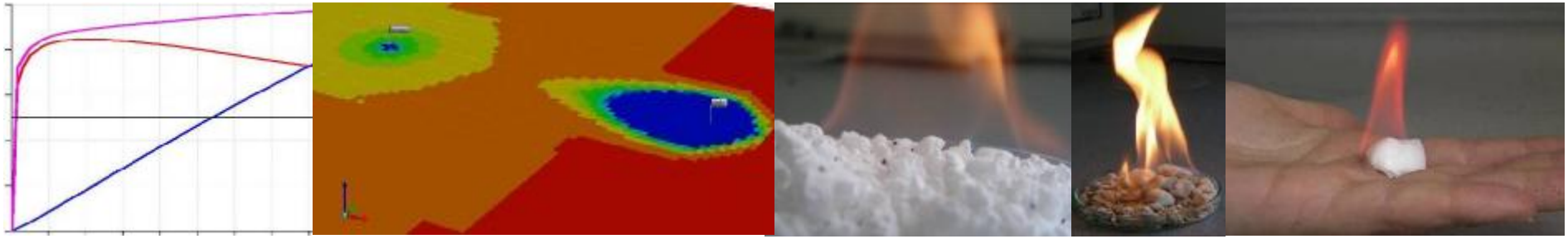
# Simulation of submarine gas hydrate deposits as a sustainable energy source and $CO_2$ storage

Georg Janicki, Torsten Hennig, Stefan Schlüter, Görge Deerberg



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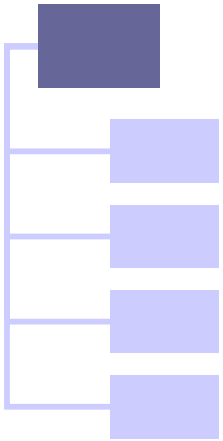
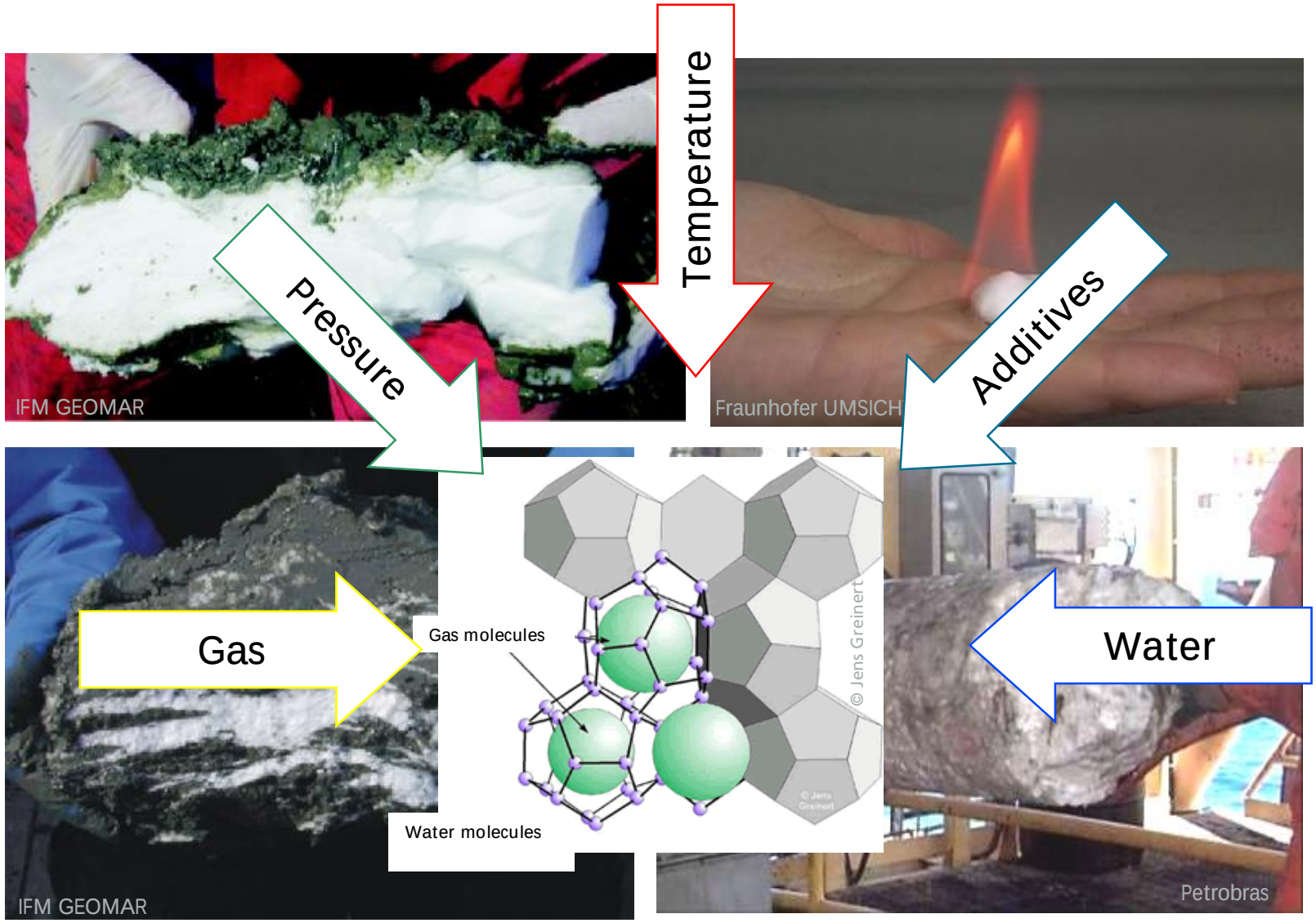
# Outline



- Introduction and background
- Project SUGAR:
  Numerical simulation of hydrate exploitation
- Modeling of hydrates in subsea deposits
- Simulation results
- Summary and conclusions

# What are gas hydrates?



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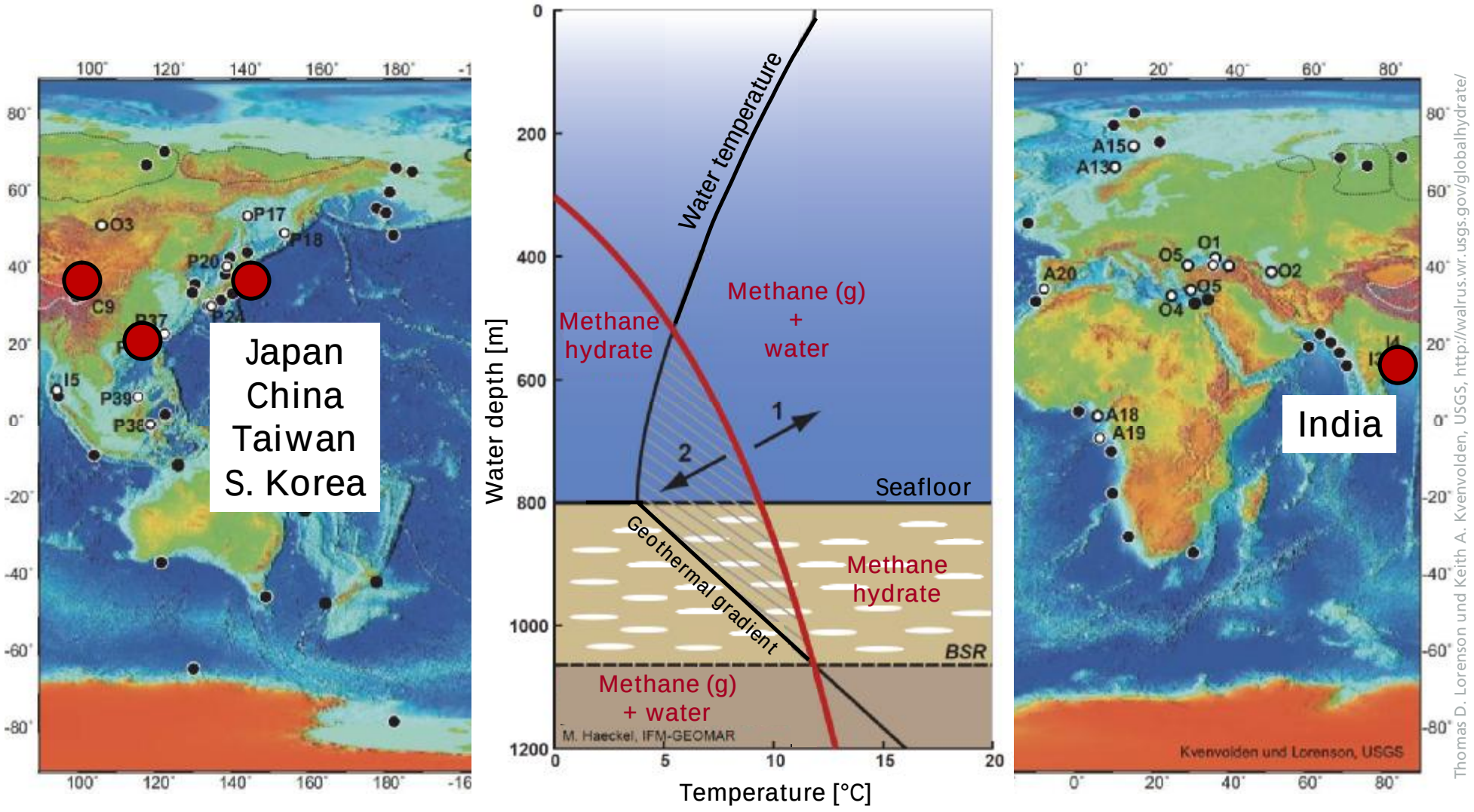
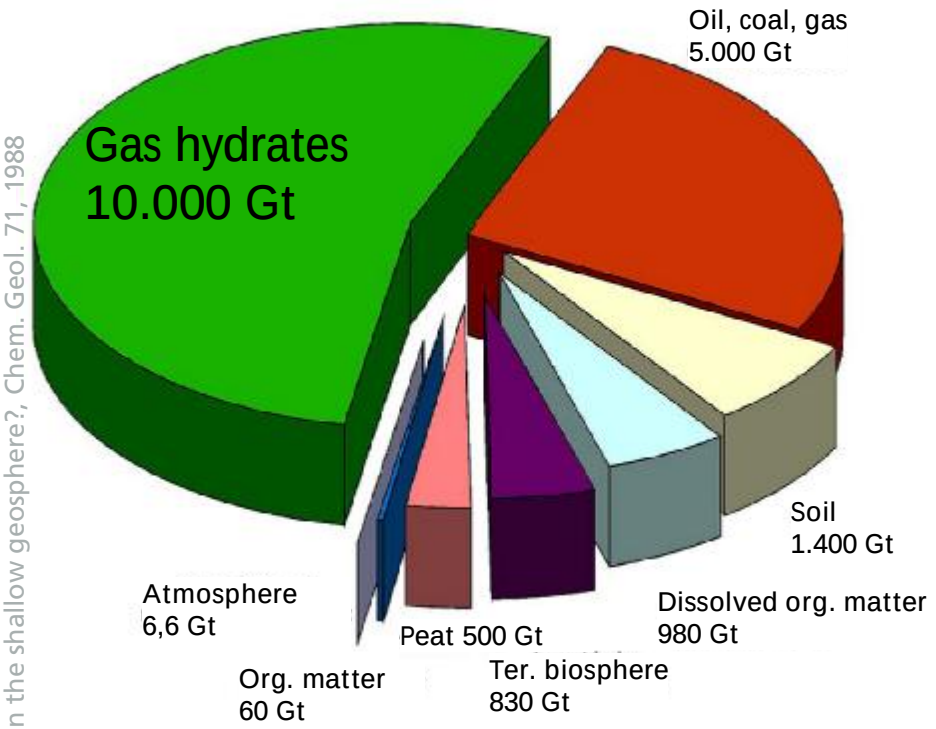
# Where you can find hydrates?



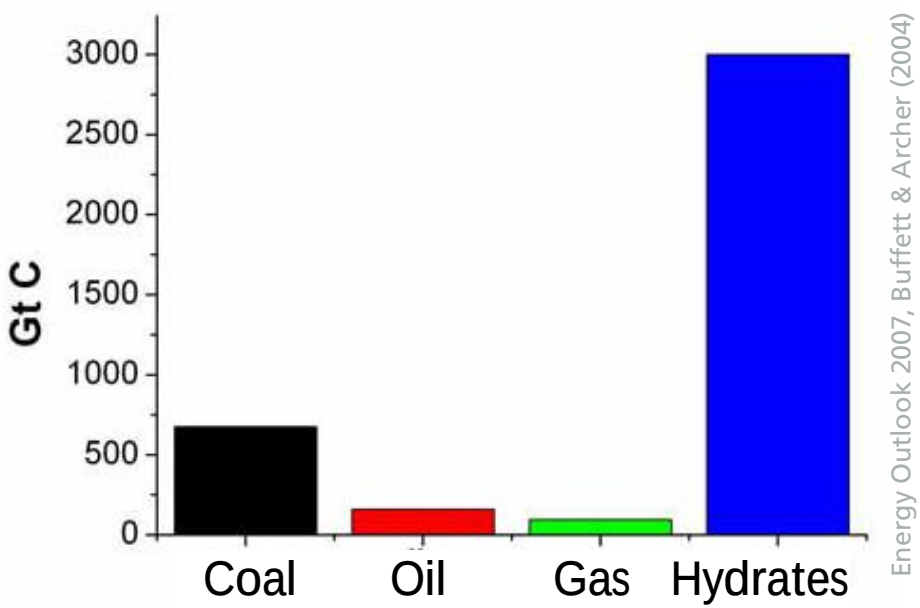
# Gas hydrates and carbon matter

## Gas hydrates and carbon matter




Keith A. Kvenvolden, Methane hydrate – A major reservoir of carbon in the shallow geosphere?, Chem. Geol. 71, 1988

## fossil fuel reserves and submarine gas hydrates




Energy Outlook 2007, Buffett & Archer (2004)



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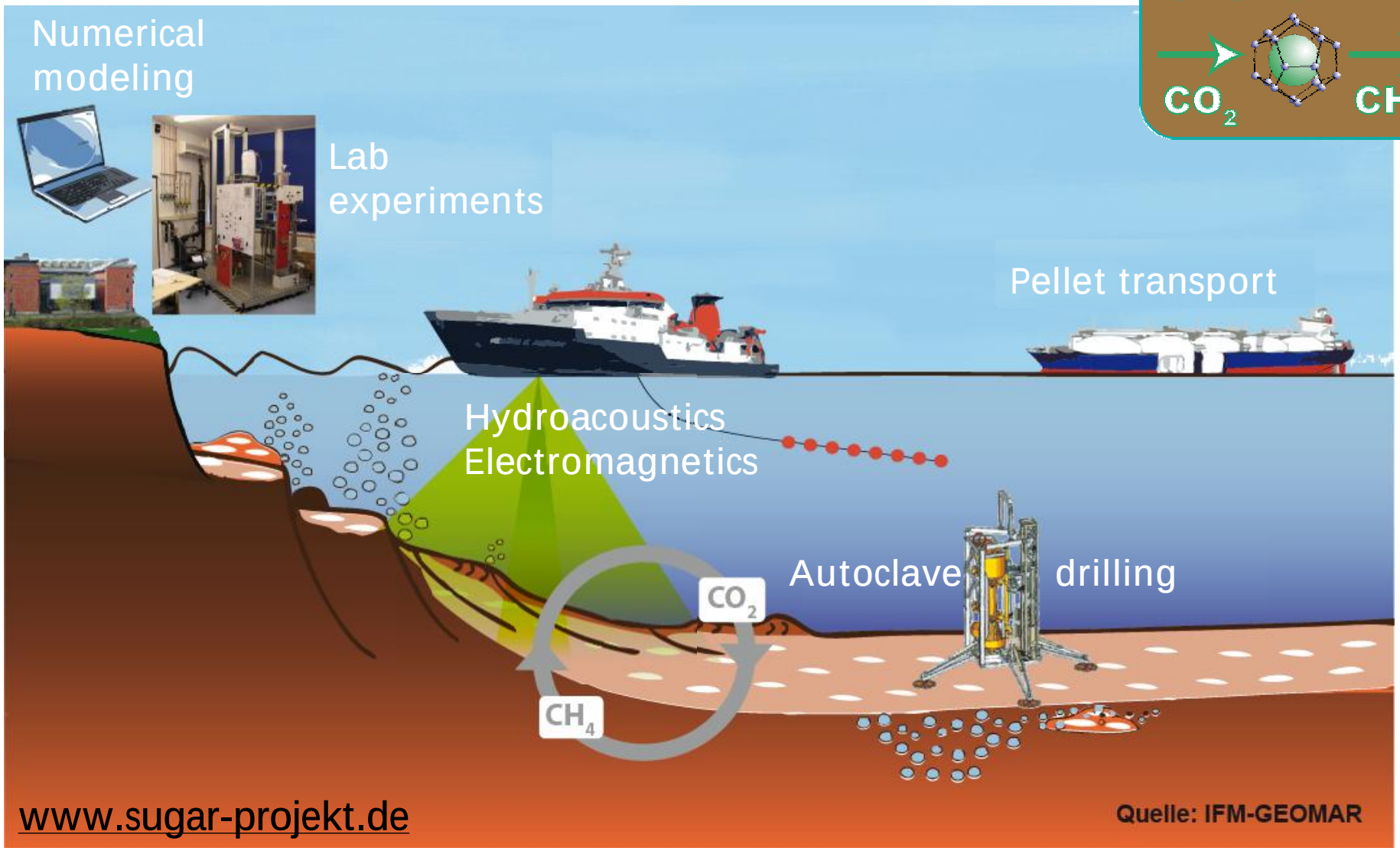
# »SUGAR« Submarine Gas Hydrate Reservoirs

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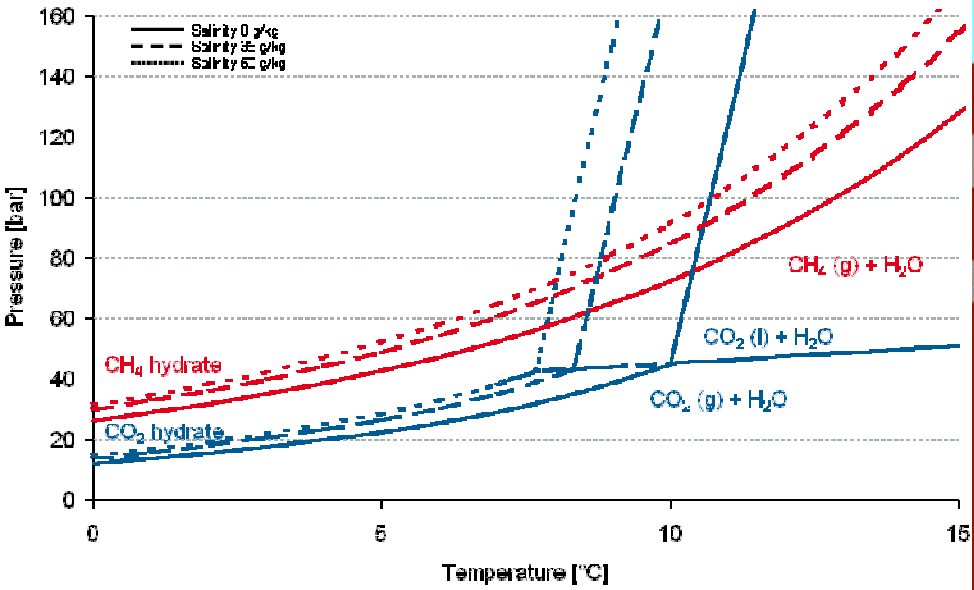
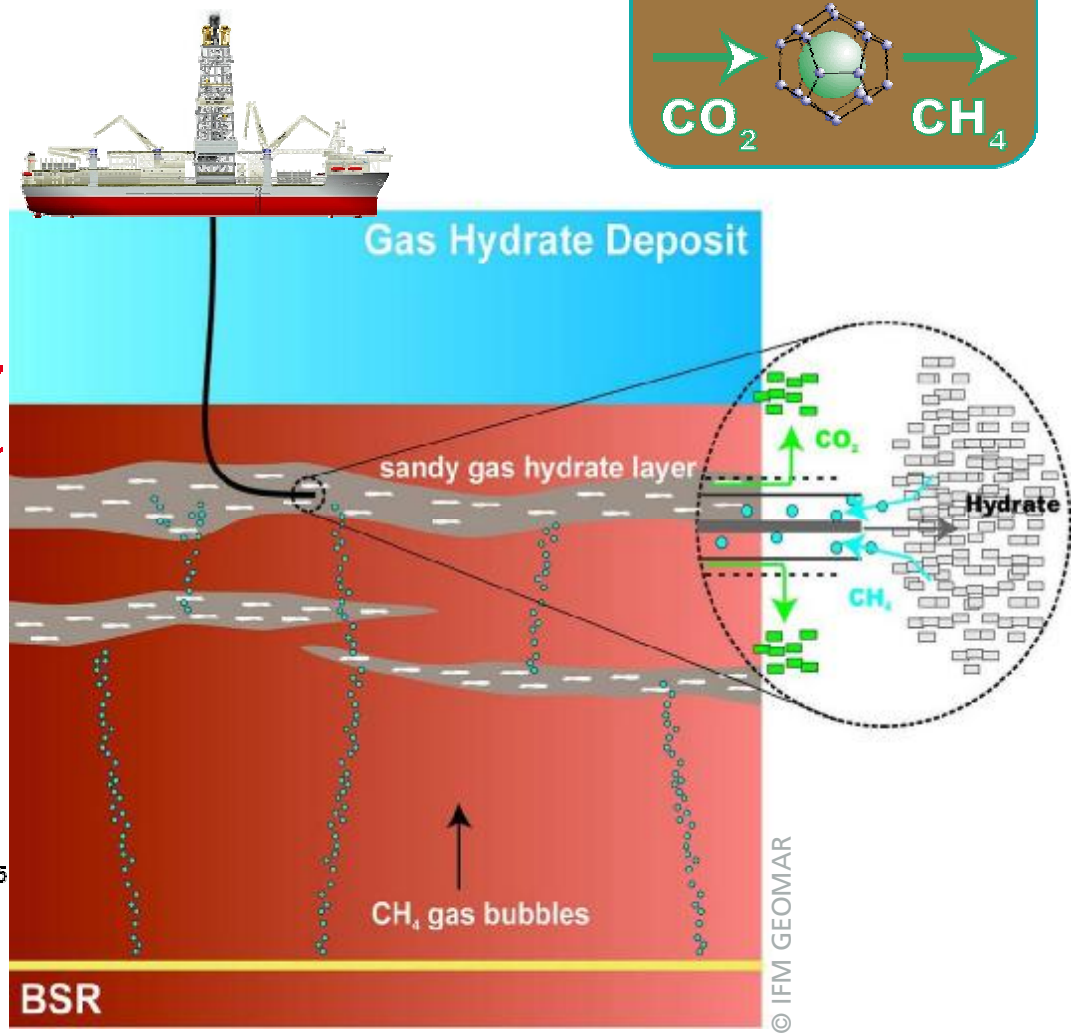
# Principle and target of SUGAR



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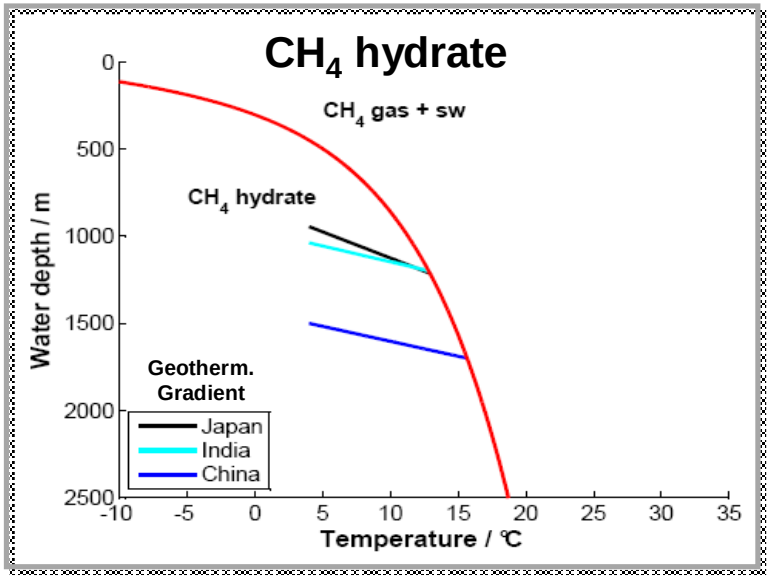
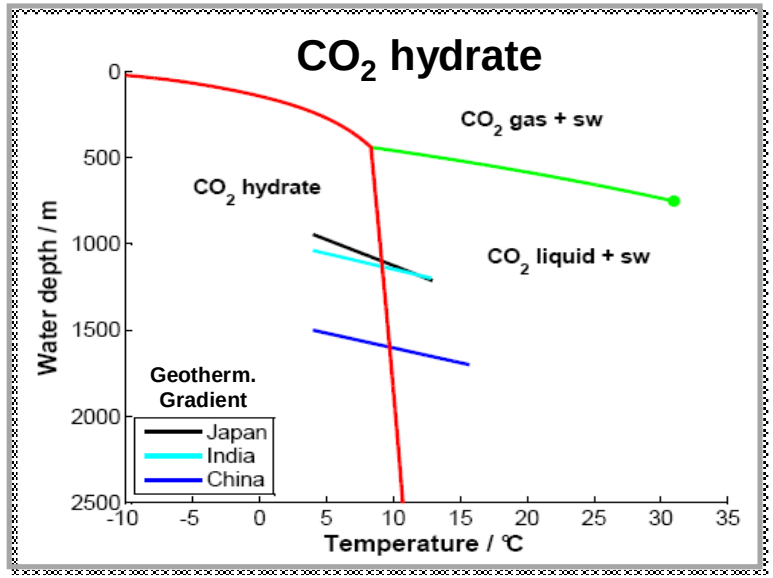
# Modeling of gas hydrate deposits






| Parameter | Japan (Nankai) | China (Shenhu) | India (K-G basin) |
|---|---|---|---|
| Water depth | 945 m | 1500 m | 1038 m |
| Geology of hydrate layer | Turbidite | clay | shale |
| Geothermal gradient | 32.9 K/km | 58.4 K/km | 55.1 K/km |
| BSR depth ($CH_4$ HSZ) | 270 m | 200 m | 160 m |
| Thickness of hydrate layer | 80 m | 10-25 m | 135 m |
| Hydrate saturation | 40-60% | 25-50% | 50-80% |
| Porosity | 0.4-0.5 | 0.5-0.75 | 0.6-0.8 |
| $CO_2$ HSZ | 154 m | 98 m | 94 m |
| Viscosity $CO_2$ | $1.0*10^{-4}$ Pa s | $1.1*10^{-4}$ Pa s | $1.0*10^{-4}$ Pa s |
| Heat conductivity of reservoir | 1.9 W/K/m | 1.3 W/K/m | 1.1 W/K/m |



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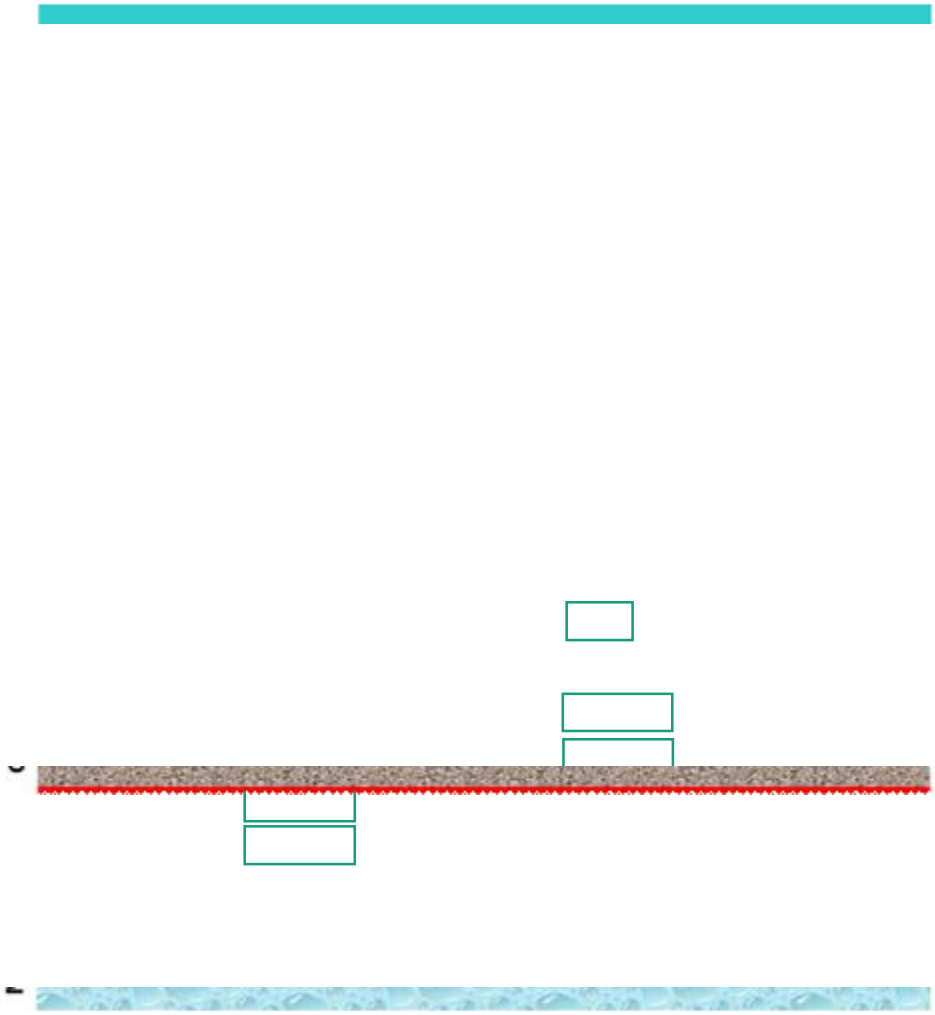
# Modeling of gas hydrate deposits





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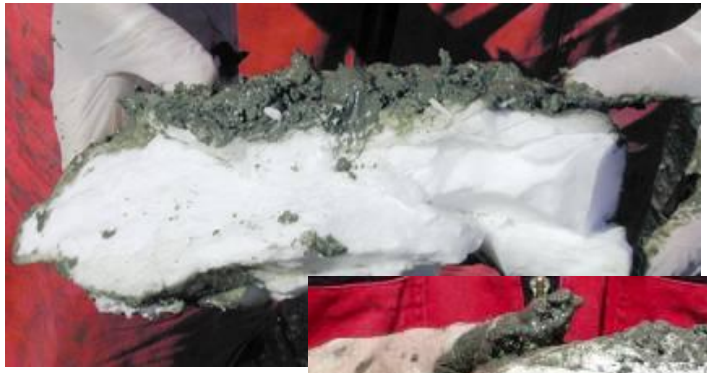
# Morphology of methane hydrates in nature

massive



In layers

dispersed in sediment

Photos © IFM GEOMAR



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# Fluid flow in sediments

Darcy's law of fluid flow : $u_a = -\frac{k_{rel,a}\, K_{abs}}{h_a}\left(\nabla P_a - g\, r_a\right)$

Absolute permeability (Carman-Kozeny)

$$K_{abs}(f_f) = K_0 \cdot \left[\frac{f_f}{f_f^0}\right]^k \cdot \left[\frac{1-f_f^0}{1-f_f}\right]^2$$

Influence of hydrate saturation on permeability

$f_f$ : Fluid porosity

$K_0$ = 10 mD (initial permeability at $S_H$=40%)

k = 0 … 10; here 5,8

Relative permeability (Brooks-Corey)

$$k_{rel,a} = k^0_{rel,a}\left(S^*_{a,e}\right)^{s_a}$$

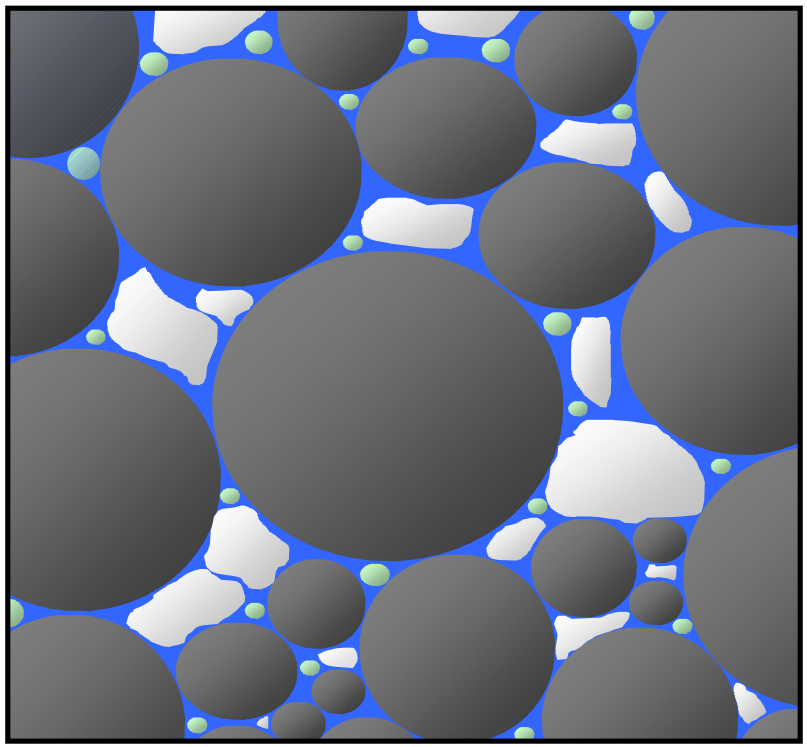
$$S^*_{G,e} = \frac{\frac{S_G}{S_G+S_L} - S^{eff}_{G,res}}{1 - S^{eff}_{G,res} - S^{eff}_{L,res}} \qquad S^*_{L,e} = \frac{\frac{S_L}{S_G+S_L} - S^{eff}_{L,res}}{1 - S^{eff}_{G,res} - S^{eff}_{L,res}}$$

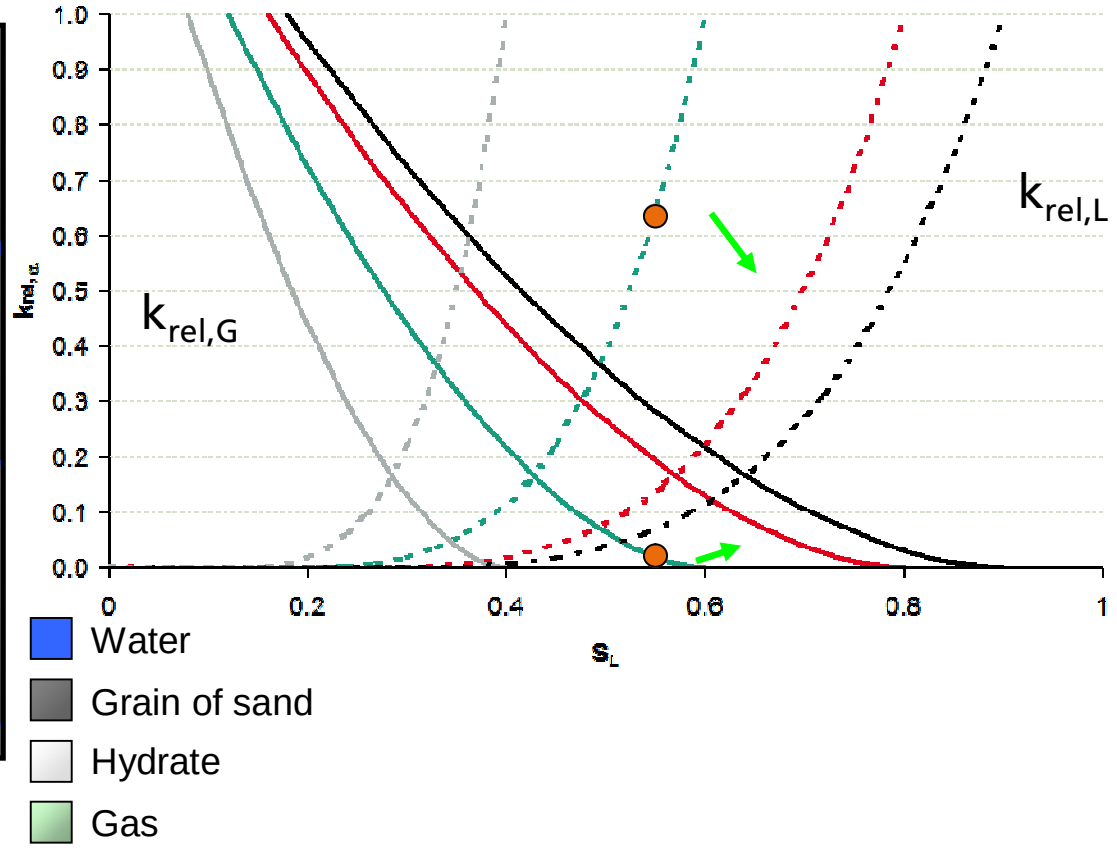
$k^0_{rel,a} = 1$

$s_G = 1{,}75; \quad s_L = 4$

$S^{eff}_{G,res} = 0; \quad S^{eff}_{L,res} = 0{,}2$

# Relative permeability





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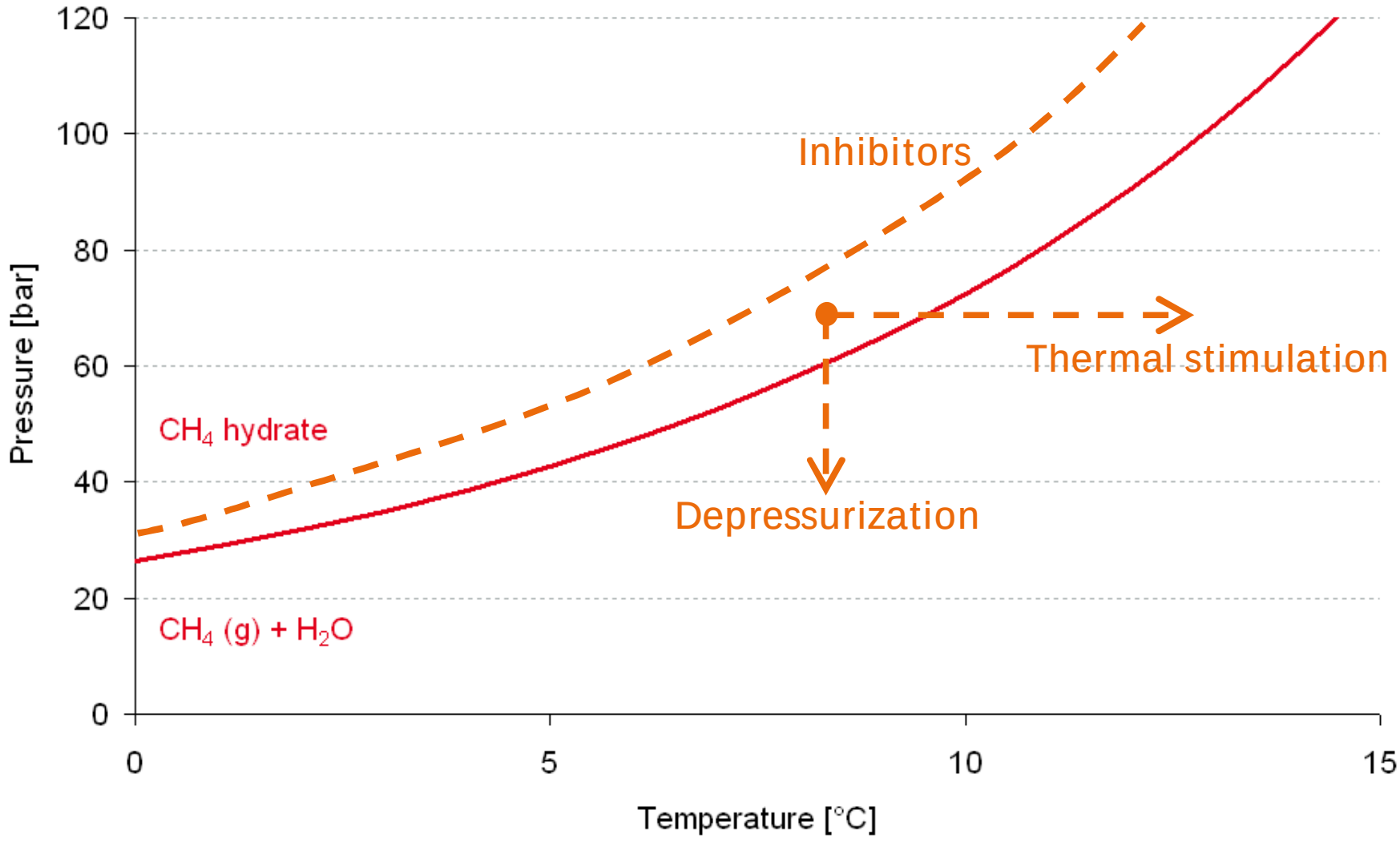
# Methods for gas hydrate decomposition



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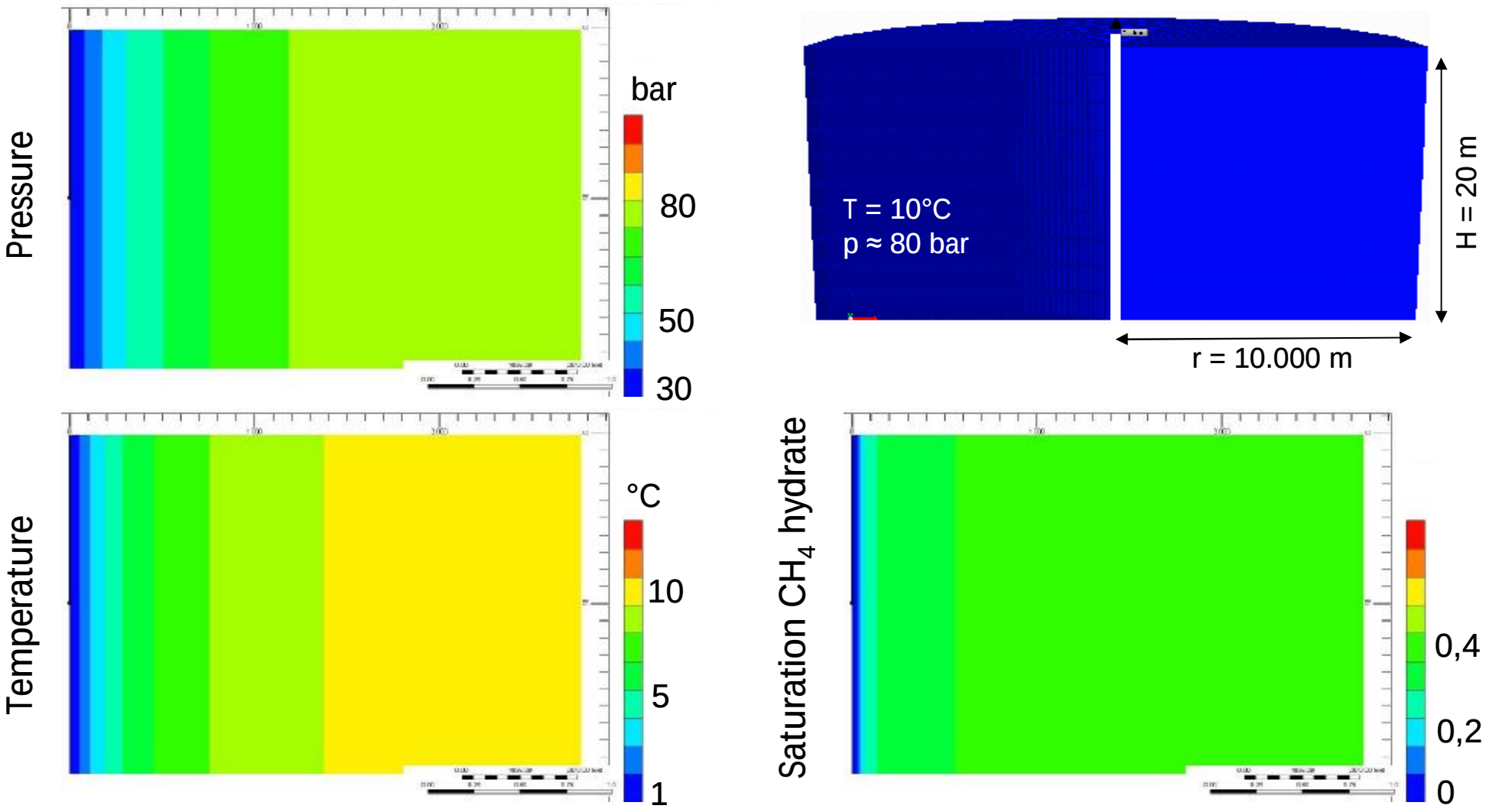
# Single hole – depressurization (1D)




t = 14 years

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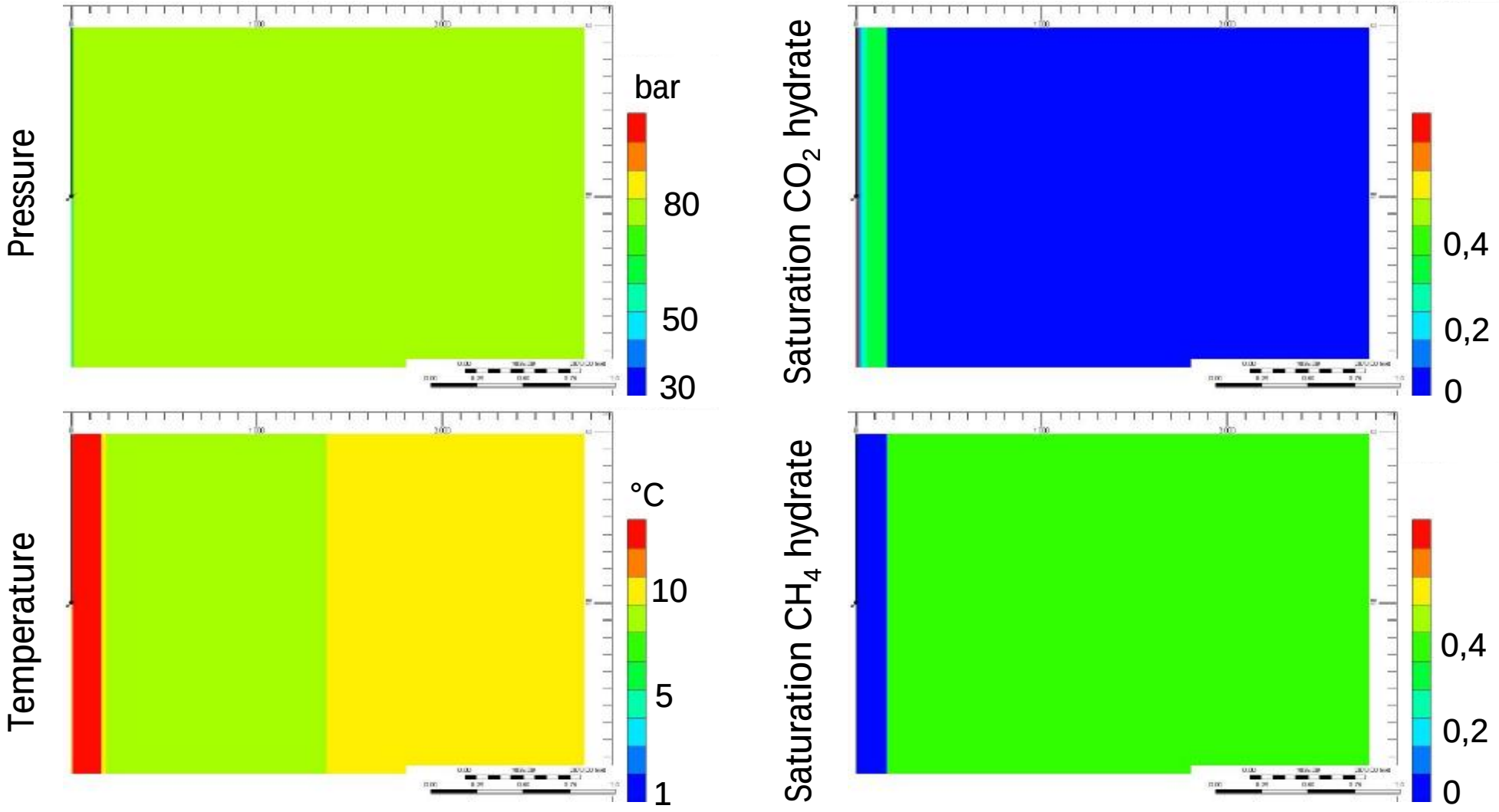
# Single hole – $CO_2$ injection after $CH_4$ production (1D)




t = 14 years



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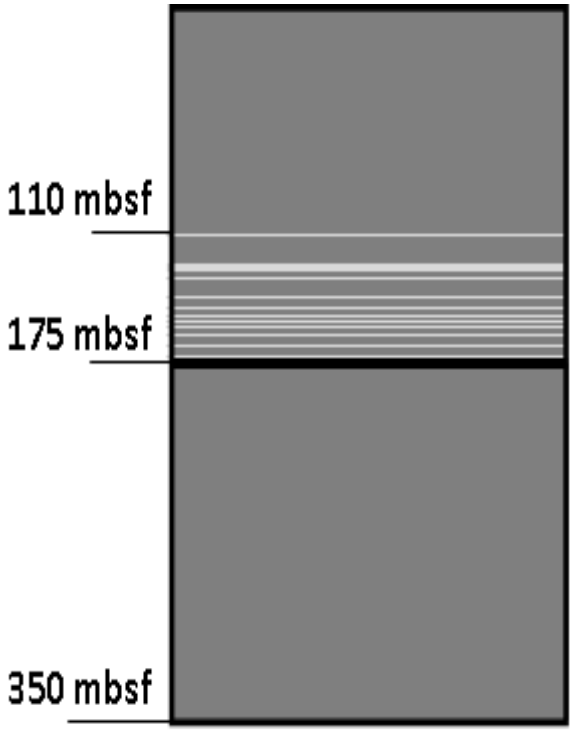
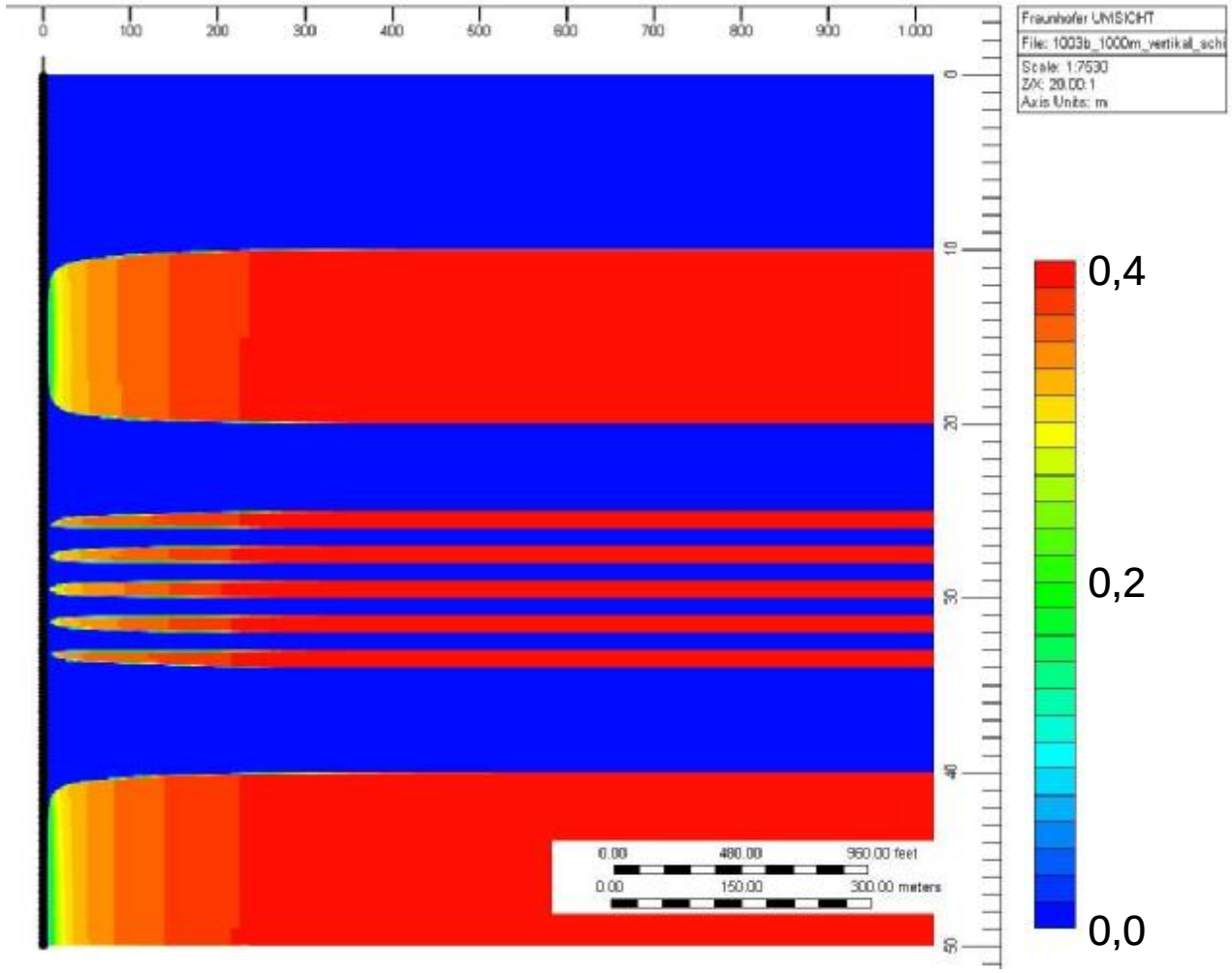
# Layered deposits
# Saturation $CH_4$ hydrate




Ulleung Basin

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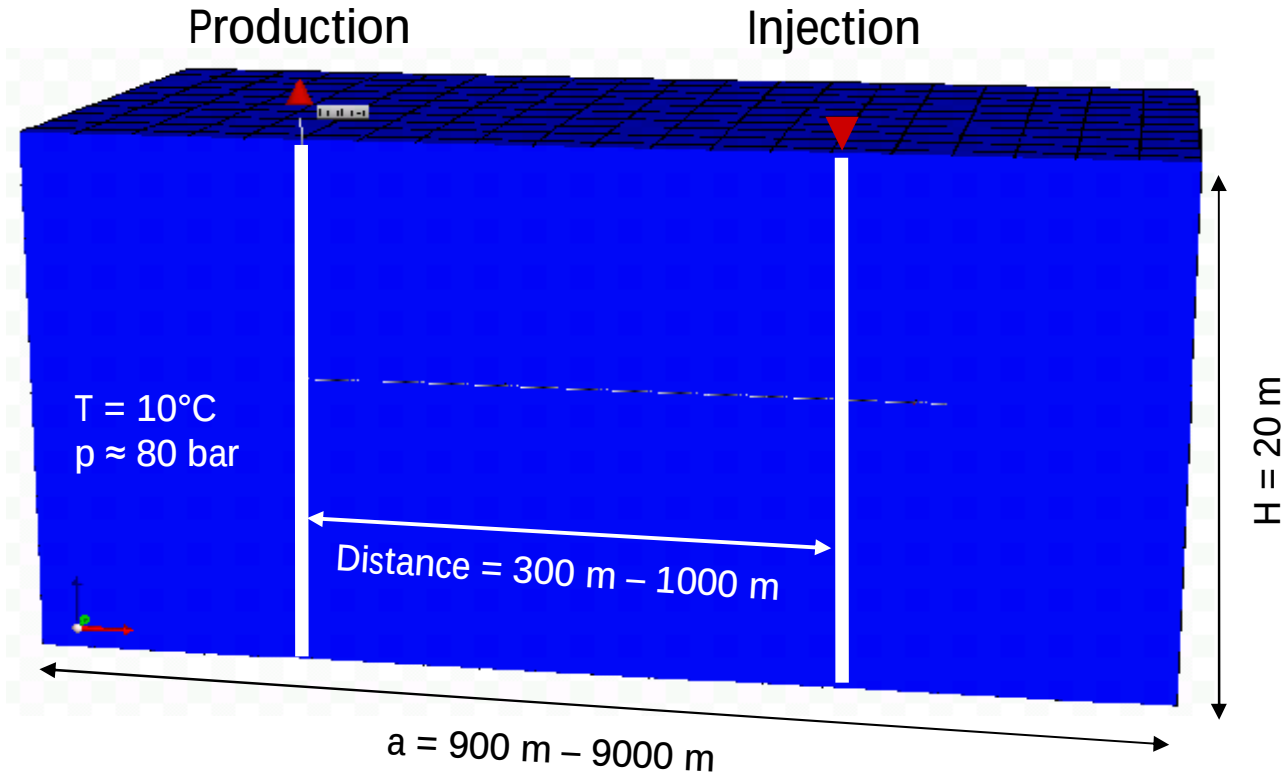
# Multiple wells
# Depressurization and $CO_2$ injection



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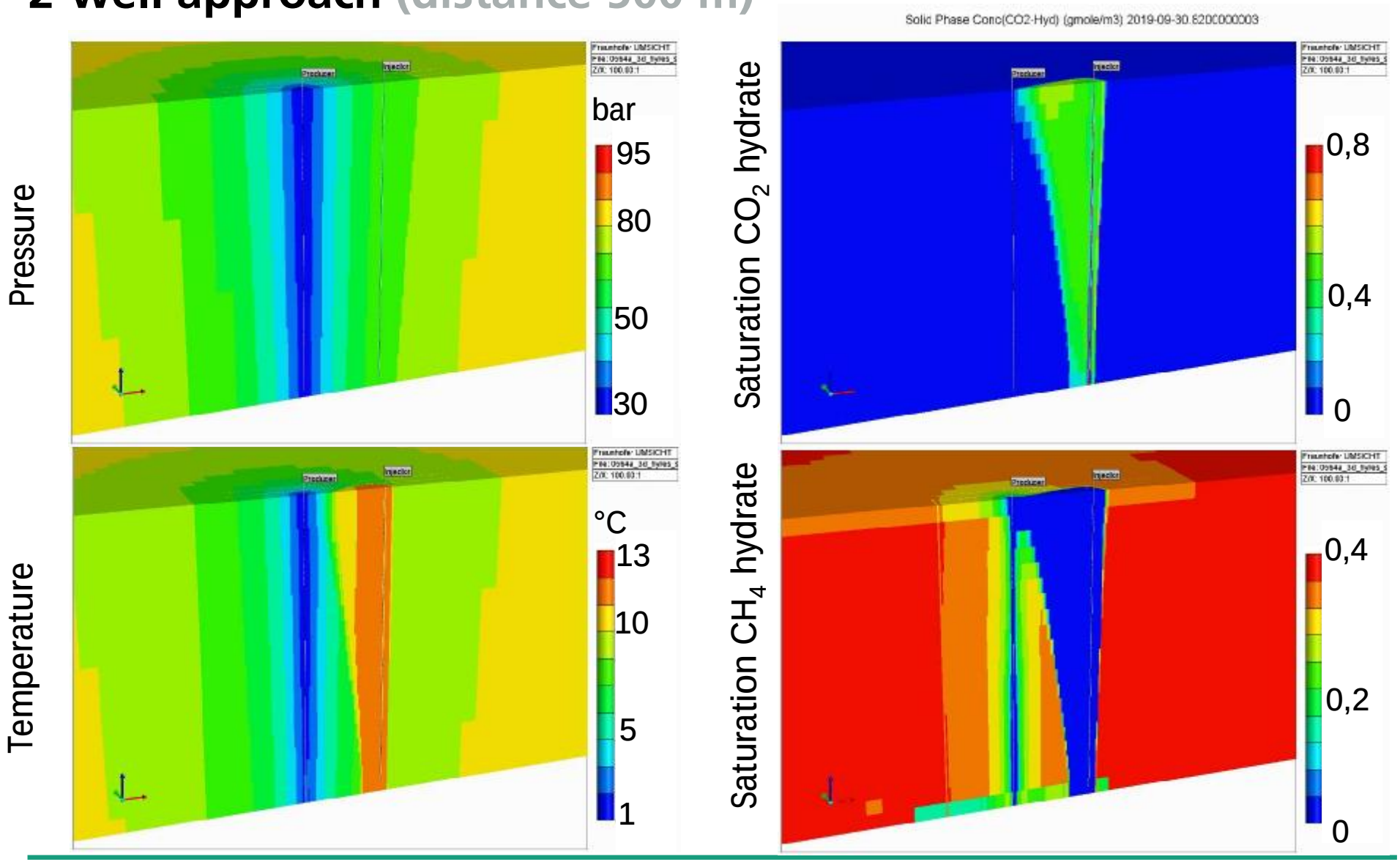
# 2-well approach (distance 500 m)



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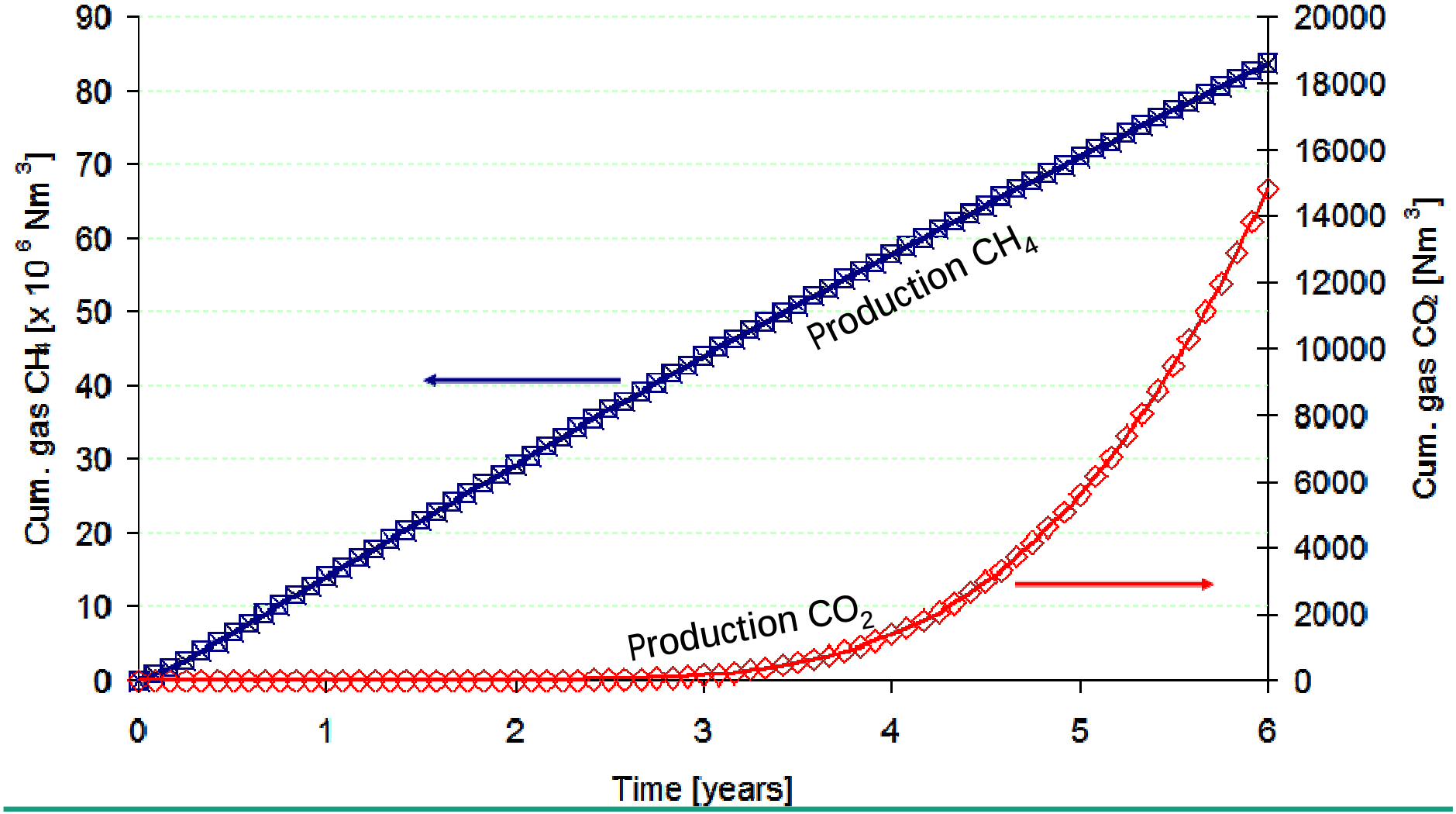
# Gas production
# 2-well approach



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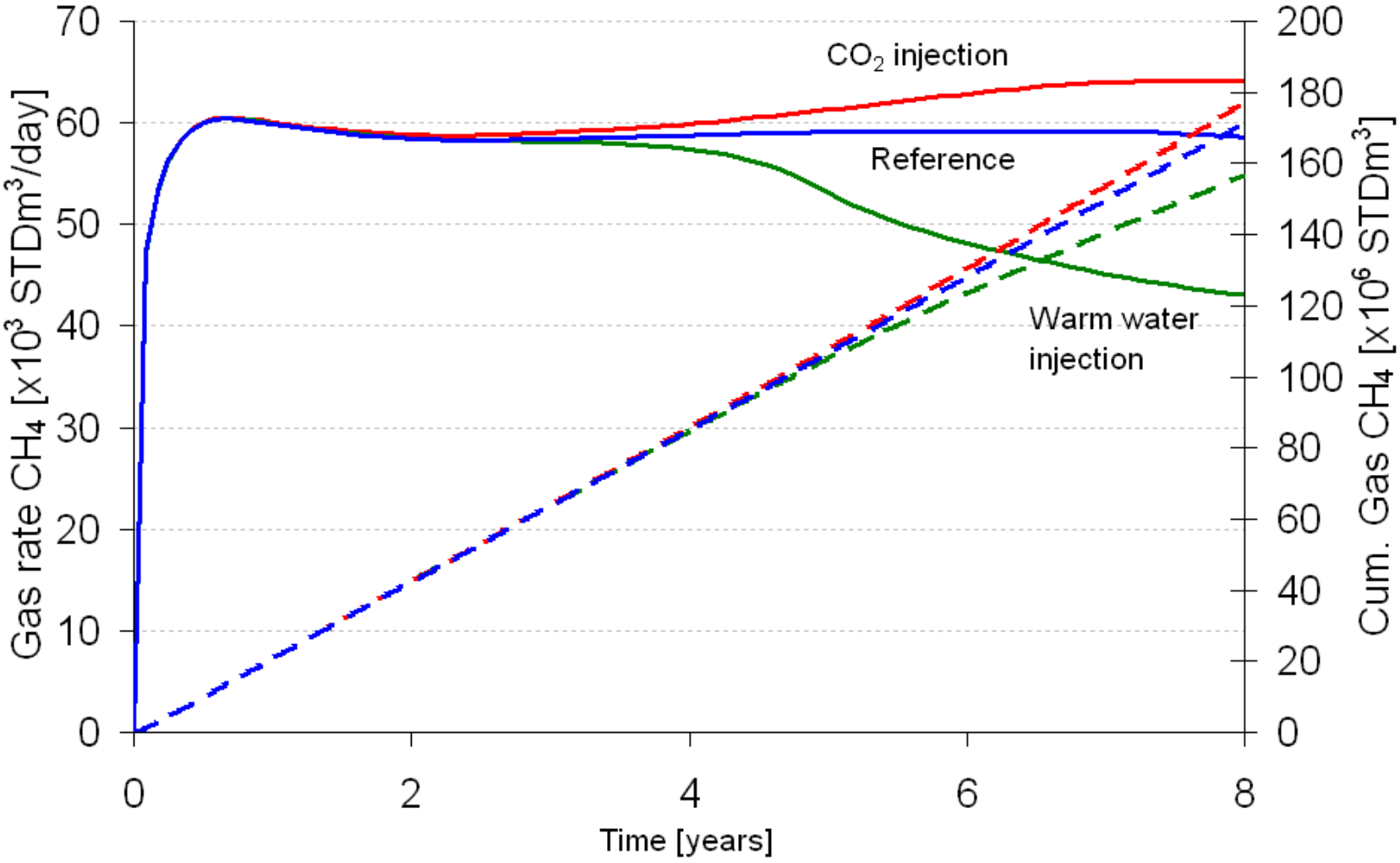
# Gas production
# 2-well approach



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# Conclusions

- Simultaneous or stepwise $CH_4$ production and $CO_2$ injection is possible with acceptable rates
- Multiphase flow in subsea sediments is dominating: Permeability
- Production rates are determined by reservoir type and geological data
  **à** enhanced recovery approaches
- Formation of mixed hydrate beneath the stability curve for $CH_4$ hydrate
  **à** Effect on the production potential
  **à** Effect on the storage capacity of $CO_2$
  **à** Implementation into simulation models necessary!

# Outlook

- Simulation of different production scenarios
- Simulation of realistic deposits
- Field development

} Evaluation of economics

# Acknowledgement


Project team

- Stefan Schlüter, Torsten Hennig, Görge Deerberg, Fraunhofer UMSICHT
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GEFÖRDERT VOM

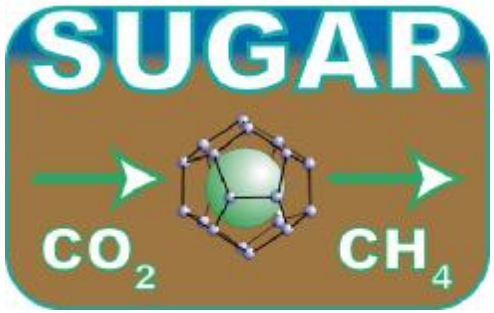
Bundesministerium für Bildung und Forschung

Bundesministerium für Wirtschaft und Technologie

# BMWi / BMBF – project

SUGAR: Submarine Gashydrate Reservoirs
www.sugar-projekt.de

Partners:

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