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Impact of hydrotalcite deposition on biogeochemical processes in a shallow tropical bay

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ABSTRACT

The biogeochemistry of a tropical shoal bay (Melville Bay, Australia) impacted by the effluent release, precipitation, and deposition of hydrotalcite from an alumina refinery was studied in both wet and dry seasons. Within the deposition zone, sulfate reduction dominated benthic carbon cycling accounting for ≈100% of total microbial activity, with rates greater than those measured in most other marine sediments. These rapid rates of anoxic metabolism resulted in high rates of sulfide and ammonium production and low C:S ratios, implying significant preservation of S in stable sulfide minerals. Rates of total microbial activity were significantly less in control sediments of equivalent grain size, where sulfate reduction accounted for ≈50% of total benthic metabolism. Rates of planktonic carbon cycling overlying the deposition zone were also greater than those measured in the control areas of southern Melville Bay. At the sediment surface, productive algal and cyanobacterial mats helped stabilize the sediment surface and oxidize sulfide to sulfate to maintain a fully oxygenated water-column overlying the impacted zone. The mats utilized a significant fraction of dissolved inorganic N and P released from the seabed; some nutrients escaped to the water-column such that benthic regeneration of NH_4^+ and PO_4^{3-} accounted for 100% and 42% of phytoplankton requirements for N and P, respectively. These percentages are high compared to other tropical coastal environments and indicate that benthic nutrient recycling may be a significant factor driving water-column production overlying the deposition zone. With regard to remediation, it is recommended that the seabed not be disturbed as attempts at removal may result in further environmental problems and would require specific assessment of the proposed removal process.

1. Introduction

The release and deposition of industrial effluent into coastal waters can have serious consequences for the structure and function of nearshore ecosystems. Dead zones, for instance, are increasing exponentially in the coastal ocean, exacerbated partly by increases in domestic and industrial runoff, especially fertilizers, and fossil fuel burning (Diaz and Rosenberg, 2008). However, not all impacted zones are truly devoid of life, or caused by coastal eutrophication or the combustion of fossil fuels. A few such zones are natural, but other human activities, including smothering of the seabed by mine tailings and other industrial effluents, can result in significant changes to the coastal ecosystem. The impact of these anthropogenic events on planktonic and benthic community composition and structure, and on the metabolism of individual organisms, has been well-documented (Rosenberg, 1972; Shumway et al., 1983; Tyson and Pearson, 1991; Diaz and Rosenberg, 1995; Burd, 2002; Rabalais et al., 2002; Dagg et al., 2008), but how they impact pelagic-benthic coupling and nutrient biogeochemistry is less well understood.

In the tropical coastal ocean, few such areas and their impacts on biogeochemical processes are known (Stoffyn et al., 1977; Perry and Taylor, 2004). One such area exists in southern Melville Bay in the Northern Territory of northern Australia. This impacted area, with an estimated sediment volume of 606,007 m^3 dispersed over an area of 885,800 m^2 (Brinkman et al., 2006), persists year-round along a semi-enclosed embayment (inner Gove Harbour) within the larger bay. Heated seawater effluent containing elevated levels of dissolved trace metals is discharged from an alumina smelter into inner Gove Harbour. The effluent contains sodium aluminate ($NaAl(OH)_4$) which when discharged and mixed into the harbor reacts with magnesium in the seawater to form hydrotalcite ($Mg_6Al_2CO_3(OH)_{16} \cdot 4H_2O$), a mineral precipitate (Smith et al., 2005). This white precipitate deposits and smothers the seabed of the inner harbor resulting in a persistent, benthic sulfidic zone devoid of any benthic infauna, but carpeted at the thin oxidized

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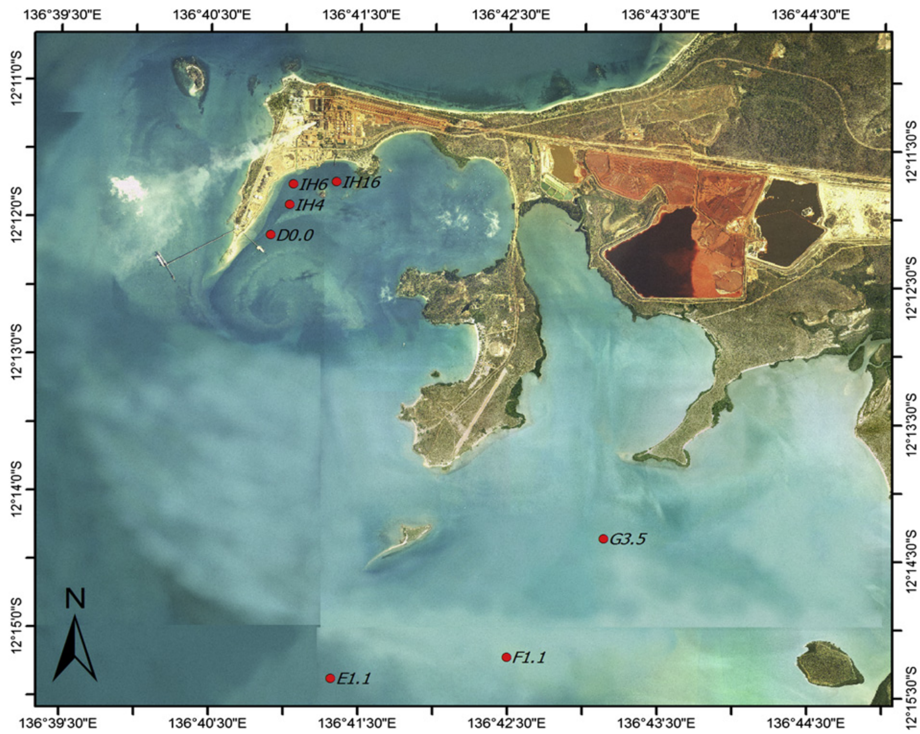

Fig. 1. Location map of the seven stations in Melville Bay sampled in the 2006 summer wet and 2007 winter dry seasons.

sediment surface by cyanobacterial and algal mats (Alcan Pty. Ltd., 2005; Parry and Munksgaard, 2005). The occurrence of industrially-derived hydrotalcite has been previously reported in the marine environment (Stoffyn et al., 1977; Vandelannoote et al., 1987; Perry and Taylor, 2004), but the impact of deposition of this material is poorly described.

This paper presents a study within and distal to the deposition zone in southern Melville Bay, with a view to describing the degree of anoxia within the sediments and its impact on benthic and pelagic biogeochemical processes.

2. Materials and methods

2.1. Sampling

Field sampling was conducted in southern Melville Bay (Northern Territory, Australia) where seven stations were sampled in the summer wet season (Mar 2006) and the winter dry season (Jun–Jul 2007). Four sites (Stas.IH4, IH6, IH16 and D0.0) were located within the impacted zone of inner Gove Harbour and three control sites (Stations E1.1, F1.1 and G3.5) were located distal to the impact zone (Fig. 1; Table 1).

2.2. Pelagic measurements

Water-column profiles were obtained for temperature, salinity, DO, and pH at each site in the wet season using a Hydrolab DataSonde 3 datalogger calibrated as per factory instructions. In the dry season, vertical profiles were obtained using a Seabird SBE911 CTD fitted with a Licor PAR sensor, a Wet Labs CStar transmissometer, a Seabird SBE43 oxygen sensor, and a Seapoint fluorometer. Separate casts were taken from surface and 2–3 m below surface waters with a pre-washed 5 L Niskin bottle for dissolved inorganic nutrients, bacterial numbers and productivity, and phytoplankton production, which were processed as described in Robertson et al. (1998). In the dry season, Niskin casts were also taken for dissolved inorganic nutrients and to obtain water at the same two depths for O_2 measurement of community respiration and gross and net primary production using methods described in McKinnon et al. (2007).

2.3. Benthic measurements

On both cruises, sediments at each site were sampled for solid-phase and pore water element concentrations and for microbial measurements to a maximum depth of 2.5 m using a Kasten corer. Sediment samples were also taken to measure solute flux across the sediment–water interface at each site using a 0.027 m^2 Bouma boxcorer.

Kasten corer samples were sub-sampled at 10–15 irregularly-spaced intervals to 2.5 m. These sub-samples were frozen, wet and dry weighed to determine water content, and ground to a fine

Table 1
Location of control (C) and impacted zone stations (I) in southern Melville Bay.

Station Number	Date Sampled	Latitude (degrees S)	Longitude (degrees E)	Mean depth (m)
IH4 (I)	24 Mar 2006, 26 June2007	12°11.91	136°41.03	6
IH6 (I)	23 Mar 2006, 27 Jun 2007	12°11.76	136°41.05	3
IH16 (I)	25 Mar 2006, 28 Jun 2007	12°11.74	136°41.34	5
D0.0 (I)	26 Mar 2006, 29 Jun 2007	12°12.13	136°40.90	11
E1.1 (C)	20 Mar 2006, 1 Jul 2007	12°15.37	136°41.32	7
F1.1 (C)	21Mar 2006, 2 Jul 2007	12°15.21	136°42.50	6
G3.5 (C)	22 Mar 2006, 3 Jul 2007	12°14.34	136°43.14	5