Deep Submarine Groundwater Discharge Indicated by Chloride Anomalies in the Sediment Pore Water in the Gulf of Gdańsk, Southern Baltic Sea


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Abstract

Submarine groundwater discharge (SGD) is a significant source of water and chemical substances, with inputs mainly to shallow coastal zones. Using chloride as the main tracer, the study was investigating a depth layer of 0–2 m, located at a water depth of 18 m, 3 km from the coastline, within the shallow coastal zone (Fig. 2). The groundwater discharge rate of 5.5 ± 3.3 × 10⁻³ m³/s (2–10) was estimated using a diagnostic approach while the SGD was shown to be an important water source to the Gulf of Gdańsk. The SGD water movement speed corresponded to the pore water distribution and cycling of selected compounds (chlorine, nutrients, organic carbon, iron, magnesium and sodium) and different faulty profile from a biogeochemical simulation model. Based on these findings, we hypothesized that fresh groundwater (SGD) flow and its circulation are responsible for the formation of gassy sediments, and diffuse fresh halite inclusions in sediments.

Graphical Abstract

Results and Discussion

SGD discharge rate

Chloride pore water profiles provide information about fluid transport in sediments (Schidlowski et al., 2006), with differences indicated by a linear increase in the CI concentration and fresh water flow from a saline-shaped area (Fig. 4a) (Oelkers et al., 2013; Schidlowski et al., 2005). Therefore, this approach was used to calculate the seasonal impact of the SGD on the study area. The discharge rate of 0.5 ± 0.2, (2–10) m³/s (1) clearly indicated an upward flow of fresh water that connected with an upwelling of measured sediments. The pore water profiles of other major ions (Na, Mg, and Ca) similarly followed the CI profile and indicated the mixing of freshwater with seawater in the suboxic (Symczewski et al., 2012).

Biosedimentary cycles and mud-related cycles

The recent studies of the sediment column (from 4–17 cm and 17–49 cm) in the front zone produced the intensive suboxic reactions (IR) layer (obtained from Fig. 5a) and the second zone of an anoxic CH₄ rise and production. While the IR layer, K and Ca were non-generously distributed (Fig. 3c) and the reduction of Mn and Fe in the production of their reduced, very soluble forms (NO₃ and NO₂⁻), which caused an increase in the Mn and Fe concentrations up to a depth of 7 cm. Below, there was a rapid increase in both metals, mostly likely due to precipitation with sulfide, as the BSG concentration decreased from 1 mmol/l to 0.8 mmol/l (Fig. 5b). The manganese reduction zone was detected 4 cm below the sediment surface, as a significant increase in Mn (Fig. 6a). These findings suggested a certain degree of coupling between suboxic processes and the formation of Mn, Fe and as well as the cycling of these chemicals. Generally, indices maintain lead to pore water phenomenon across the redox boundary of reduced levels of molybdenum (Burdige and Morel, 2001), both elements change from the sediment surface to the core of the water column, as well as the formation of new oxides and probably also of sulfides (Fig. 4b). Stable has been observed in the shallower depth of other sites in the Gulf of Gdańsk for the layer formed several anomalies down to the sediment (Kokocka-Matuszewska & Kalicki, 2010) and there was observed with other species. The presence of manganese in the IR layer was also suggested and can be explained by the rapid introduction of iron into the IR layer by vertical advection. The manganese-rich water was also characterized by the absence of organic manganese oxidation (AMO), which located in the IR layer to provide a complete barrier to Mn escape following the anaerobic oxidation of manganese (AMO). The STM is typically located one to several meters below the sediment surface, in continental margin sediments and plays a key role in the biogeochemistry of the bottom water (Burdige and Morel, 2001), for this study the STM is located at the variability of Mn, Fe and Cu concentration in the Gulf of Gdańsk, the location was determined as the intense redox reaction layer (IR). The Mn content of the sediment (Burdige and Morel, 2001), which is in 2020 higher than in the present study (Matuszewska et al., 2014). In the second zone (17–49 cm), the pore water profiles of CI, Mn, Fe, DOC and CO₂ also did not follow the BSI model but instead were cycled with depth, and by the definition of the redox-manganese transition zone (MMT), which located in the IR layer to provide a complete barrier to Mn escape following the anaerobic oxidation of manganese (AMO). The MMT is typically located one to several meters below the sediment surface, in continental margin sediments and plays a key role in the biogeochemistry of the bottom water (Burdige and Morel, 2001), for this study the STM is located at the variability of Mn, Fe and Cu concentration in the Gulf of Gdańsk, the location was determined as the intense redox reaction layer (IR). The Mn content of the sediment (Burdige and Morel, 2001), which is in 2020 higher than in the present study (Matuszewska et al., 2014).

Figure 2 (a) The view of hydrodynamic survey along the northern part of the Gulf of Gdańsk along three perpendicular transects, which lengths were about 2.5 km each, gassy sediments are marked by (c) hydrographic transect 1 with marked gassy sediments between 1490 and 2000 sample (c) hydrographic transect 2 with marked gassy sediments between 1590 and 2000 sample (d) hydrographic transect 3 with marked gassy sediments between 1950 and 3600 sample (a) Annual isopach of the sea bottom with the Rower. The ‘gassy’ sediments in close proximity of Ci 1

Figure 3 (c) Chloride (CI) and sodium pore water profiles in the study area. (a) Measured rates and intermediate lines: chloride concentrations in pore water (lines).

Taking into account average (CI) and equal to 40 cm (CI)

Figure 4 (a) Chloride pore water profiles of CI, pH, H₂CO₃, Fe, Mn, DIC, O₂, SO₄ and CH₄ in the study area. The white circles refer to a part area white black lines refer to other areas. The shaded area corresponds to the intense redox reaction layer (IR). (b) The concentration of organic carbon (Corg), inorganic carbon (CINH), iron, magnesium and sodium in the study area. The white circles refer to a part area white black lines refer to other areas. The shaded area corresponds to the intense redox reaction layer (IR).