

Benthic respiration in a seep habitat dominated by dense beds of ampharetid polychaetes at the Hikurangi Margin (New Zealand)

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ARTICLE INFO

Article history:

Received 22 July 2008

Received in revised form 30 March 2009

Accepted 1 June 2009

Available online 11 June 2009

Communicated by G.J. de Lange

Keywords:

Ampharetidae

cold seeps

Hikurangi Margin

total oxygen uptake

diffusive oxygen uptake

methane oxidation

carbon turnover

rain drop site

ABSTRACT

Many biological seep studies focused on the distribution, structure, nutrition and food web architecture of seep communities as well as on their interaction with the seep geochemistry. However, overall respiration at cold seeps received only little attention. We conducted in-situ oxygen flux measurements in combination with ex-situ oxygen micro-profiles, respiration measurements, as well as rate determinations of microbial methane and sulfate turnover to assess respiration pathways as well as carbon turnover at a seep habitat that was recently discovered alongside the Hikurangi Margin offshore northern New Zealand. This habitat is dominated by dense beds of tube-building, heterotrophic ampharetid polychaetes. Average total oxygen uptake (TOU) from this habitat was very high ($83.7 \text{ mmol m}^{-2} \text{ day}^{-1}$). TOU at a non-seep reference site ranged between 2.7 and $5.8 \text{ mmol m}^{-2} \text{ day}^{-1}$. About 37% ($30.8 \text{ mmol m}^{-2} \text{ day}^{-1}$) of the average TOU was consumed by ampharetids. Considering mean diffusive oxygen uptake ($8.5 \text{ mmol m}^{-2} \text{ day}^{-1}$) the remaining fraction of ~53% of the TOU ($44.4 \text{ mmol m}^{-2} \text{ day}^{-1}$) might be explained by respiration of epibenthic organisms as well as aerobic methane and sulfide oxidation at the sediment–water interface. The strongly negative carbon isotopic signatures ($-52.9 \pm 5\%$ VPDB) of the ampharetid tissues indicate a methane derived diet. However, carbon production via anaerobic oxidation of methane (AOM) was too low ($0.1 \text{ mmol C m}^{-2} \text{ day}^{-1}$) to cover the mean carbon demand of the ampharetid communities ($21 \text{ mmol C m}^{-2} \text{ day}^{-1}$). Likely, organic carbon generated via aerobic methane oxidation represents their major carbon source. This is in contrast to other seep habitats, where energy bound in methane is partly transferred to sulfide via AOM and finally consumed by sulfide-oxidizing chemoautotrophs providing carbon that subsequently enters the benthic food web.

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1. Introduction

Hydrocarbon based ecosystems, known as cold seeps occur in tectonically active and passive margins, where the supply of reduced hydrocarbons from deeper sources and their subsequent microbial transformation in surface sediments sustains specific microbial and metazoan communities. During anaerobic methanotrophy, which represents a major sink of methane in marine sediments (cf. Boetius and Suess, 2004; Reeburgh, 2003, 2007, and references therein), a significant fraction of the energy bound in methane is transferred to sulfide. High fluxes of methane and sulfide support chemoautotrophic free-living and symbiotic bacteria. They provide the basis for complex microbial and metazoan seep communities, which in the deep sea often far exceed the biomass and abundance of non-seep communities (Levin, 2005). Many biological seep studies focused on the distribution, structure, nutrition, and food web architecture of seep commu-

nities as well as on their interaction with the geochemistry of their environment. For a comprehensive review see Levin (2005) and Judd and Hovland (2007). However, with regard to their overall respiration and carbon demand, seep communities received less attention.

Since the end of the 1970s, autonomous chamber deployments were conducted successfully in deep-sea environments to study benthic carbon turnover and benthic–pelagic coupling (Viollier et al., 2003; Wenzhöfer and Glud, 2002; Witte et al., 2003, and references therein). It was only recently that benthic flux chambers were deployed at cold seeps, e.g., at Hydrate Ridge (Sommer et al., 2006) and in the Gulf of Mexico (Sommer et al., unpubl. data) as well as at mud volcanoes off Costa Rica (Linke et al., 2005) and in the Gulf of Cadiz (Sommer et al., 2008a, 2009). The few total oxygen consumption rates that are available indicate that cold-seep sediments covered with sulfide-oxidizing bacterial mats of the genus *Beggiatoa* have a high total oxygen demand of up to $53 \text{ mmol m}^{-2} \text{ day}^{-1}$, which, e.g. at Hydrate Ridge, can be up to 25-fold higher than at respective non-seep areas (Sommer et al., 2006). Lower total oxygen uptake rates were measured in habitats covered with chemosynthetic tube worm

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colonies (*Polybrachia*, *Siboglinum*) at the Captain Arutyunov mud volcano in the Gulf of Cadiz (max.: 13 mmol m⁻² day⁻¹, Sommer et al., 2008a) or sediments populated by *Calyptogena* clam beds at Hydrate Ridge (max.: 5 mmol m⁻² day⁻¹, Sommer et al., 2006).

Recently, a seep habitat colonized by extremely dense beds of heterotrophic ampharetid polychaetes with a maximum abundance of 72,000 individuals m⁻² was discovered at several cold seep sites at the Hikurangi Margin (Sommer et al. 2008b). The ampharetid beds were associated with unusually high methane sea bed emission rates of up to 265 mmol m⁻² day⁻¹ and high methane concentrations (up to 1962 μM) close to the sediment surface. In the present study, we demonstrate that these ampharetid polychaetes significantly contribute to the total oxygen uptake and benthic carbon turnover of this particular seep habitat. This study further indicates that biomass of aerobic methanotrophs likely represents an important carbon source to cover the high carbon demand of these organisms.

2. Regional setting

During cruise SO191 with RV SONNE in February/March 2007 in-situ flux measurements of oxygen were conducted at three cold-seep areas (Opouawe Bank in the Wairarapa area, Omakere Ridge, Rock Garden) alongside the Hikurangi Margin offshore northern New Zealand, (Table 1, Fig. 1). Site selection was based on previous surveys with RV TANGAROA (Law et al., 2010-this volume). The Hikurangi Margin forms as a compressional accretionary prism associated with oblique subduction of the Pacific plate beneath the Australian plate. This area is known for the occurrence of a widespread, strong bottom simulating reflector

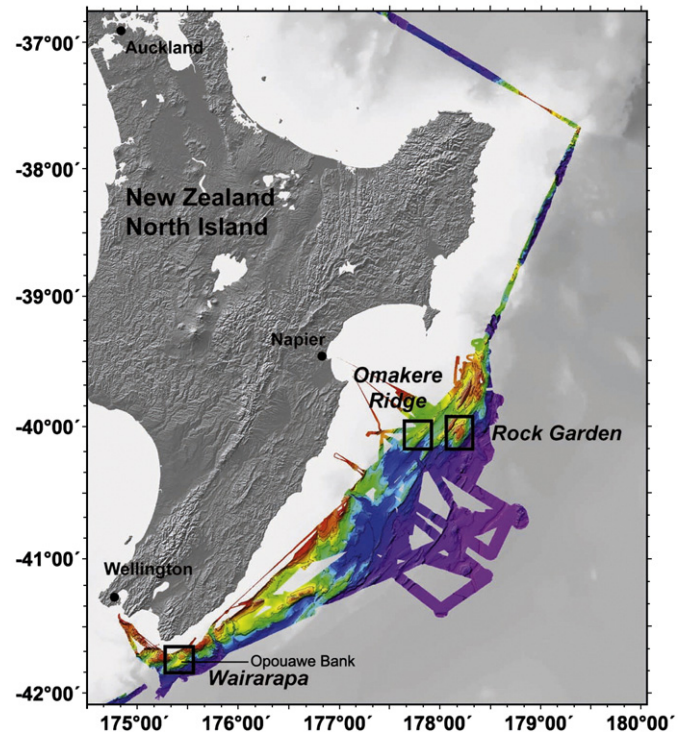


Fig. 1. Research areas. For more details see Linke et al. (2010-this volume).

Table 1
Station data of Cruise SO191-2/3.

Area/site	Date	Position	Depth (m)	TOU	DOU	O ₂ penetr.
<i>Opouawe Bank (Wairarapa area)</i>						
Ampharetid bed (BIGO-5EX)	11.03.07	41°46.919'S 175°24.097'E	1057	51.6	n.d.	n.d.
Reference (BIGO-6CO) (BIGO-6EX)	16.03.07	41°46.74'S 175°25.14'E	1051	2.7	3.1	11.5
Ampharetid bed (FLUFO-6FLUX)	"	"	"	5.8	3.1	13.5
Ampharetid bed (MUC 12)	16.02.07	41°46.908'S 175°24.024'E	1048	n.d.	8.7 (6.6–11.3)	1.00–1.25
Ampharetid bed (MUC 15)	20.02.07	41°46.851'S 175°24.107'E	1056	n.d.	5.7 (3.4–9.4)	1.75–3.00
Ampharetid bed (MUC 40)	11.03.07	41°46.986'S 175°24.251'E	1059	n.d.	11.2 (6.6–15.7)	1.00–1.25
<i>Rock Garden/Faure Site</i>						
Tube worm habitat (BIGO-4EX)	05.03.07	40°01.91'S 178°09.65'E	659	65.2	n.d.	n.d.
Ampharetid bed (FLUFO-5BU) (FLUFO-5FLUX)	08.03.07	40°01.88'S 178°09.62'E	658	116.2	n.d.	n.d.
Ampharetid bed (MUC 26)	04.03.07	40°01.96'S 178°09.54'E	660	n.d.	n.d.	n.d.
<i>Omakere Ridge/Bear's Paw</i>						
Tube worm habitat (FLUFO-1FLUX)	11.02.07	40°03.214'S 177°49.216'E	1098	4.1	n.d.	n.d.
Ampharetid bed (MUC 20)	28.02.07	40°03.17'S 177°49.12'E	1118	n.d.	n.d.	n.d.
Ampharetid bed (MUC 22)	01.03.07	40°03.173'S 177°49.258'E	1102	n.d.	n.d.	n.d.

Total oxygen uptake (TOU, mmol m⁻² day⁻¹) measured in-situ in benthic flux chambers of the BIGO and FLUFO observatories. Diffusive oxygen uptake (DOU, mmol m⁻² day⁻¹) was calculated from ex situ micro-profiles.

O₂ penetr. refers to the maximum oxygen penetration (mm) into the sediment derived from ex situ micro-profiles.

(Henrys et al., 2003) and indications of active methane seepage (Lewis and Marshall, 1996; Faure et al., 2006, in review; Law et al., 2010-this volume). High resolution sidescan imaging at the Opouawe Bank (~1050 m water depth) revealed two massive carbonate complexes (chemoherms; North Tower and South Tower) each 300 to 400 m wide (Klaucke et al., 2010-this volume). Between these chemoherms and surrounding sediments dark colored sediment spots of several meters in diameter were frequently observed (Sommer et al., 2008b). These sediment patches were densely populated by two novel species belonging to two new genera of the family Ampharetidae (Geoff Read pers. comm.). Through their feeding activity, the tube-building polychaetes form crater-like depressions in the sediment surface. Thereby black sediments, whose color origins from a high content of iron monosulfides, are exposed. The depressions gave the sediment surface an appearance similar to mud surfaces sparkled with rain drops, giving the habitat the name "rain drop sites". In the following, the rain drop sites are synonymously referred to as ampharetid beds or ampharetid sites. Often these sediments were only a few tens of centimeters thick overlying buried carbonates.

At the Opouawe Bank, sediment sampling (MUC 12/15/40) and in-situ flux measurements (BIGO-5, FLUFO-6) focused on rain drop sites at the fringe of the Northern Tower seep site, and on a non-seep reference site (BIGO-6) (Table 1). At Bear's Paw, a seep site at the Omakere Ridge (~1100 m depth; MUC 20/22), and at Rock Garden (660 m depth; FLUFO-5) similar carbonate concretions associated with rain drop sites were detected and investigated (Jones et al., 2010-this volume; Naudts et al., this volume). Furthermore, seep sites dominated by small-sized tube worms (presumably frenulate pogonophorans, cf. taxonomy of Southward et al., 2005) were studied at Rock Garden (BIGO-4) and Bear's Paw (FLUFO-1, see also Linke et al., 2010-this volume). At these sites and at the reference site no ampharetids were observed.

3. Methods

Sediment sampling was conducted using benthic observatories (see below) and a TV-guided multicorer (MUC). The MUC retrieved up to eight sediment cores (inner diameter, i.d.: 10 cm). Upon recovery,

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