between the mean high water level at neap tide and the mean tide level. Wimereux beach sediment is characterized by medium-grained sand (median grain size: 0.2 mm; Spilmont et al., 2005) and is regularly affected by spring *Phaeocystis*-derived foam deposition (Hubas et al., 2007). The temporal evolution of the *P. globosa* bloom was characterized using the chlorophyll *a* data from the SOMLIT network (SOMLIT: *Service d'Observation du Milieu Littoral*; http://www.domino.u-bordeaux.fr/somlit_national/; located on the coast near the harbor at Boulogne-sur-mer; 50°40′75 N, 1°31′17 E), which was measured by spectrophotometry (Lorenzen, 1967).

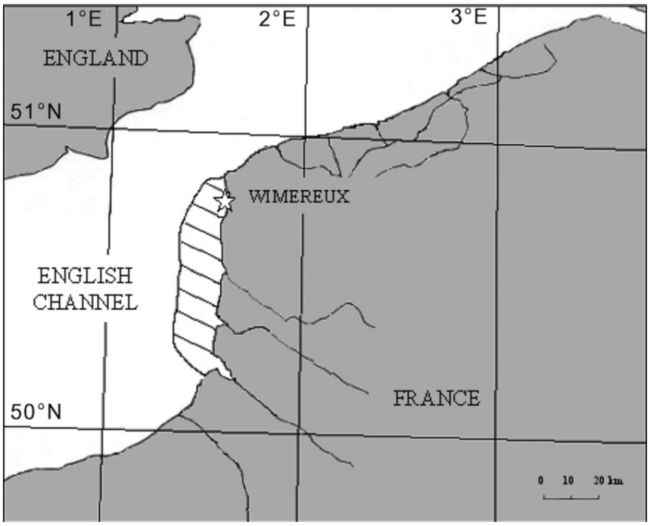

Fig. 1. Location of the sampling site (Wimereux beach) with the indication of the area affected by the spring *Phaeocystis globosa* bloom (hatched).

2.2. Sampling and incubation device

All samples were taken at the end of the immersion period, in areas under approximately 50 cm of water. Three or four sediment cores were manually collected in Perspex tubes (15 cm in diameter; 35 cm in length) and rapidly returned to the laboratory, located about 100 m from the sampling zone. Bottom waters were also sampled and placed in an inflatable reserve tank. Incubations were performed according to the protocol proposed by Denis et al. (2001). Briefly, the reserve tank and sediment cores were sealed (excluding air bubbles) and placed in dark, refrigerated cabinets at field temperatures; magnetic stirring was implemented to prevent concentration gradients from developing in the water. During the 24 h incubation period, each core's overlying water and the bottom waters in the reserve tank were sampled every 3 h, and the recorded difference between the changes in sediment concentrations in the overlying water and the bottom waters was used to calculate the sediment–water flux. Given the short delay between the moment of core sampling and the beginning of the incubations, the first sampling point in the reserve tank was considered as representative of the nutrient conditions in the water column and was used to characterize the hydrological dynamics of the sample.

Flux was determined by regressing changes in the overlying water concentrations over time. Non-significant regressions (Pearson's correlation: $P < 0.05$) (i.e., changes over time that were less than the analytical variability) were interpreted as zero flux. To compensate for the low sediment sample volume compared to the overlying water volume, a correction was systematically applied for water replacement, using bottom waters from the reserve tank. At the end of the incubation period, 2.7 cm sub-samples were taken from each core to allow porosity profile measurements, elemental analysis and pore water extraction.