

# Microbial conversion of higher hydrocarbons to methane in oil and coal reservoirs

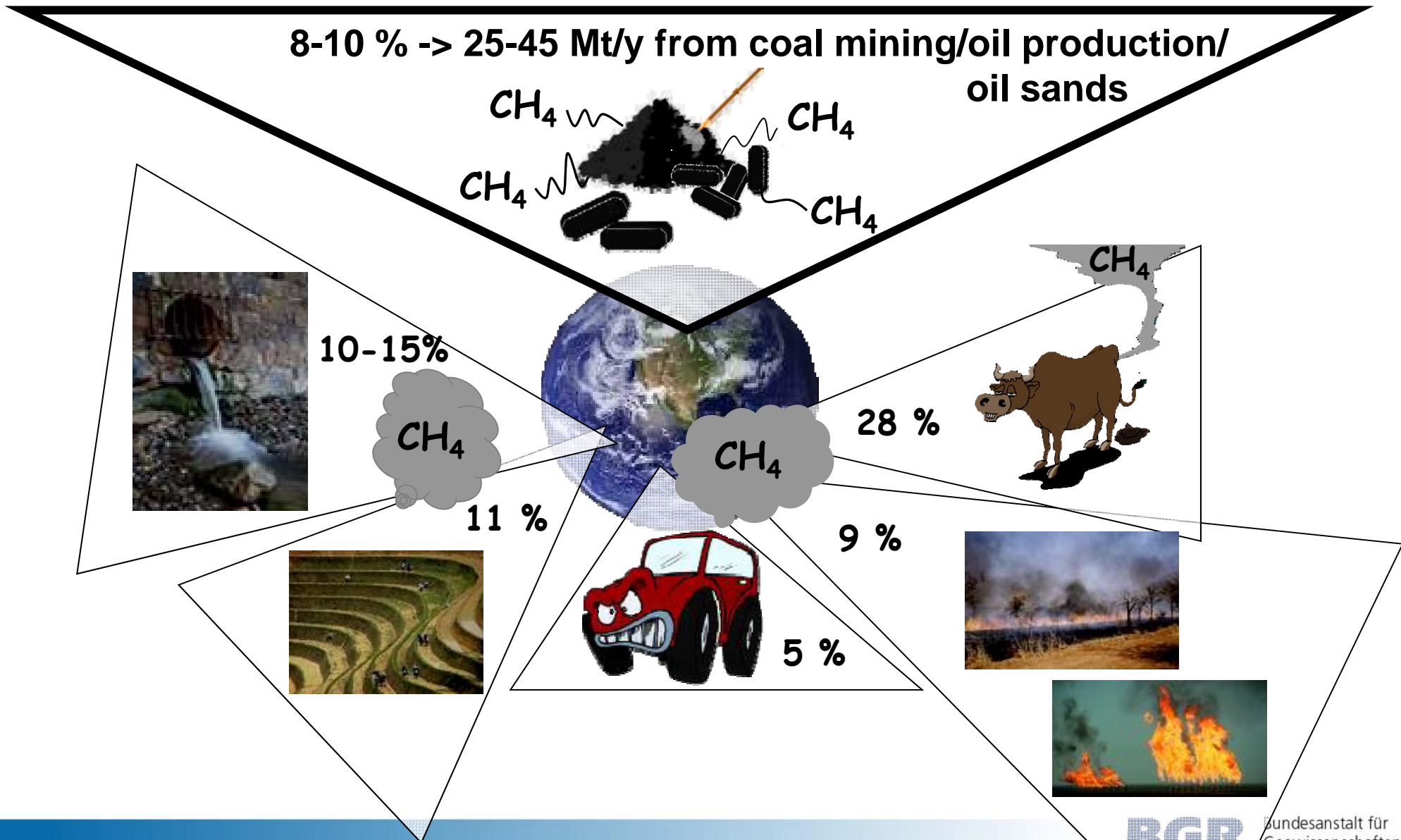


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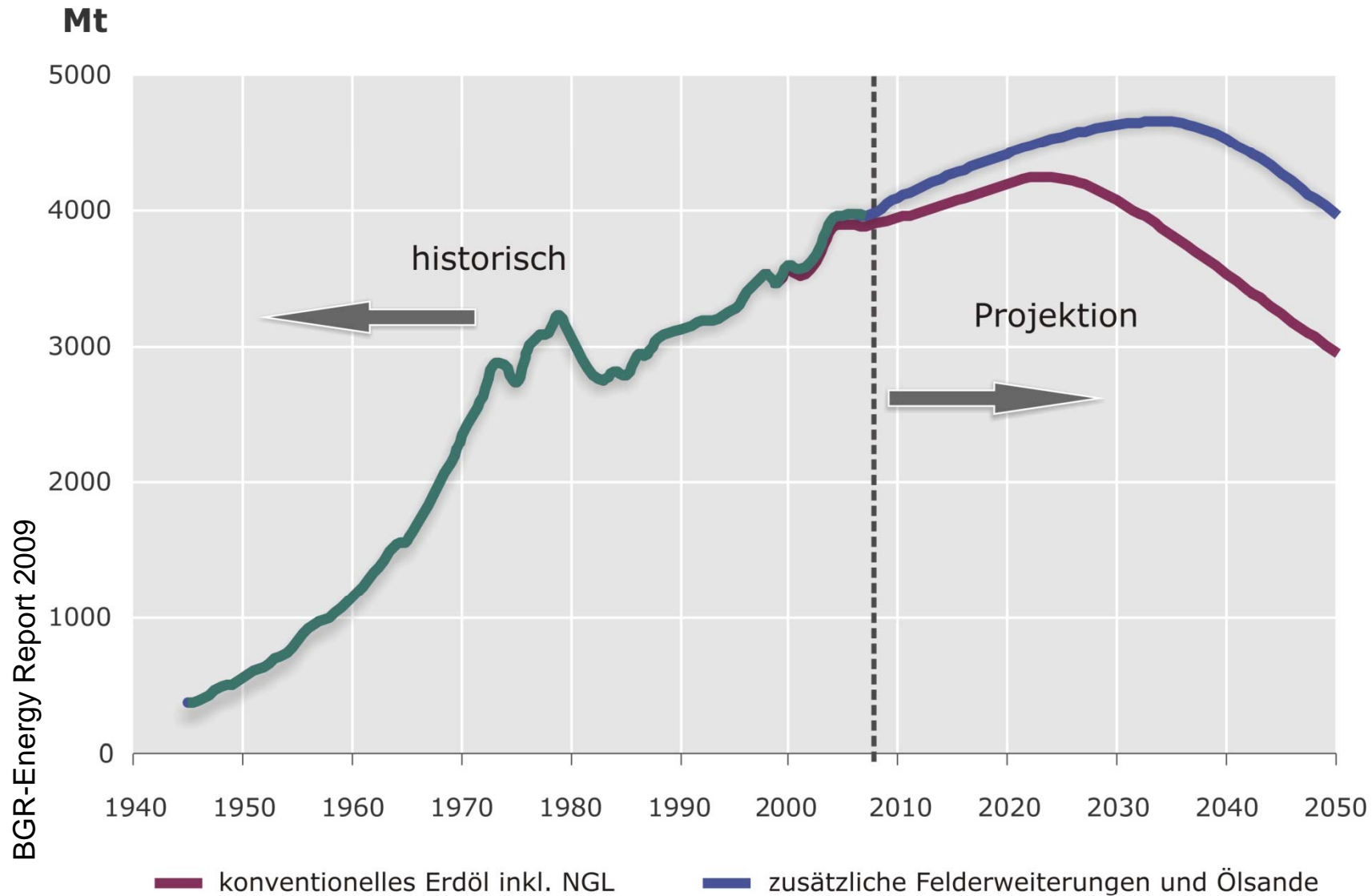
# Motivation

## Global methane emissions



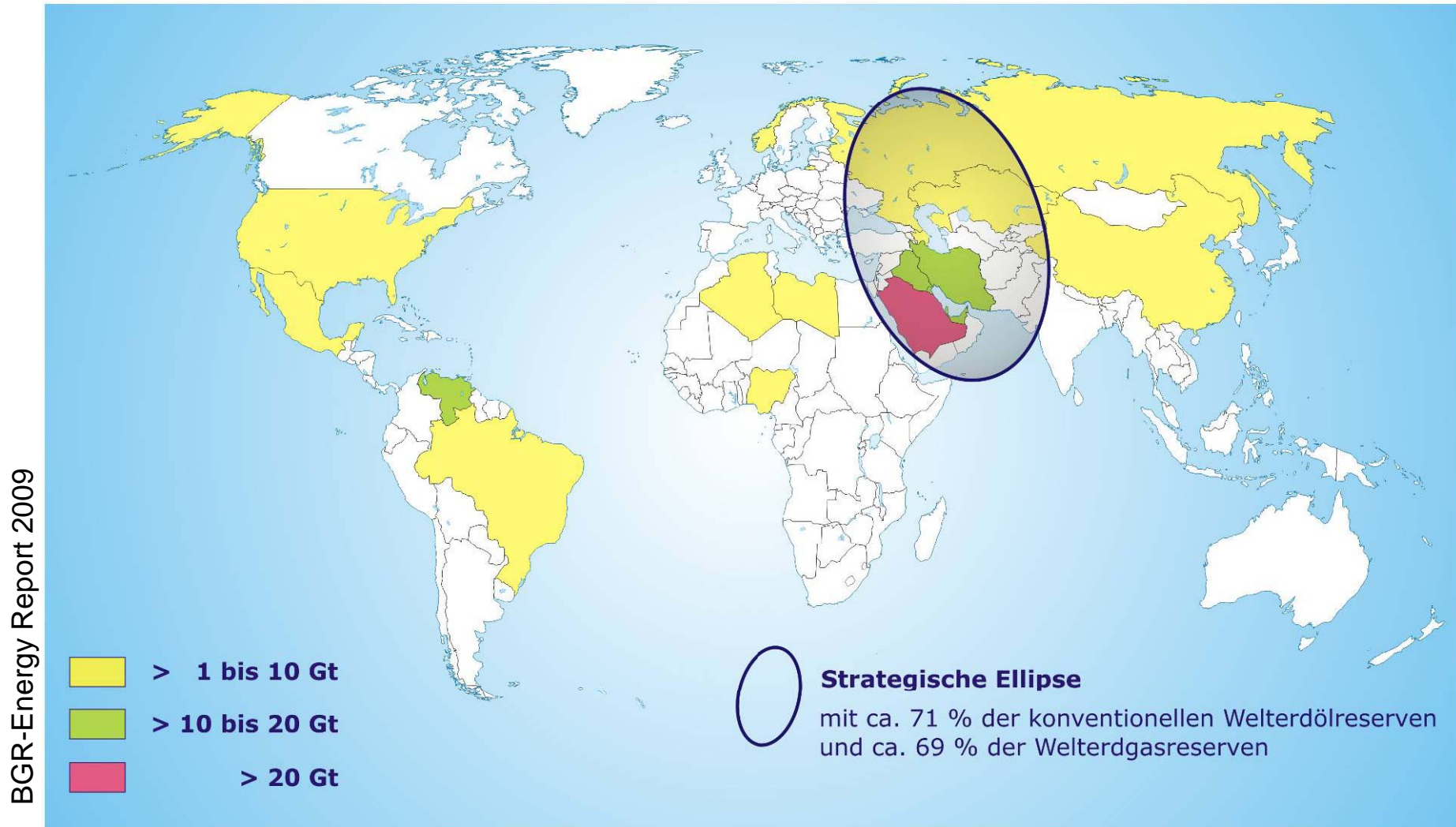
# Motivation

## Projected oil production worldwide



# Motivation

„Strategic Ellipse“ of countries with major oil reserves >10Gt



# Motivation

- Generally, 50-70% of oil remain unproducable in reservoir
- Majority of oil left is heavy/biodegraded or unconventional oil (oil sands, deep oil...), same with coal and shales...

=> Need for new (production) technology

=> Need for diversification of energy supply

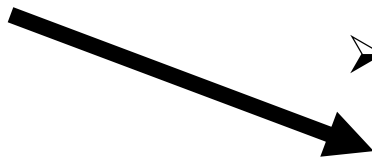
**==> Microbial conversion of oil or coal to methane**

# Objectives

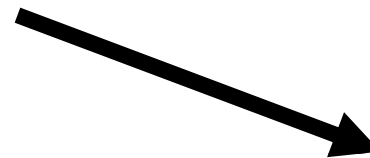
**Overall: Identify microbial & geochemical controls on methanogenesis in reservoirs**

- Possibility of a direct stimulation in reservoirs
- Amounts of coal & oil that can be converted into methane
- Exploration tools for methanogenesis
- New MEOR approaches

**Oil & Coal**



**Acetate, H<sub>2</sub>**

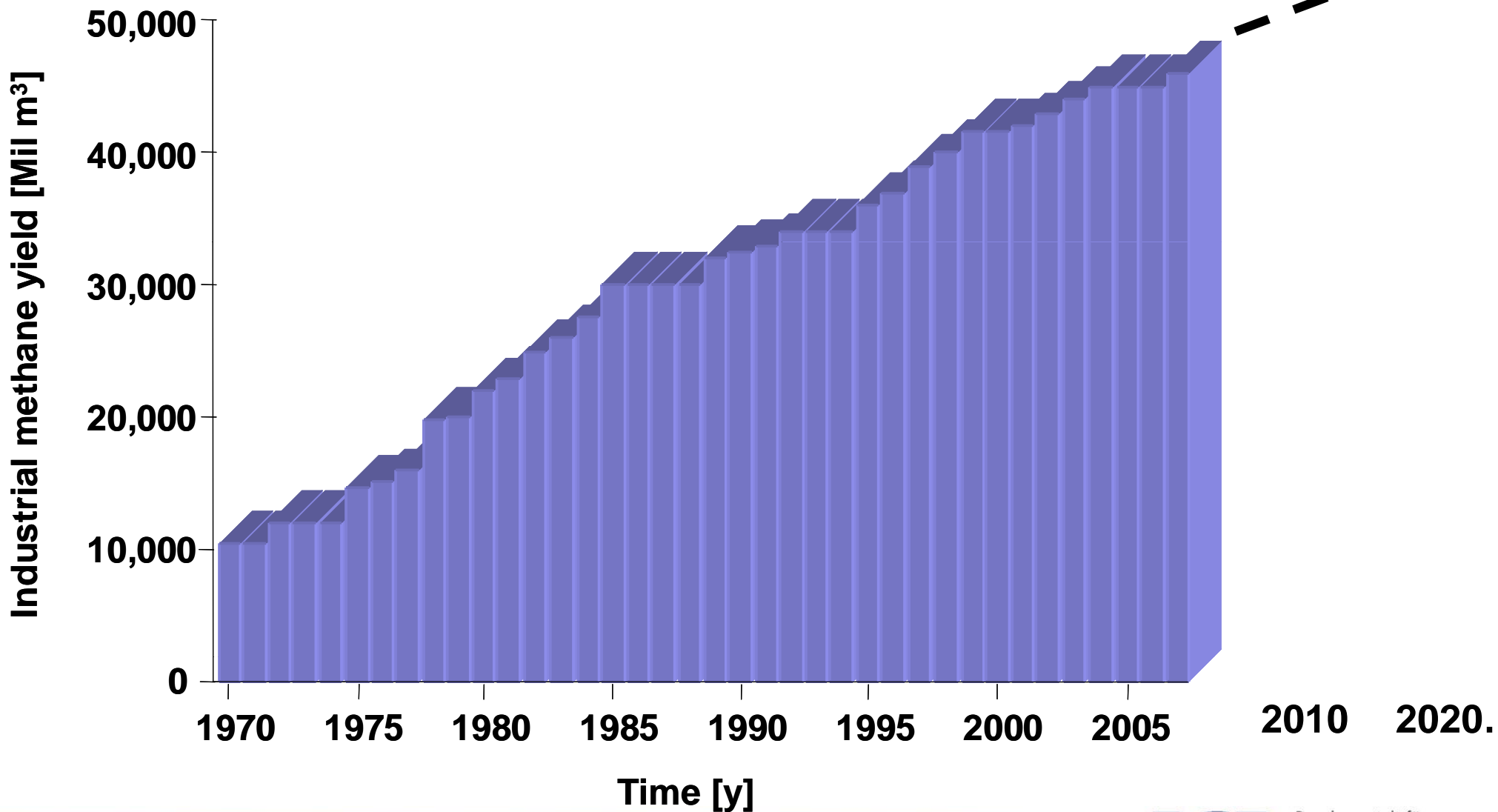


**CH<sub>4</sub> & CO<sub>2</sub>**

# Methane from coal

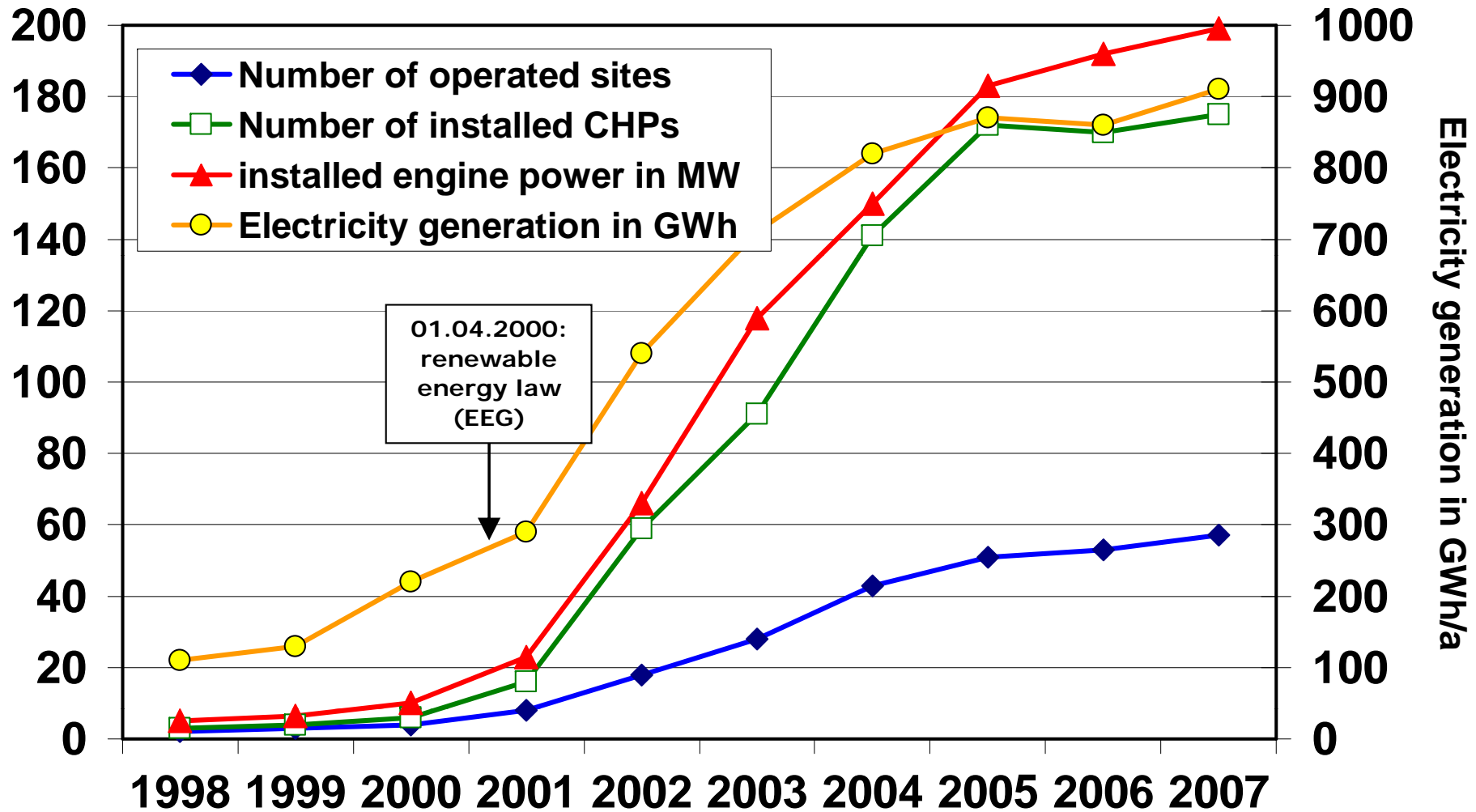
# Coal-bed methane

## Worldwide production

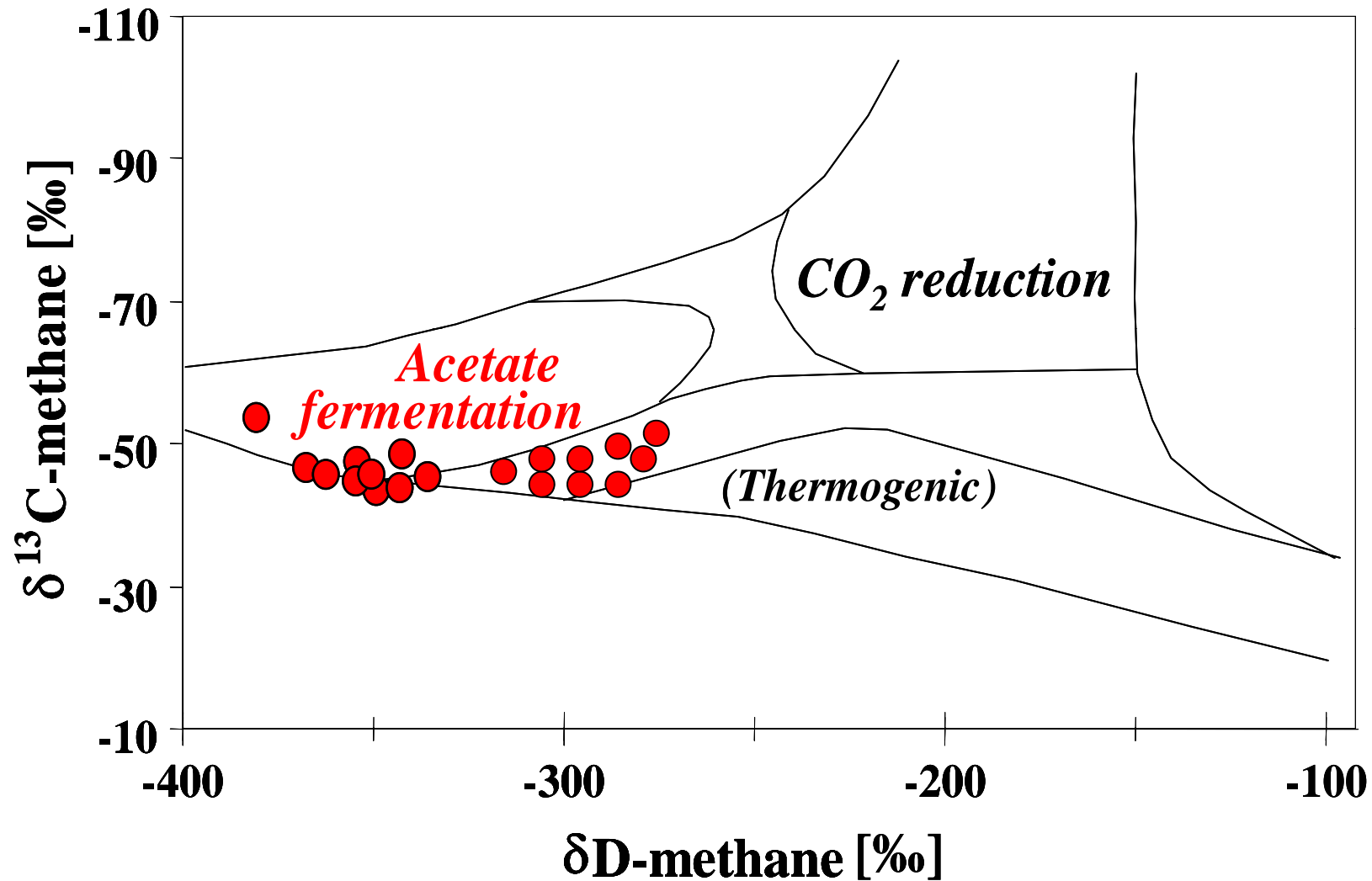


# Methane from coal

## Coal Mine Methane Utilization in Germany 1998 to 2007



# Methane from coal



# Sampling abandoned mines

Ruhr Basin 2006 & 2007



# Sampling abandoned mines



**Depth 700-800 m**

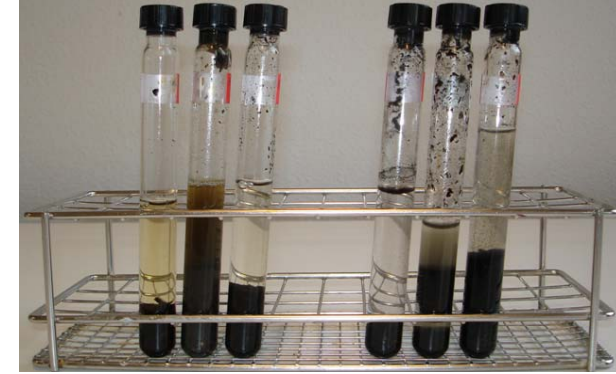


**37 to 40 °C**

**Humidity 100 %**

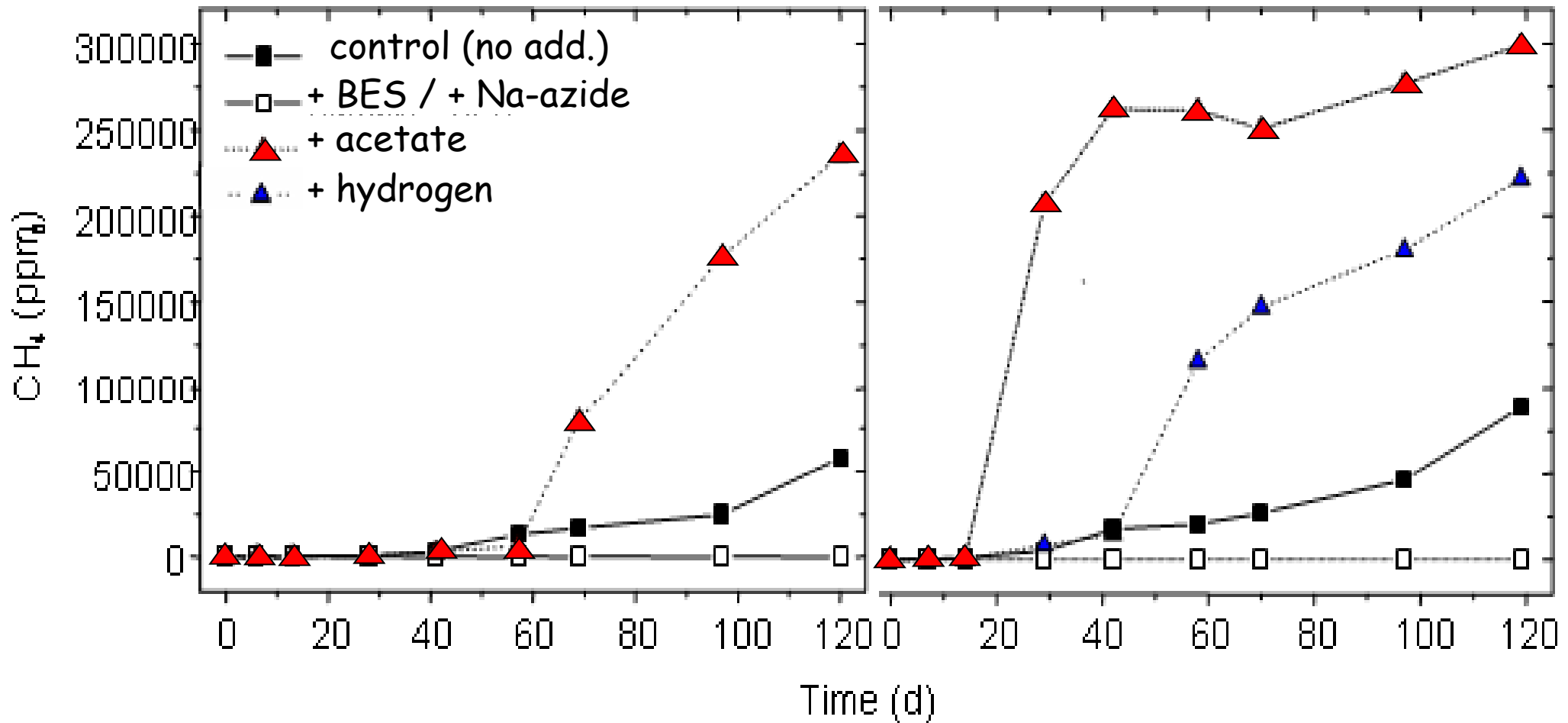


# Methane production in vitro



hard coal

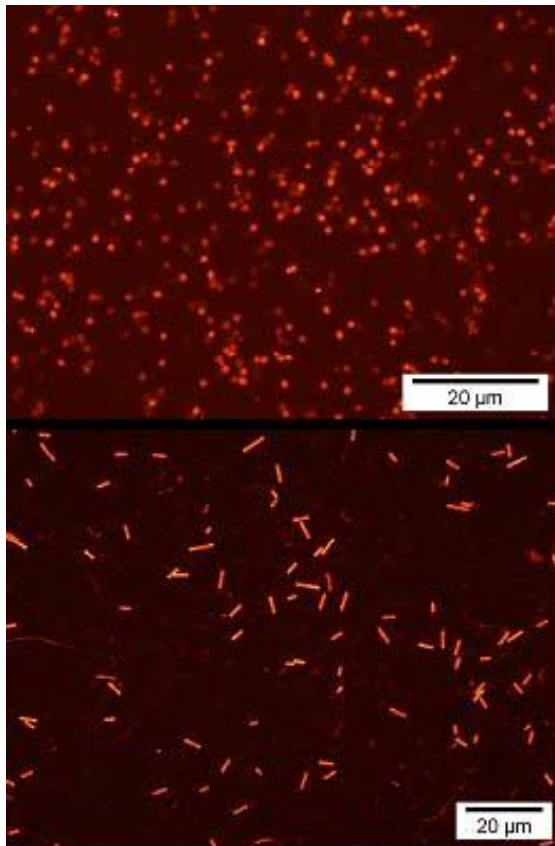
mine timber



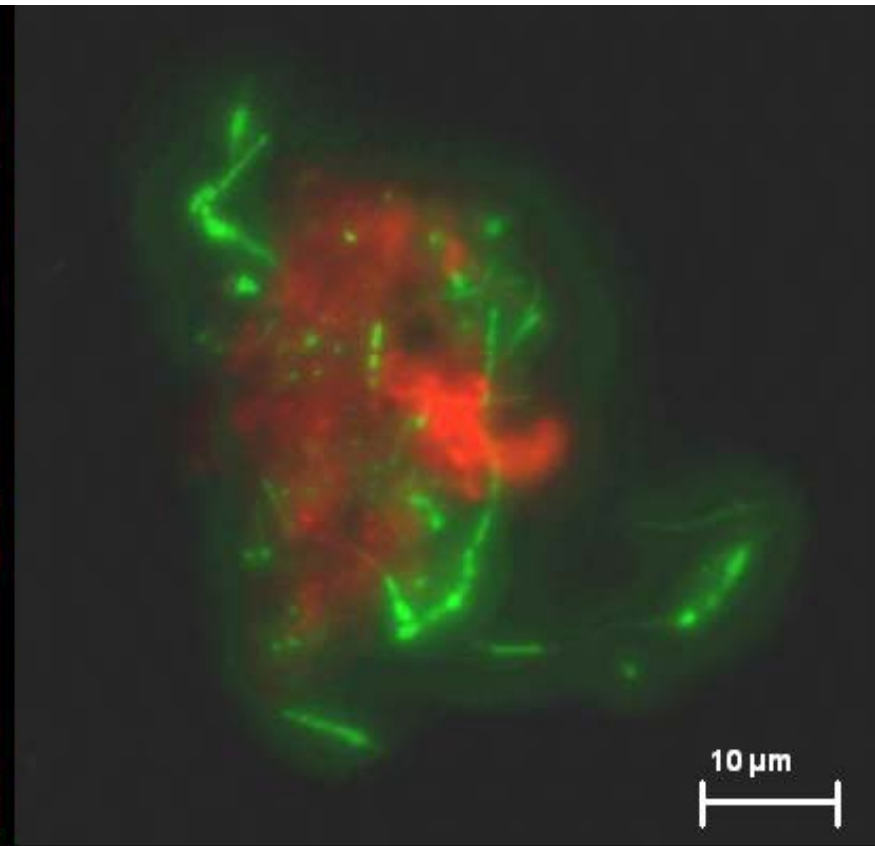
# Detection of methanogenic Archaea

Methanogenic Archaea FISHed from coal

Enrichments



In situ on coal particle



Agar shakes

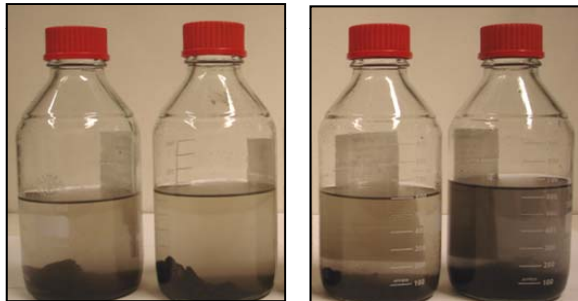


# Stable Isotope Probing

Long-term incubation

Coal

Timber



+

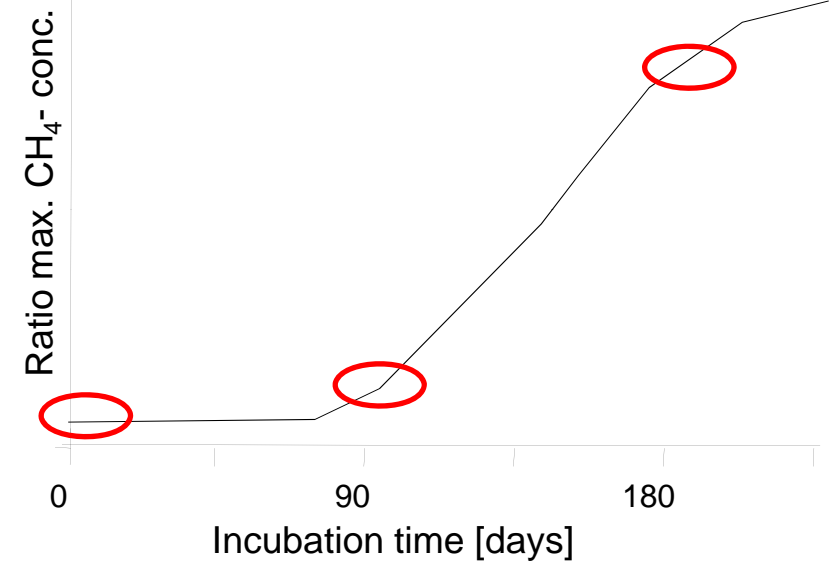
<sup>13</sup>C-labelled

H<sub>2</sub>+CO<sub>2</sub>

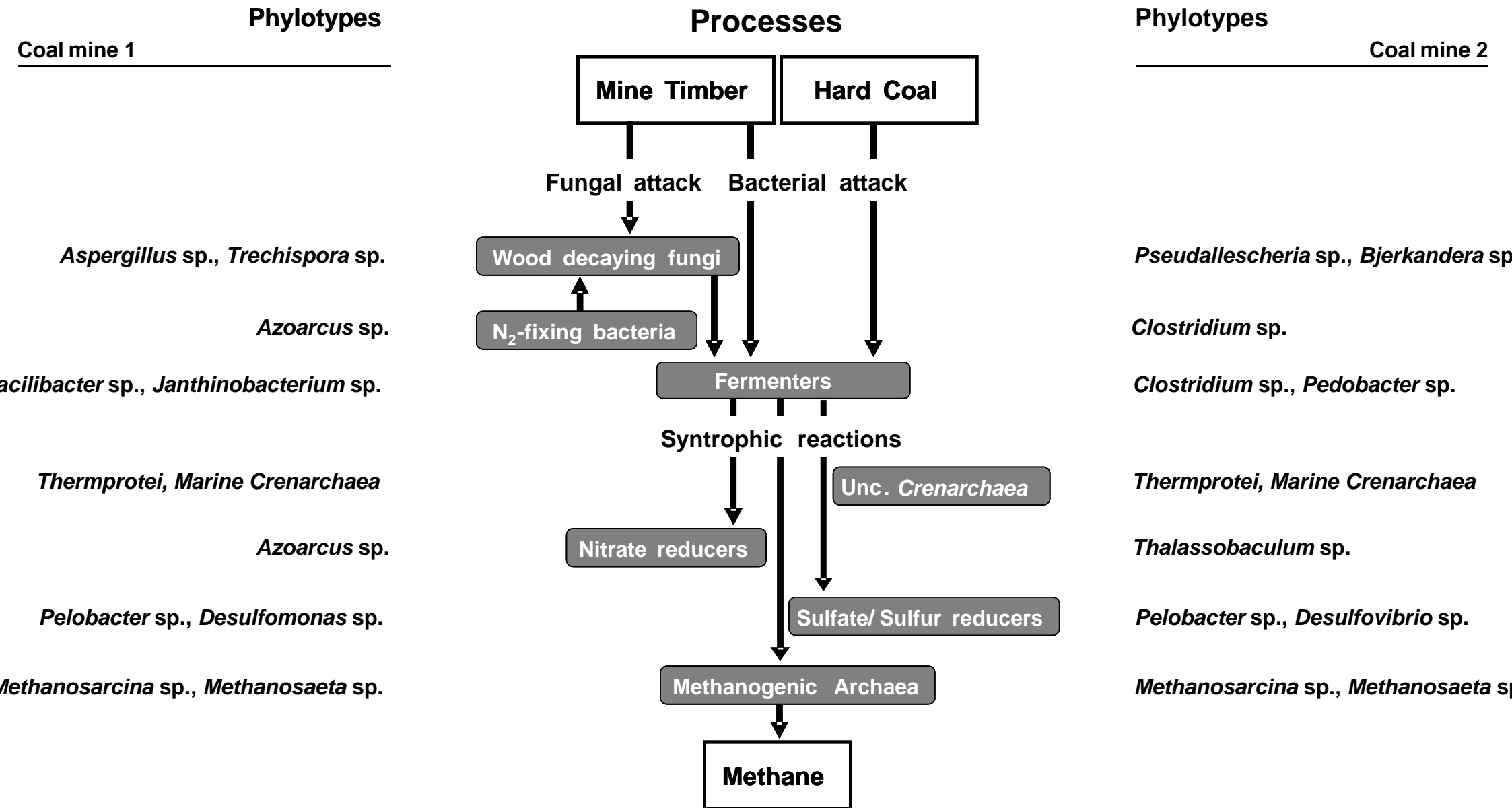
Acetate

Hexadecane

Sampling of RNA/DNA



# Proposed degradation scheme



# Methane from oil

# Methanogenic enrichments

|                        | Hexadecane | Oil light | Oil heavy | Ethyl-<br>benzene | Methyl-<br>naphtaline | Butane | Benzene |
|------------------------|------------|-----------|-----------|-------------------|-----------------------|--------|---------|
| Plußsee                | +          | +         | +         | +                 | +                     |        |         |
| Eckernförde Bay        | +          | +         |           |                   | +                     |        |         |
| Freshwater ditch       | +          | +         | +         | +                 |                       |        |         |
| Mangroves              | +          | +         |           | +                 | +                     |        | +       |
| Oil reservoirs         | +          | +         | +         | +                 | +                     |        |         |
| Gulf of Mexico         | +          | +         | +         |                   |                       | +      |         |
| Mud vulcano Rumania*   | +          |           |           |                   | +                     |        | +       |
| Mud VulcanoAzerbaijan* | +          |           |           |                   | +                     |        | +       |
| Gölsau (Aquifer) **    | +          | +         |           |                   |                       | +      |         |
| Coal mines             | +          | +         | +         |                   |                       |        |         |
| Gas fields             | +          | +         | +         |                   |                       |        |         |

(\*) with F. Musat, MPI Bremen

(\*\*) with H. Richnow, UFZ Leipzig

# Activity

## $^{12}\text{C} / ^{13}\text{C}$ – substrate-experiments

> Enrichments with several substrates: Alkanes, BTEX, PAHs

> Incubations of oil reservoir enrichment show **hexadecane- $^{13}\text{C}_{16}$**  conversion into methane

|       |  |                  |           |
|-------|--|------------------|-----------|
| T=0   | -45.9 ‰  | (CO <sub>2</sub> | -17.4 ‰)  |
| T=95d | -37.9 ‰ (with $^{12}\text{C-C}_{16}$ )         | (CO <sub>2</sub> | -6.5 ‰)   |
| T=95d | <b>+15147 ‰</b> (with $^{13}\text{C-C}_{16}$ ) | (CO <sub>2</sub> | +16740 ‰) |

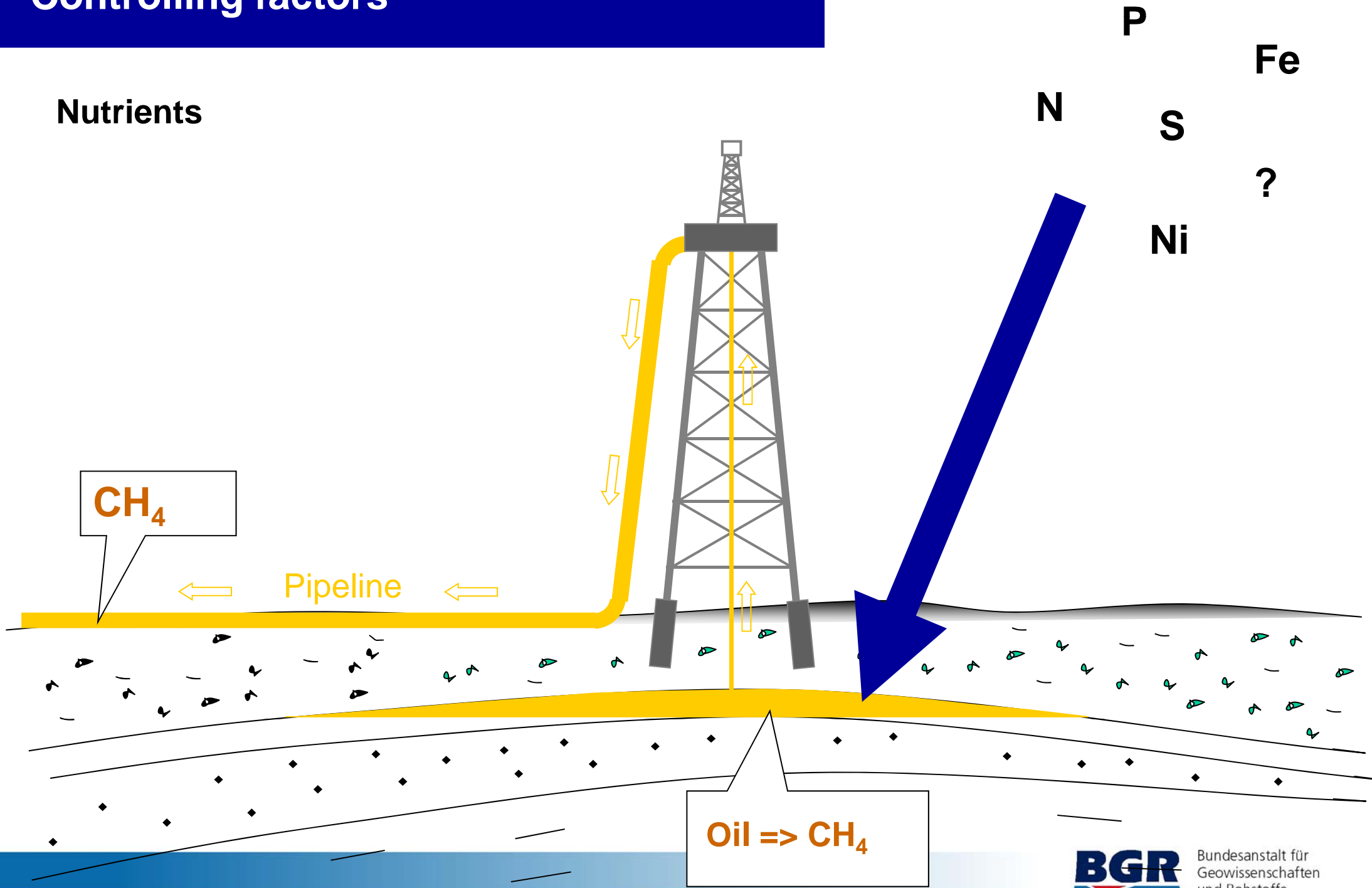
> Incubations of mangrove enrichment show **benzene- $^{13}\text{C}_1$**  conversion into methane

|        |  |                  |          |
|--------|--|------------------|----------|
| T=0    | -52.2 ‰  | (CO <sub>2</sub> | -9.4 ‰)  |
| T=195d | -50.6‰ (with $^{12}\text{C-C}_6\text{H}_6$ )           | (CO <sub>2</sub> | -10.4‰)  |
| T=195d | <b>+1754.4 ‰</b> (with $^{13}\text{C-C}_6\text{H}_6$ ) | (CO <sub>2</sub> | +30.3 ‰) |

(same with ethylbenzene, methyl-naphtalene, naphtalene....)

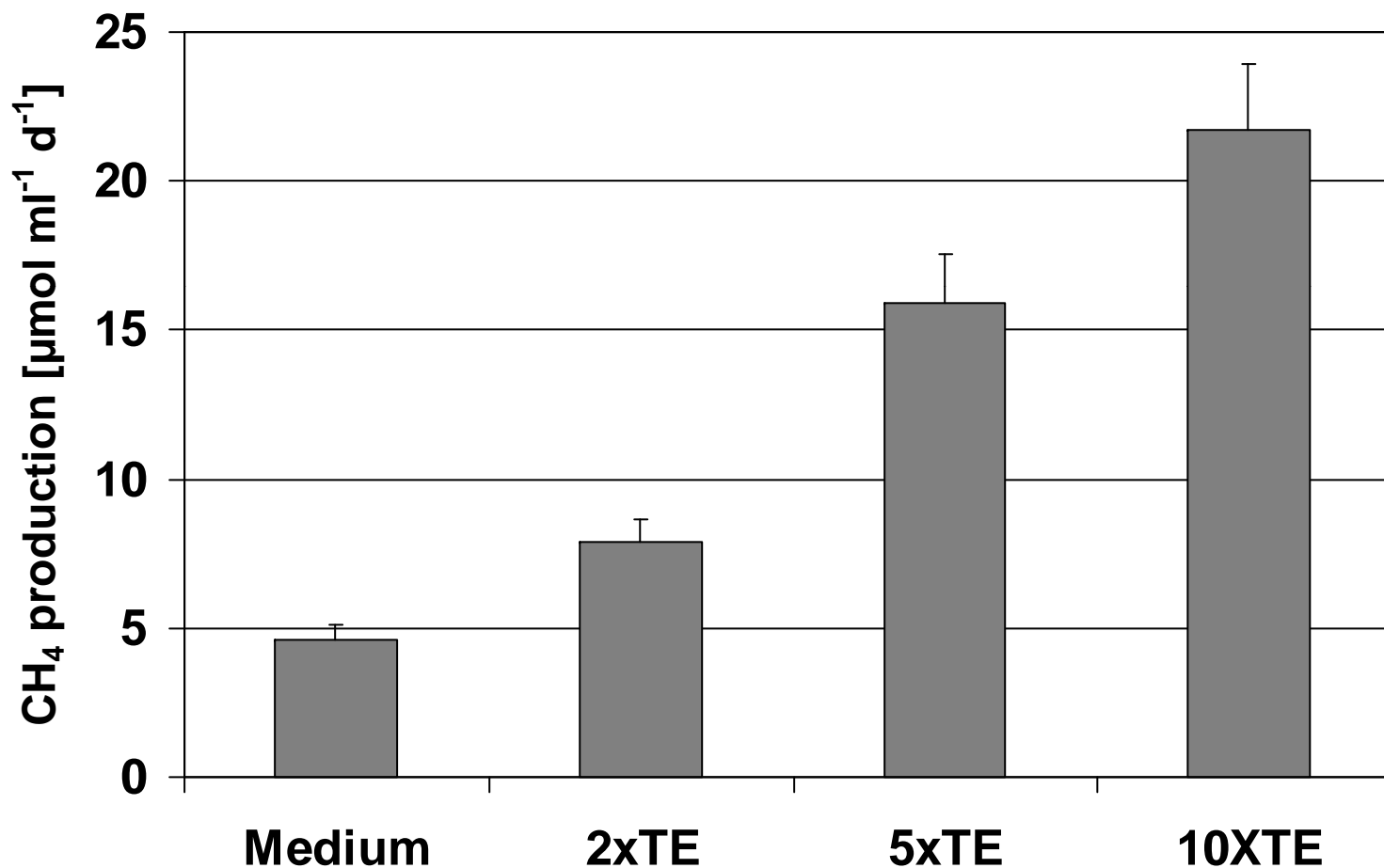
# Controlling factors

Nutrients



# Controlling factors

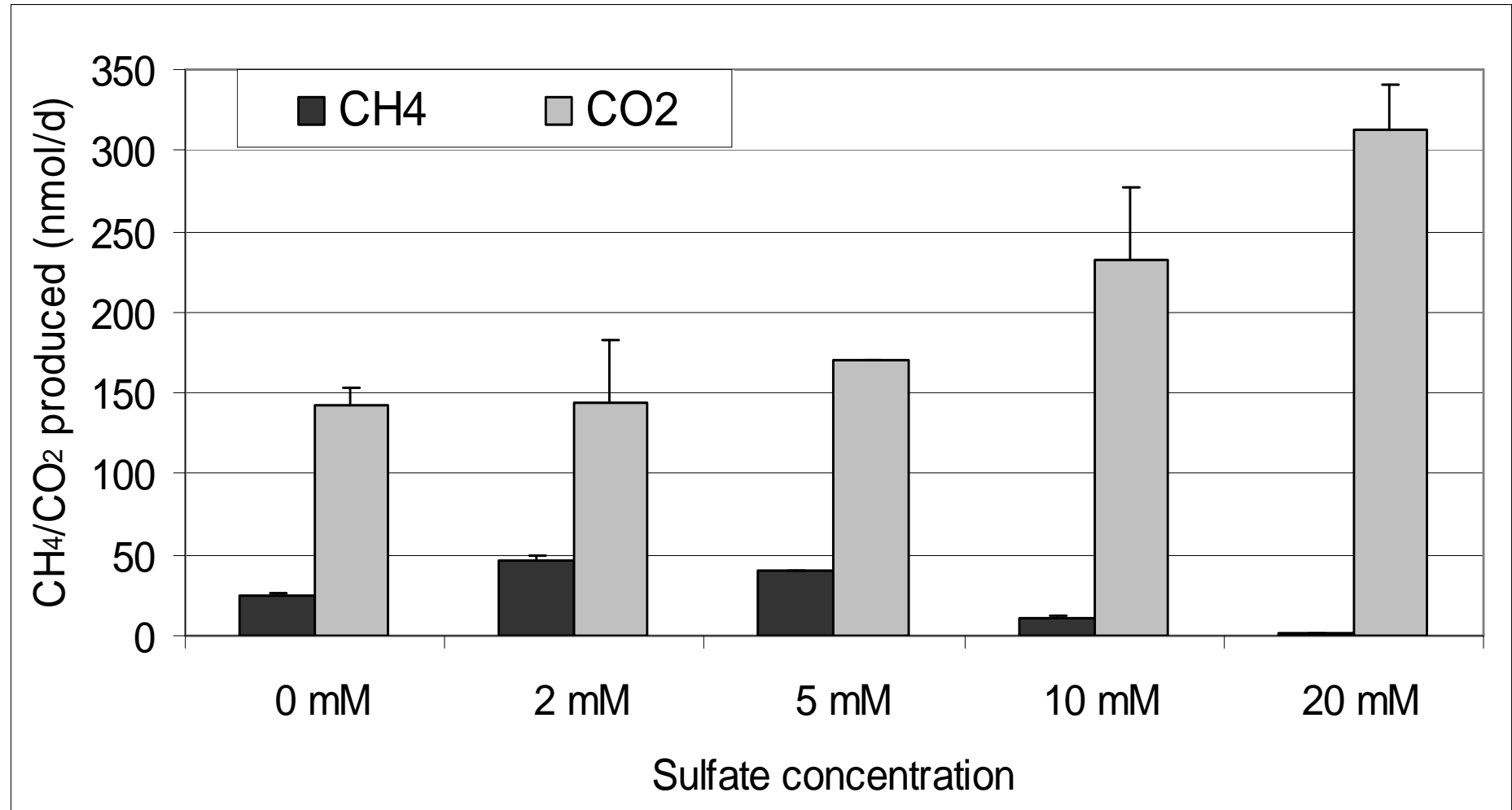
Addition of varying amounts of trace elements



**=> Simple & cheap tools to accelerate methanogenesis in reservoirs**

# Controlling factors

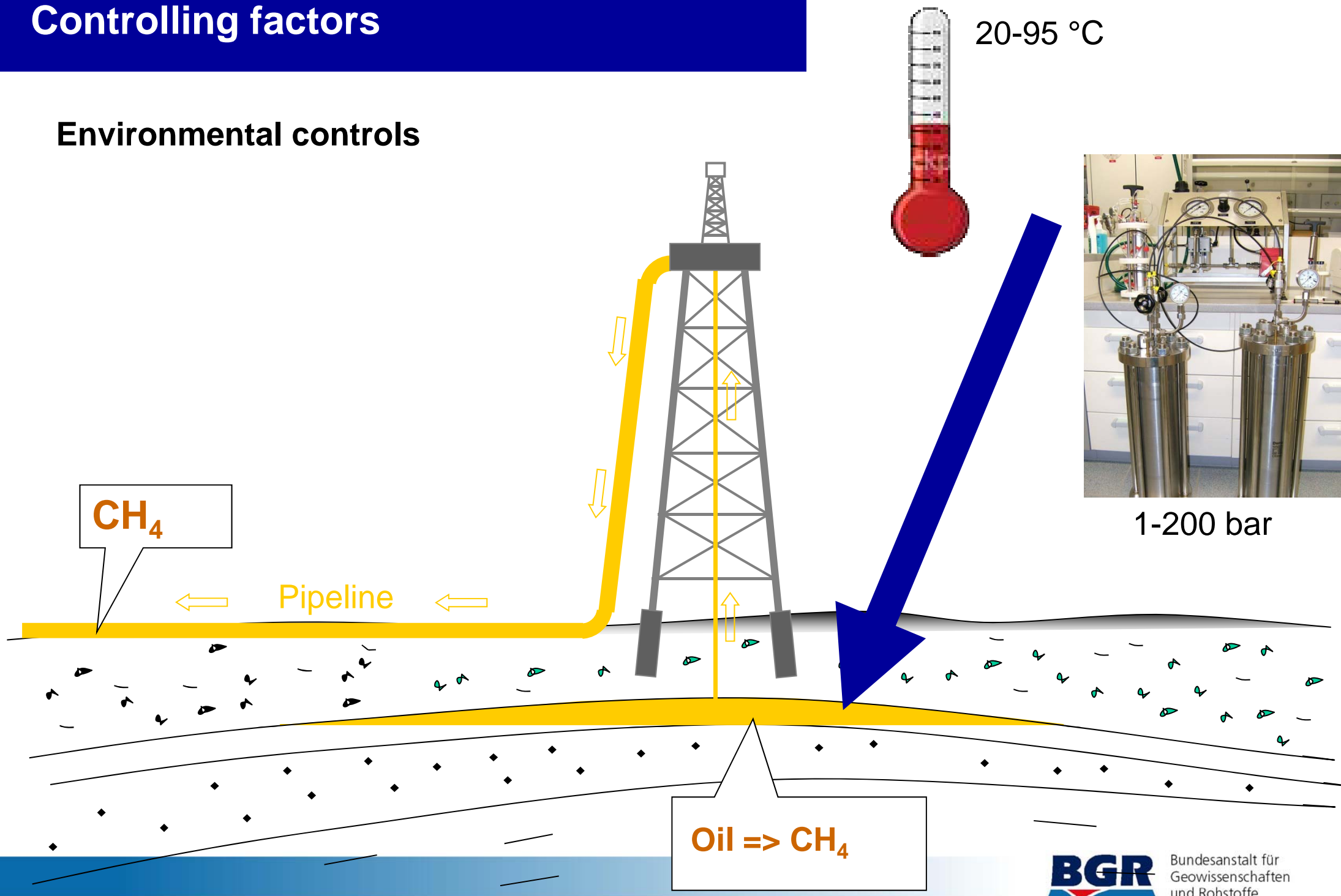
## Mechanistic experiments



=> Similar beneficial effects of low Fe- and Mn-oxide concentrations, but not of nitrate

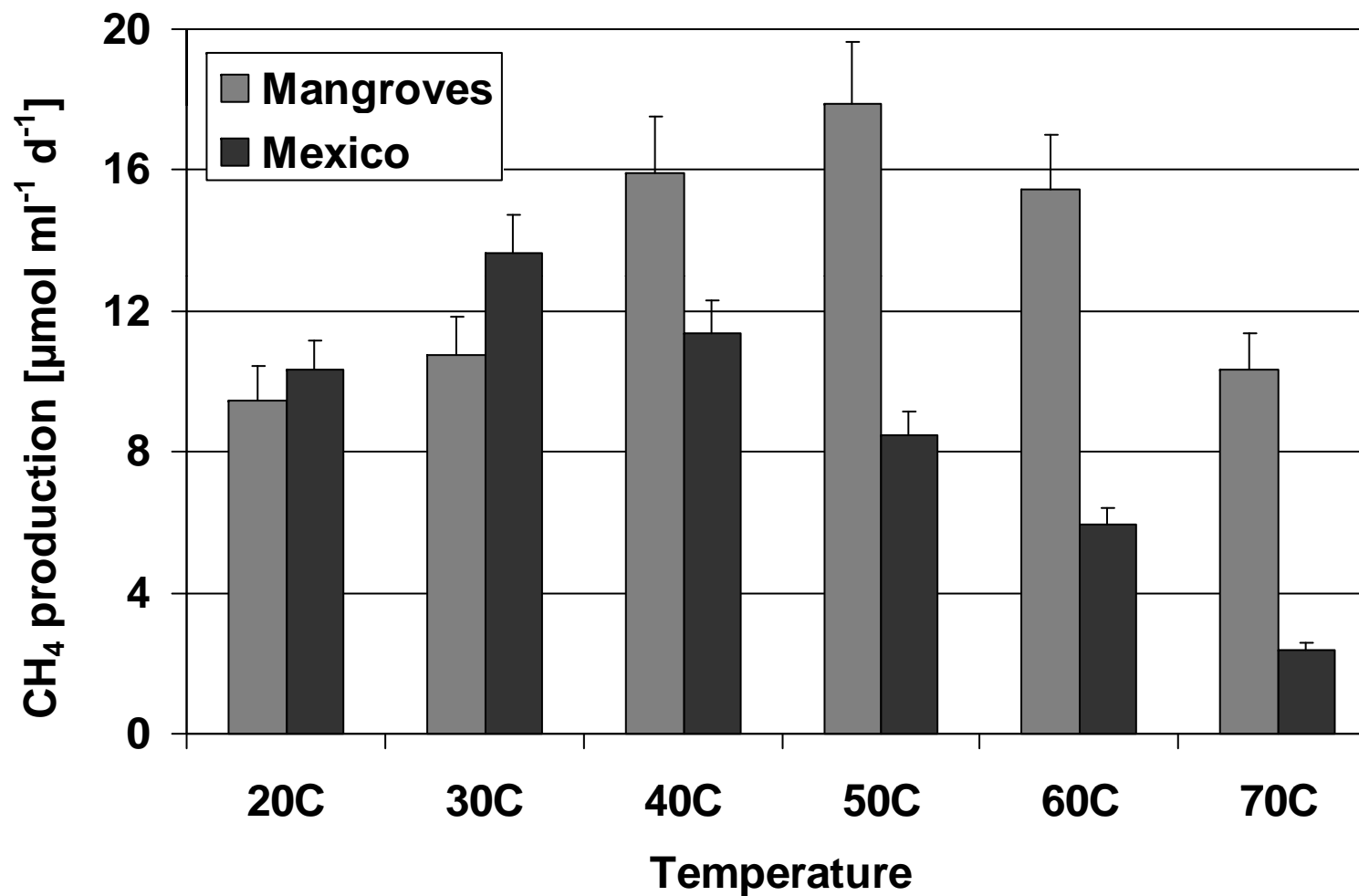
# Controlling factors

## Environmental controls



# Controlling factors

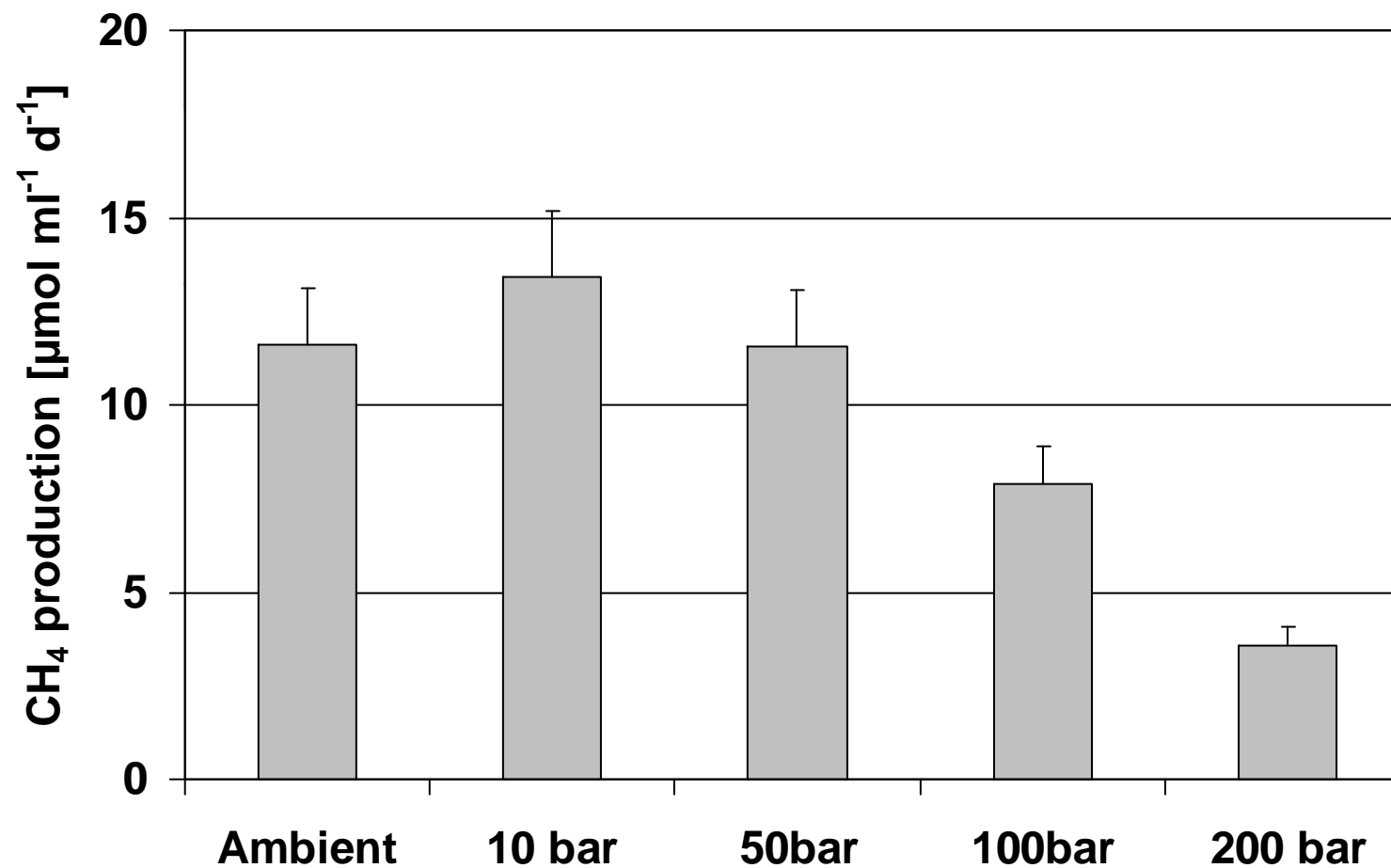
Identification of temperature optima for hexadecane degradation



situ: mangroves 35°C, Gulf of Mexico 12°C

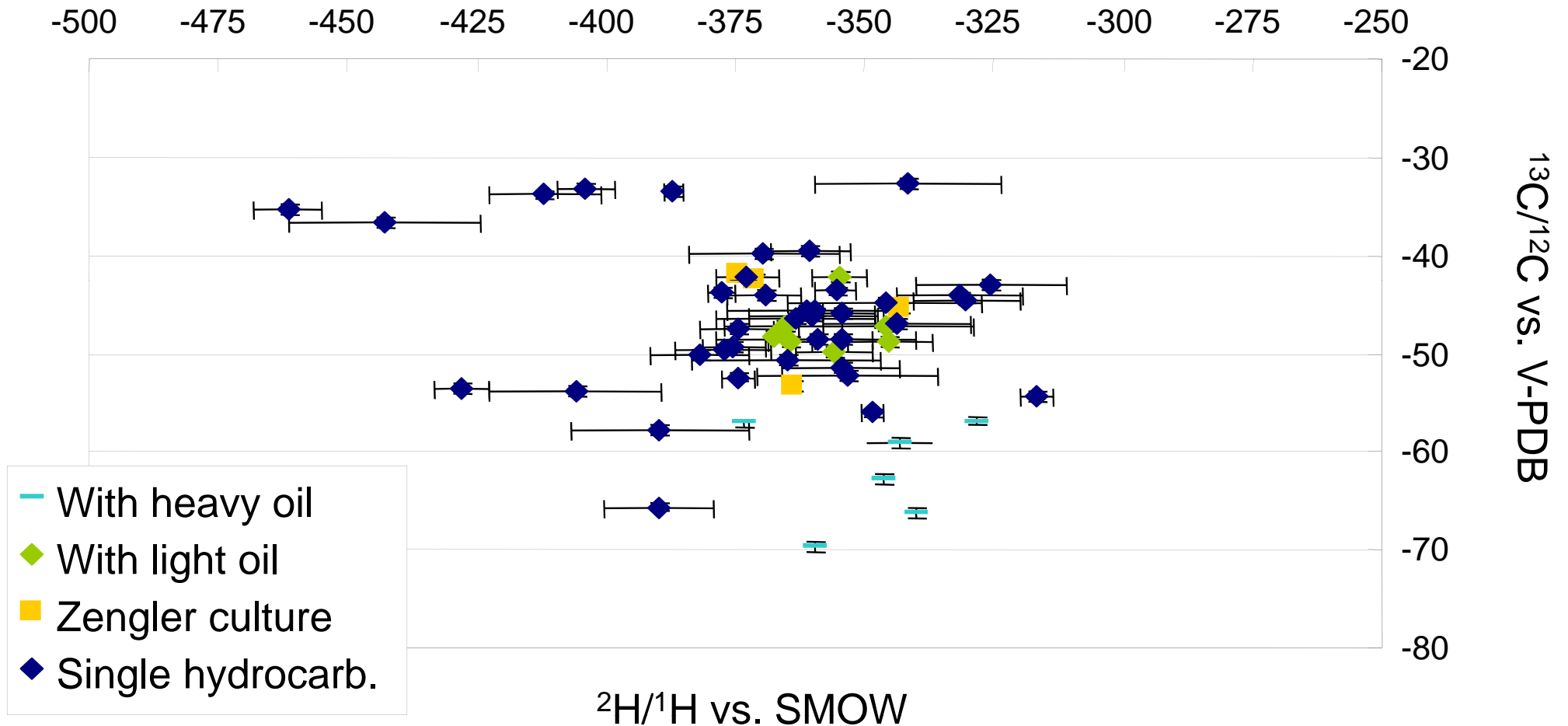
# Controlling factors

Effects of increasing incubation pressures (+hexadecane)



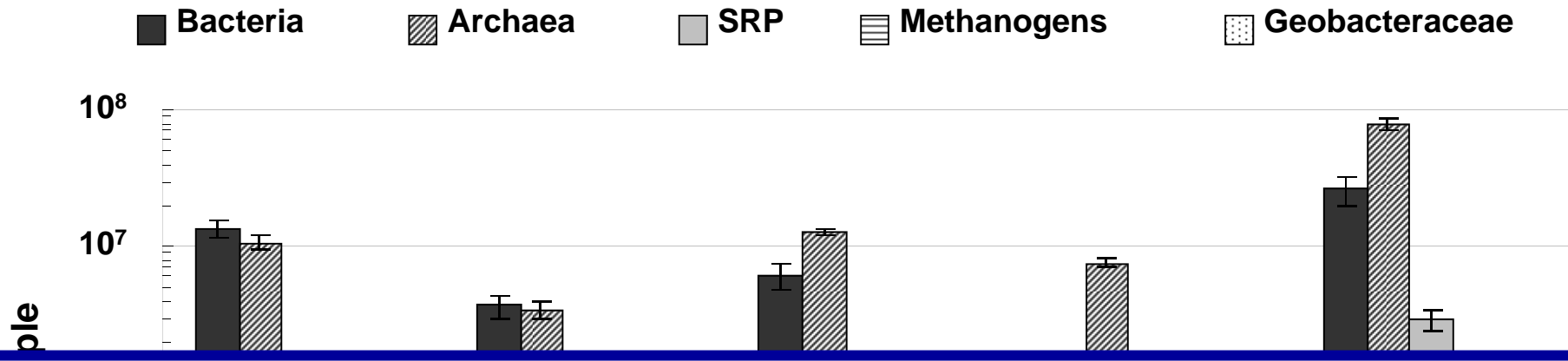
**=> Process also functioning at reservoir P & T conditions**

## Hydrogen- vs. carbon isotopy of methane

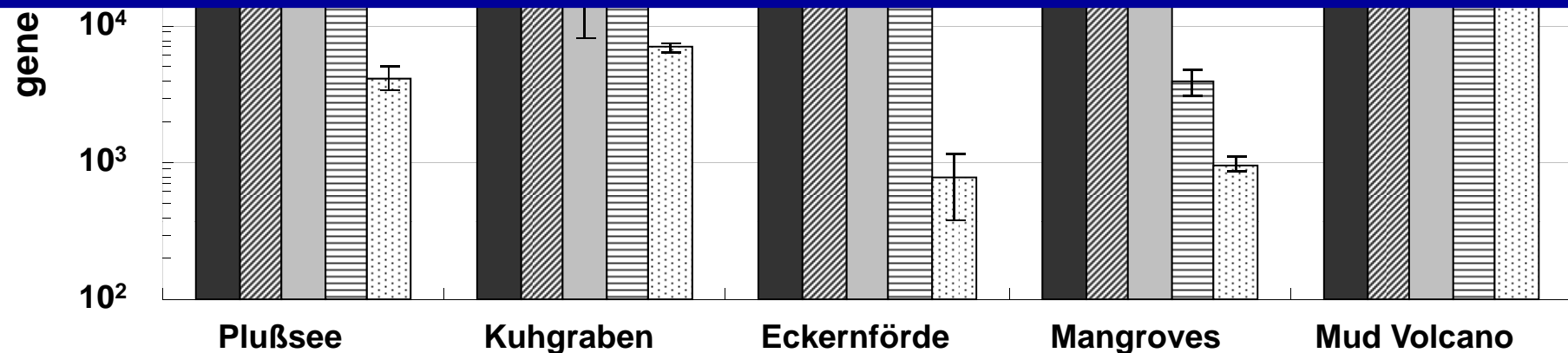


=> Exploration tool to identify candidate reservoirs

# Methanogenic enrichments



- MG, SRP and Geobacteraceae seem to be involved in hexadecane degradation
- Enrichments from different sites show similar quantitative community composition
- Addition of different substrates results in similar quantitative community composition



# Summary

- Microbial conversion of a broad range of oils and coals to methane
- Enrichment cultures on alkanes and aromatic compounds
- Adapted to reservoir conditions (high P & T, salinity)
- Isotopes of methane provide exploration tool for reservoir selection
- Controlling influence of nutrient availability => in situ stimulation?

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