CO₂ leakage in the deep ocean and its effect on biota and biogeochemistry – lessons from natural analogues for CO₂ disposal in the ocean

1,2Antje Boetius, 1Dirk de Beer, 1Judith Ufkes, 3Matthias Haeckel, 4Fumio Inagaki, 5Koichi Nakamura, 6Gregor Rehder

1 Max Planck Institute for Marine Microbiology
2 Jacobs University Bremen
3 Leibniz-Institute for Marine Sciences IFM-GEOMAR
4 Kochi Institute for Core Sample Research, JAMSTEC
5 National Institute of Advanced Industrial Science and Technology (AIST)
6 Baltic Research Institute
Marine CO₂ storage options

- Gas Hydrates
- Deep-Sea Sediment
- Oceanic Crust
- Cap Rock
- Depleted Oil/Gas Reservoir
- Deep Saline Aquifer

Safety

Cost

M. Haeckel
(IFM-GEOMAR)
**CO₂ phases**

CO₂ hydrates are stable at low temperatures and high pressures, liquid CO₂ becomes heavier than water >3000 m
CO$_2$ forms a sealing hydrate cap rock and will slowly dissolve into the porewater, thereby inducing weathering of the sediments:

$$\text{sediments} + \text{CO}_2 \rightarrow \text{weathered clays} + \text{HCO}_3^- + \text{metal cations}$$

Wallmann et al. (2008)
CO2 vents as natural analogues for CO2 leakage from deep subseafloor sequestration

RV SONNE 169 expedition SUMSUN, March 2008; G. Rehder IOW
Liquid CO2 and hydrate system at the Yonaguni Knoll hydrothermal field, southern Okinawa Trough

Inagaki et al. 2006 PNAS
The wonders of CO2 venting -
video footage from ROV QUEST (MARUM)
Mean currents in the lower 100 m of the water column follow the topography and reverse with the tides, washing the basin with high CO2 water

C. Mertens, M. Rhein Univ. Bremen
TV- Multicorer-Microsensor Profiler Transect

Temperature
4-4.2°C

2 sensor packages
1.5 m a.b.
2.5 m a.b.

DeBeer, Boetius unpublished data
Low pH ($\Delta -0.1$) / high CO2 ($\Delta +30 \mu\text{M}$) controls the distribution of megafauna.
Benthic sampling

Low seepage

Swallow chim

Vent

Abyss vent

reference

Lion chim

Tiger chim

Swallow chim

Abyss vent

Carp chim

Mosquito chim
Observations from sieving macrofauna in the CO$_2$ vent field:

- lack of diversity, no benthic foraminifera/echinoderms
- highly patchy, low diversity „pioneer“ communities (including bivalves and some polychaetes)
In situ microsensor profiling

'Svent site'

DeBeer, unpublished data
In situ microsensor profiling

,low seepage`

ORP (mV)

T (°C)

sulfide (mol m⁻³)

CO₂

DIC

pH

T

O₂

DeBeer, unpublished data

Reference

In situ microsensor profiling

,low seepage`

ORP (mV)

T (°C)

sulfide (mol m⁻³)

CO₂

DIC

pH

T

O₂

DeBeer, unpublished data

Reference
Effect of CO$_2$ leakage on total microbial cell numbers

At „Abyss vent“

Low seepage

Total microbial cell numbers (x10$^9$ cm$^{-3}$)
Similarity analyses of bacterial community structure at Yonaguni Knoll (T-RFLP)
Similarity analyses of bacterial communities at Yonaguni Knoll (T-RFLP)
reference

**Background respiration rate:** 1 mM O₂ m⁻² d⁻¹

low seepage

**Low heat flux, low CO₂/SiO₄ flux, elevated respiration rate:** (8 mM O₂ m⁻² d⁻¹)

abyss vent

**Heat flux, CO₂+CH₄ efflux, silicate efflux, low respiration rate:** (7 mM O₂ m⁻² d⁻¹)

But: normal respiration rates at methane seeps: 100 mM O₂ m⁻² d⁻¹ (Boetius, Wenzhöfer et al. Unpublished data)
Conclusions:

CO2 leakage strongly controls the distribution and composition of benthic communities.

Many organisms - especially members of the Echinoderms and Polychaetes - are absent from high CO2 environments.

Some organisms, especially typical vent-associated symbiotic animals, can adapt to high CO2 levels.

Microbial communities and their functions are highly impacted.

Natural CO2 vent systems are interesting exploratories for research on the effects of CO2 disposal and in general, for CO2 effects.
Thanks to scientific crew and ship’s crew of SUMSUN (SONNE196)!