Use of microsensors in sediments and mats

Dirk de Beer
Max-Planck-Institute Marine Microbiology
dbeer@mpi-bremen.de
Where is life and what controls it?

- water
- thermodynamic disequilibrium that drives redox reactions
- cycling of essential elements (tectonics)

- seawater: $10^2$-$10^5$ cells/ml
- deep biosphere: $10^2$-$10^7$ cells/ml
- sediments/mats: $10^9$-$10^{11}$ cells/ml
sediments and mats
Microsensors

Signal

Shielding

Ag / AgCl half cell

Tip with membrane (1-10 µm)
Amperometric, optical, potentio-metric and bio-microsensors

- **C** CO$_2$, CO$_3^{2-}$, CH$_4$, glucose
- **H** H$^+$, H$_2$
- **O** O$_2$, H$_2$O$_2$
- **N** NH$_4^+$, NO$_3^-$, NO$_2^-$, NO, N$_2$O
- **S** S$^{2-}$, H$_2$S
- **P** -
- Ca$^{2+}$, redox potential, temperature, light, diffusion/flow, HClO
Microbial mats

Dark

O₂ (mol m⁻³)

Light

O₂ (mol m⁻³)

Sulfide (mol m⁻³)

Sulfide (mol m⁻³)
Interfacial fluxes

Transport is diffusive: \( J = D \frac{dC}{dx} \)

\[ D(O_2) \approx 2 \times 10^{-9} \text{ m}^2\text{s}^{-1} \]
\[ D(\text{sulfide}) \approx 1.2 \times 10^{-9} \text{ m}^2\text{s}^{-1} \]

\( J_{O2} \gg J_{\text{sulfide}} \)
photosynthesis rate

total OP: upward + downward O$_2$ fluxes

gap O$_2$-H$_2$S (AP)
High spatial resolution analysis

Local mass balances:
Subtract adjacent $J$'s:
$$\frac{\Delta J_{i,j}}{\Delta x_{i,j}} = R_{i,j} \text{ (mol m}^{-3}\text{ s}^{-1})$$
Reaction rates

High resolution activity
+ R respiration
- R net photosynthesis
red line: sulfide at 1 cm depth responds instantly to light
Oxygen production starts after sulfide is consumed by AP
Deep sea seeps
Håkon Mosby Mud Volcano

- Norwegian margin, 1250 m depth
- Methane emitting geostructure
- Hydrate reservoir
- Chemosynthetic ecosystem
Microbial processes

AOM

Archea   SRB

\[ \text{CH}_4 + \text{SO}_4^{2-} \rightarrow \text{HCO}_3^- + \text{HS}^- \]

Beggiatoa

\[ \text{HS}^- + \text{O}_2 \text{ or NO}_3^- \rightarrow \text{S}(0) \rightarrow \rightarrow \text{SO}_4^{2-} + \text{biomass} \]

primary production
Deep sea seep (mud volcano)

transport is diffusive and advective

\[ J = D \frac{dC}{dx} + vC \]
Peak caused by upward porewater flow

\[ J = D \frac{dC}{dx} + vC = 0 \]

\[ J_{\text{Diffusion}} = -J_{\text{Advection}} \]

\[ D \frac{dC}{dx} = -u \cdot C \]

or

\[ u = -\frac{J_{\text{Diffusion}}}{C} \]

\[ u \approx -0.1 \text{ µm/s} \]

(3 m/year)
microsensor profiling

• minimally invasive
• sensors pressure insensitive (>11 km ocean depth)
• autonomous measurements possible

• spatial scale relevant for microbes
• data on microenvironments, fluxes, rates
Thanks
Methane-sulfate transition

Anaerobic Oxidation of Methane zone: sulfide production