Journal of Marine Systems 75 (2009) 360–370

Contents lists available at ScienceDirect

Journal of Marine Systems

journal homepage: www.elsevier.com/locate/jmarsys

Thorium-234 derived information on particle residence times and sediment deposition in shallow waters of the south-western Baltic Sea

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ARTICLE INFO

Article history:
Received 24 July 2006
Received in revised form 25 June 2007
Accepted 2 July 2007
Available online 24 April 2008

Keywords:
Thorium-234
Particulate matter
Residence time
Coastal
Sediment deposition
Resuspension
Baltic Sea

ABSTRACT

Activities of the naturally occurring, short-lived and highly particle-reactive radionuclide tracer ^{234}Th in the dissolved and particulate phase were measured at three shallow-water stations (maximum water depths: 15.6, 22.7 and 30.1 m) in Mecklenburg Bay (south-western Baltic Sea) to constrain the time scales of the dynamics and the depositional fate of particulate matter. Activities of particle-associated (>0.4 µm) and total (particulate+dissolved) ^{234}Th were in the range of 0.08–0.11 dpm L^{-1} and 0.11–0.20 dpm L^{-1}, respectively. The activity ratio of total ^{234}Th and its long-lived and conservative parent nuclide ^{238}U was well below unity (range: 0.09–0.19) indicating substantial radioactive disequilibria throughout the water column, very dynamic trace-metal scavenging and particle export from the water column at all three stations. For the discussion the ^{234}Th data of this study were combined with previously published water-column ^{234}Th and particulate-matter data from Mecklenburg Bay (Kersten et al., 1998. Applied Geochemistry 13, 339–347). The resulting average vertical distribution of total $^{234}Th/^{238}U$ disequilibria was used to estimate the depositional ^{234}Th flux to the sediment. There was a virtually constant net downward flux of ^{234}Th of about 28 dpm m^{-2} d^{-1} leaving each water layer of one meter thickness. Thorium-234-derived net residence times of particulate material regarding settling from a given layer in the water column were typically on the order of days, but with maximum values of up to a couple of weeks. Based on an average ratio of particulate matter (PM) to particle-associated ^{234}Th a net flux of about 145 mg PM m^{-2} d^{-1} was estimated to leave each water layer of one meter thickness. The estimated cumulative water-column-derived particulate-matter fluxes at the seafloor are higher by a factor of about 2 than previously published sediment-derived estimates for Mecklenburg Bay. This suggests that about half of the settling particulate material is exported from the study area and/or subject to processes such as mechanical breakdown, remineralisation and dissolution. Lateral particulate-matter redistribution and particle breakdown in the water column (as opposed to the sediment) seem to be favoured by (repeated) particle resuspension from and resettling to the seafloor before ultimate sedimentary burial. The importance of net lateral redistribution of particulate material seems to increase towards the seafloor and be particularly high within the bottommost few meters of the water column.

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doi:10.1016/j.jmarsys.2008.04.004

1. Introduction

Despite the relatively small global area covered by shelf seas a significant amount of organic carbon is buried in shelf sea sediments (e.g. Hedges and Keil, 1995). Owing to autochtonous and terrigenous inputs, close proximity of the seafloor and benthic-pelagic coupling, coastal seas in general play a major role in the turnover of particulate material at the interface between land and oceans (e.g., Jørgensen, 1996). To improve the understanding of exchange processes between water column, sediment, land and open ocean, residence times and transport, redistribution and deposition pathways of particulate matter and its constituents need to be traced and quantified.

Particle-associated processes such as particle formation through primary and secondary production of biomass, dissolution, mechanical and microbial decomposition, aggregation and disaggregation, feeding, defecation and excretion, sedimentation, biodeposition, resuspension and bioresuspension can have an impact on residence times and transport, redistribution and deposition pathways of particulate matter. These processes have characteristic time scales of up to a few weeks. Naturally occurring particle-reactive radionuclide tracers with known half lives and well defined source functions can help to elucidate the mechanistic interplay and time-integrated effect of these processes. One such radionuclide of suitable half life (24.1 d) is the short-lived highly particle-reactive isotope thorium-234 (^{234}Th). This tracer has been widely used to study particle cycling in the surface ocean and also near the seafloor (e.g., Turnewitsch and Springer, 2001; Rutgers van der Loeff et al., 2002; Miller and Sværen, 2003; Radakovitch et al., 2003; Muir et al., 2005). In seawater it occurs as a $Th(OH)_n^{(4-n)+}$ ion and is produced by the radioactive decay of its direct very long-lived parent ^{238}U (half-life: 4.45 billion years) which occurs in seawater as the anionic uranyl carbonate complex $[UO_2(CO_3)_2{}^{2-}]$. In oxygenated waters ^{238}U behaves conservatively, i.e., in the same way as the main components of sea salt. The activity distribution of ^{234}Th can be used to infer both fluxes and residence times of the particulate matter onto which it adsorbs. With a signal quasi-integrating over several weeks (mean life: 34.8 d), ^{234}Th reflects the net effect of the aforementioned processes acting on similar and shorter time scales.

We measured activities of ^{234}Th in the dynamic coastal shallow water system of the Mecklenburg Bay (south-western Baltic Sea) to help constrain the time scales of the dynamics and the depositional fate of particulate-matter. The new data are combined with previously published ones (Kersten et al., 1998) and the overall data set is used to estimate the depositional flux of particulate matter at the seafloor. The particulate-matter fluxes are discussed within the context of previously published estimates of deposition rates. By calculating ^{234}Th-derived residence times of particulate material and by discussing the ^{234}Th data within the context of other particle-associated parameters, a likely scenario of particulate-matter dynamics, redistribution and deposition in the Mecklenburg Bay is derived.

2. Material and methods

2.1. Study area

The study area in Mecklenburg Bay is part of the western Baltic Sea with a maximum depth of ~28–30 m (Fig. 1) and located at the western end of the 'Western Baltic Sea–Gulf of Finland' seiche system (Magaard, 1974). Stratification of the water column is governed by pronounced salinity gradients maintained by episodic saline inflow from the North Sea into the deep water column. These longer-term processes (time scale: years up to decades) are superimposed by the impact of the seasonality of the wind and air-temperature regime (Siedler and Hatje, 1974). Particularly from early spring until early autumn the water column tends to exhibit stable density stratification. Tidal influence is negligible (Magaard, 1974) and wind is the main driver for currents and wave action. Below ~20 m water depth the seafloor is covered with mud; above ~20 m depth sandy and mixed sediments prevail (Ziervogel

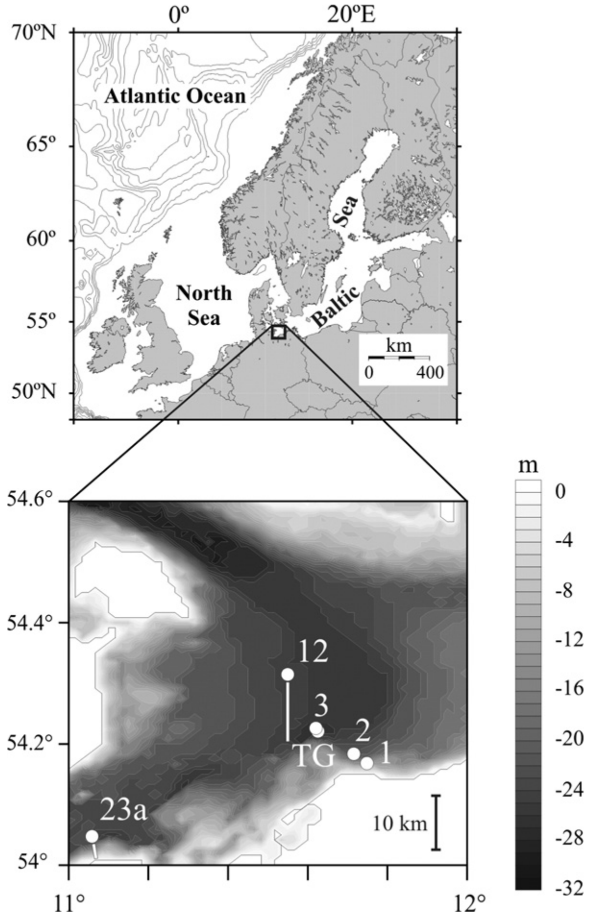

Fig. 1. Map of the location of the Mecklenburg Bay study area in the south-western Baltic Sea. The enlarged map shows the bathymetry of the area [map obtained from the dataset provided by Seifert and Kayser (1995)]. Sediment sampling sites 12 and 23a of Kersten et al. (2005a,b) and the study site of Turnewitsch and Graf (2003) are indicated by "12", "23a" and "TG", respectively. The locations of stations 1, 2, and 3 of the October 2003 study are indicated by the numbers "1", "2" and "3" (also see Table 1). The white lines indicate transects along which Kersten et al. (1998) took water-column samples for particulate and dissolved ^{234}Th, ^{238}U and total particulate matter.