Biogeochemistry (2007) 83:235–244
DOI 10.1007/s10533-007-9094-2

ORIGINAL PAPER

Vernal sedimentation trends in north Norwegian fjords: temporary anomaly in ^{234}Th particulate fluxes related to *Phaeocystis pouchetii* proliferation

Sabine Schmidt · Sauveur Belviso · Paul Wassmann · Gérard Thouzeau · Jacqueline Stefels

Received: 23 May 2006 / Accepted: 5 October 2006 / Published online: 8 March 2007

Abstract We report data of a naturally occurring radionuclide, ^{234}Th, an in situ tracer, to investigate vertical export of biogenic matter during a vernal bloom of *Phaeocystis pouchetii* in the fjords of northern Norway. To optimise sampling of different stages of the bloom, three fjords with increasing oceanic influence (Balsfjord, Malangen fjord and Ullsfjord, respectively) were investigated in April 1997. Contrasting situations were encountered between the three fjords: the proliferation of *P. pouchetii* in Ullsfjord surface waters coincided with a drastic reduction of particulate ^{234}Th fluxes in traps, although particulate organic carbon (POC) and dimethylsulphoniopropionate (DMSP) were exported and ^{234}Th was available in surface waters. When large colonies make up a significant fraction of the vertical flux, as observed in Ullsfjord in April 1997, there may be a large and rapid change in the POC/^{234}Th ratio, further complicating the use of ^{234}Th as a tracer for POC export. The results suggest that the proliferation of *Phaeocystis pouchetii* during vernal bloom could temporary increase OC/^{234}Th ratio of particles and delay the particulate export of ^{234}Th, and probably of other particle-reactive species, from surface waters.

Keywords fjord · Northern Norwegian shelf waters · Particle flux · *Phaeocystis* · Sediment trap · ^{234}Th

S. Schmidt (✉)
EPOC, UMR 5805, Avenue des facultés, Talence Cedex 33405, France
e-mail: s.schmidt@epoc.u-bordeaux1.fr

S. Belviso
LSCE, UMR 1572, Gif sur Yvette Cedex 91 198, France

P. Wassmann
Institute for Aquatic Resources and Environmental Biology, The Norwegian College of Fishery Science, University of Tromso, Tromso, Norway

G. Thouzeau
IUEM, UMR 6539, Technopôle Brest-Iroise, Plouzane 29280, France

J. Stefels
Laboratory of Plant Physiology, University of Groningen, P.O. Box 14, 9750 AA Haren, The Netherlands

Introduction

The microalga genus *Phaeocystis* has a worldwide distribution and is known to develop massive blooms in polar and temperate waters (Riebesell et al. 1995). Spring blooms of *Phaeocystis* often follow diatom blooms, after the decline of dissolved silicate (Lancelot et al. 2005; Wassman et al. 2005). This colony-forming alga is an important source of the volatile organic sulphur compound dimethyl sulphide (DMS) and its

dense blooms can act as a carbon sink (Rousseau et al. 2000; Belviso et al. 2006). Both sulfur and carbon cycles are relevant to climate change studies, sulphur as an important source of cloud condensation nuclei, and carbon being the main contributor to the greenhouse effect. Quantifying the role of *Phaeocystis* blooms in particle fluxes and export is therefore important if we want to understand their potential control on the escape of carbon from the photic zone of coastal waters. Indeed, the community structure determines how much of the primary production settles via the classical food web, via large phytoplankton and their grazers, and how much nutrients are regenerated via the microbial food web (Eppley and Peterson 1979; Verity 2000; Stelfox-Widdicombe et al. 2004). Within the EU funded program Escape (Entangled Sulphur and Carbon cycles in *Phaeocystis* dominated Ecosystems), this study focused upon the vertical export of biogenic material in relation to the plankton community dynamics and structures in north Norwegian fjords.

Thorium-234 (^{234}Th, $t_{1/2}$ = 24.1 days), a naturally occurring radionuclide, was used in this work to explore particle dynamics during the development of a *Phaeocystis* bloom. ^{234}Th is produced in seawater via the decay of its long-lived and highly soluble parent, uranium-238 (^{238}U). Since ^{234}Th is highly particle-reactive, and hence sticks to all particle surfaces, the clearance of ^{234}Th from surface waters is a direct indication of the removal rate of material on sinking particles from the upper ocean. Review papers clearly show the interest in this tracer as a tool for estimating particulate organic carbon export (Buesseler et al. 2006 and references herein). In surface waters, biological activity is the main source of particles and can vary considerably on short time scales. Previous studies have shown the close coupling between dissolved ^{234}Th scavenging and new production in the ocean (Coale and Bruland 1985). The particulate ^{234}Th residence time in oceanic surface waters is of the order of a few days to a few weeks (Moran and Buesseler 1992) and appears to be mainly governed by the classical food web, via the export of detritus (marine snow, aggregates, faecal pellets) (Schmidt et al. 1992; Buesseler et al. 2006).

The present paper discusses ^{234}Th data in the water column and in settling particles, together with the determination of the stocks of *Phaeocystis pouchetii* and DMSP in surface waters of north Norwegian fjords. The aims of this study are: (i) to describe temporal variability of ^{234}Th activities and fluxes during the progress of a vernal bloom, (ii) to calibrate trap collection efficiencies using ^{234}Th data, and (iii) to assess the impact of *Phaeocystis* proliferation on vertical export of particles.

Material and methods

Study area

To optimize sampling of different stages of the recurrent vernal *Phaeocystis pouchetii* bloom in northern Norway, three fjords with decreasing oceanic influence were investigated in the north Norwegian coastal zone (Fig. 1). The westernmost fjord, Malangen fjord, is relatively open and exposed to shelf waters. Ullsfjord, the northernmost is the most open to coastal waters with a wide entrance. Both fjords are wide and have deep sills. Balsfjord is the least exposed: it is a tapered inland fjord, which is separated from the Malangen fjord and Ullsfjord by three narrow straits. More details on sampling areas including their physical, chemical and biological characteristics can be found in Wassman et al. (1996), Keck and Wassmann (1996), Reigstad et al. (2000) and Archer et al. (2000). The stations were visited sequentially five times, between April 7 and April 25, 1997, aboard the RV Johan Ruud.

Measurements

To sample the settling flux directly, free-floating multiple-sample programmable sediment traps (Pro-Trap) were deployed at all three fjords for about 16 h at each time (trap depth: 60 m). The Pro-Trap system consists of four polyvinyl chloride (PVC) sediment tubes, each of 0.018 square meter exposed area (cylinder height of 80 cm, trap aspect ratio A ¼ 5.3), mounted on a stainless-steel frame. Depth and angle sensors allowed defining the position of the traps in the water