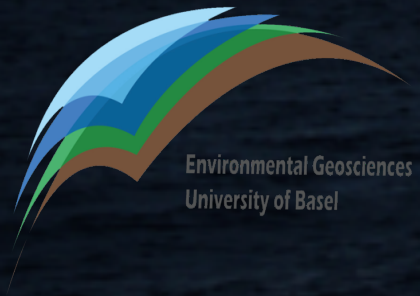
Environmental controls on marine methane oxidation: from deep-sea brines to shallow coastal systems

Lea Irina Steinle

Prix de Quervain – November 25th, 2016

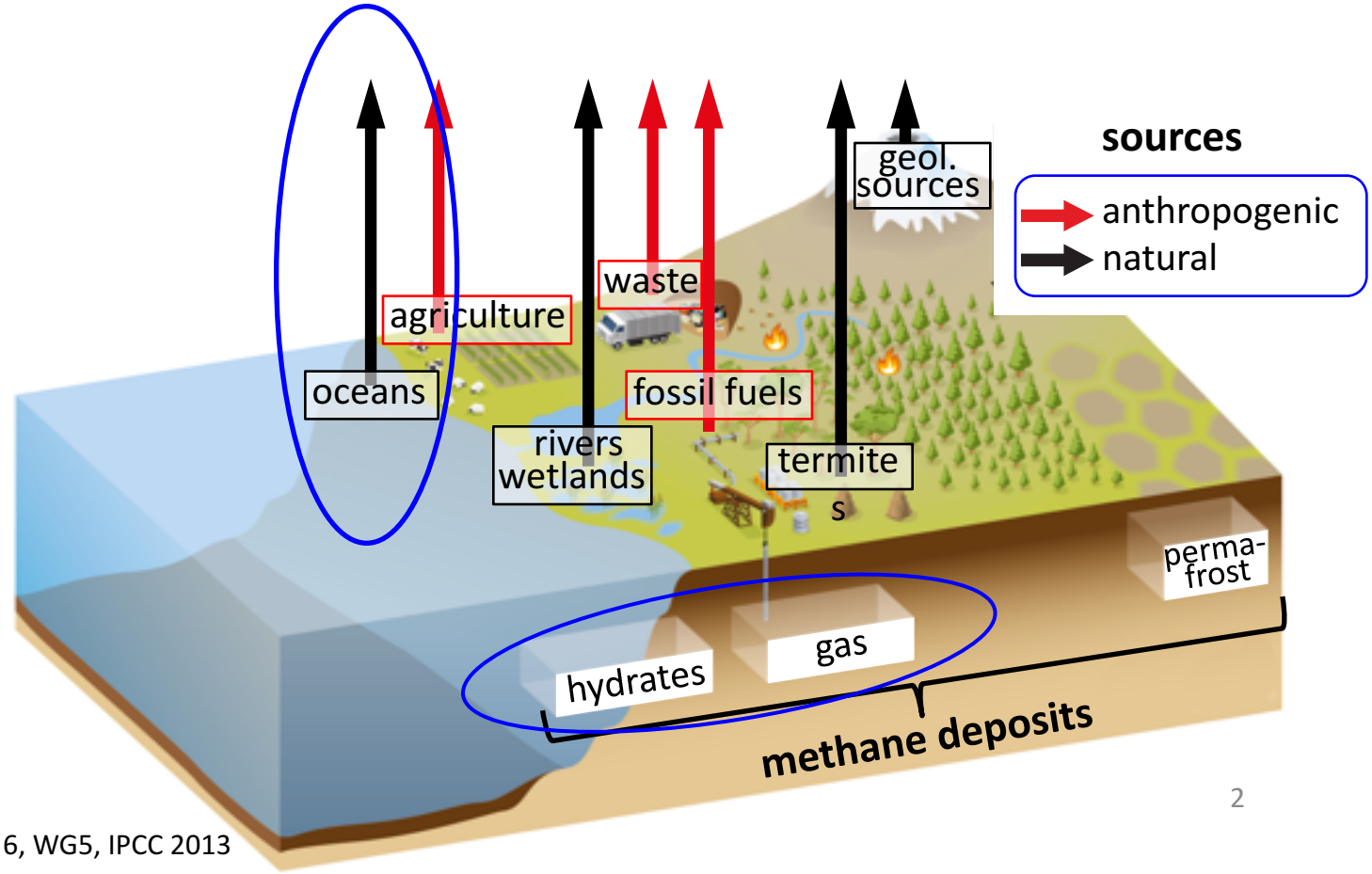


University of Basel

GEOMAR

Ich war an Methan im Ozean interessiert:

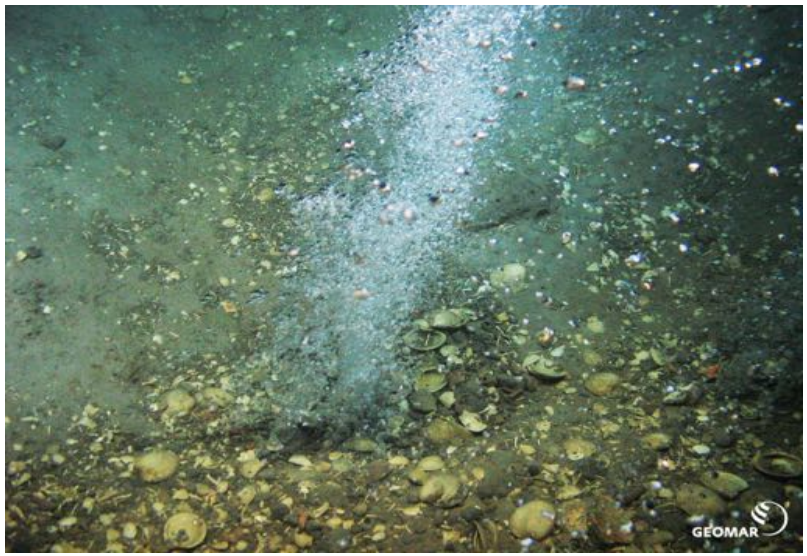
- grosse Vorkommen, Stabilität temperaturabhängig
- Methanemission in die Atmosphäre

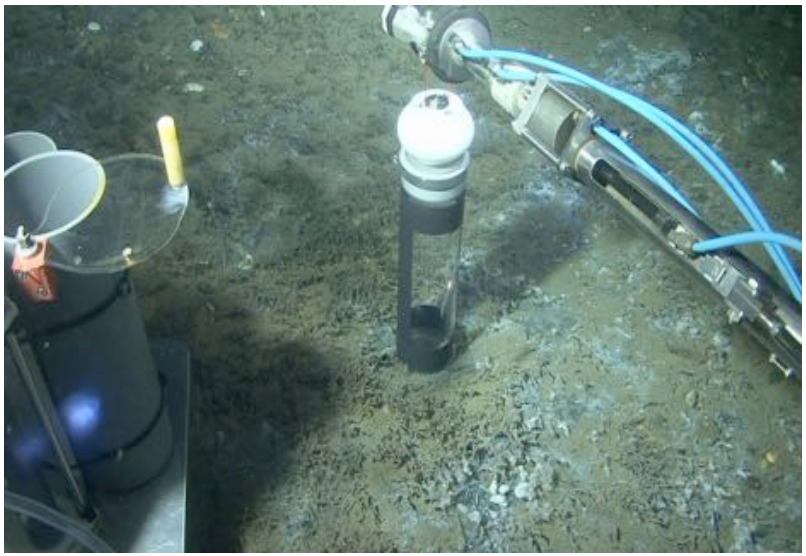


modified after Fig. 6.2 of Chapter 6, WG5, IPCC 2013

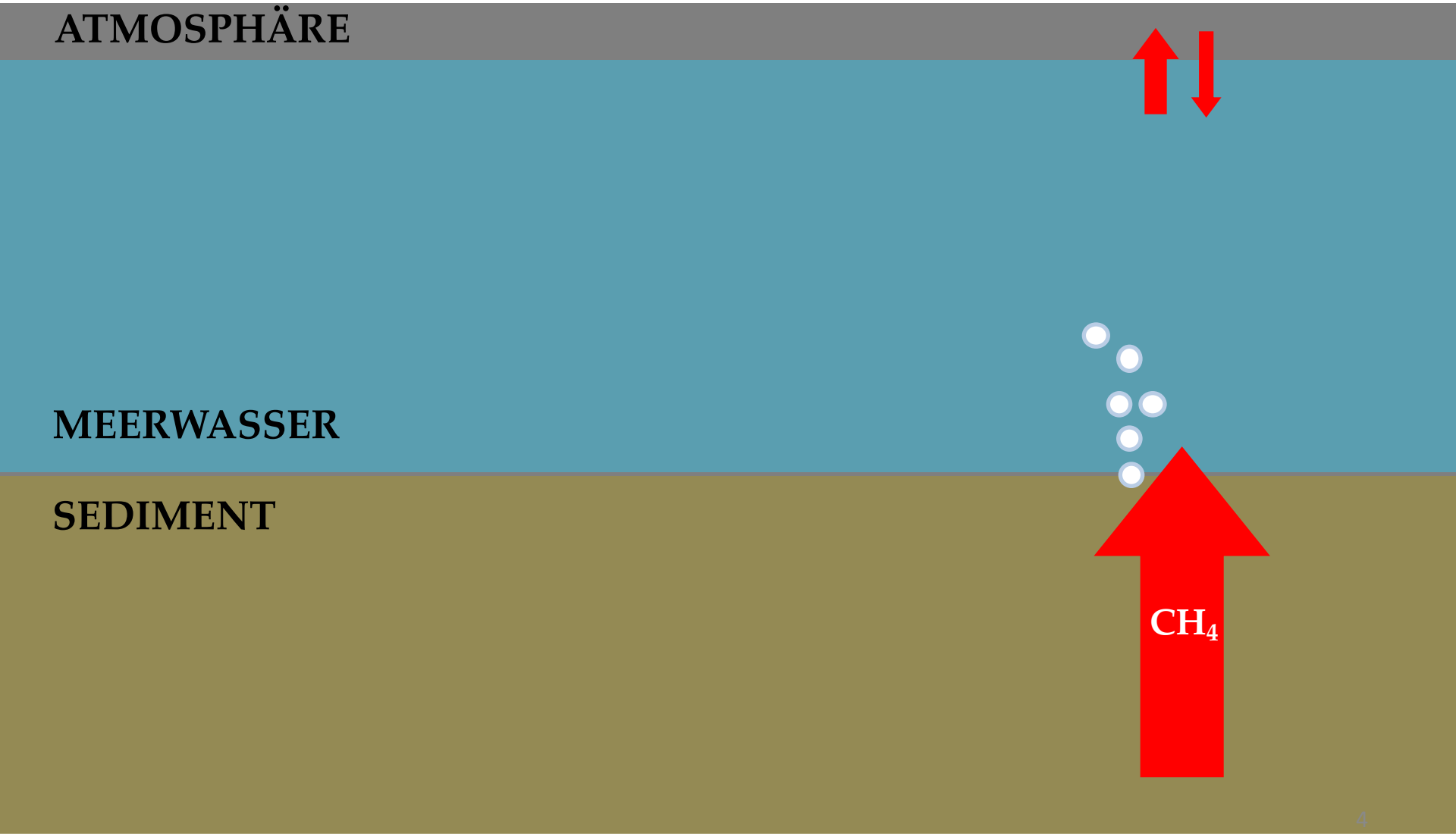
Was geschieht mit Methan im Ozean?

- Methan aus Ablagerung migriert durch die Ozeansedimente und erreicht das Wasser an ‘kalten Quellen’ (cold seeps)
- kalte Quellen sind Oasen: Methan ≙ Wasser

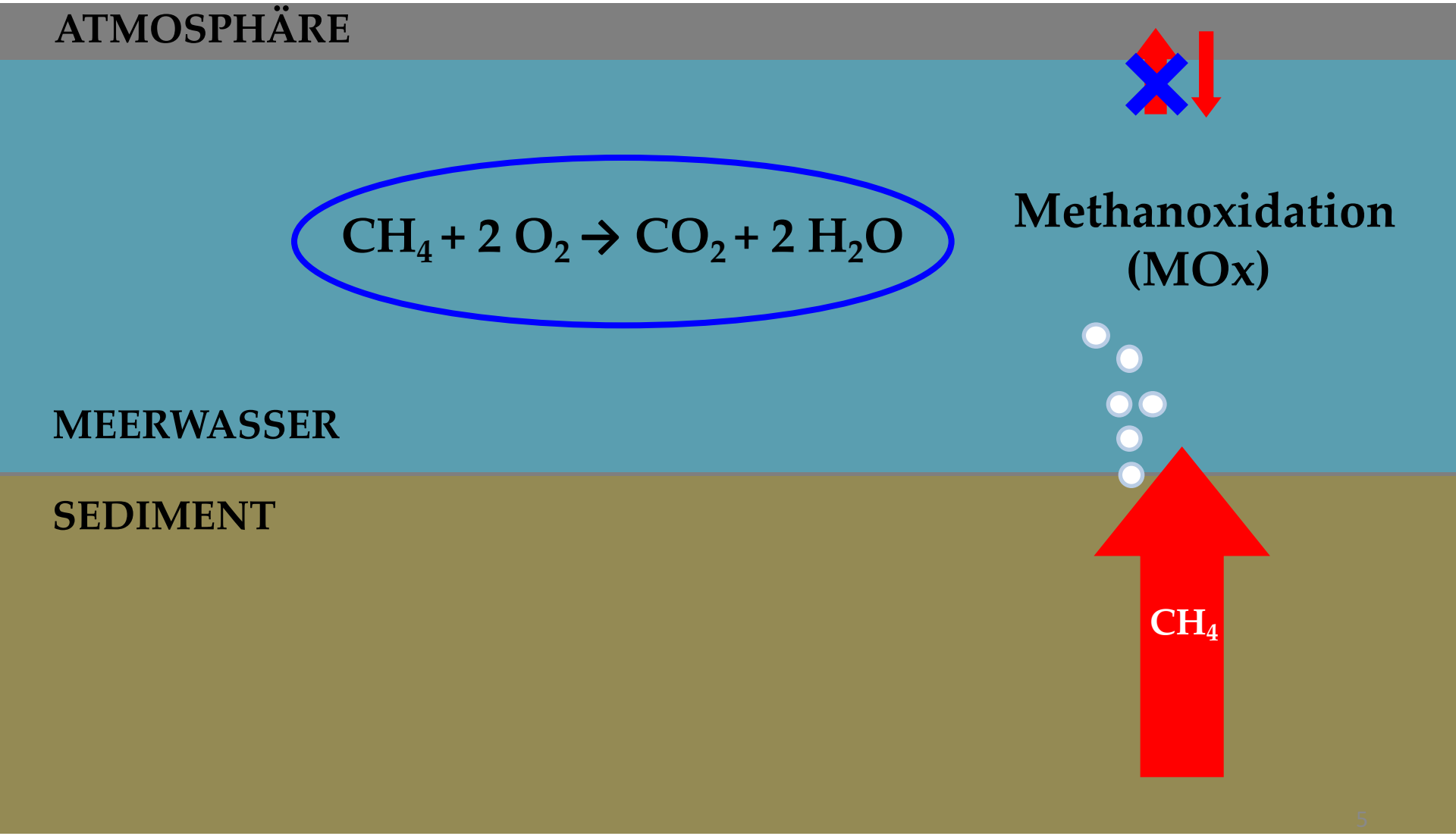




Methan kann vom Ozeanboden in die Atmosphäre gelangen!



Bakterien im Wasser können Methan abbauen und reduzieren so die Emissionen!



Bakterien im Wasser können Methan abbauen und reduzieren so die Emissionen!

ATMOSPHÄRE

$$CH_4 + 2\ O_2 \rightarrow CO_2 + 2\ H_2O$$

Methanoxidation (MOx)

MEERWASSER

Methanbakterien benützen Methan

- als Energiequelle
- als Kohlenstoffquelle

Über diesen Methanabbauprozess im Ozean weiss man sehr wenig…

Während meiner Dissertation habe ich Methanoxidationsraten gemessen..

ATMOSPHÄRE

$$C^{3}H_4 + 2\,O_2 \rightarrow CO_2 + 2\,{}^{3}H_2O$$

Wo?
Wie effizient?
Wer?

MEERWASSER

..und Umweltfaktoren bestimmt, welche diesen Methanabbau kontrollieren.

Vier verschiedene methanreiche Systeme, um verschiedene Umwelfaktoren zu untersuchen..

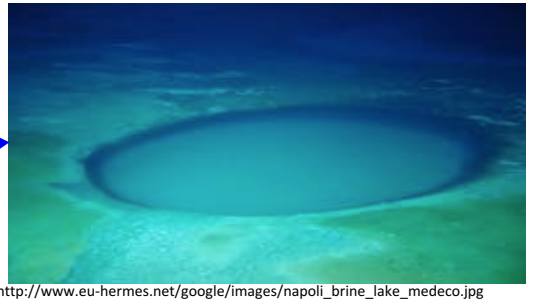
Eckernförde Bucht

http://de.holidayinsider.com/urlaub/eckernfoerder-bucht/ferienwohnung

Svalbard – kalte Quellen

Blowout

Salzsee



http://www.eu-hermes.net/google/images/napoli_brine_lake_medeco.jpg

Svalbard Probennahme: Forschungsschiff, Wassersampler, Unterseeboot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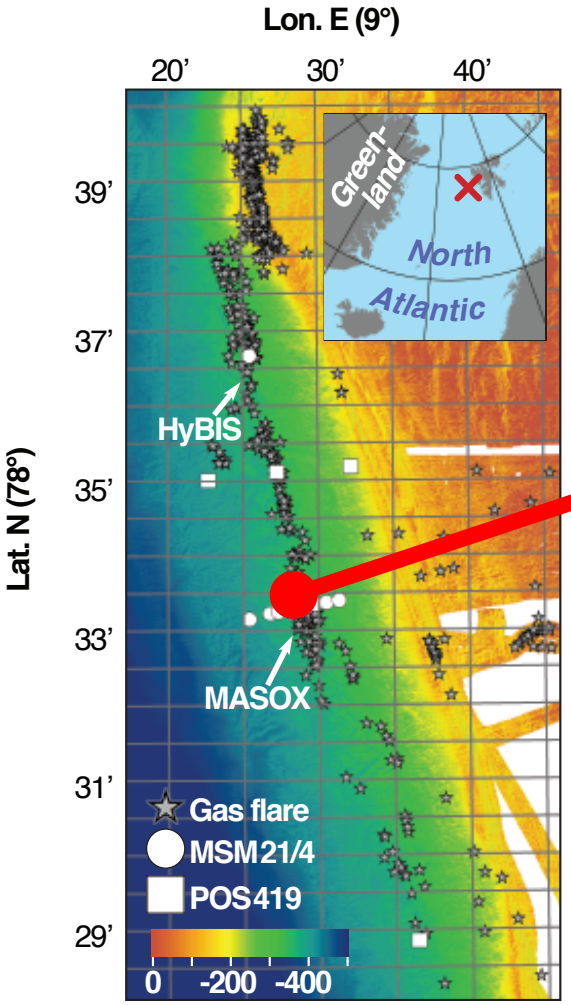
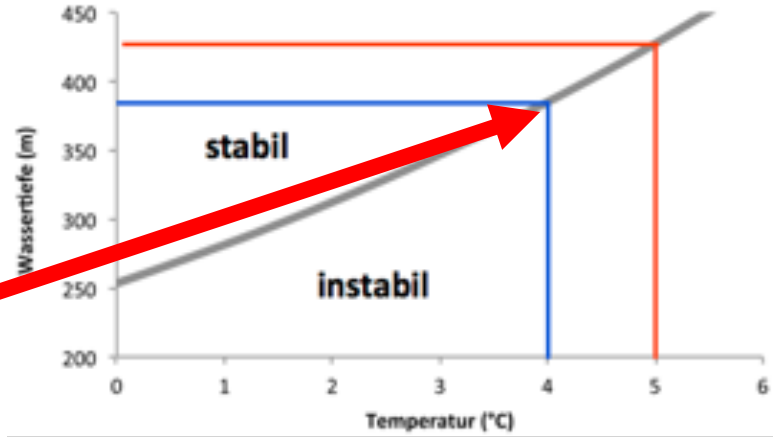
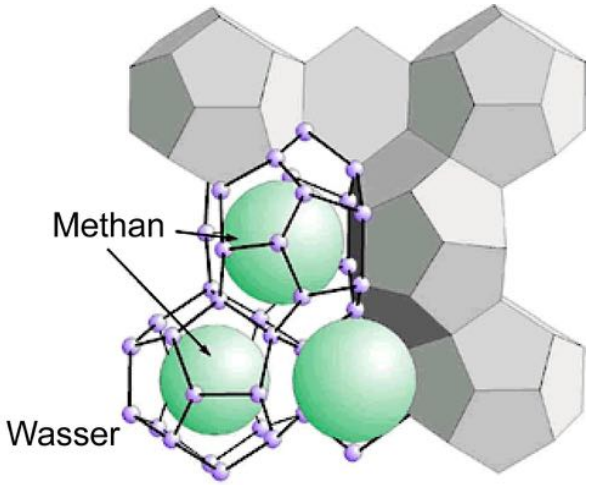
Warum genau sind die kalten Quellen bei Svalbard interessant?

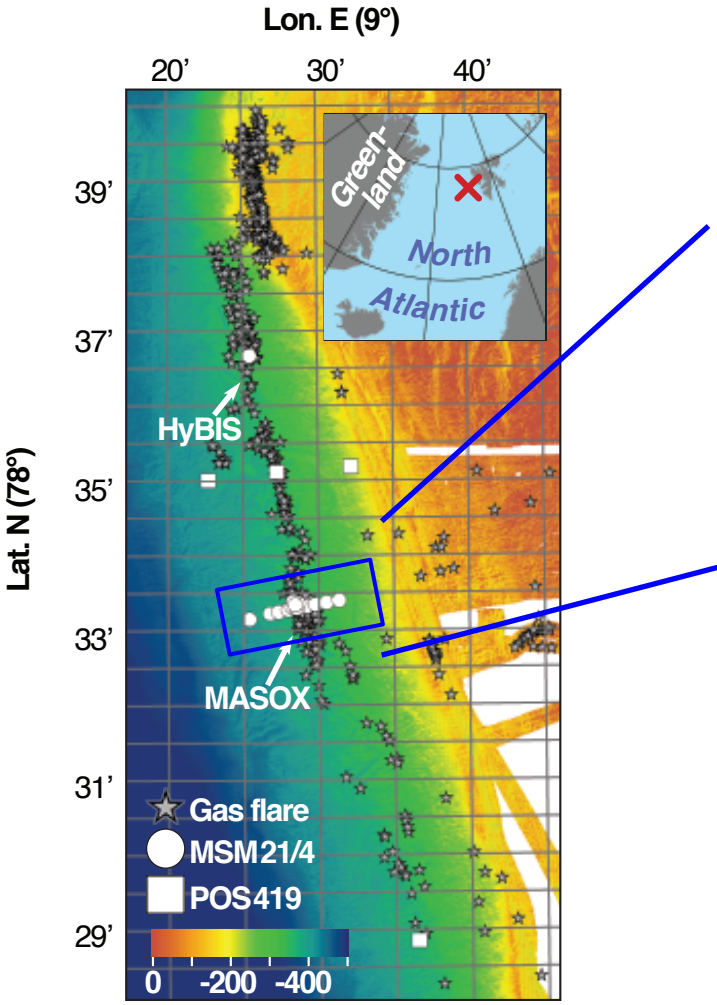


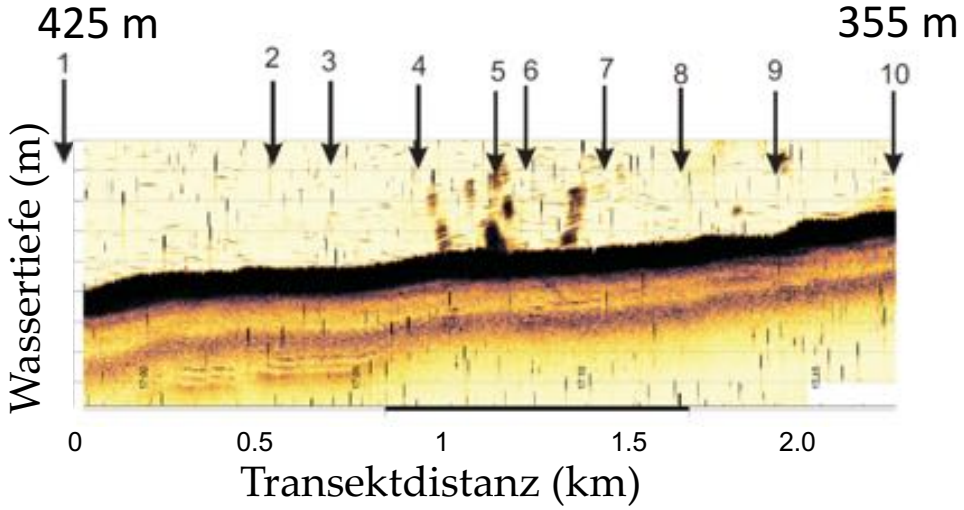


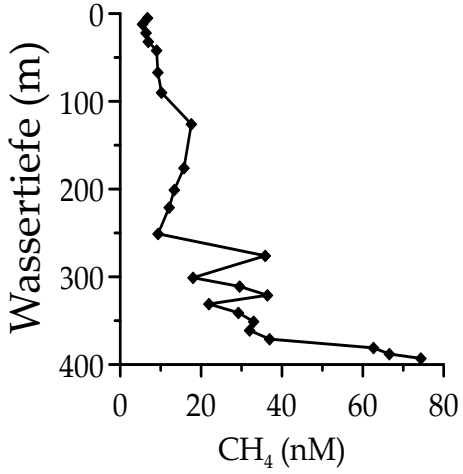


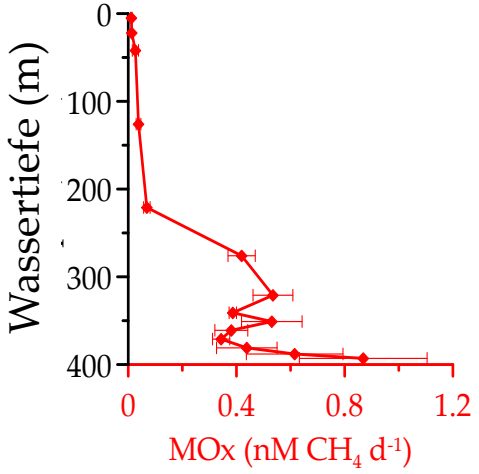
published as Steinle et al., Nature Geoscience, 2015

Transektbeprobung über die Ausstrittsstellen



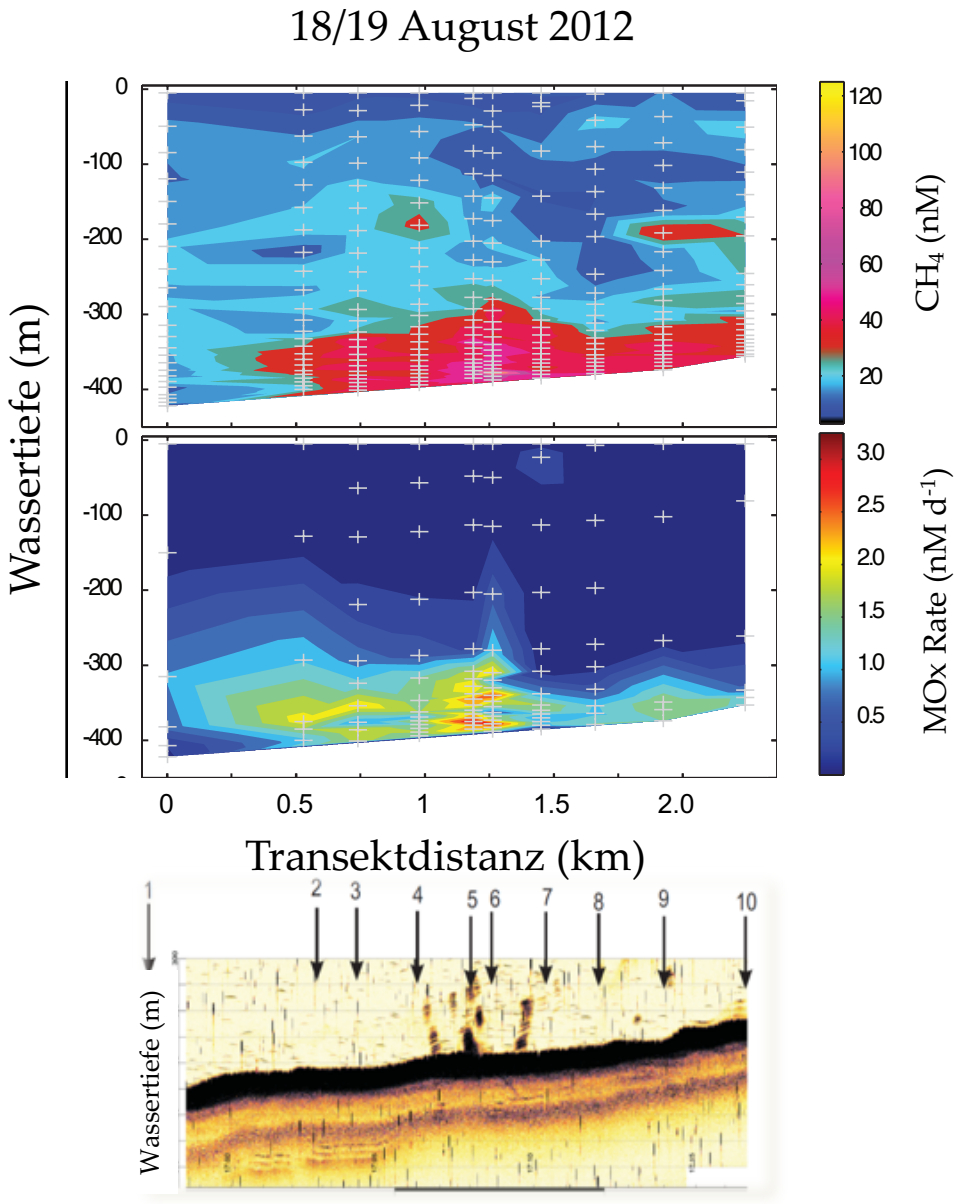






published as Steinle et al., Nature Geoscience, 2015

Räumliche Verteilung: Methan und Methanoxidation



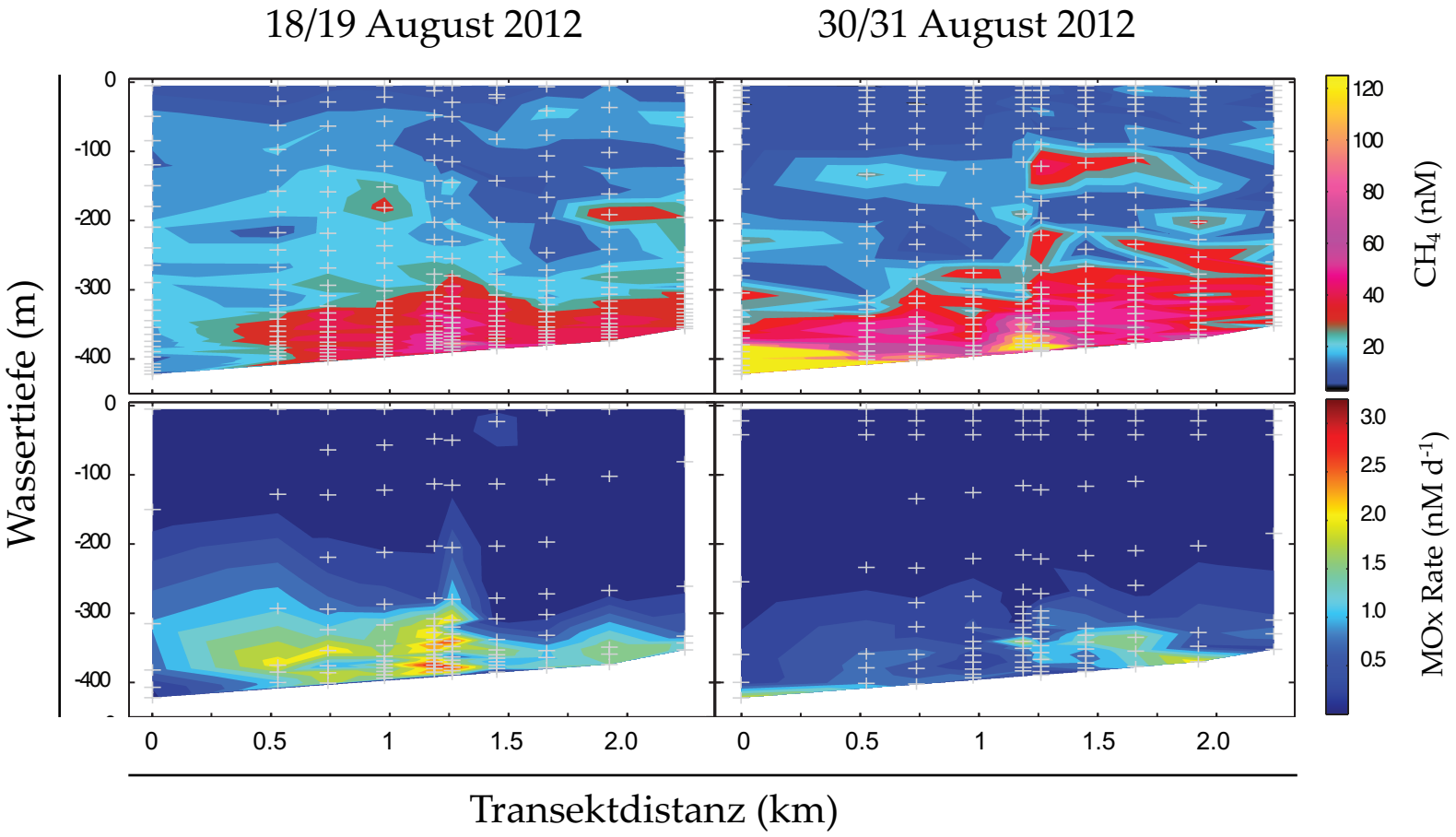
Methankonzentration:

- bis zu 120 nM
- an der Oberfläche ca. 10 nM

Methanoxidationsraten:

- 0.002 – 3.1 nM d^{-1}
- max. ~50 m über Meeresboden

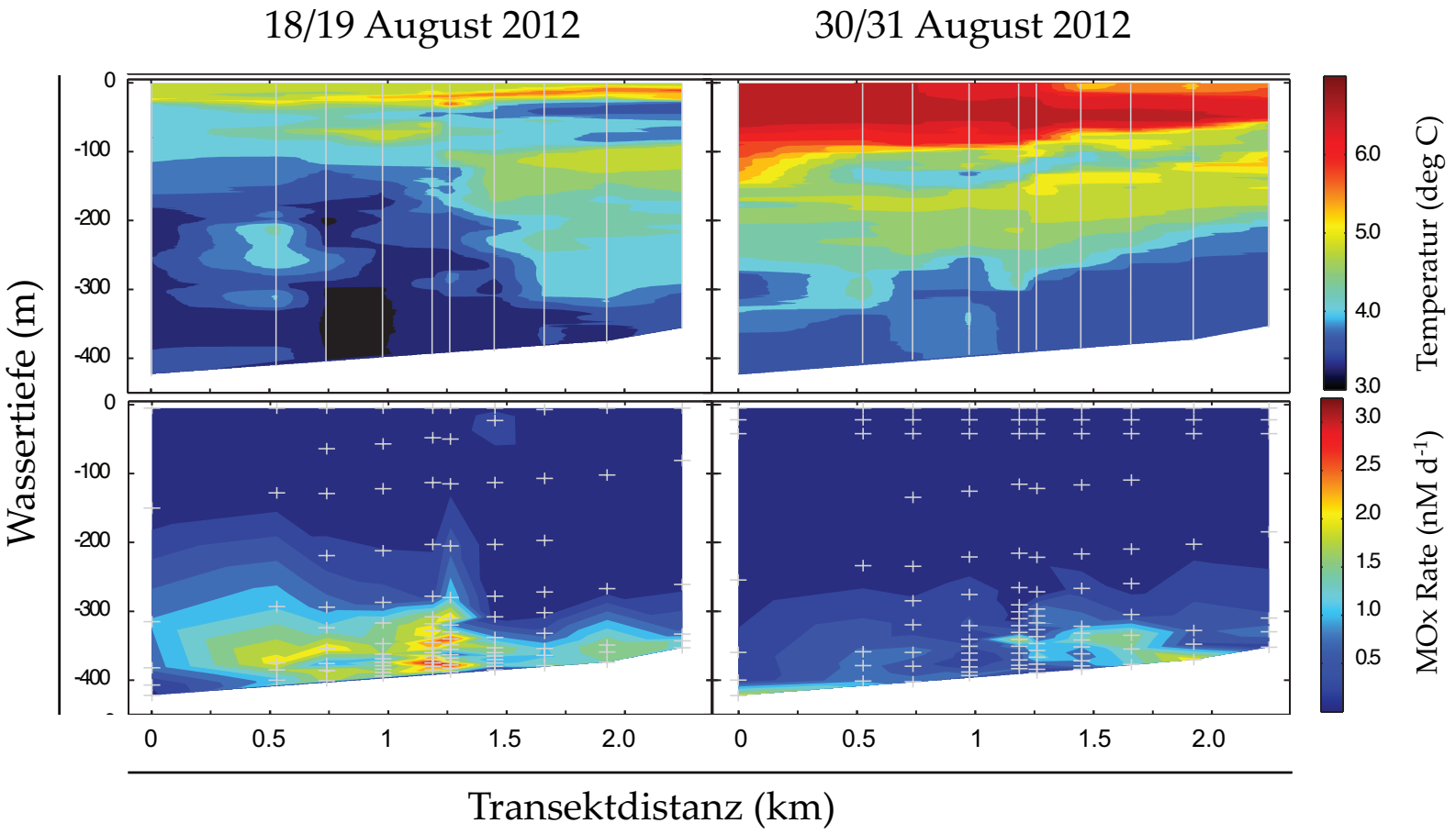
Zeitliche Variabilität: Methan und Methanoxidation



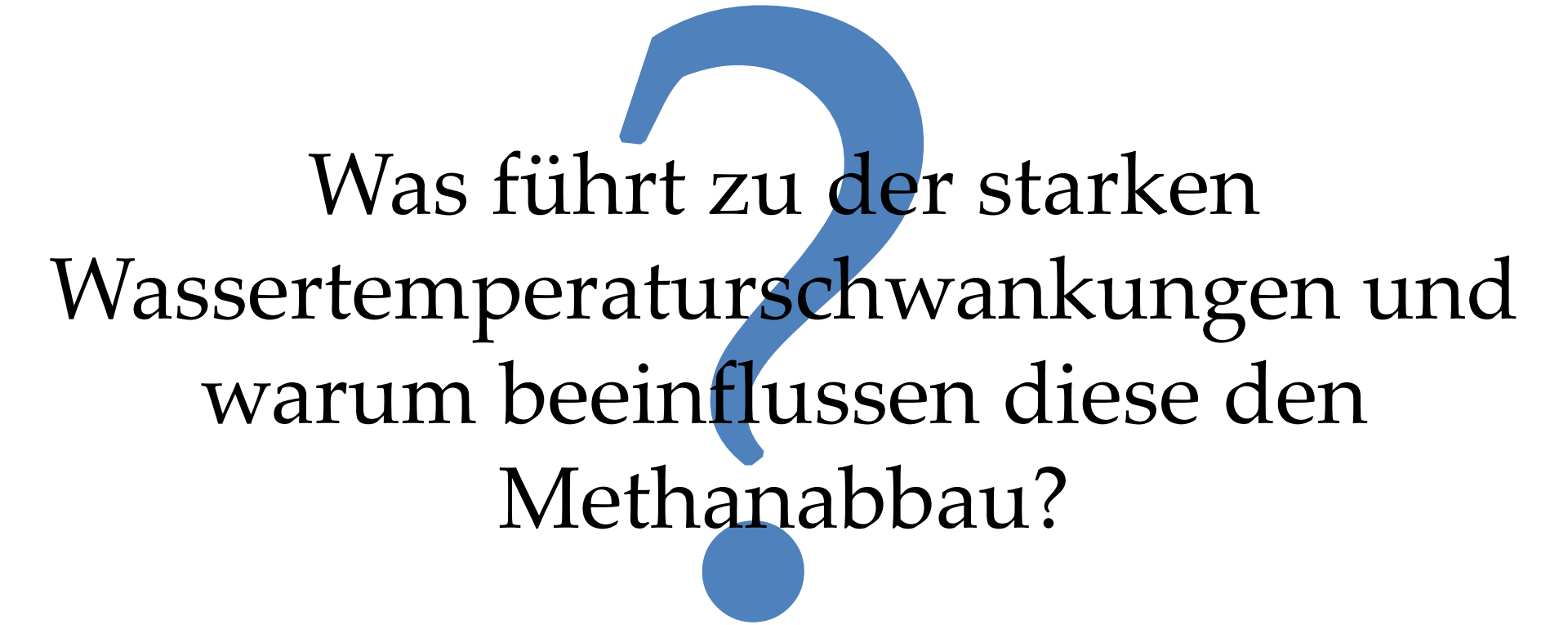
Methan ist immer genügend da, aber die Methanabbauraten variieren stark..

Welche Umweltfaktoren kontrollieren den Methanabbau?

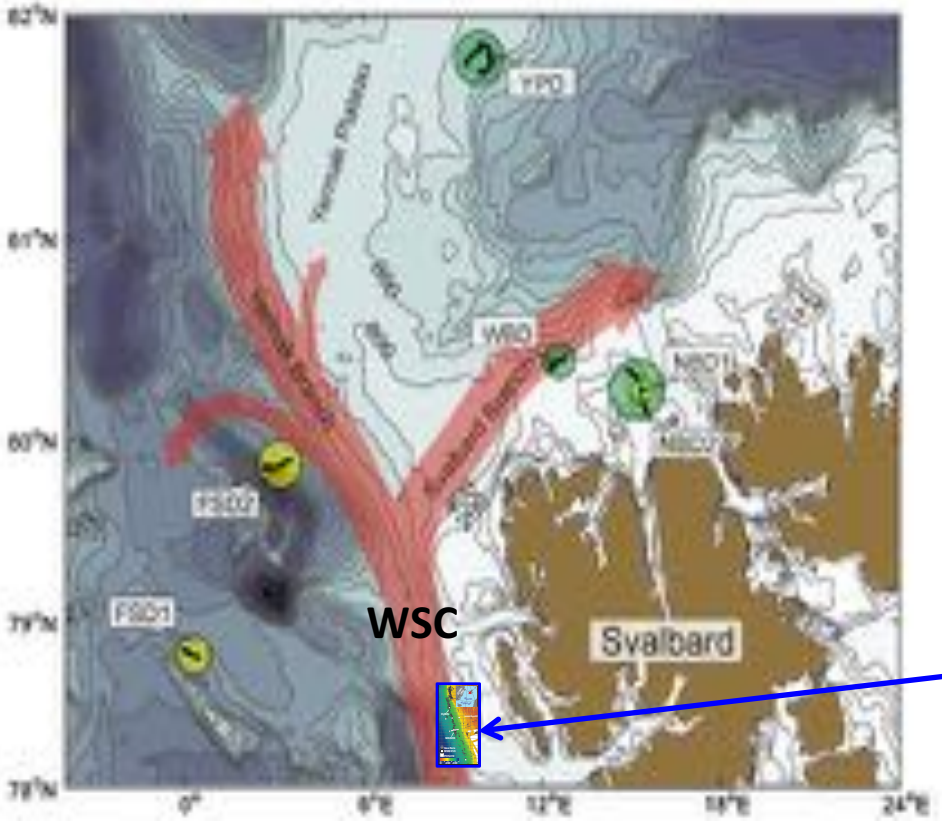
Methanoxidation undWassertemperatur



Hohe Methanabbauraten in kaltem Wasser..



Westspitzbergenstrom drückt das kalte Arktische Wasser weg!

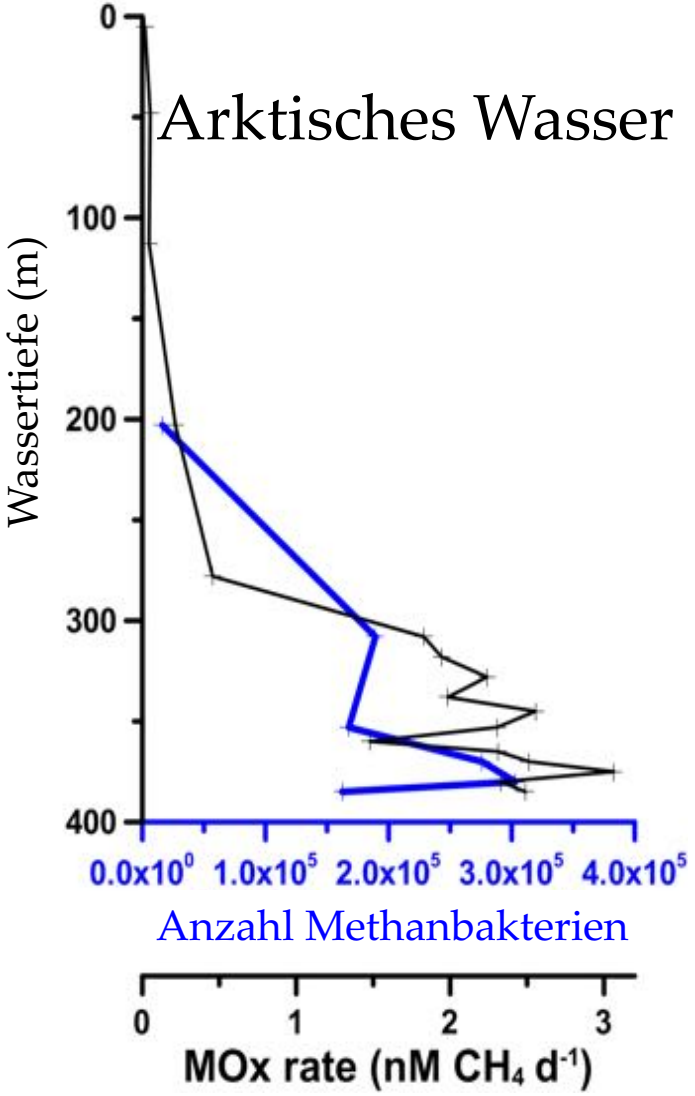


- sehr schnelle Strömung (bis zu 35 cm/s)
- kann das Arktische Wasser innerhalb von 0.5 – 2 Stunden ersetzen!

Probennahme

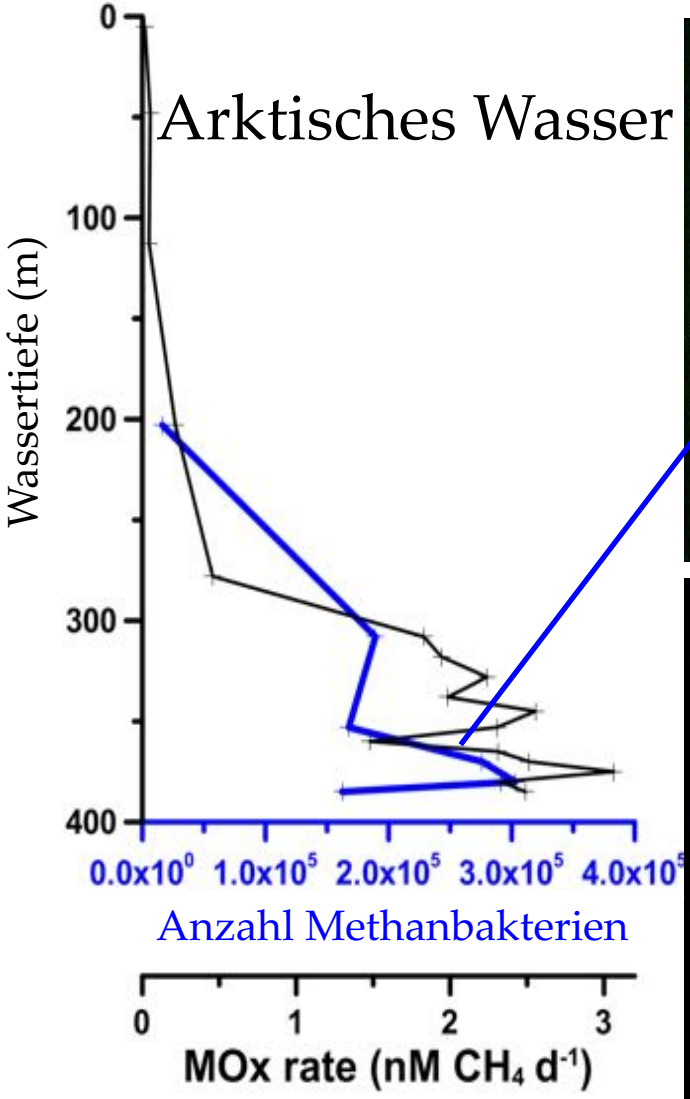
Adapted from Sirevaag, A. and I. Fer (2009).

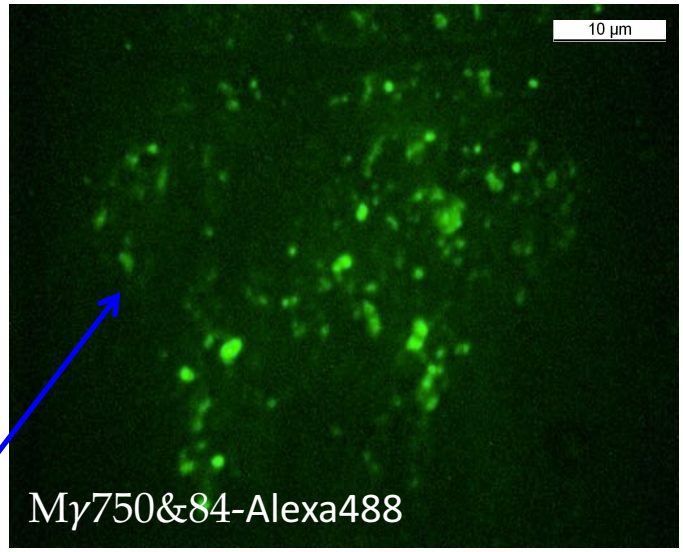
CARD-FISH: Wieviele Methanbakterien sind da?

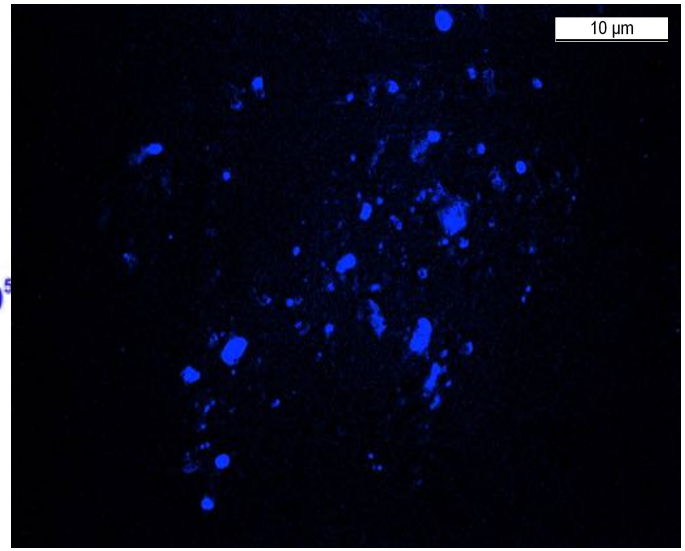


- Bakterienanzahl insgesamt: ca. 3×10^6 ml^{-1}
- bis zu 15 % davon sind Methanbakterien

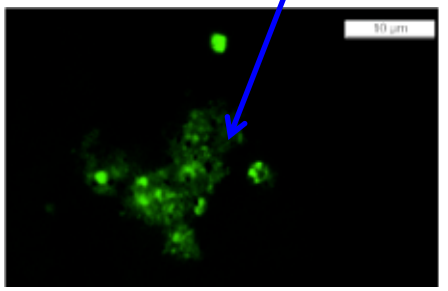
Methanbakterien unter dem Mikroskop

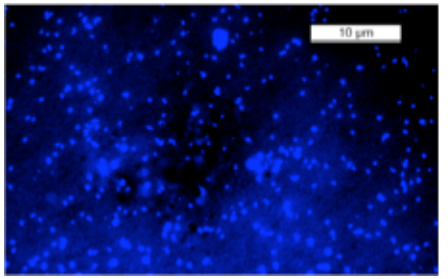




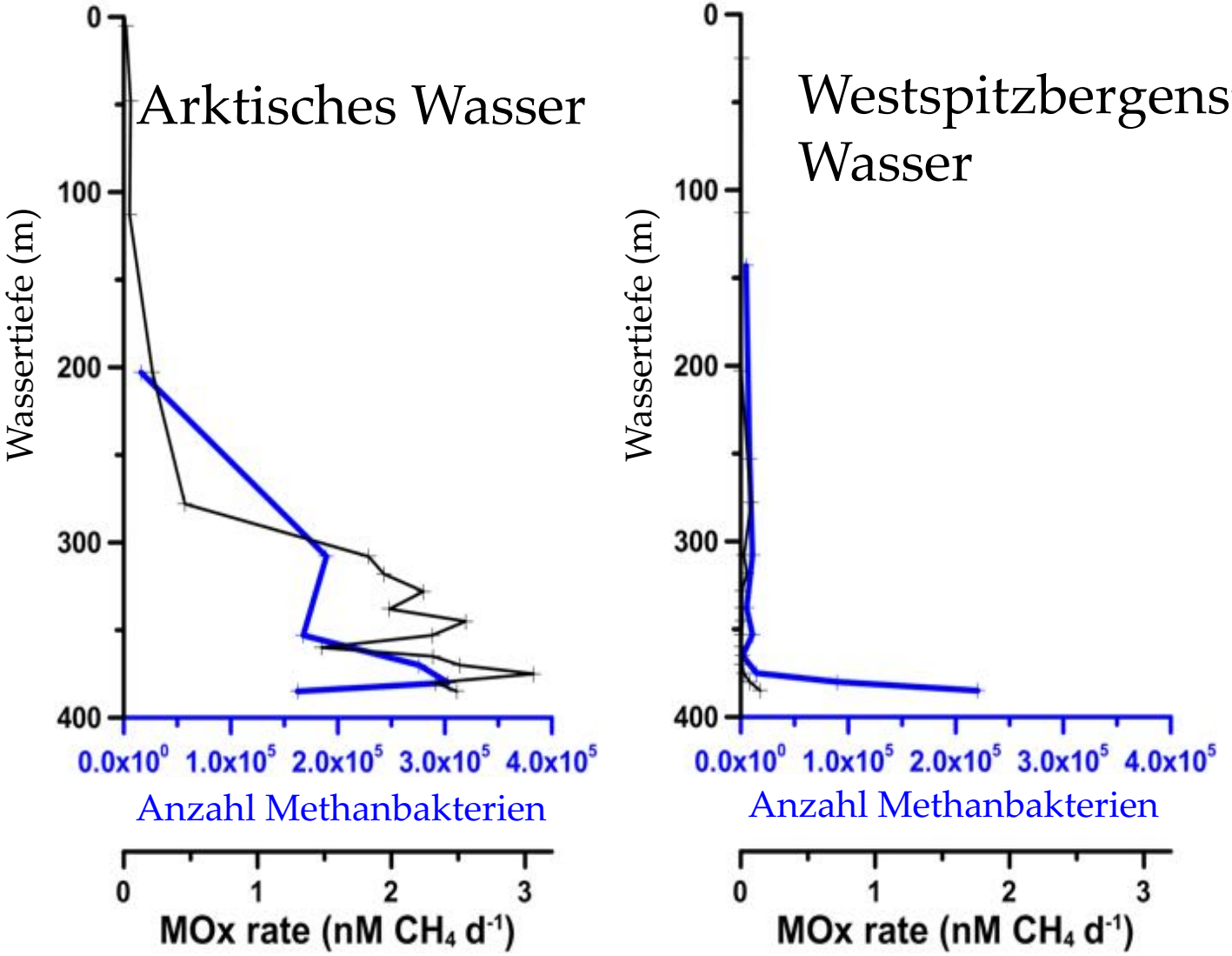


EPS?





..viel weniger Methanbakterien im Wasser des Westspitzbergenstroms!!



Zusammenfassung der Resultate:

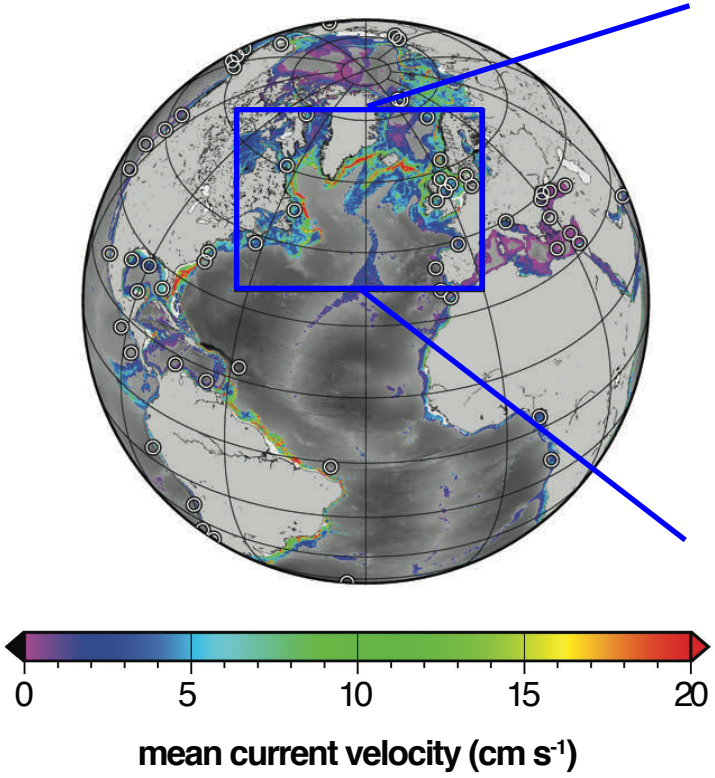
- Kaltes **Arktisches Wasser:** enthält **viele** Methanbakterien
  → **hohe Methanoxidationsraten**
  → Methanabbaupotential 280 kg d^{-1}

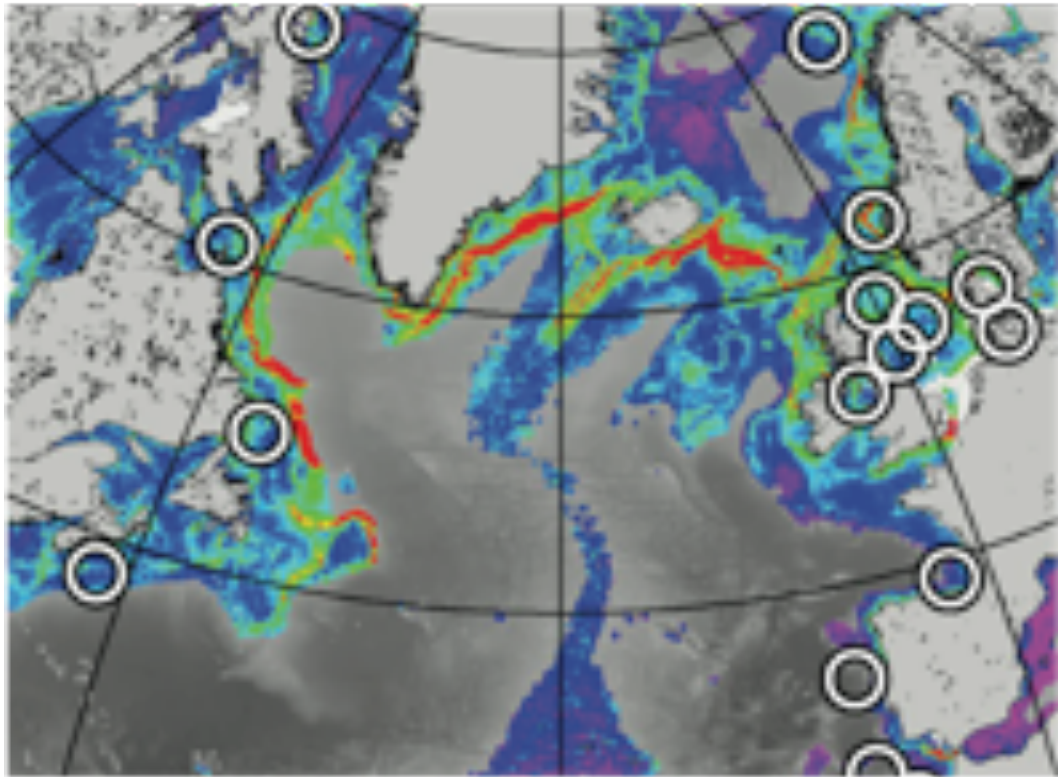
- Warmer **Westspitzbergenstrom:** sehr **wenig** Methanbakterien
  → **tiefe Methanoxidationsraten**
  → **Methanabbaupotential ~60% niedriger!** (90 kg d^{-1})

- Modelierungen zeigen: Westspitzbergenstrom dominiert 85 % der Zeit
  → **zeitliche Auflösung der Probennahme wichtig!**

Was bedeuten diese Resultate im globalen Zusammenhang?

Es gibt überall starke und variierende Meeresströmungen über Methanquellen!





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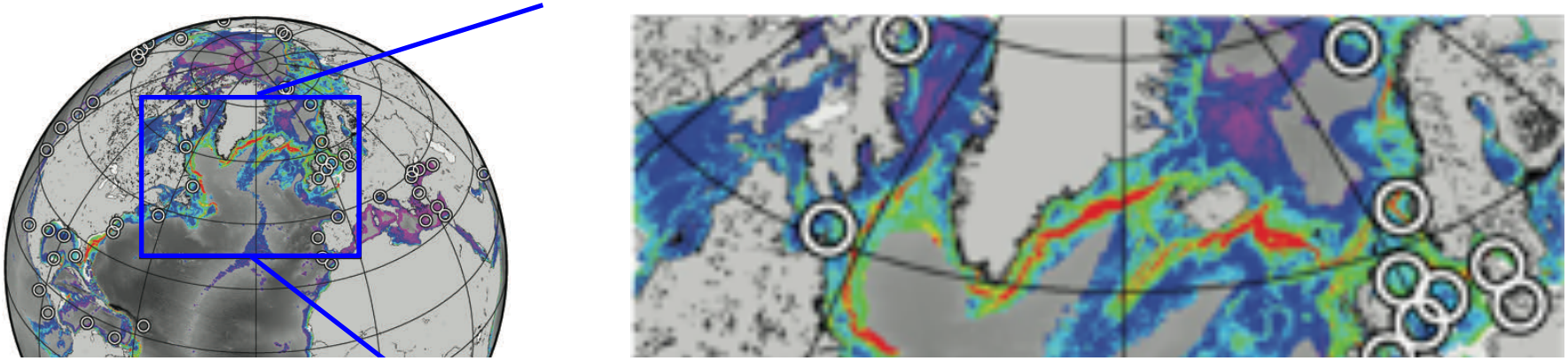


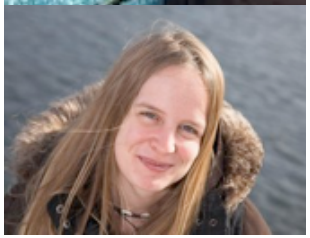
Könnten Meeresströmungen den Methanabbau auch an anderen Standorten kontrollieren?

→ Sehr wahrscheinlich, ja!

→ Wichtig für Methan-/Treibhausgasbudgets

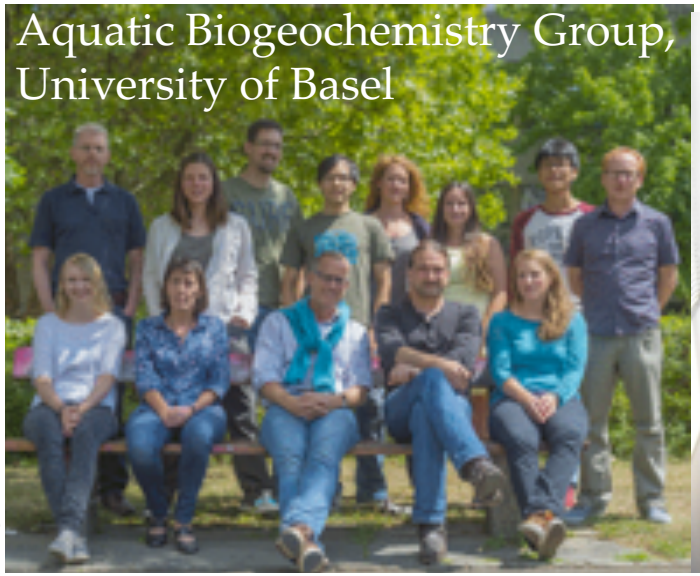
Mein Dank geht an:

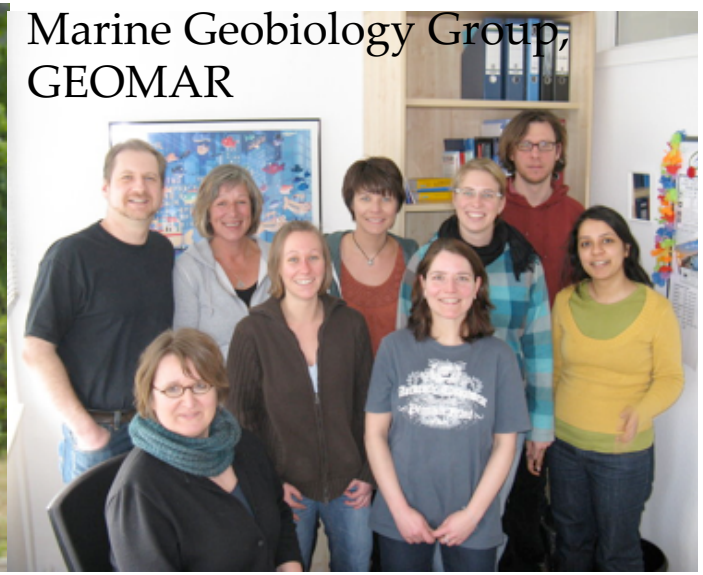
Helge

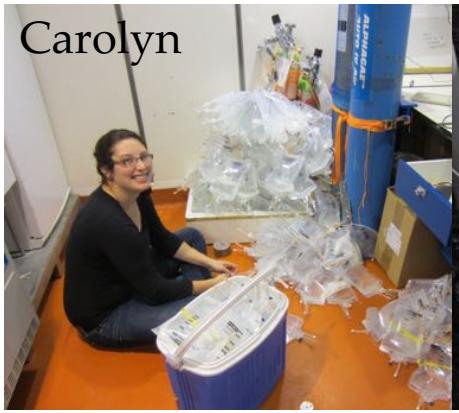


Tina

my thesis committee

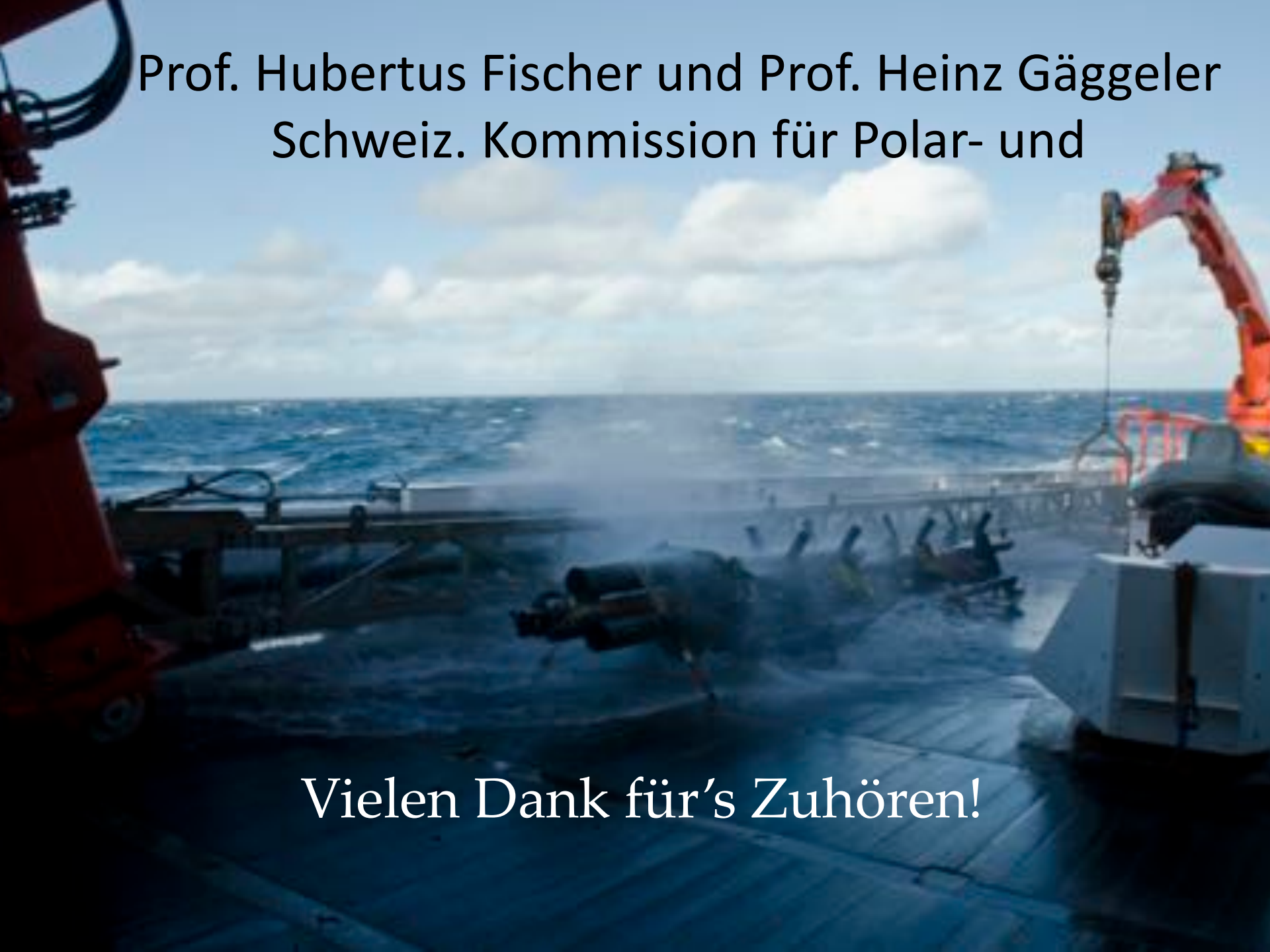






funding:

and: the whole UGW group, all collaborators, the TLZ crew, Claude, Michael, and the crews of F.K. Polarfuchs, F.B. Littorina, and R/V Alkor, Maria S. Merian, Celtic Explorer and Voyager


Prof. Hubertus Fischer und Prof. Heinz Gäggeler
Schweiz. Kommission für Polar- und
Vielen Dank für's Zuhören!


Fragen?

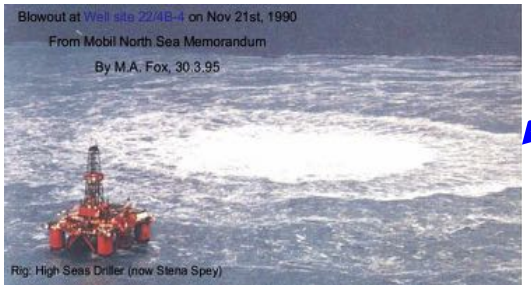
Four methane-rich areas to study four different potential environmental controls on MOx

Eckernförde Bay

http://de.holidayinsider.com/urlaub/eckernfoerder-bucht/ferienwohnung

- coastal area (28m)
- seasonal stratification
- control: **OXYGEN**

Blowout

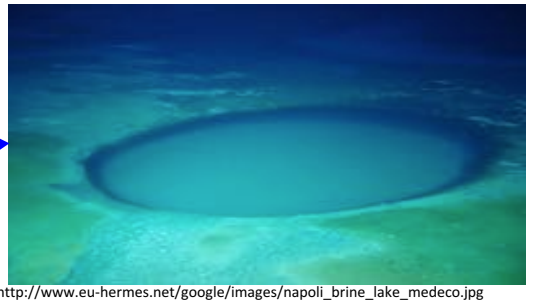


- shelf sea (100m)
- known onset of seepage
- control: **CH_4 ↗↗**

Svalbard seeps

- continental slope (400m)
- gas hydrate fueled (?)
- control: ~~**TEMPERATURE**~~ **CURRENTS!**

Brine lake

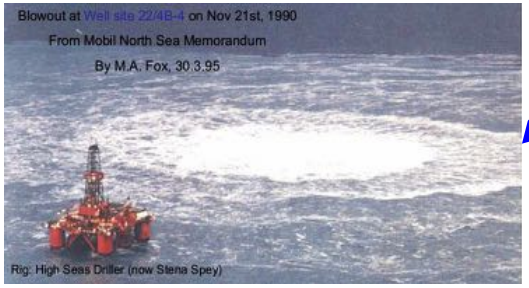


http://www.eu-hermes.net/google/images/napoli_brine_lake_medeco.jpg

- deep ocean (3000m)
- CH_4 ↗↗
- control: **SALINITY**

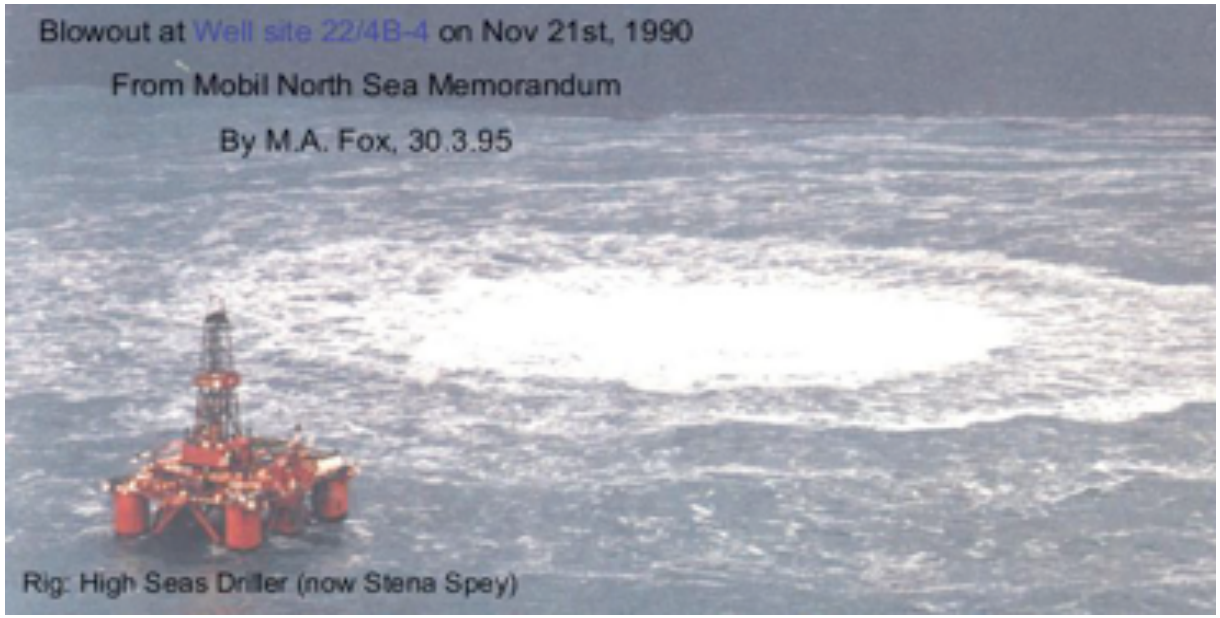
Second case study: the Blowout

Blowout



- shelf sea (100m)
- known onset of seepage
- control: CH_4 ↗↗

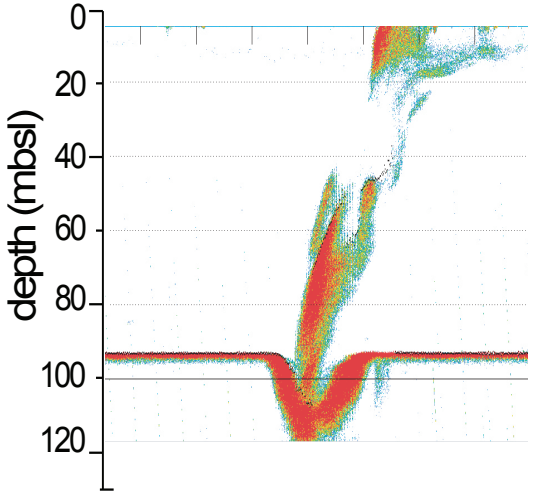
The Blowout: "man-made super seep"



1990
explosion of a gas pocket pierced while drilling for oil

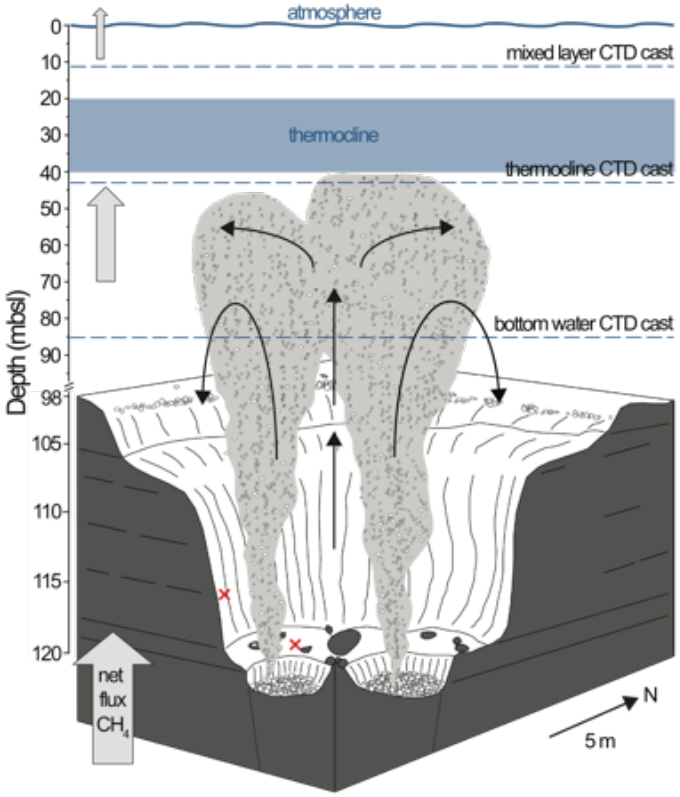
1994
estimated to emit ~25% of methane of the North Sea!

2012
still highly active seep



Steinle et al., Limnology & Oceanography, under revision

In brief: methane and MOx at the Blowout



- Methane concentrations up to **42,000 nM**

  → 100 times more than in Svalbard!

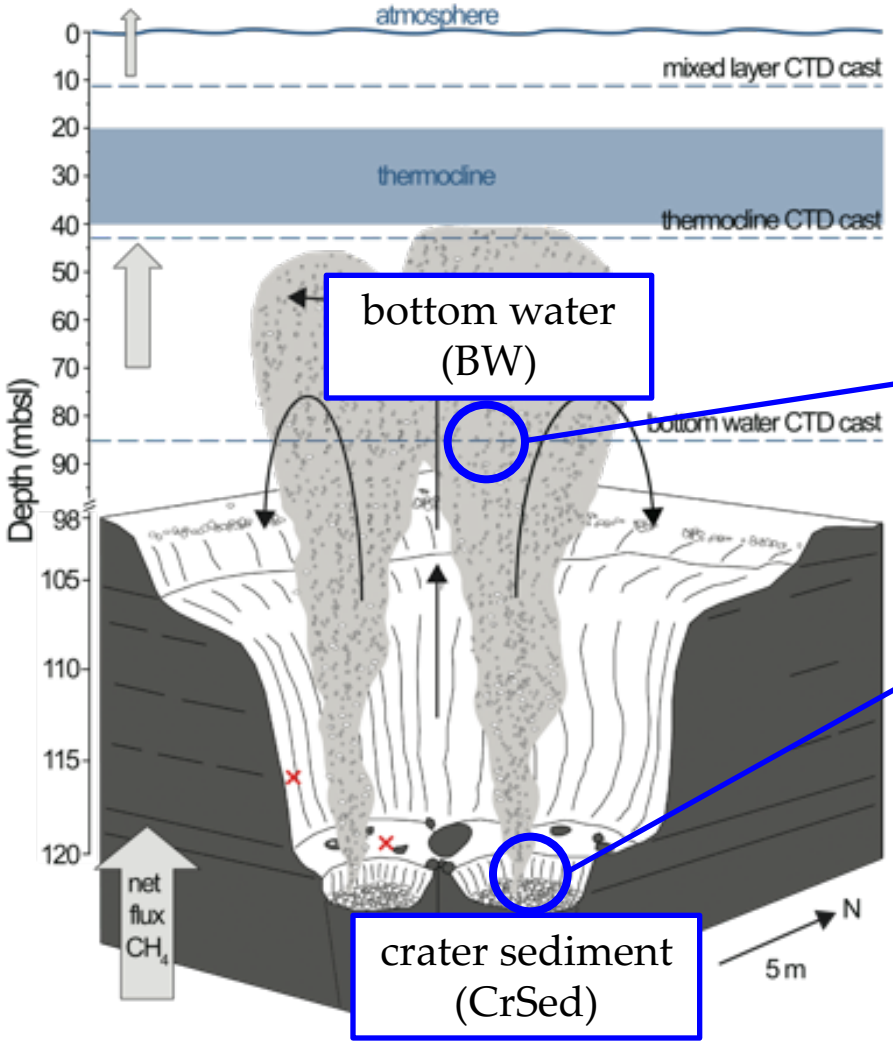
- MOx rates up to **498 nM d^{-1}**

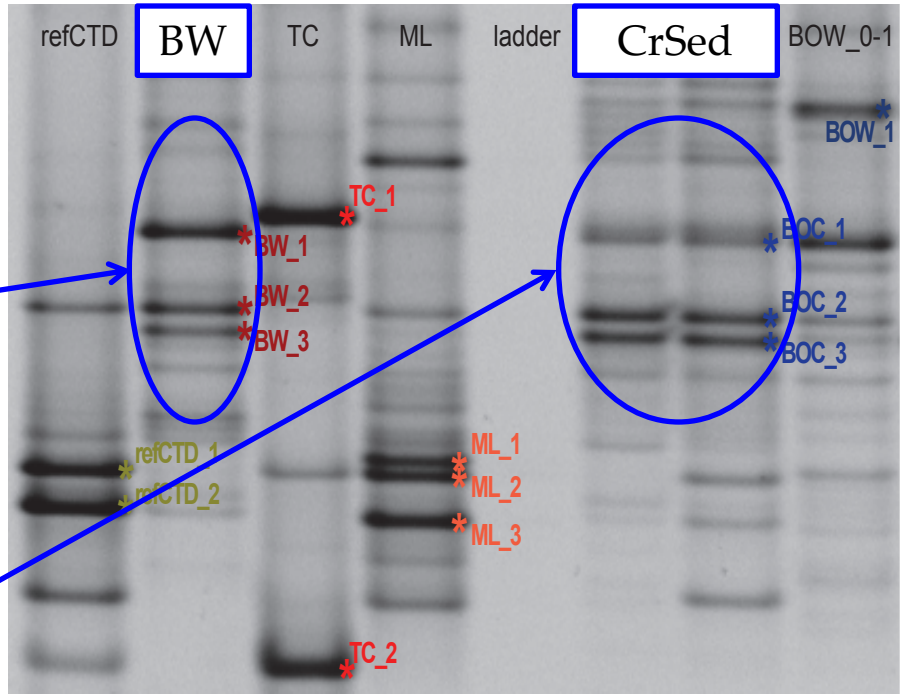
  → 500 times more than in Svalbard!

Very high MOx rates but also strong (tidal) currents…

How can such an effective methanotrophic community develop?

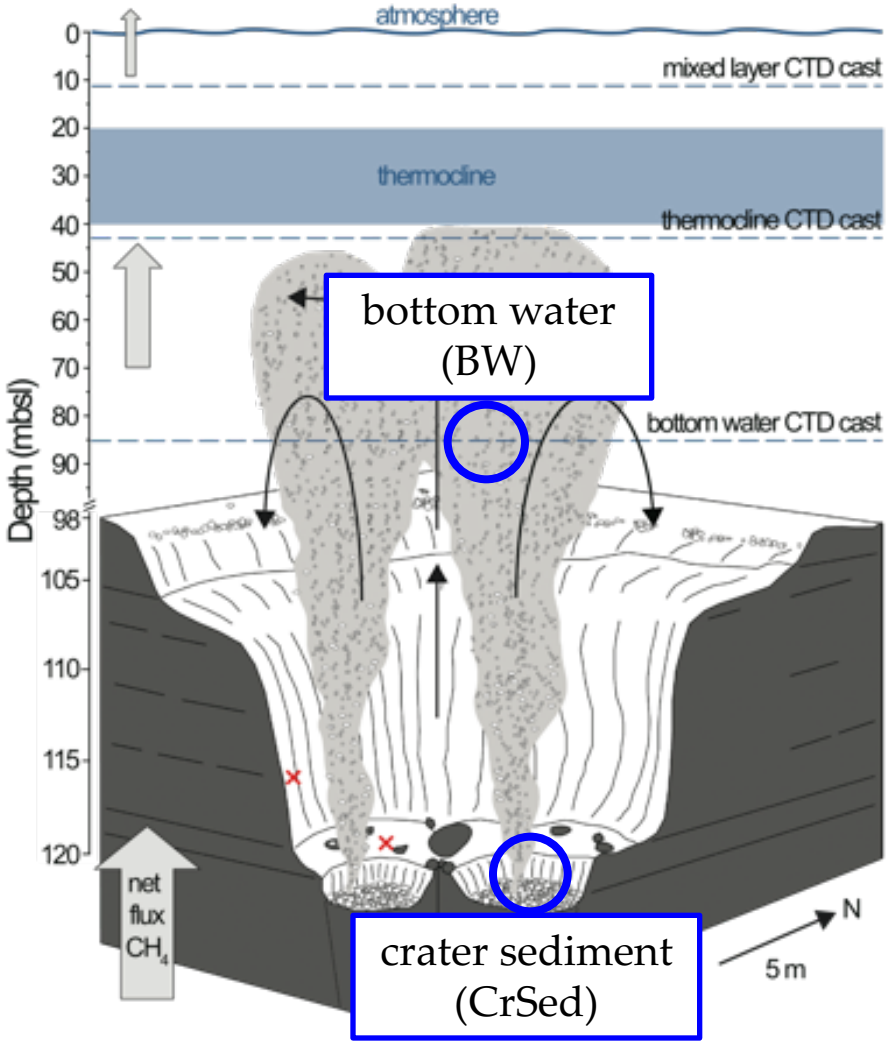
Sediment and bottom water: similar genetic "fingerprints"

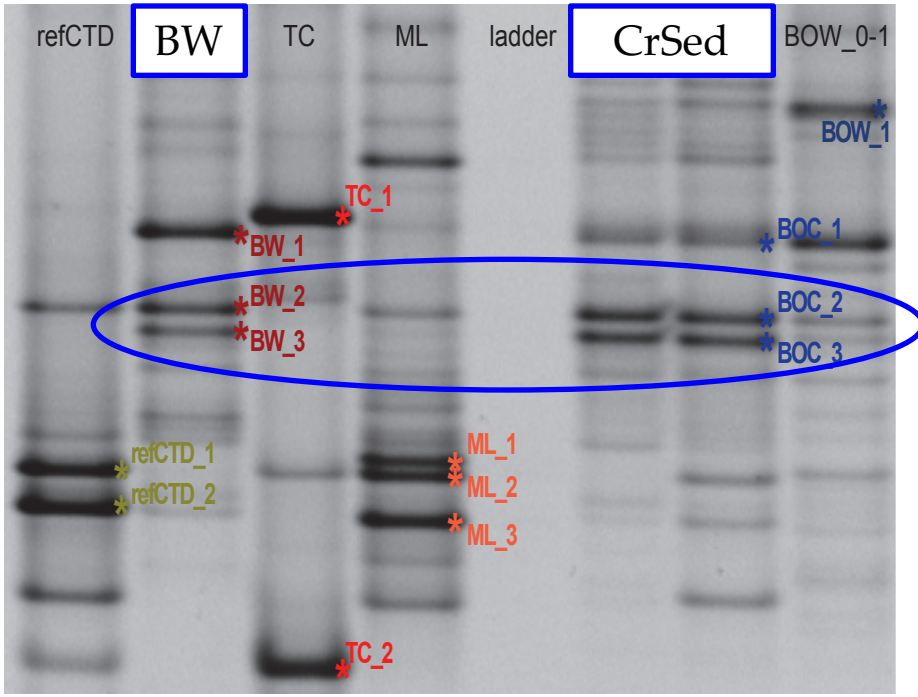




reference CTD thermocline
Bottom Water CTD grid
Thermocline CTD grid
Mixed Layer CTD grid
Blowout crater sed. 1-2 cm
Blowout wall sed. 0-1 cm

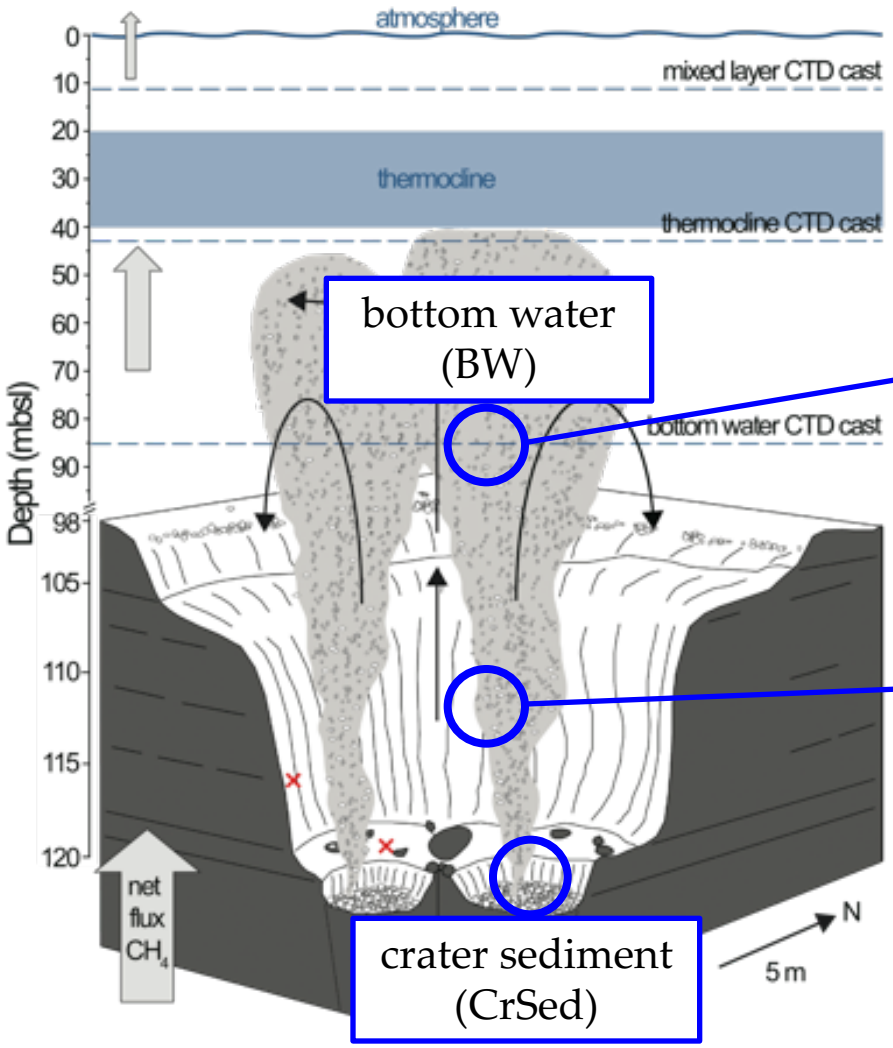
Identical sequences in sediments and bottom water!?

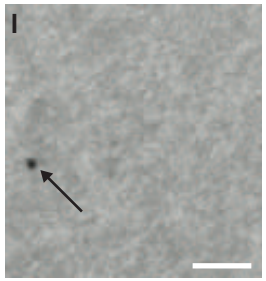


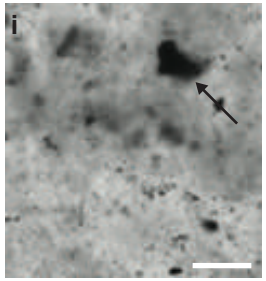


reference CTD thermocline
Bottom Water CTD grid
Thermocline CTD grid
Mixed Layer CTD grid
Blowout crater sed. 1-2 cm
Blowout wall sed. 0-1 cm

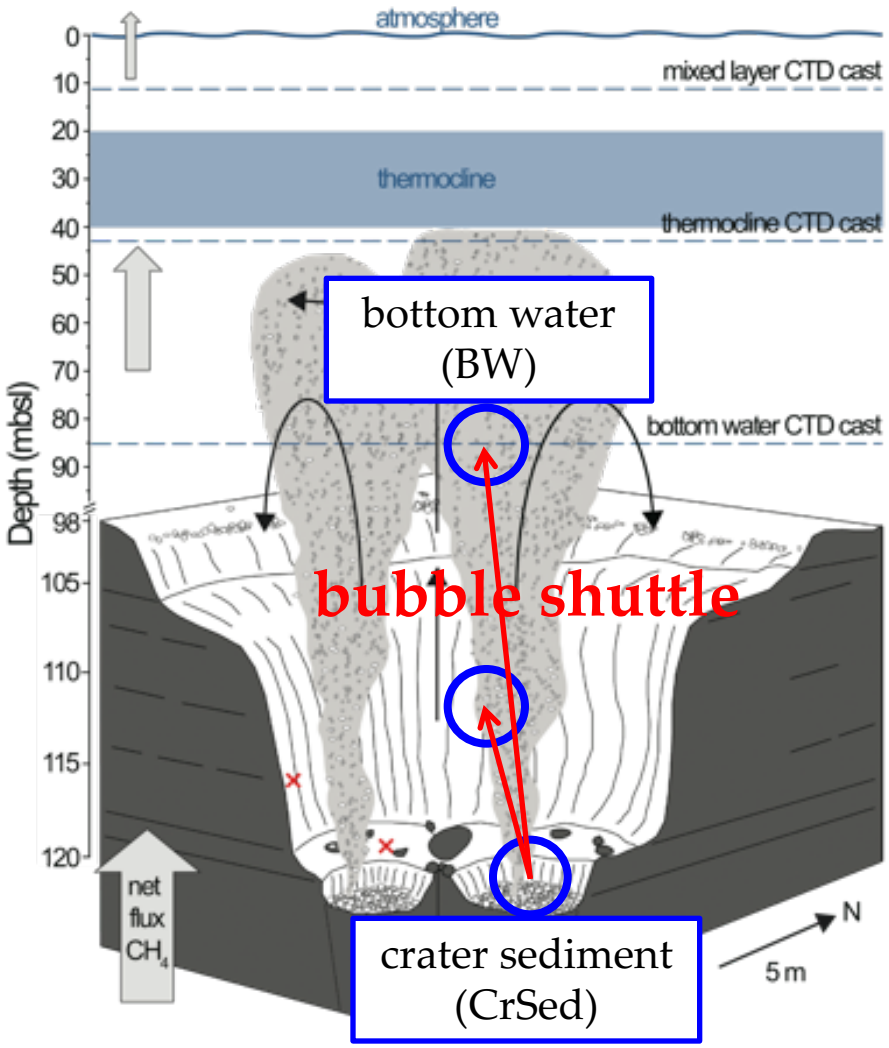
Sediment particles are transported up into the water column by the bubble stream…



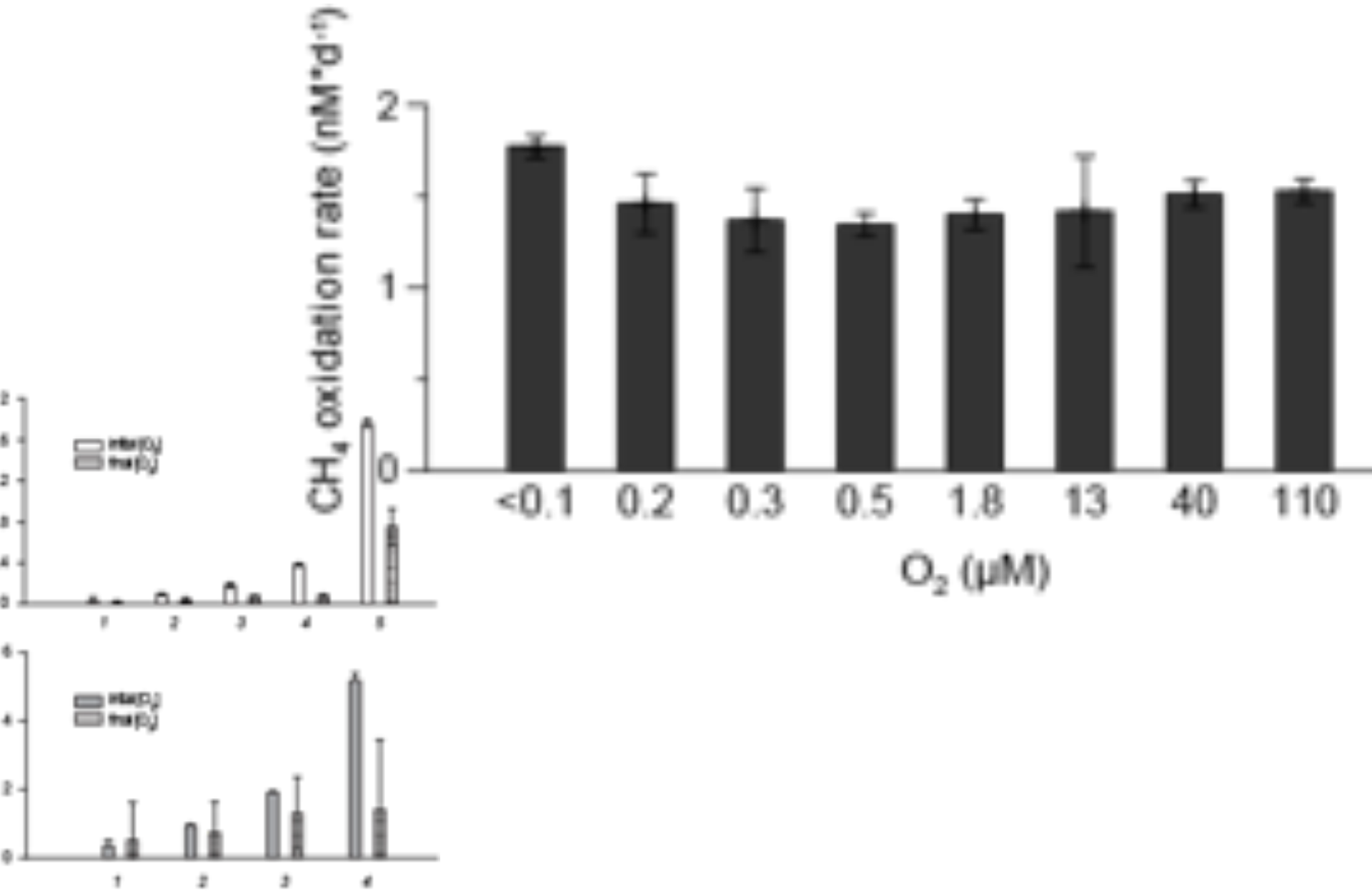




..which is hence a "bubble shuttle" for sedimentary bacteria!



- Physical control on the abundance of methanotrophs
- ..and thus on MOx
- **global importance?!**
  - → bubbles at almost all seeps
  - → biogeography

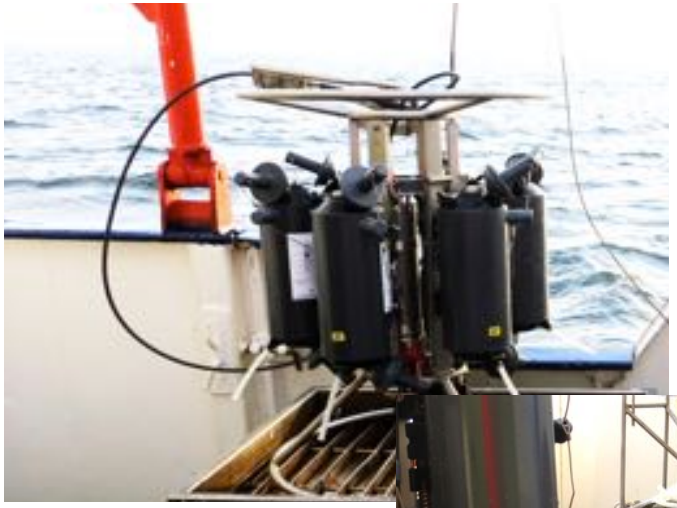

CH_4 oxidation rate (nM^*d^{-1})
2
1
0
<0.1
0.2
0.3
0.5
1.8
13
40
110
O_2 (μM)

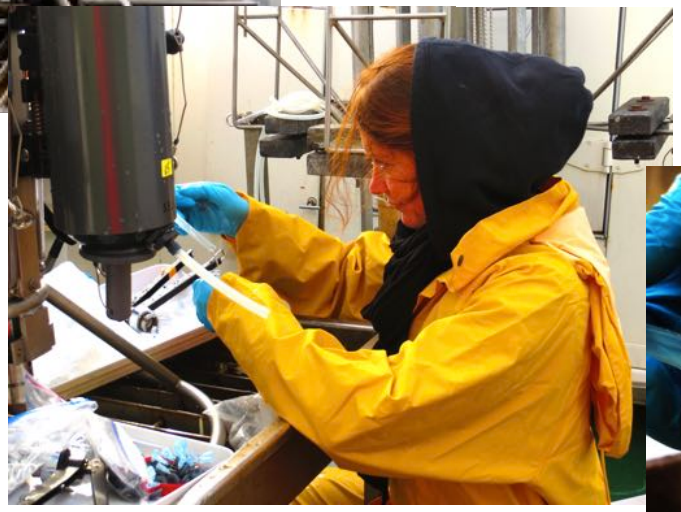
Thanks to:

- JAGO team

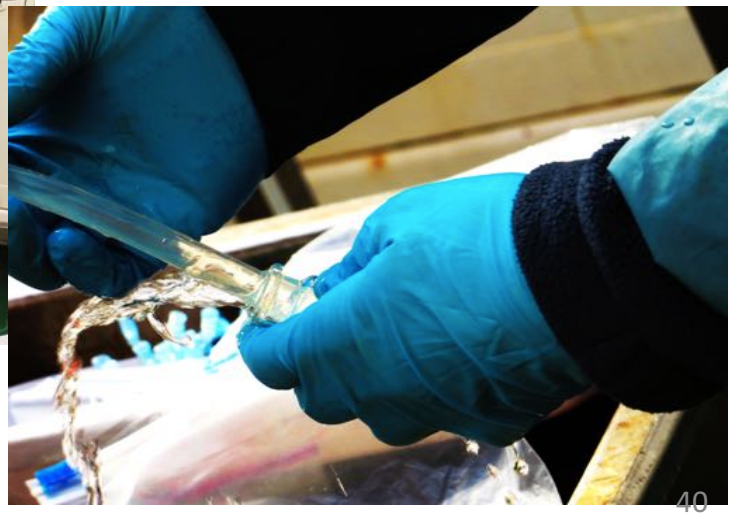
- Bettina Domeyer
- Crew of

- DFG Deutsche Forschungsgemeinschaft
- FNSNF Schweizerischer Nationalfonds
- future ocean
- PERGAMON





- T; S; pH; [O2]
- $[CH_4]$
- CH_4 oxidation rates



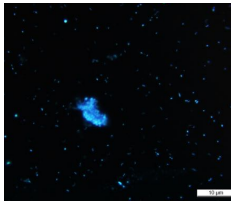
workflow/methods

1. water sampling with CTD rosette sampl

2. head-space measurements of CH_4

3. radio-tracer based quantification of MOx

$$C^3H_4 + 2O_2 \rightleftharpoons CO_2 + {}^3H_2O$$



identification of microbes with CARD-FISH

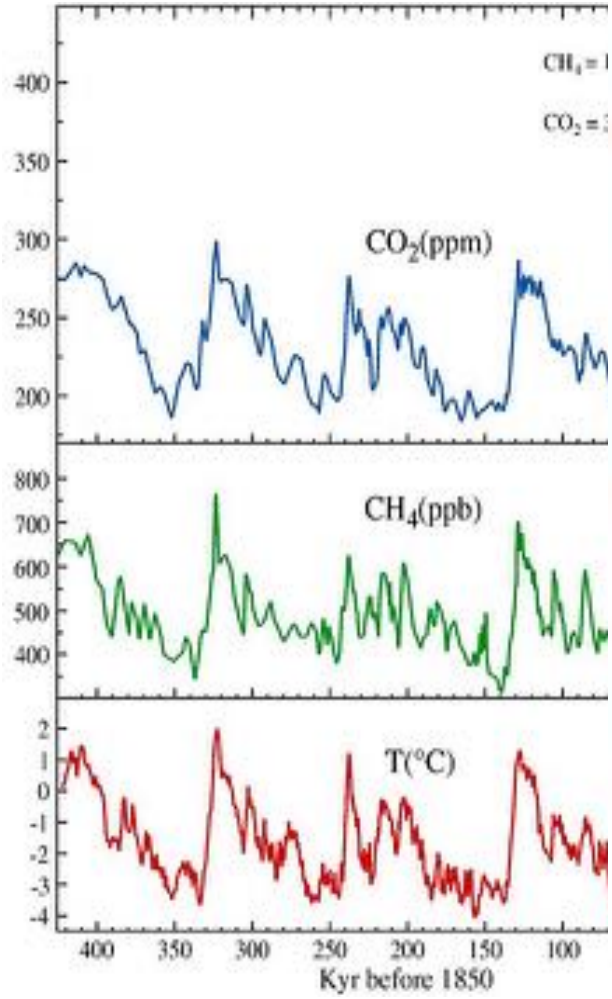
Methane Oxidation Rate (r)

- 1: 
- 2: $C^{3}H_{4} + 2O_{2} \rightleftharpoons CO_{2} + {}^{3}H_{2}O$
- 3: $$r = \frac{{}^{3}H_{2}O}{{}^{3}H_{2}O + C^{3}H_{4}} \; x \; [CH_{4}] \; x \; t^{-1}$$

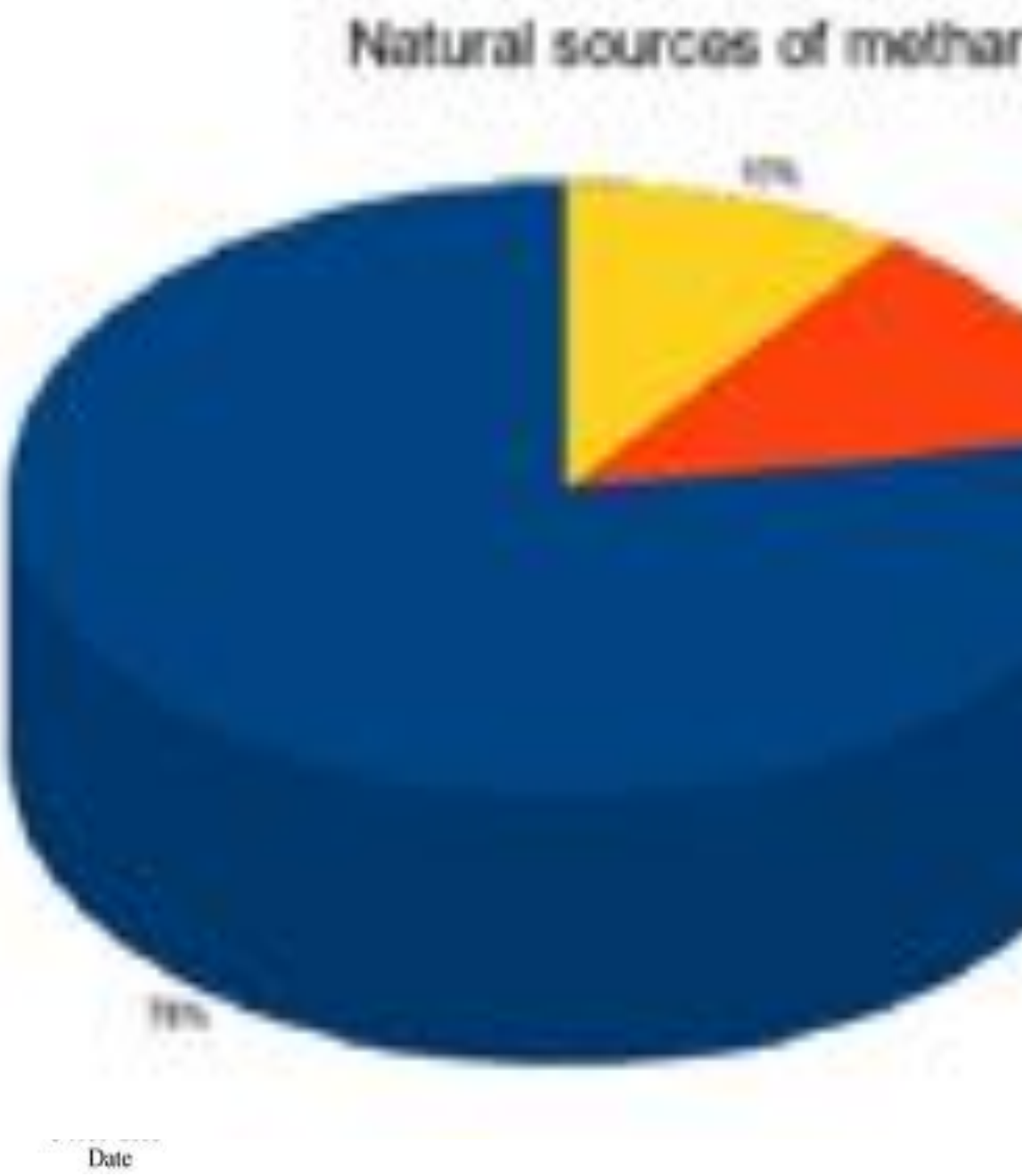
rate constant

in nM

Temperat

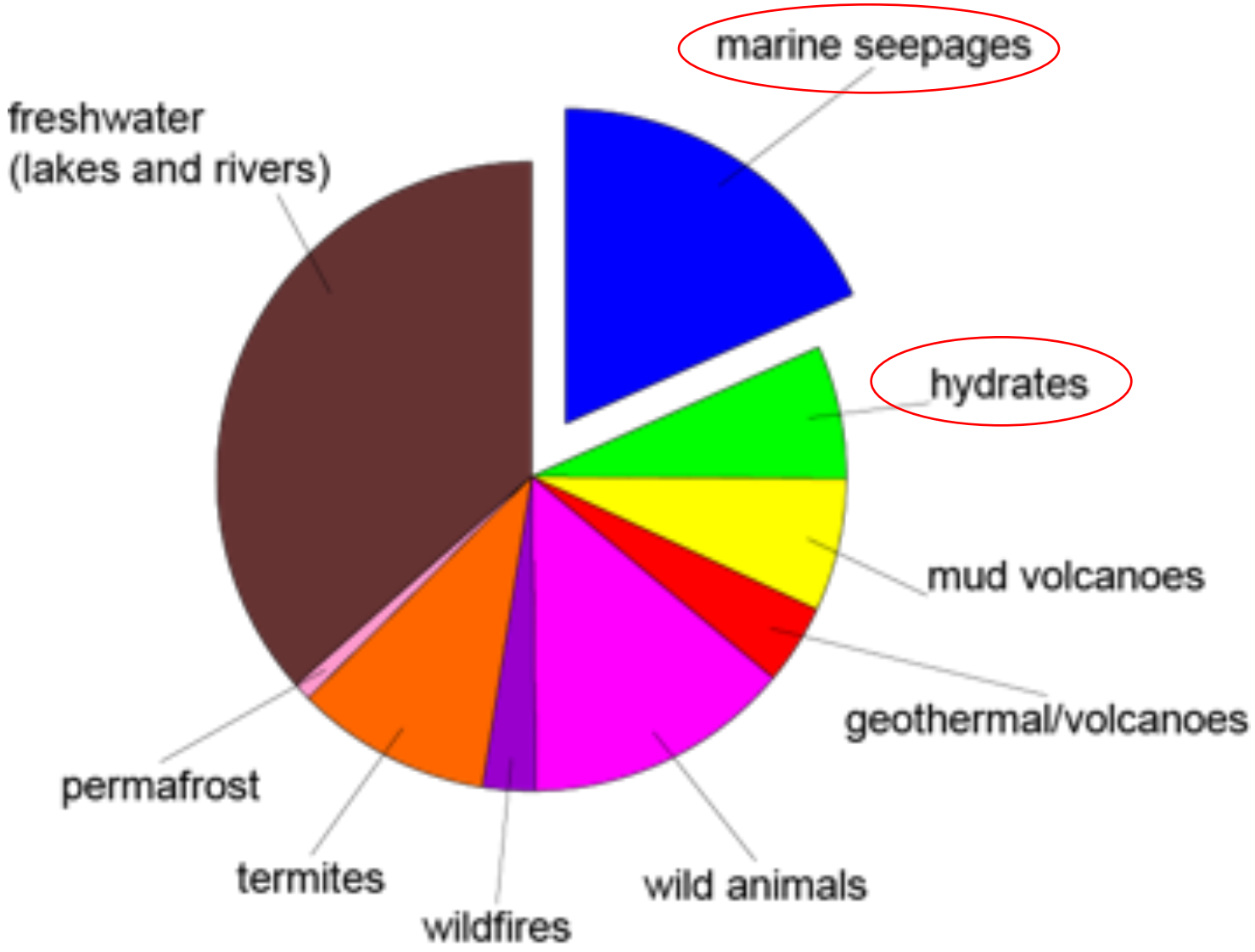


Source: Hansen (2005), Climatic Change 68: 269.



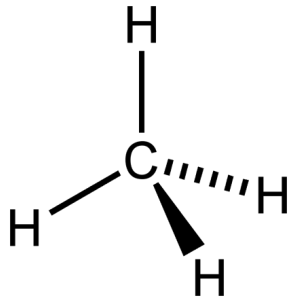
Bousquet, P. et al. (2006). Contribution of anthropogenic and natural source atmospheric methane variability

natural methane emissions (w/o wetlands)

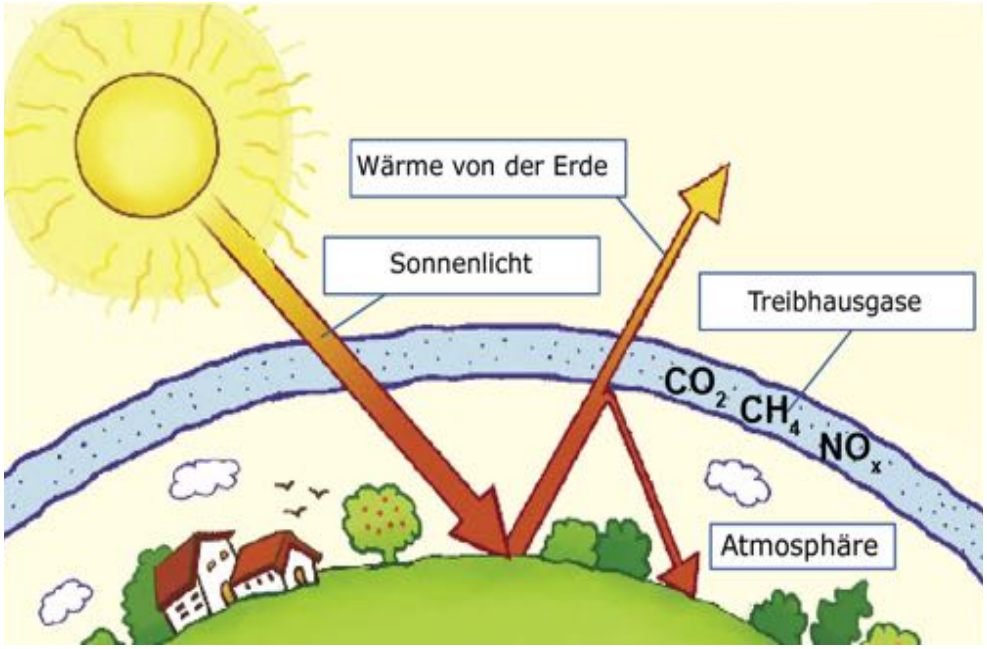


bottom-up estimates 2000-2009; IPPC 2013; EPA 2010

Greenhouse gas methane (CH_4)

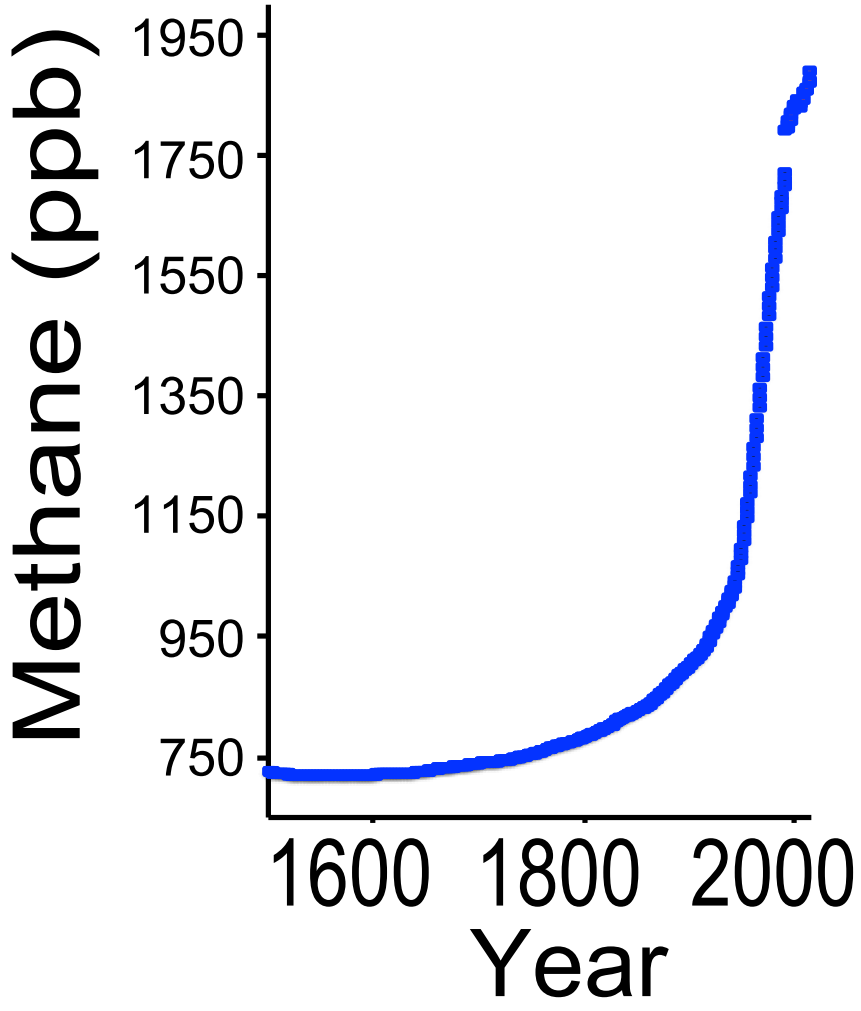


- simple hydrocarbon
- flammable gas (…Erdgas)
- produced by the breakdown of organic material

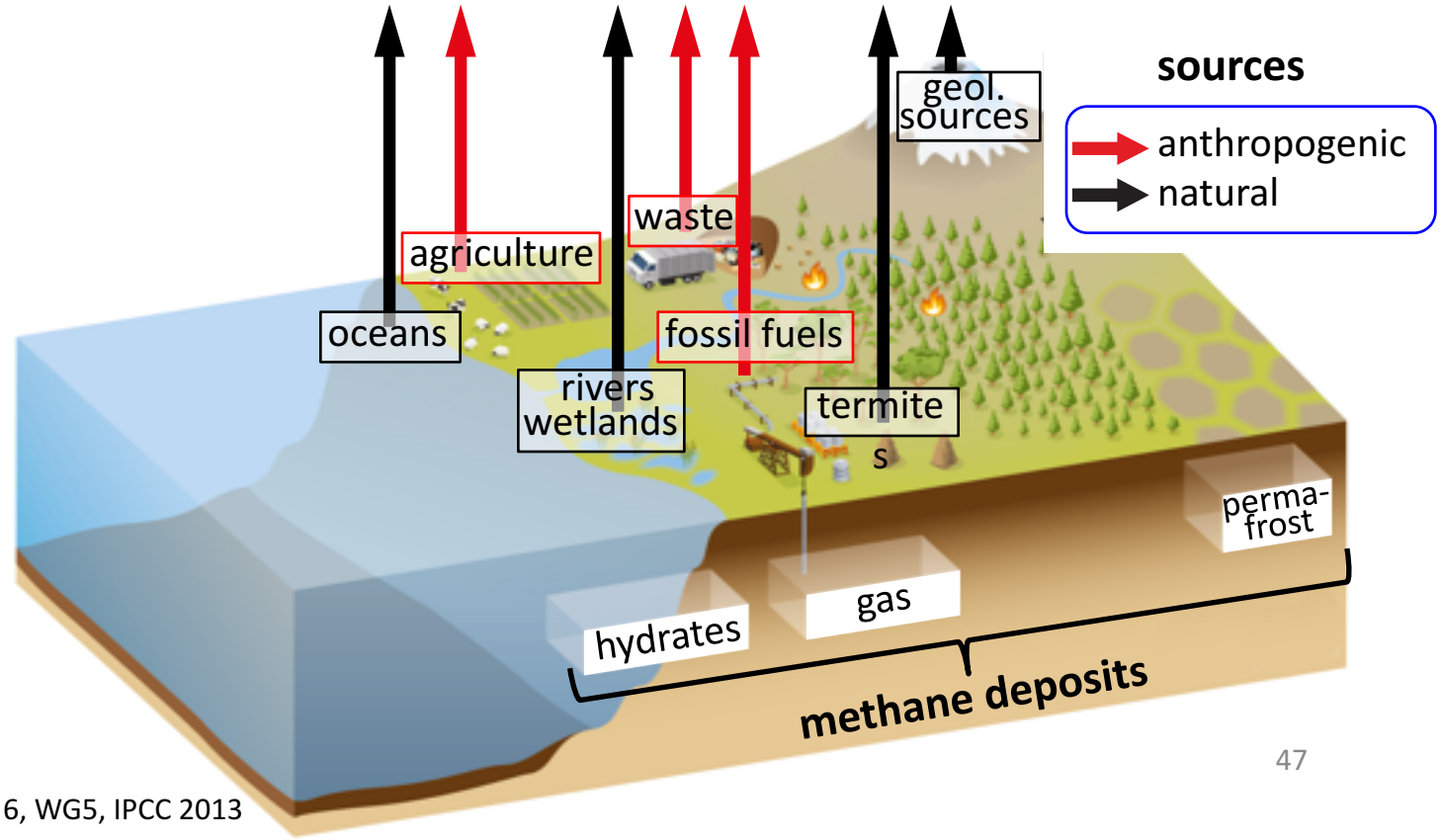


- responsible for ~30% of greenhouse gas effect
- ~25 times stronger global warming potential than CO_2

Strong increase in atmospheric concentration of methane in the last 150 years…



..because of increased emissions!



modified after Fig. 6.2 of Chapter 6, WG5, IPCC 2013