ORGANIC MATTER DEGRADATION PROCESSES IN PERMEABLE SEDIMENTS – METHODOLOGICAL APPROACHES

Ursula Werner, Lubos Polerecky, Eva Walpersdorf, Ulrich Franke, Markus Billerbeck, Michael Böttcher, Tim Ferdelman & Dirk de Beer

Introduction

Despite the low carbon content, permeable sands have lately been considered active biofilters, and organic carbon mineralization rates are reported to be high (CAMMEN, 1991; GRANT *et al*., 1991; D'ANDREA *et al*., 2002). In permeable sands, advection determines transport of substrates, electron acceptors and products. Rapid exchange between porewater and overlying water is thought to be the major cause of high microbial turnover rates. The aim of this study is to estimate the contribution of aerobic respiration and sulfate reduction to organic matter degradation in intertidal surface sediments.

Oxygen, being the energetically most valuable electron acceptor, is of special interest in intertidal permeable sediments, as it can penetrate deeply, and the penetration depth varies considerably (see WALPERSDORF *et al.*, this volume) with tidal or wind-induced currents. These oxygen dynamics are difficult to mimic under laboratory conditions which strongly complicates the measurement of oxygen consumption rates. We present here a novel method for the assessment of oxygen consumption rate (OCR) in permeable sediments enabling the measurement of horizontal profiles of OCR with high spatial resolution.

Sulfate is an electron acceptor which in seawater is available in high quantities. Because of the high sulfate availability, sulfate reduction is the most important process in sediments when oxygen is limited. We present here an adaptation of the whole-core-incubation method for sulfate reduction rates for permeable sediments.

Study site and investigation periods

The study site (see Fig. 1) is the Janssand sandflat in the backbarrier tidal flat of Spiekeroog Island, Germany. Data presented here are from a number of sandy locations on the flat. The seasonality of various factors, such as temperature or organic matter availability, determines the microbial processes in the sediments. This study therefore covers all seasons (December 2001 and 2002, March, June and October 2002).

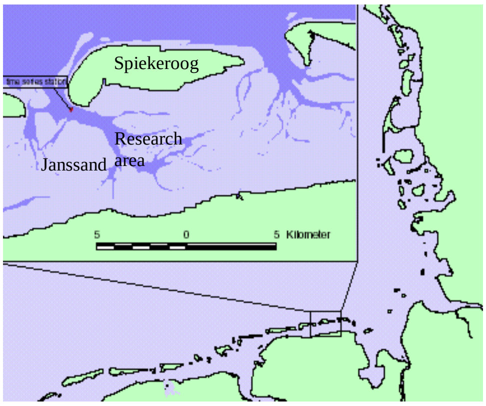

Fig. 1. Study site Janssand, close to Spiekeroog Island, Germany.

Investigated parameters and methods used

Oxygen availability and oxygen consumption rate

Oxygen availability in the sediments was measured *in situ* by continuous profiling using microsensors attached to a lander (see WALPERSDORF *et al*., this volume). The rates of oxygen consumption were measured by using oxygen microsensors and planar optodes, resulting in potential oxygen consumption rates with a high spatial resolution. The method is based on facilitating an artificial flow of oxygen-saturated water through a sediment core until an approximately stationary oxygen distribution over the entire core is established. The flow is subsequently stopped, and the decrease of the oxygen concentration is monitored using microsensors and planar optodes (HOLST & GRUNWALD, 2001), as shown in Fig. 2.

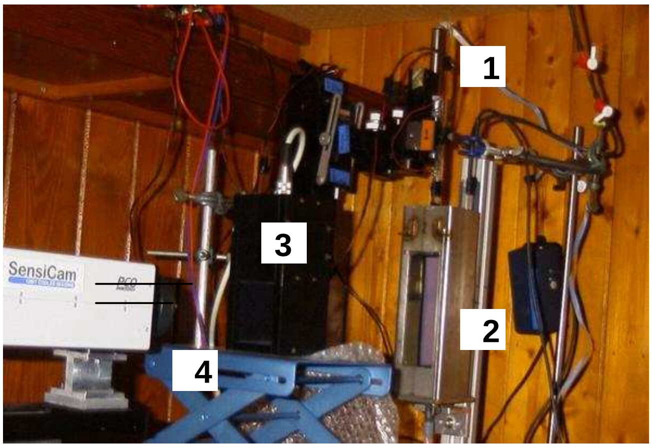

Fig. 2. Image of an experimental apparatus for the measurement of 1D and 2D profiles of oxygen consumption rate. 1-microsensor measuring system, 2-planar oxygen optode attached to the wall of the core, 3-excitation light source, 4-CCD camera.

In the method employing microsensors, oxygen is monitored by positioning the sensor at discrete depths and repeating the on-off pumping cycle for each depth. Another possibility is to measure oxygen profiles continuously after the flow has been stopped. The method using planar optodes has advantages over the one using microsensors in that the former is much quicker as well as it enables the measurement of two-dimensional profiles of consumption rates over a considerably large cross-section of the sediment (in this study, the area was approximately 2 cm wide and 10 cm deep) with a high spatial resolution (down to 200 µm) by processing the obtained time-series of oxygen images. For this purpose, a special software was developed which facilitates pixelwise calculation of OCR over the sediment cross-section (Fig. 2).

Combining the potential oxygen consumption rates with the amount of available oxygen (*in situ* oxygen profiles), we can calculate the actual oxygen consumption rates of the sediment and thus estimate the contribution of the respiration to organic matter degradation.

Sulfate reduction rate (SRR)

SRR measurements were performed using a modified approach for permeable sediments. Whole cores filled with sediment were taken. Radiolabeled $^{35}SO_4^{2-}$ was added to ambient seawater, and this radiolabeled solution was placed on top of the core and allowed to drain into the core by opening a valve at the bottom. The permeability of the sediment allowed an equal distribution of the tracer. The cores were incubated at ambient temperatures (4℃ in December and March, 16℃ in June).

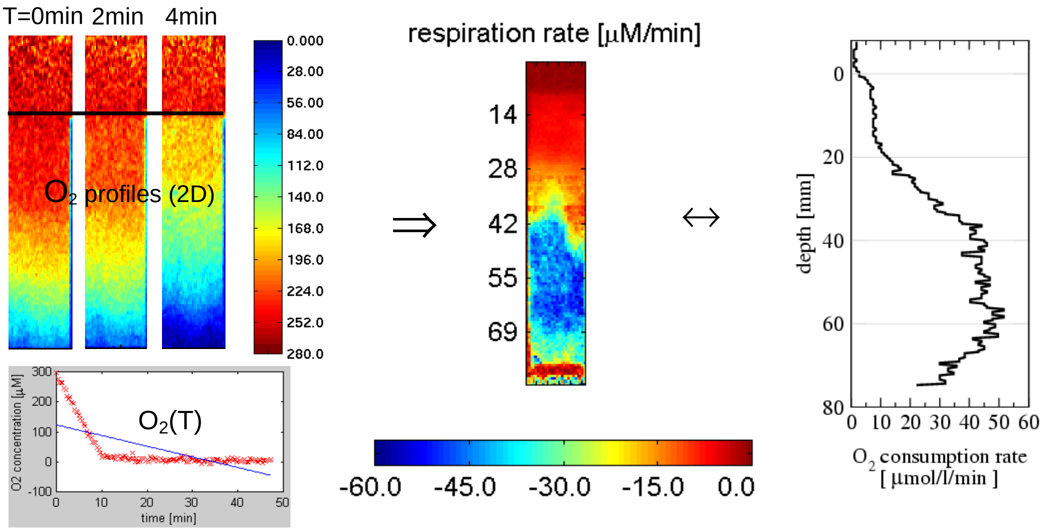

Fig. 3. Schematic diagram showing the process of how the 2D profile of O_2 consumption rate is obtained from the time-series of oxygen images. The right-most graph shows a 1D profile of OCR extracted from the OCR image in the center.

Results

Examples of OCR profiles obtained by measurements during October and December are shown in Fig. 4. It can be seen that oxygen consumption is greater during the month of October throughout the entire studied region of the sediment at location 3, whereas the consumption rate in deeper parts of the sediment at location 2 in December can exceed the values in October. The increased oxygen consumption rates were observed in such parts of the sediment where oxygen typically is not present (as determined by the lander measurements) and could be attributed to chemical oxidation or the presence of accumulated organic material. Within the top approximately 2 cm of the sediment, the seasonal difference is pronounced, as shown in Fig. 4(c).

Areal OCR are obtained by integrating the profiles of OCR over the depth of oxygen penetration, provided that the consumption rates are independent of the oxygen concentration.

Examples of the time evolution of the areal OCR during approximately 17-20 hours long time intervals in October and December are shown in Fig. 5. Due to deeper penetration of oxygen during high tides, the areal oxygen consumption is higher than during low tides. In October, the difference is less pronounced compared to the situation in winter when the OCR at high tide can be approximately 3-5 times higher than at low tide. Fig. 5 demonstrates not only a considerable seasonal variability of the OCR but also its variability between different locations on the sandflat (stations were separated by approximately 30 m).

Fig. 6 shows that SRR is low during all seasons, and the seasonal variability is not pronounced. Surprisingly, the measured winter rates are close to those in June. Nevertheless, depth-integrated rates over the first 15 cm are slightly higher in the summer. March rates are comparably low, possibly due to a long-term depletion of organic material over the winter months. Analysis of organic carbon content will provide further evidence.

Conclusions

A first overview over quantitative results obtained by the measurement of oxygen consumption and sulfate reduction are summarized in Table 1.

Assuming that the oxygen consumption is entirely comprised of aerobic respiration (neglecting possible chemical oxidation), Table 1 indicates that the aerobic respiration has a significantly higher contribution to the overall organic matter turnover, in the upper 15 cm of the sediment, than sulfate reduction.

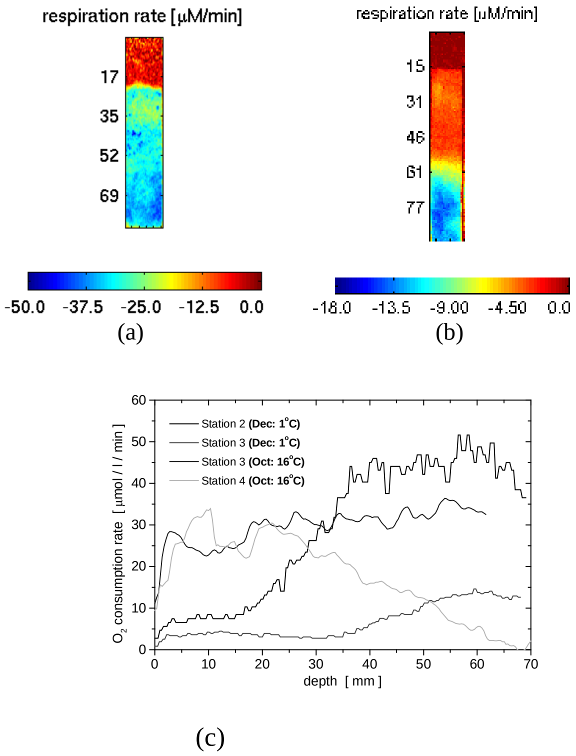

Fig. 4. Examples of two-dimensional profiles of potential oxygen consumption rates of a sandy sediment measured in October (a) and December (b). The horizontal lines indicate the sediment surface. Graph (c) shows examples of 1D profiles extracted from 2D images obtained at various locations and times.

This finding is different from previous ones, where aerobic respiration was estimated to account for 50% of carbon mineralization in coastal sediments (Jørgensen, 1982). However, apart form the complication of the simultaneous oxygen consumption via reoxidation reactions with reduced inorganic substances, the trends in the SRR profiles suggest that sulfate reduction takes place even in deeper (more than 15 cm) parts of the sediment and so additional measurements are necessary for the estimation of the contribution of sulfate reduction.

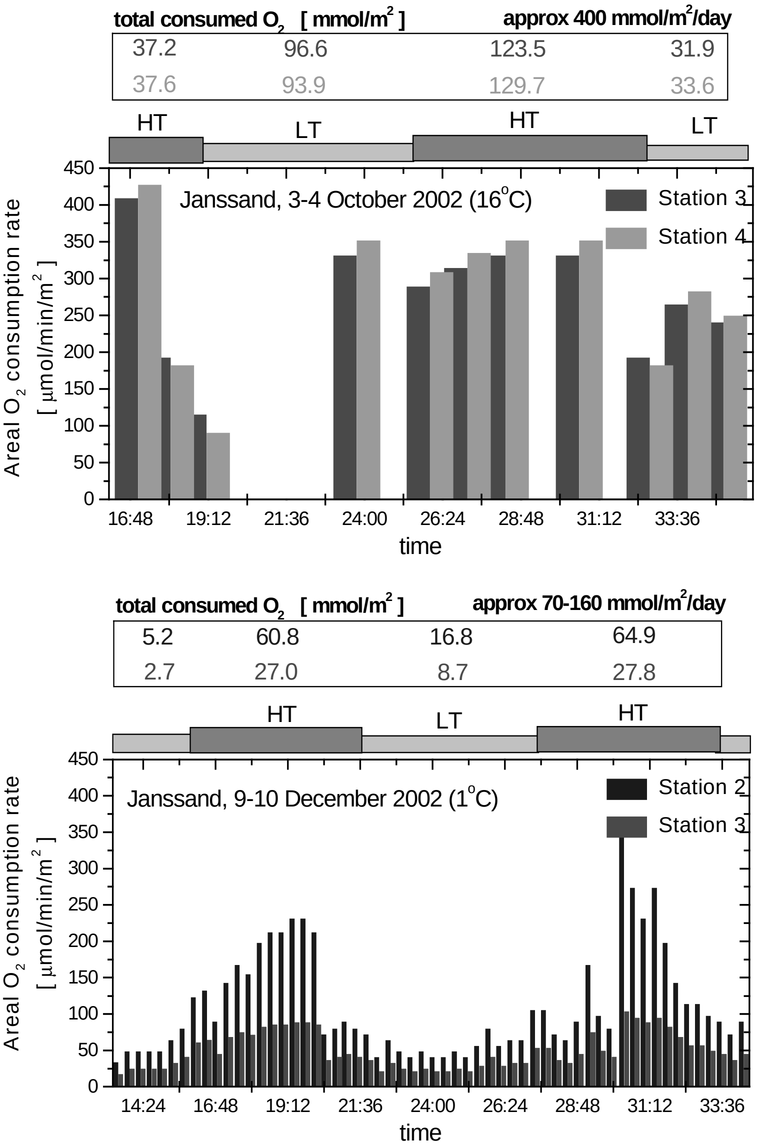

Fig. 5. Examples of a time evolution of areal oxygen consumption rates during approximately 17-20 hours long time periods in October and December. Values are shown for three locations on a sandflat separated by approximately 30 m. The numbers above the graph indicate the total amount of oxygen consumed per m^2 of sediment during the period of high and low tide.

Table 1: Preliminary quantitative estimates of the depth-integrated rates of SSR and areal aerobic respiration.

SRR	December	March	June	October
Depth-integrated rate * mmol/m^2/d	3.5	1.5	5.1	5.9
Carbon turnover (mmol/m^2/d)	7	3	10.2	11.7
OCR	December			October
Areal rate mmol/m^2/d	≈ 70-160			≈ 400
Carbon turnover (mmol/m^2/d)	≈ 22-50			≈ 128

*Integration depth for SRR was 15 cm, aerobic respiration was calculated by integrating the profile of oxygen consumption rate over the depth of oxygen penetration.

Acknowledgement

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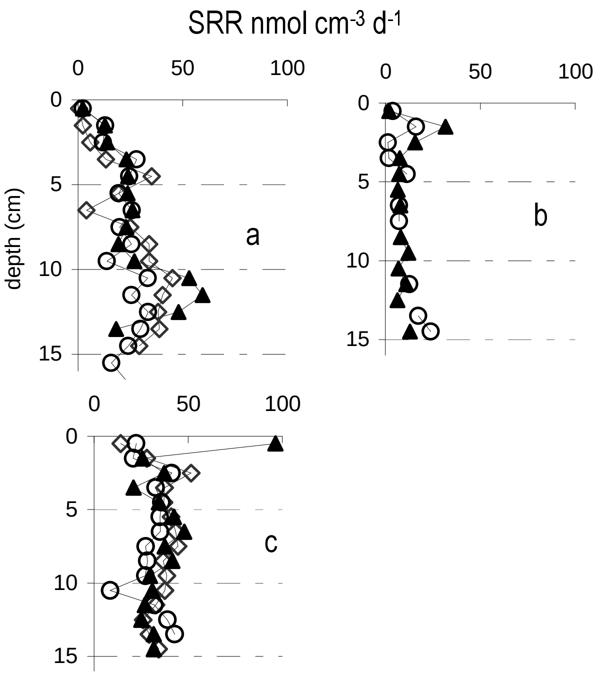

Fig. 6. SRR in December 2001 (a), March 2002 (b), June 2002(c).

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Ursula Werner, Lubos Polerecky, Eva Walpersdorf, Ulrich Franke, Markus Billerbeck, Michael Böttcher, Tim Ferdelman & Dirk de Beer, Max-Planck Institute for Marine Microbiology, Celsiusstr. 1, D-28359 Bremen, Germany; phone: ++49 +421 2028-830; fax ++49 +421 2028-690; e-mail: uwerner@mpi-bremen.de.