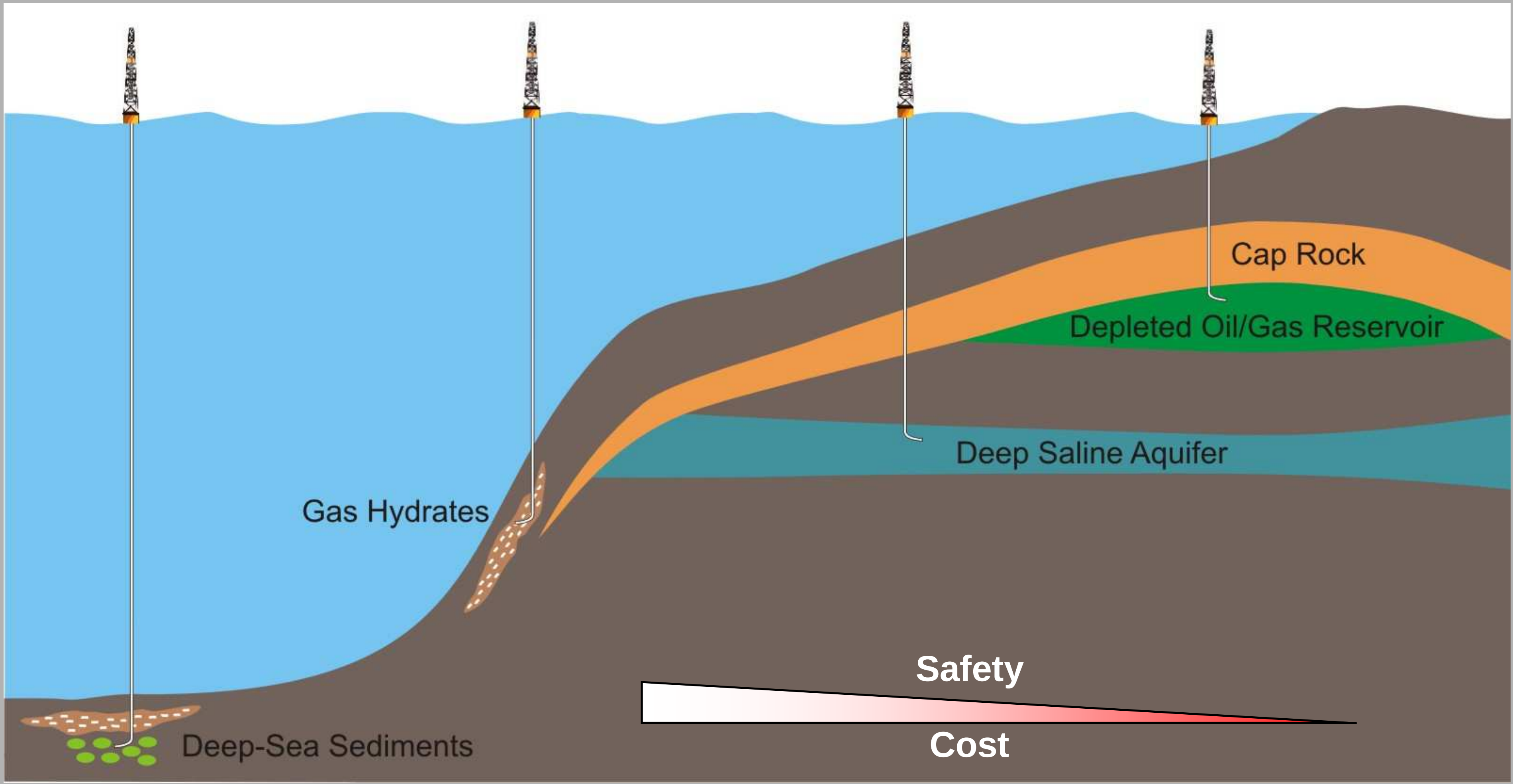
CO_2 storage in marine sediments

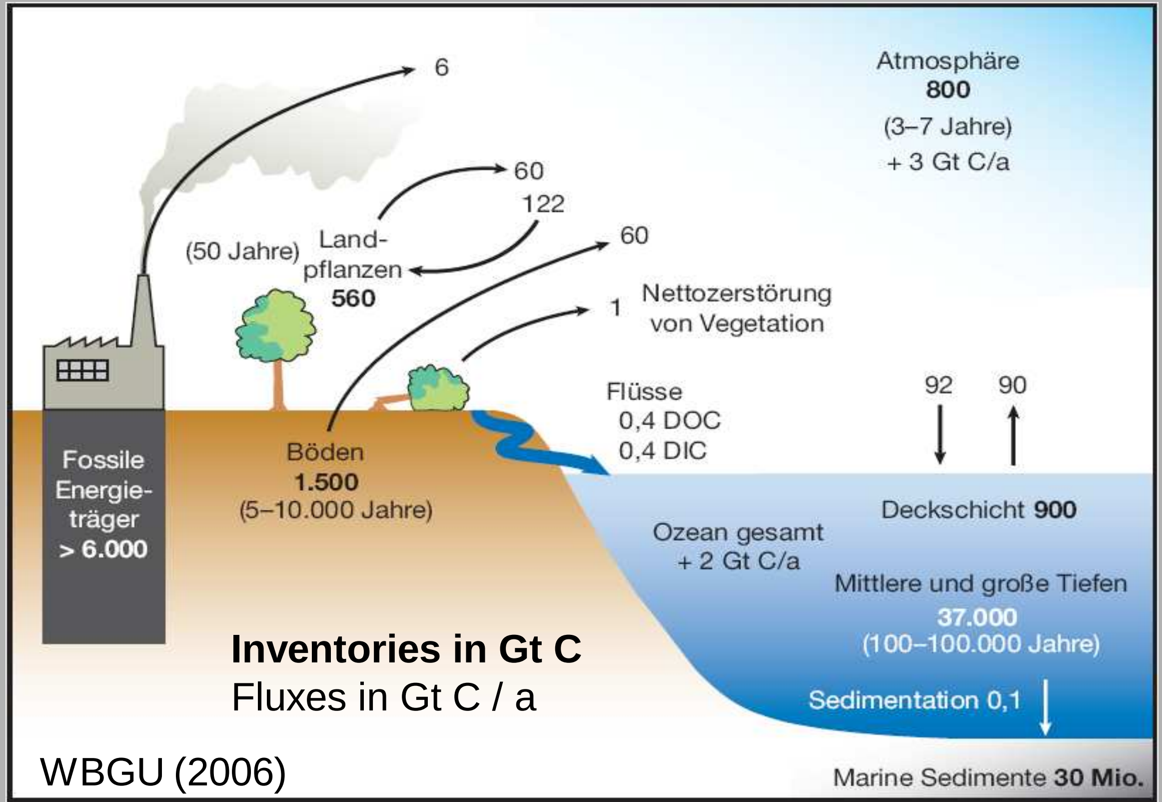
Matthias Haeckel



The oceanic CO_2 sink

Global Carbon Budget

The ocean has taken up ~40% of anthropogenic CO_2 emissions

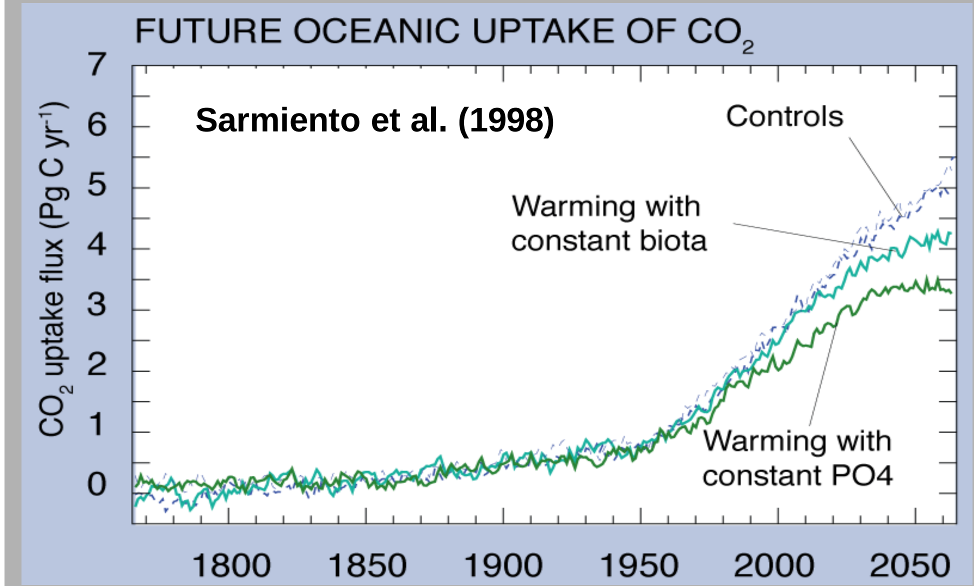


WBGU (2006)

Fluxes in Gt C / a (1 Gt C = 3.67 Gt CO_2)	1980s	1990s	2000–2005
Atmospheric increase	3.3 ± 0.1	3.2 ± 0.1	4.1 ± 0.1
Fossil carbon dioxide emissions	5.4 ± 0.3	6.4 ± 0.4	7.2 ± 0.3
Net ocean-to-atmosphere flux	–1.8 ± 0.8	–2.2 ± 0.4	–2.2 ± 0.5
Net land-to-atmosphere flux	–0.3 ± 0.9	–1.0 ± 0.6	–0.9 ± 0.6
Partitioned as follows			
Land use change flux	1.4 (0.4 to 2.3)	1.6 (0.5 to 2.7)	NA
Residual land sink	–1.7 (–3.4 to 0.2)	–2.6 (–4.3 to –0.9)	NA

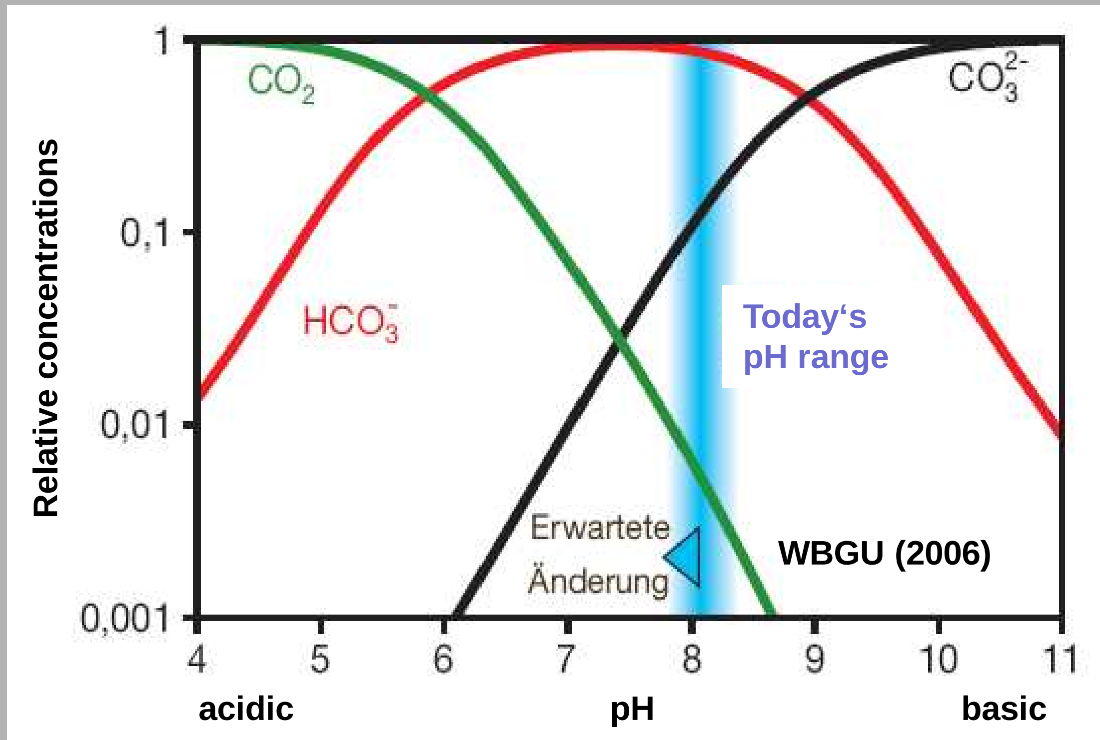
IPCC (2007)

The oceanic CO_2 sink

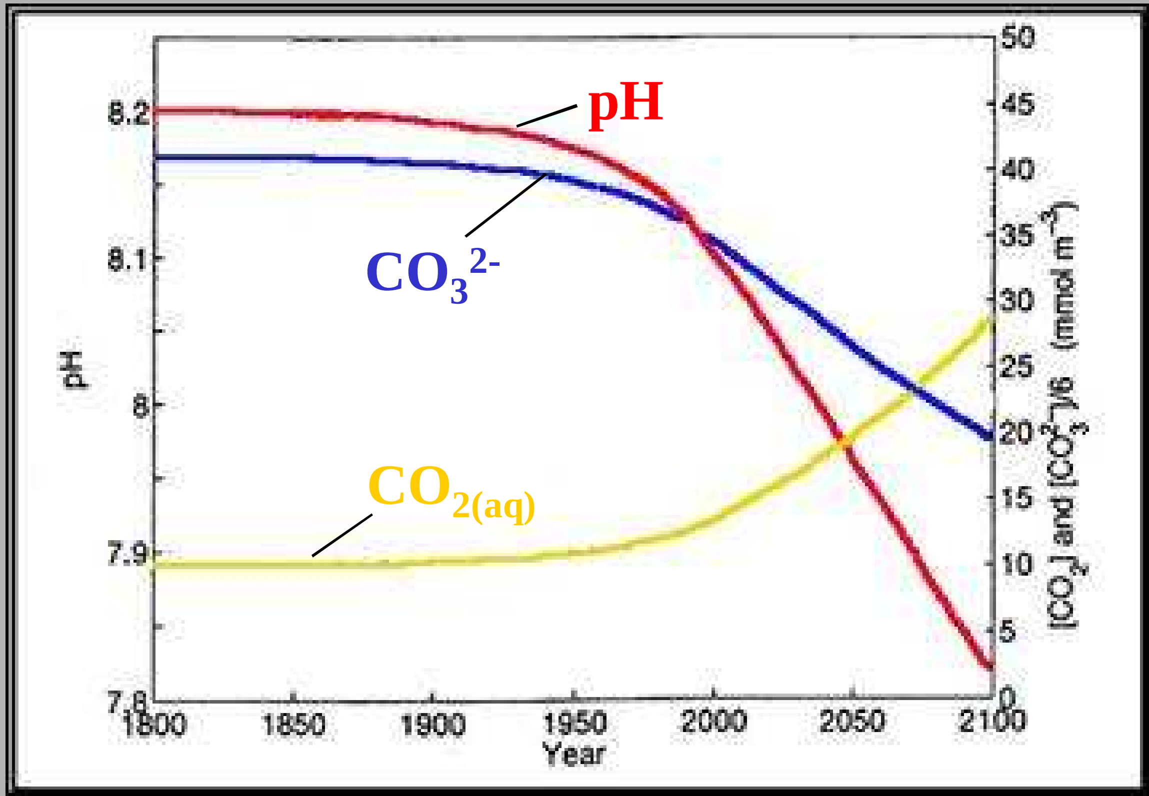


The oceanic sink for anthropogenic CO_2 is likely to further increase in the coming decades ......

...... and this will further increase ocean acidification



The oceanic CO_2 sink



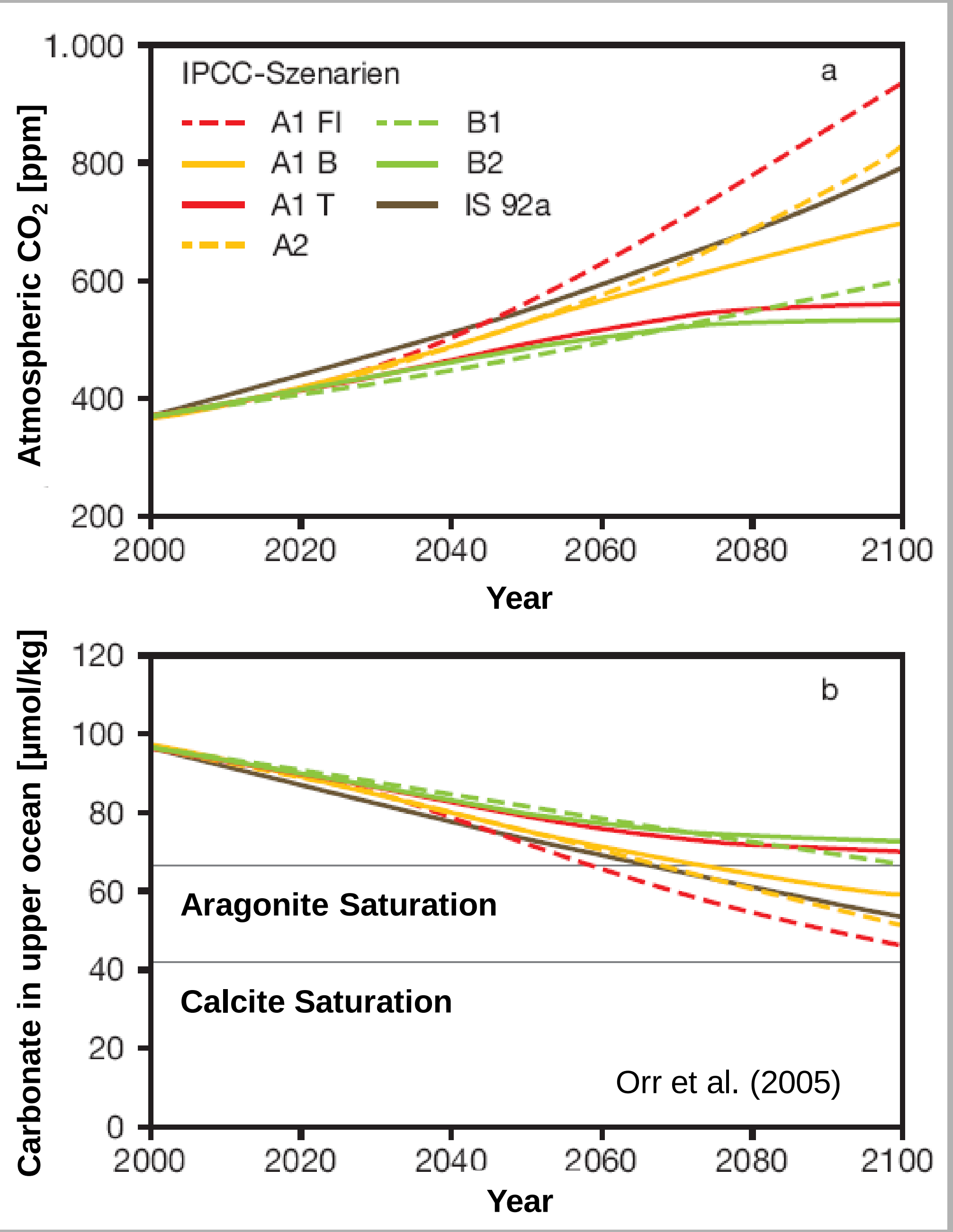
Wolf-Gladrow et al. (1999)

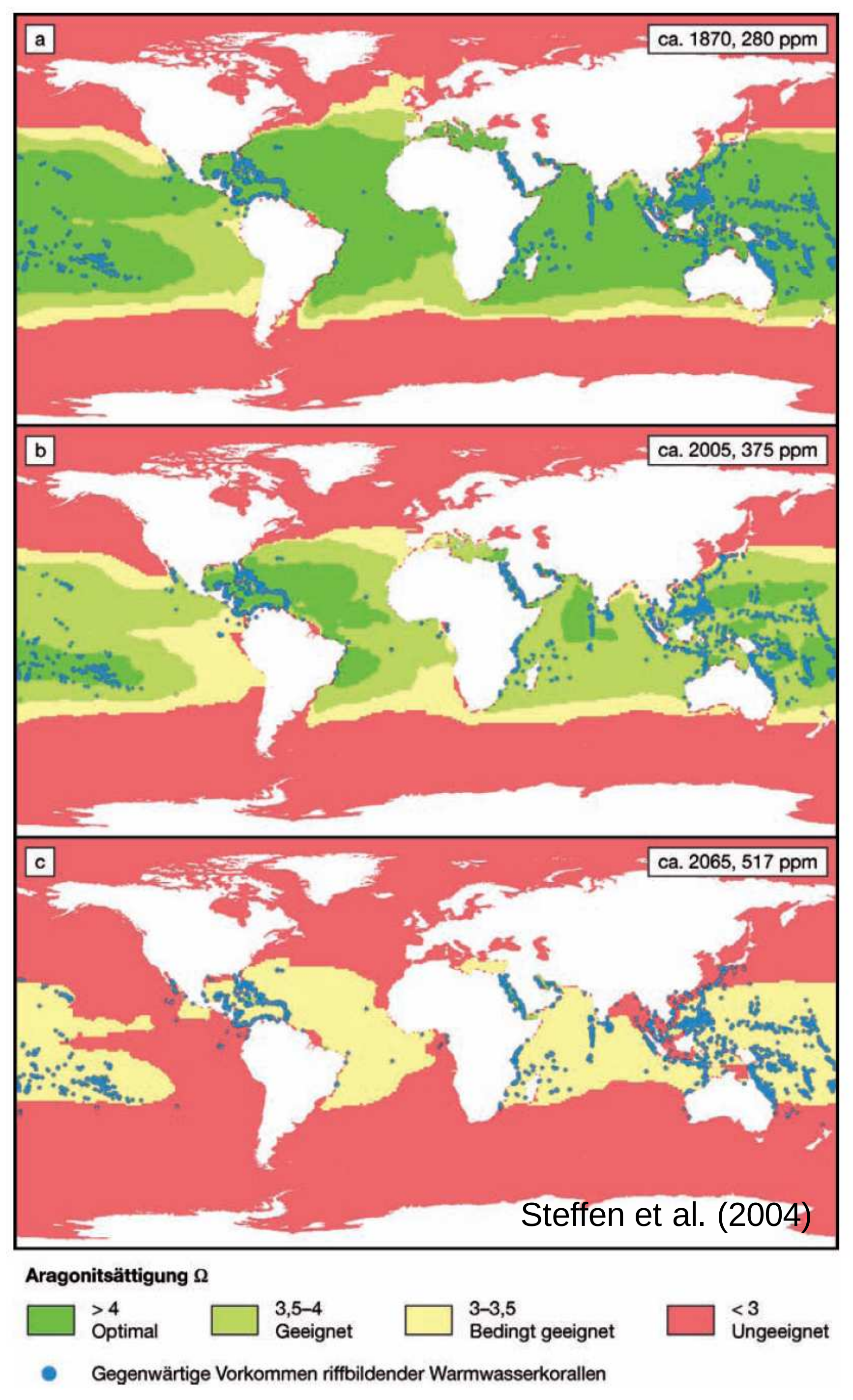
Pre-industrial present $\Delta pH = -0.12$ (280 380 ppm CO_2)

present 2100 $\Delta pH = -0.45$ (380 800 ppm CO_2)

... and the marine ecosystem is quite sensitive to changes in the pH

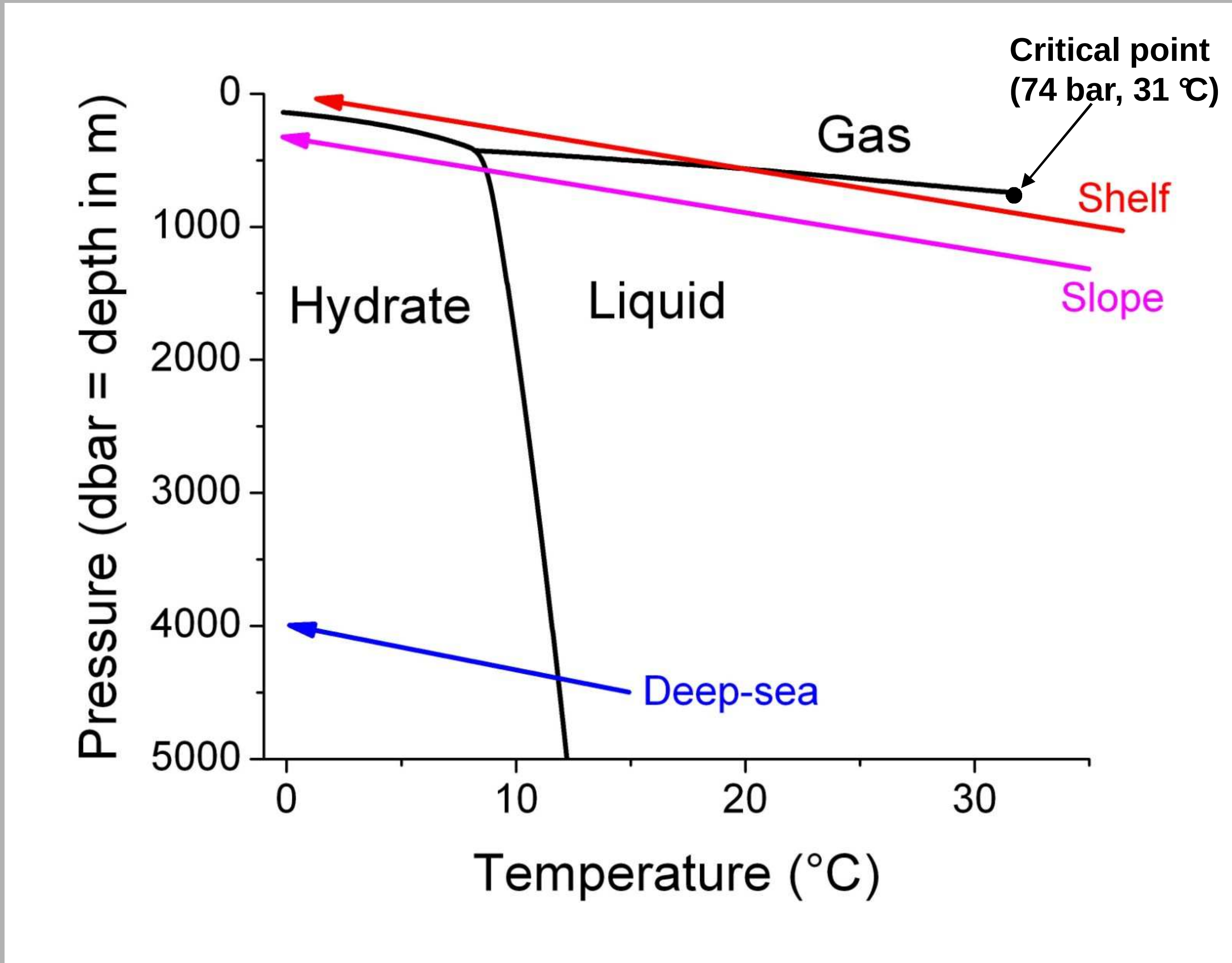
The oceanic CO_2 sink





Warm-water corals need a saturation index >3.5 to build reefs

CO_2 Phase Diagram

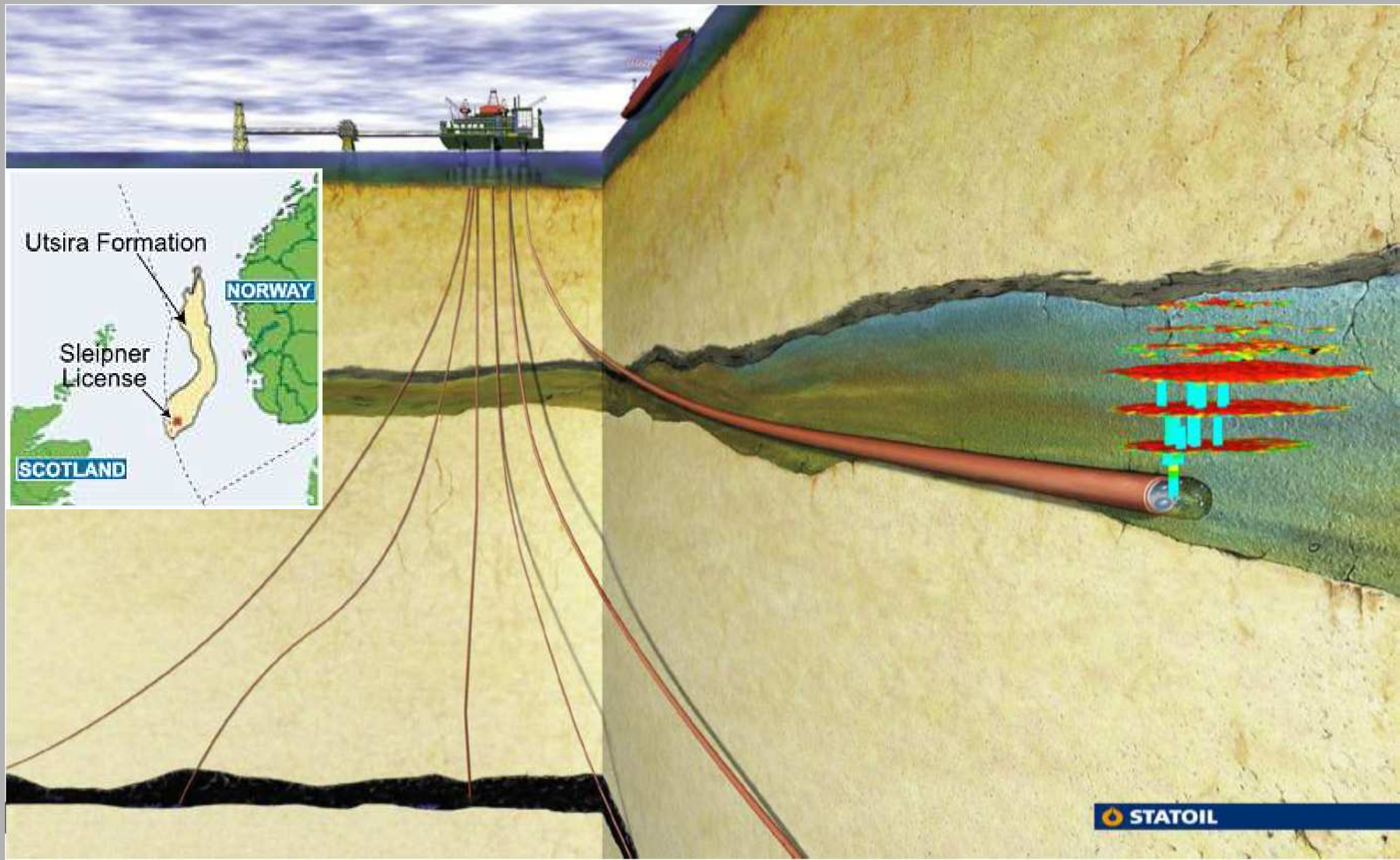


Marine CO_2 storage options

CO_2 Storage in Shelf Sediments - Sleipner field

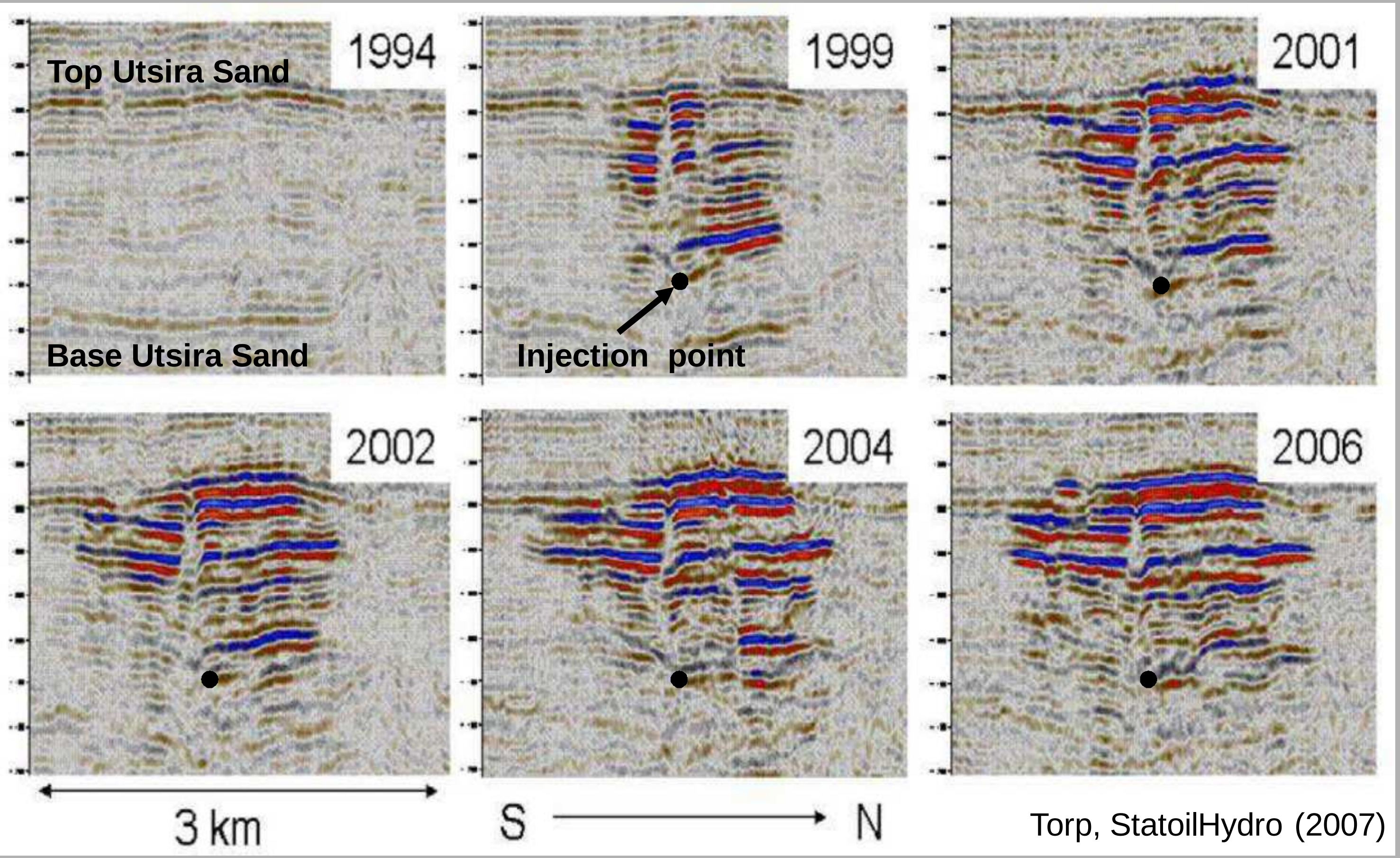
Amount: 1 Mt/a CO_2 since 1996 (total planned: 20 Mt)

water depth: 80 m; sediment depth: 800-1000 m; investment costs: 94 Mio€



Marine CO_2 storage options

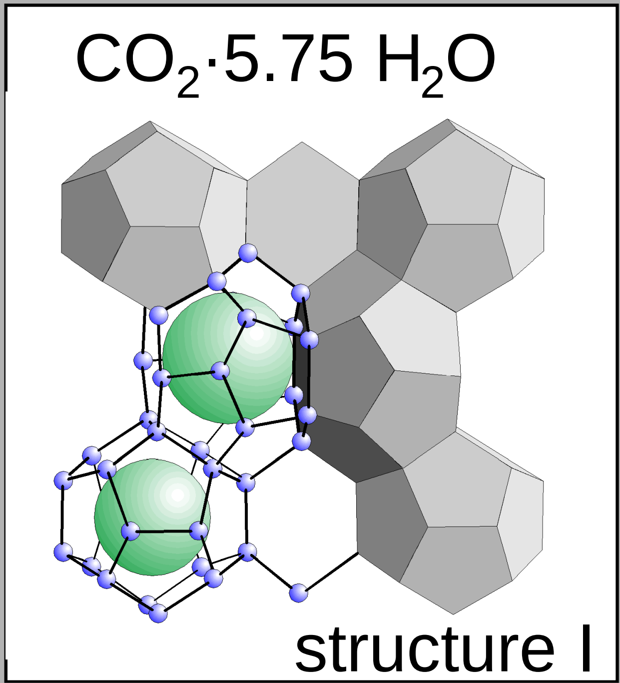
- Seismic monitoring indicates rapid ascent of sCO_2 through the Utsira sandstone formation (~200 m in less than a year)
- ~5 m thick clay layers were penetrated or bypassed by sCO_2 within a few years

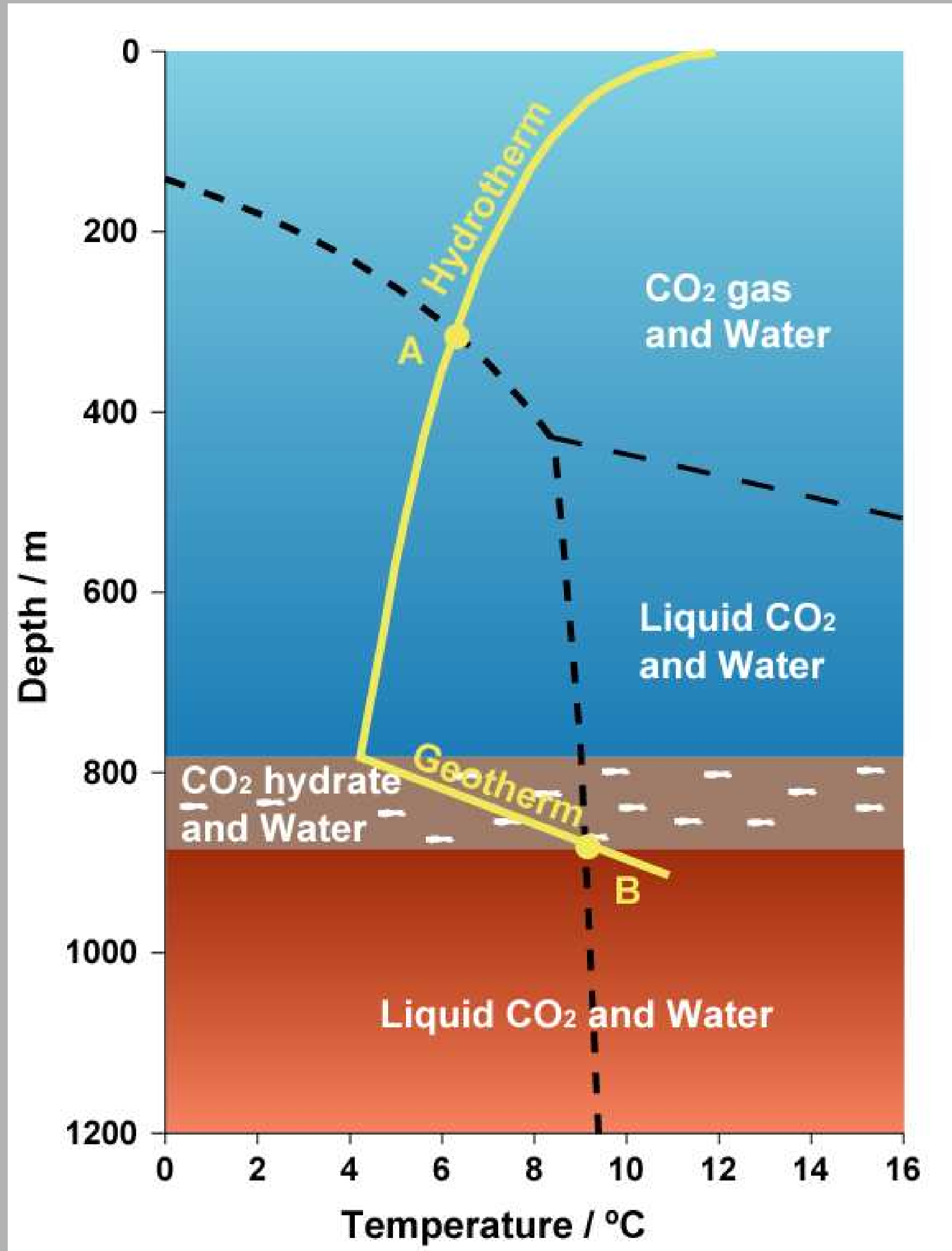


Some open questions: Where does the replaced saline water go?
What about small scale leakage?
How does a site behave when injecting in Gt-scale?

Marine CO_2 storage options

I. CO_2 Hydrates





Gas hydrates are stable at low temperatures and high pressures

Marine CO_2 storage options

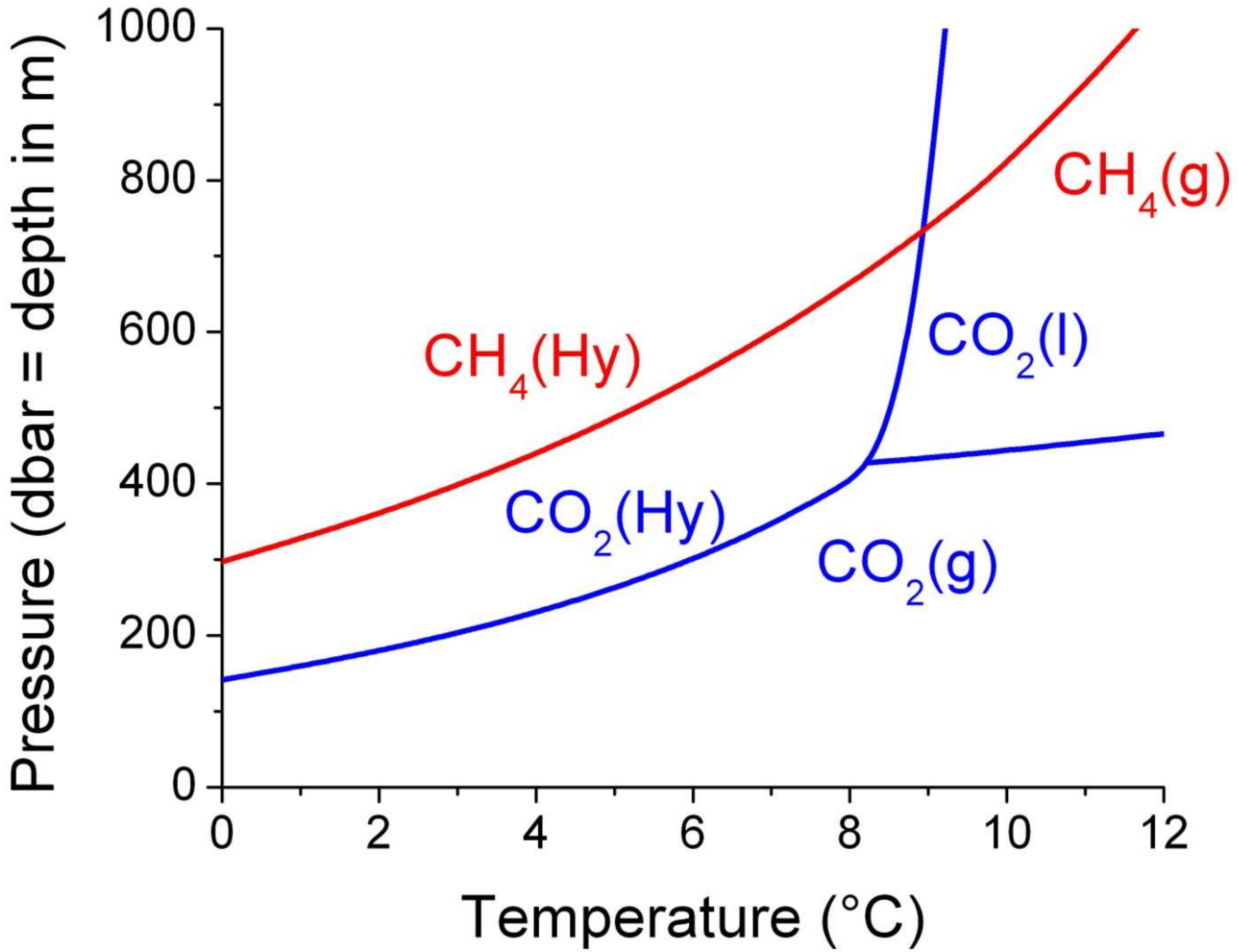
Combination of CO_2 storage and methane hydrate exploitation

CO_2 →  → CH_4

projects CLATHRAT and SUGAR

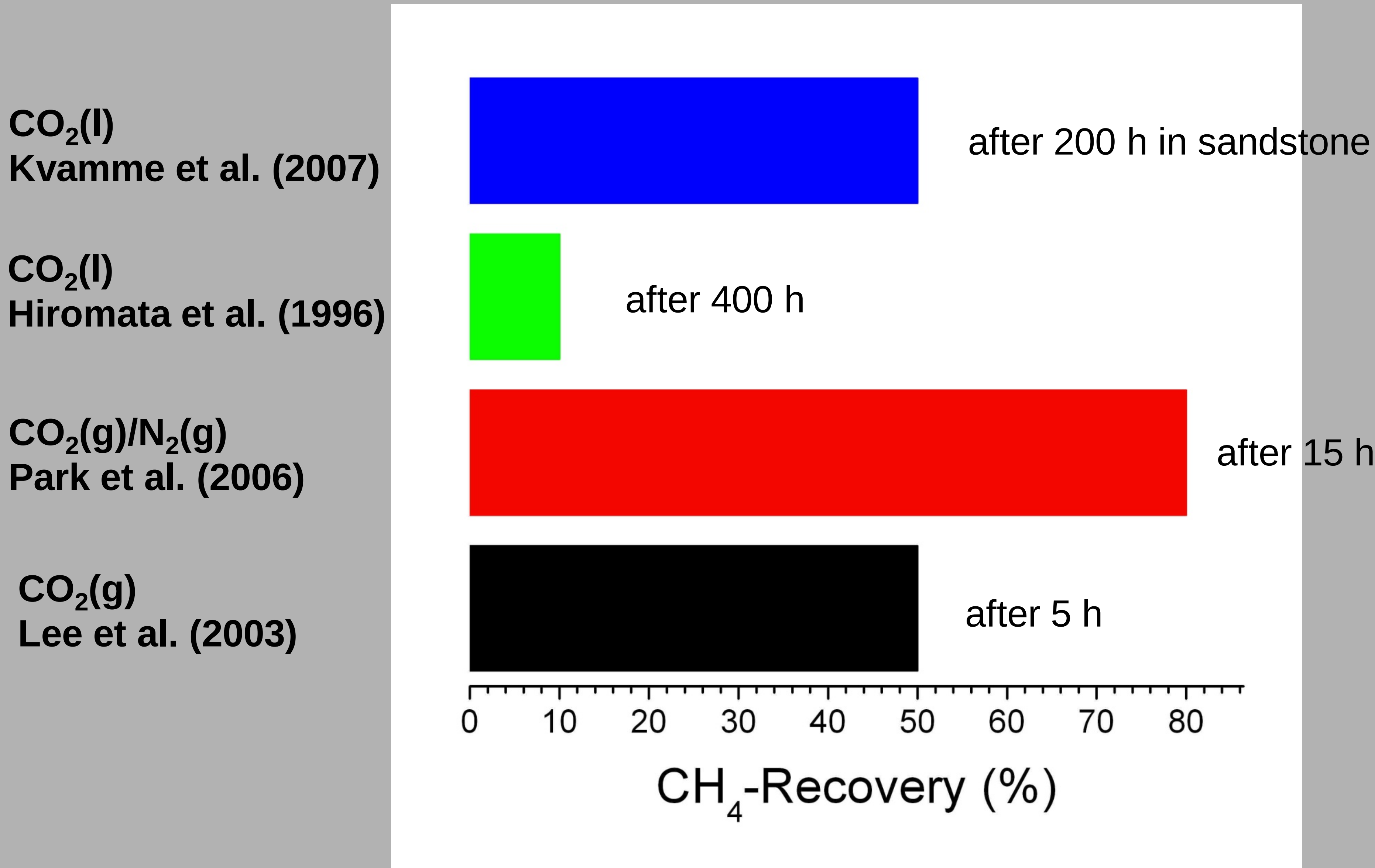
Marine CO_2 storage options

CO_2 hydrate is more stable than CH_4 hydrate



Duan & Sun (2006)

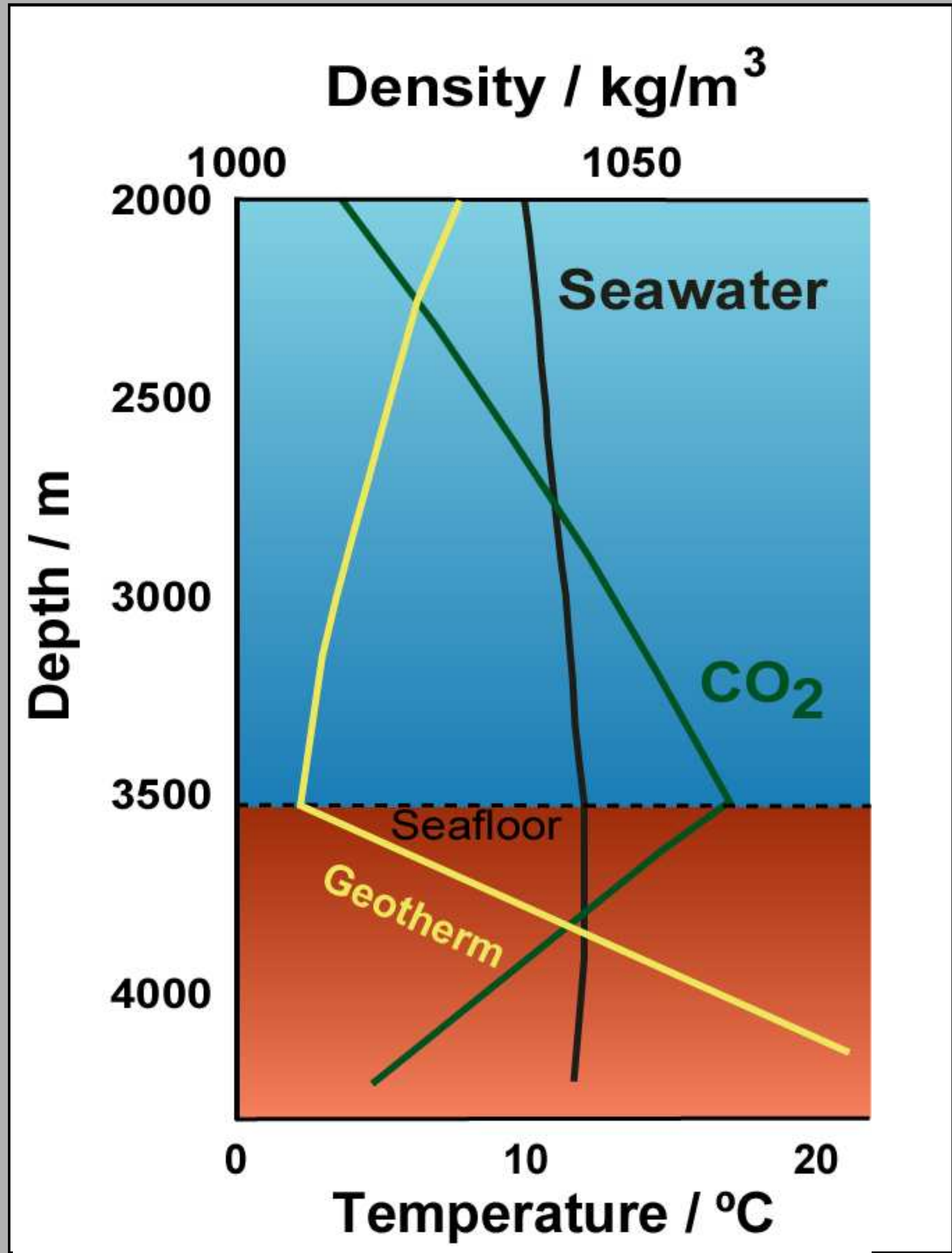
Methane gas recovery from hydrates exposed to CO_2



Marine CO_2 storage options

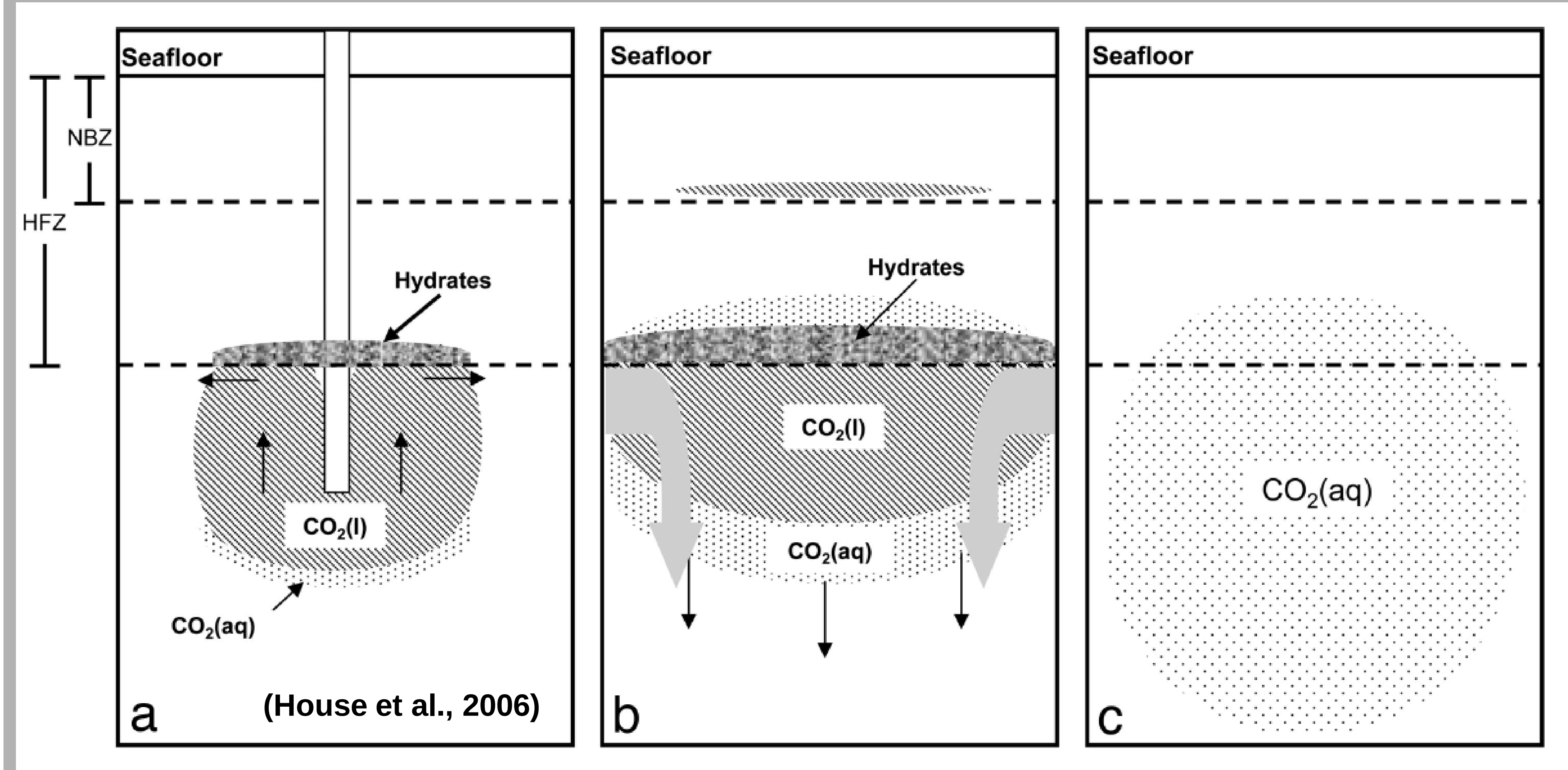
II. Liquid CO_2

In deep-sea sediments, pressure and temperature conditions form a zone where liquid CO_2 is gravitationally stable.



Marine CO_2 storage options

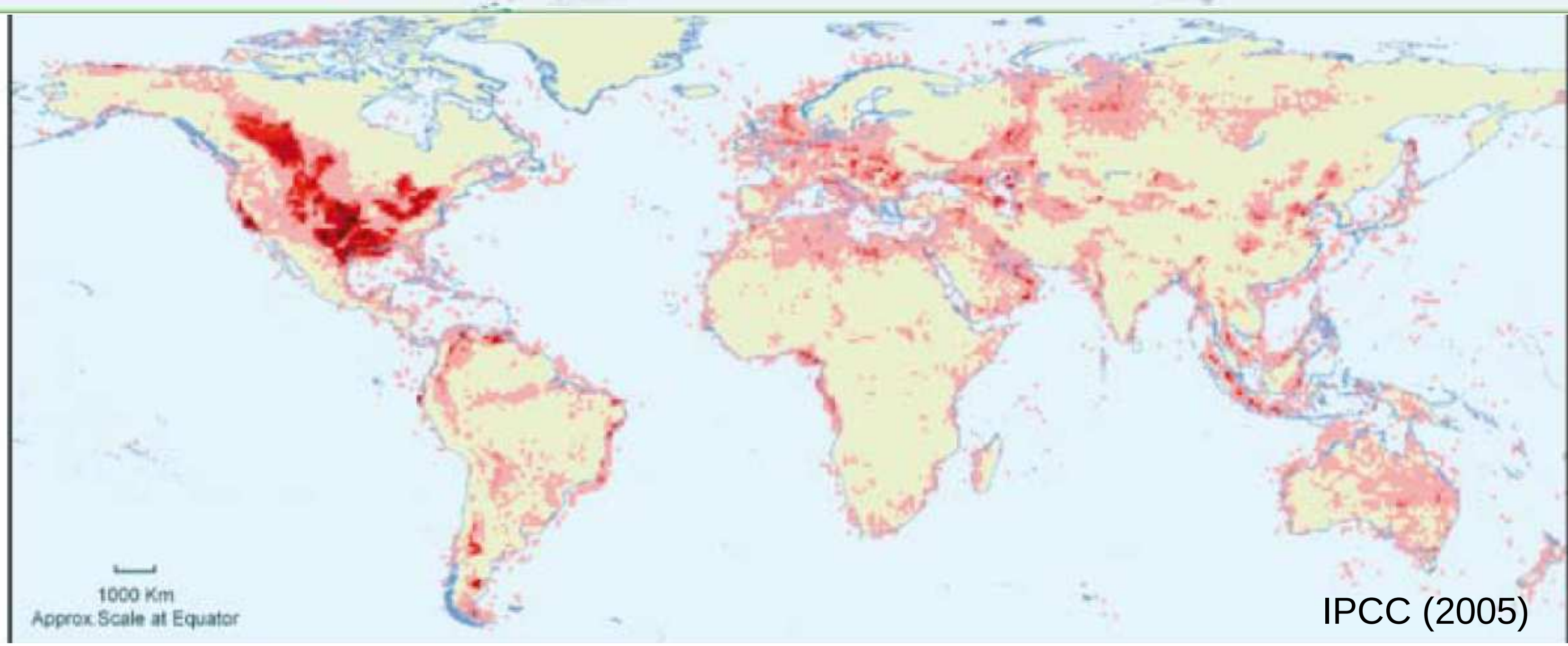
CO_2 storage in deep-sea sediments



CO_2(l) will slowly dissolve into the porewater and react with the sediment

Marine CO_2 storage options

IPCC (2005)



IPCC (2005)

Potential capacities for CO_2 storage

Global estimates (IPCC, 2005)

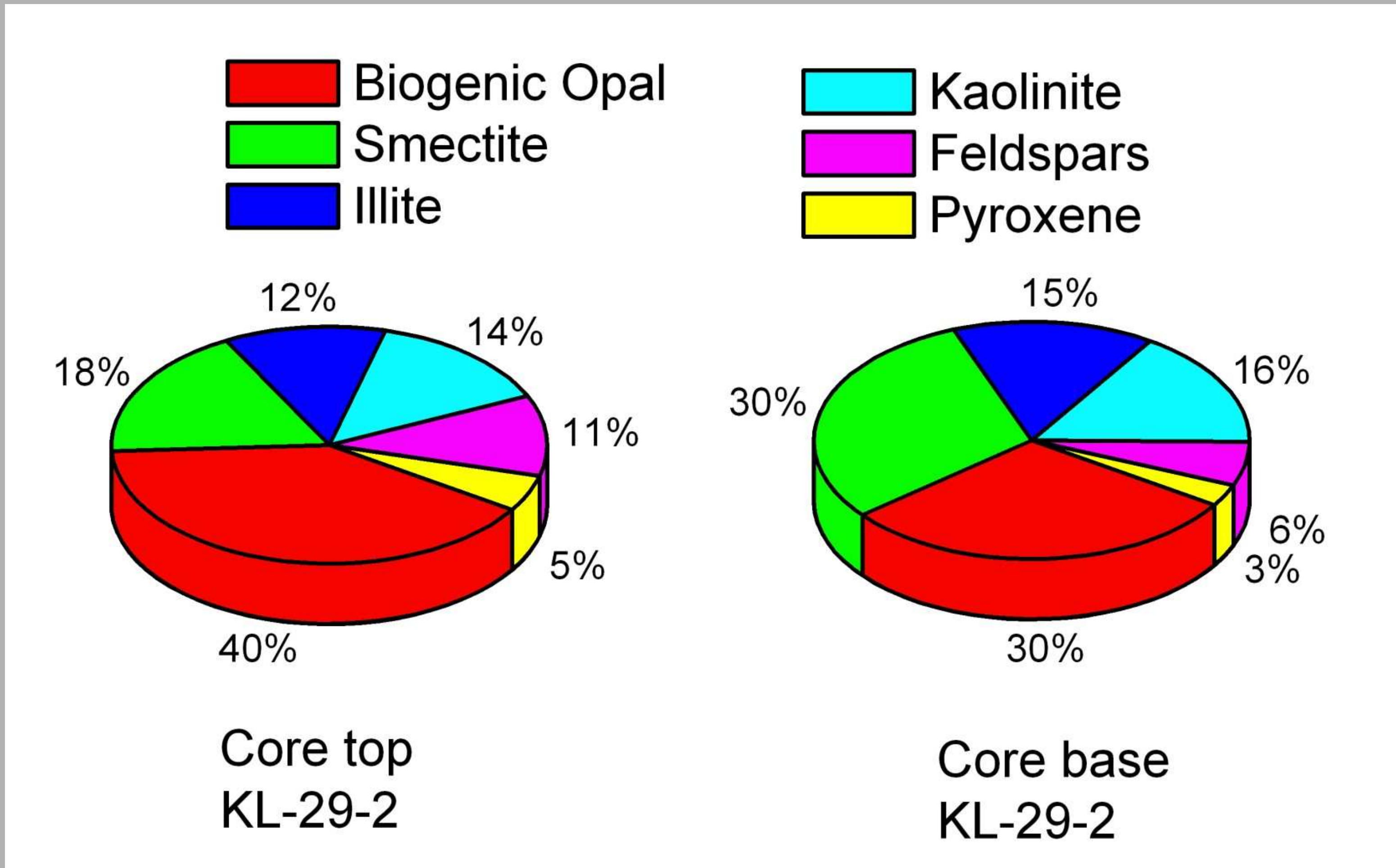
- Oil & gas fields: <1,000 Gt
- Deep saline formations: 1,000 – 10,000 Gt

Regional estimates (Zweigel, 2004; Chadwick, 2004; House, 2006)

• Utsira formation -	total pore volume: 600 km^3	360 Gt
	structural traps: 50 km^3	30 Gt
• UK offshore Bunter Sandstone: 110 km^3		70 Gt
• US coast deep-sea sediments:		>10,000 Gt

- less than 0.01 % of the deep-sea floor is needed to store the global anthropogenic CO_2 production of the entire 21st century

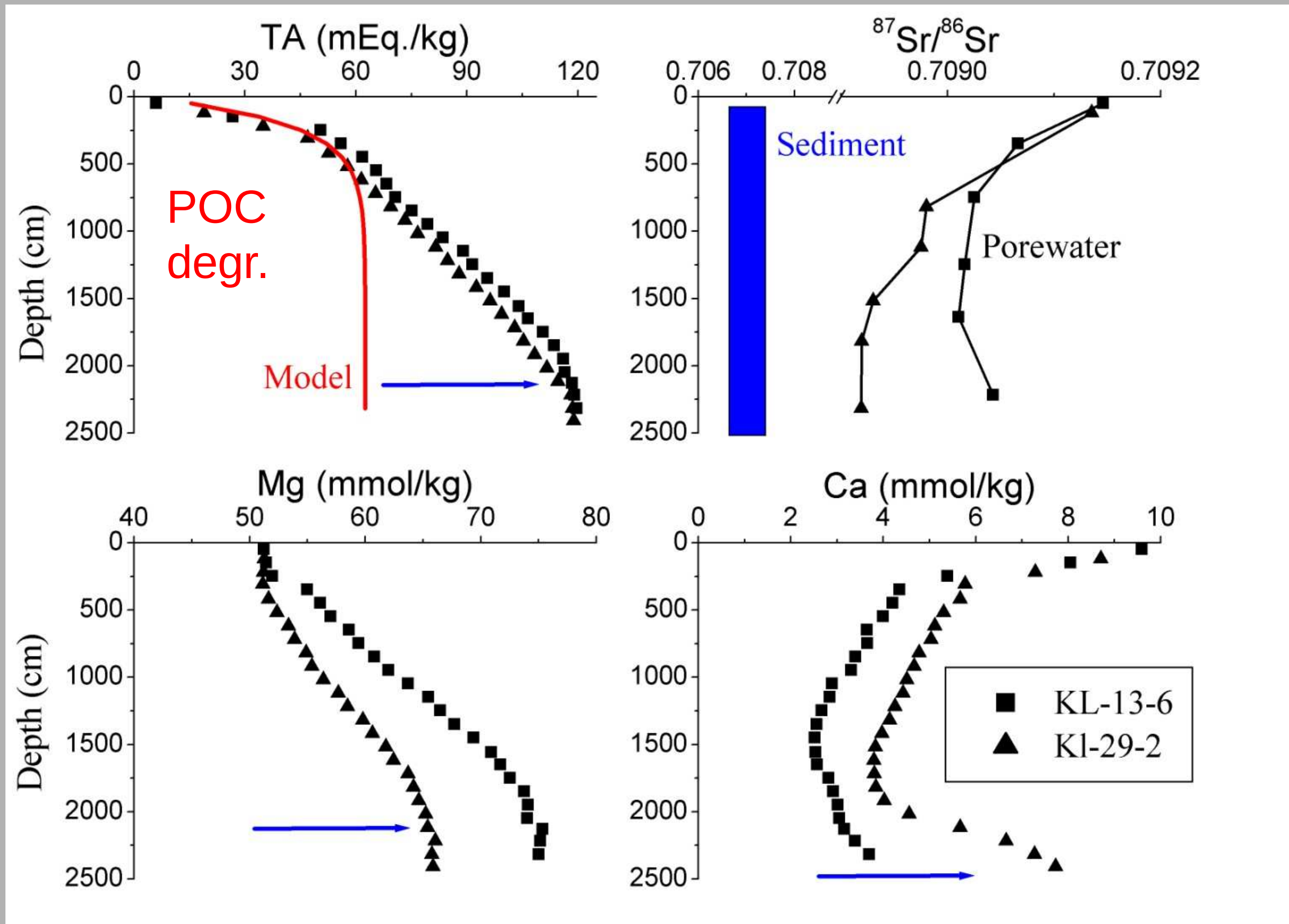
Silicate weathering in anoxic marine sediments



Feldspars + CO_2 => clays + HCO_3^- + metal cations

Wallmann et al. (2008)

Further evidence for silicate weathering

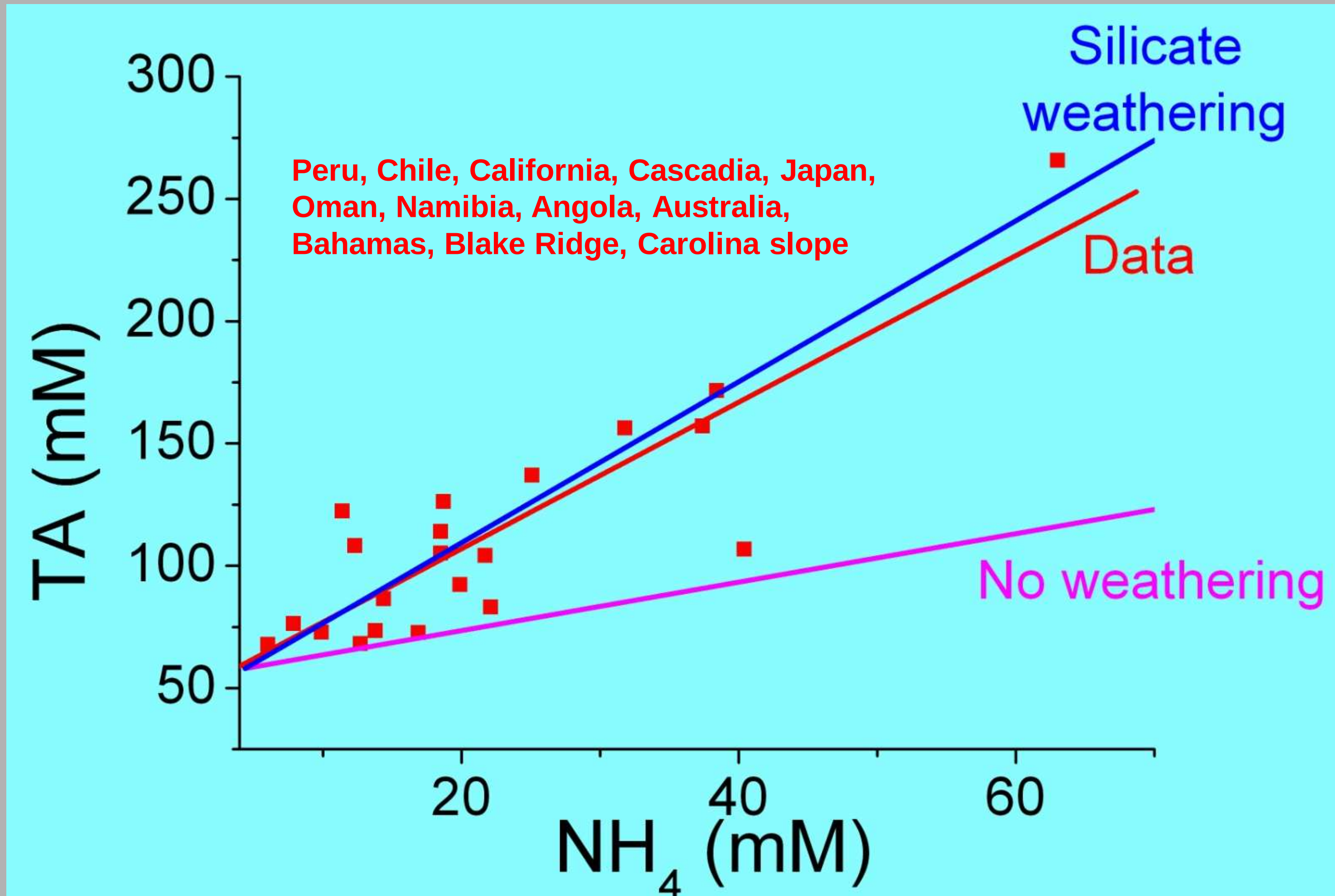


Feldspars + CO_2 => clays + HCO_3^- + metal cations

Wallmann et al. (2008)

Natural analogues

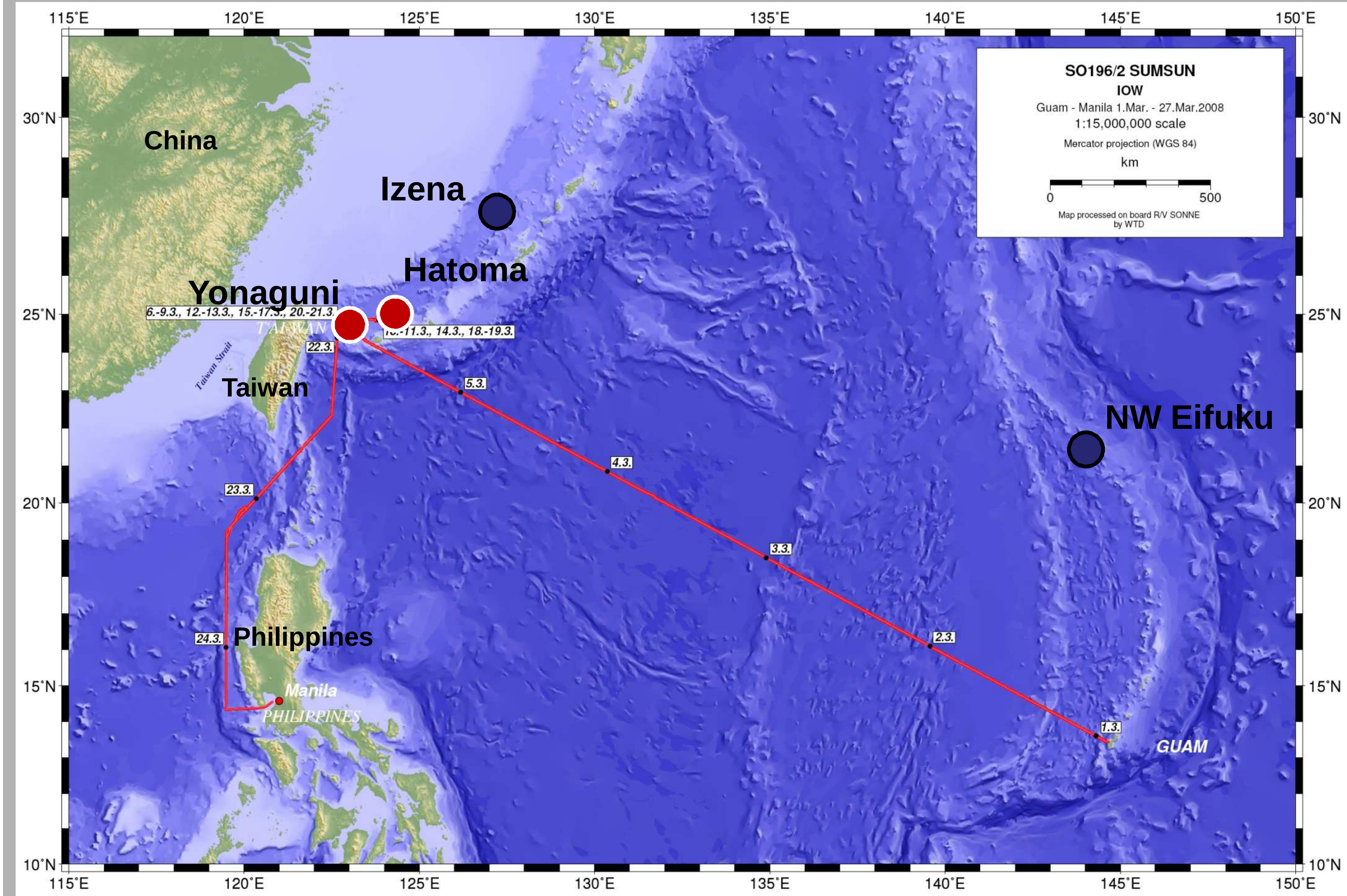
Microbial CO_2 produced in anoxic sediments is almost completely neutralized through silicate weathering



Pore water data from methanogenic sediments deposited at productive continental margins

Wallmann et al. (2008)

Natural analogues

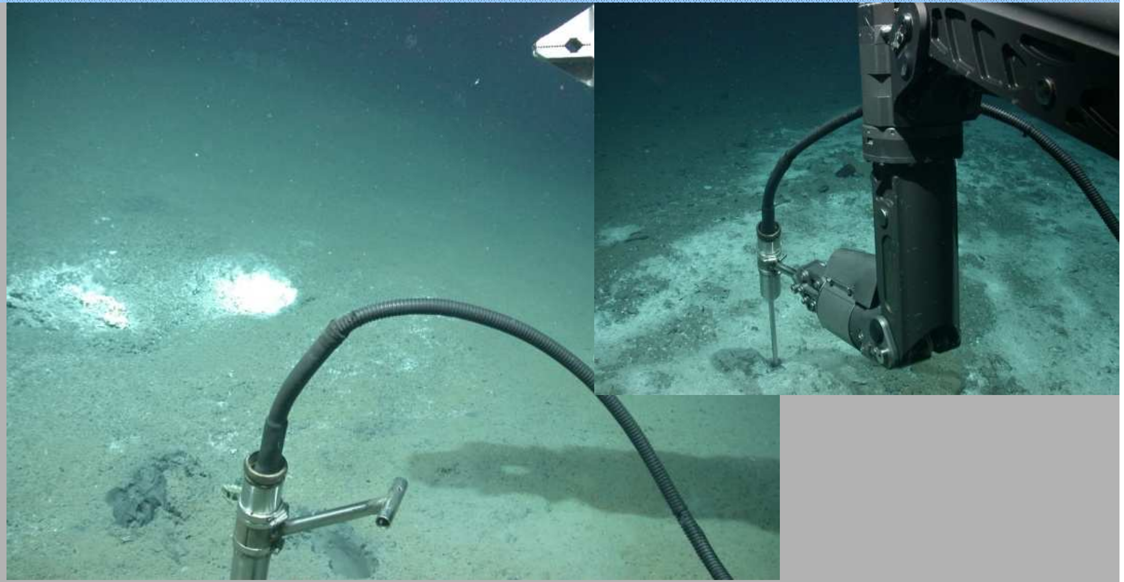


Plume mapping of natural seepage

Vertical pH profiles of the water column along a SE-NW transect across a natural CO_2 seep at Yonaguni Knoll, Okinawa Trough

Sensitive monitoring techniques are available for the marine realm:
e.g., hydro-acoustic bubble detection, water sampling, benthic flux measurements

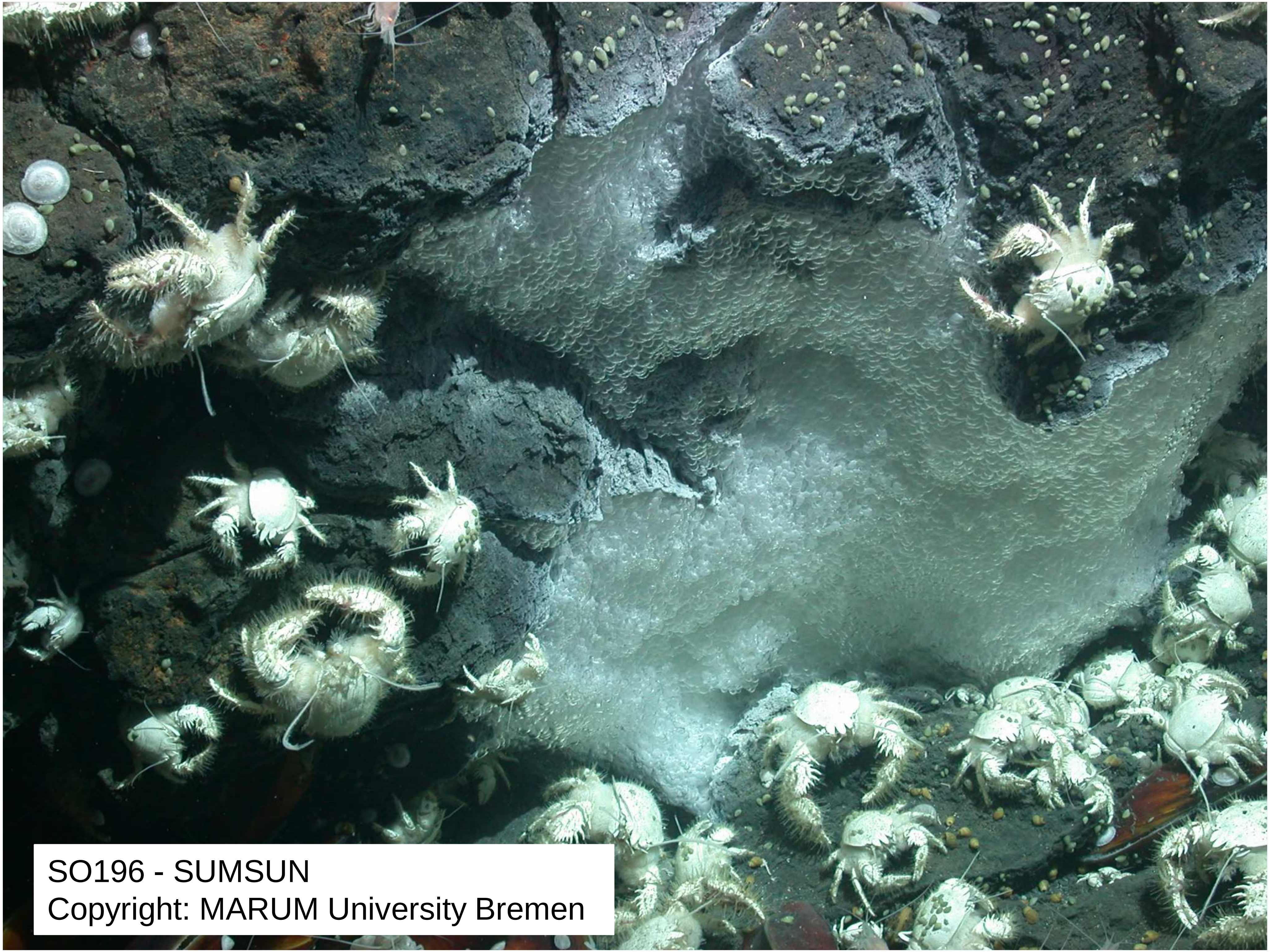
Natural analogues



Photos: SO196 - SUMSUN

Environmental effects of natural CO_2 emissions

- high CO_2 and low pH in the bottom water
- „normal“ benthic megafauna (e.g., echinoderms) is replaced by „dead zone“ area and specific fauna at vents (chemoautotrophs, opportunistic species, predators)
- reduced microbial activity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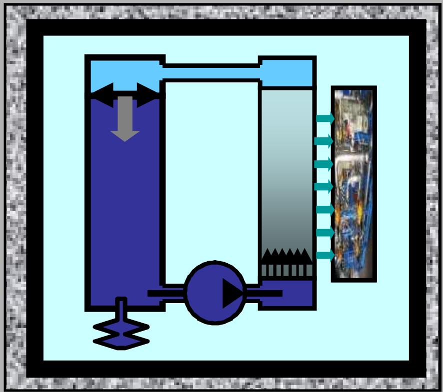
Conclusions

Projects SUGAR and CLATHRAT

Lab experiments



Kinetics of sediment weathering

Hydrate formation in sediments

pressure reactors + Raman + NMR-MAS

Numerical Modelling

$$\frac{\partial C}{\partial t} = \nabla\left(D\nabla C - uC\right) + \sum R_i$$

$$u = -\frac{\kappa}{\eta}\nabla p$$

$$CO_2 \rightarrow HCO_3^- \rightarrow CaCO_3$$

$$CO_2 + 5.75H_2O \rightarrow GH$$

Analysing lab results

Upscaling from lab into field

Field work

In situ process study in natural laboratory

Conclusions

1. CO_2 storage below the seafloor is a realistic option and should be organized at the European level

2. Negative effects on ocean ecosystems can be avoided at small leakage rates ≤10 t CO_2/km^2/a

3. Appropriate monitoring strategies for leakage detection must be developed; sensitive techniques are available

4. On long time scales, CO_2 leakage is mitigated through silicate weathering processes

5. CO_2 leakage can be further minimized via CO_2 storage in solid gas hydrates at large water depths (>300 m)

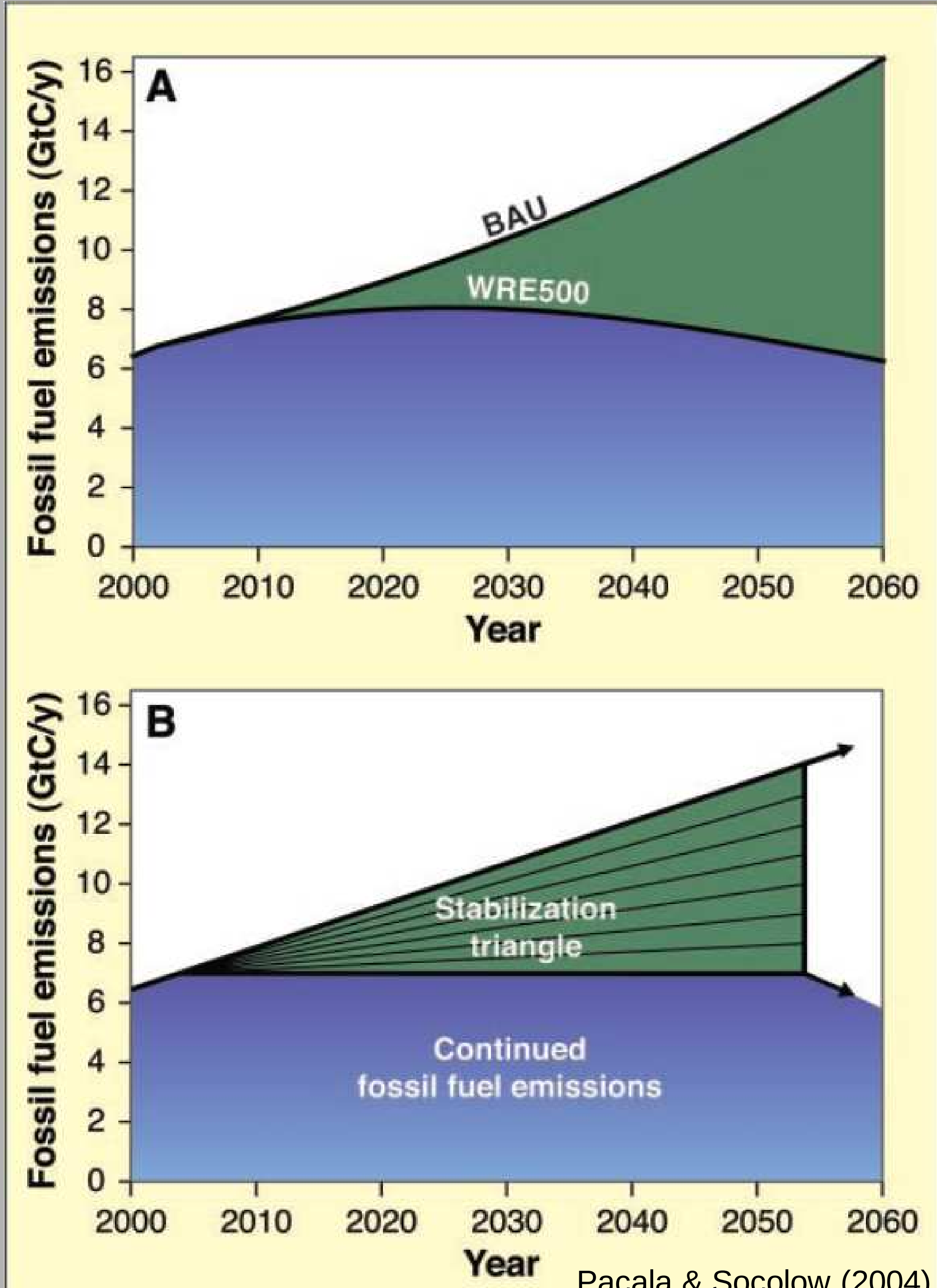
6. Production of natural gas by hydrate conversion could provide incentives for off-shore CO_2 storage

Conclusions

Stabilizing atmospheric CO_2 concentrations by reducing anthropogenic CO_2 emissions

Definition of 7 (8) wedges: each wedge leads to a CO_2 emission reduction of 1 Gt C / a in 50 years from now (equiv. to 25 Gt C)

in total CO_2 emissions of 175 (200) Gt C have to be avoided over the next 50 years



Pacala & Socolow (2004)

Conclusions

Table 1. Potential wedges: Strategies available to reduce the carbon emission rate in 2054 by 1 GtC/year or to reduce carbon emissions from 2004 to 2054 by 25 GtC.

Option	Effort by 2054 for one wedge, relative to 14 GtC/year BAU	Comments, issues
	Energy efficiency and conservation	
Economy-wide carbon-intensity reduction (emissions/$GDP)	Increase reduction by additional 0.15% per year (e.g., increase U.S. goal of 1.96% reduction per year to 2.11% per year)	Can be tuned by carbon policy
1. Efficient vehicles	Increase fuel economy for 2 billion cars from 30 to 60 mpg	Car size, power
2. Reduced use of vehicles	Decrease car travel for 2 billion 30-mpg cars from 10,000 to 5000 miles per year	Urban design, mass transit, telecommuting
3. Efficient buildings	Cut carbon emissions by one-fourth in buildings and appliances projected for 2054	Weak incentives
4. Efficient baseload coal plants	Produce twice today's coal power output at 60% instead of 40% efficiency (compared with 32% today)	Advanced high-temperature materials
	Fuel shift	
5. Gas baseload power for coal baseload power	Replace 1400 GW 50%-efficient coal plants with gas plants (four times the current production of gas-based power)	Competing demands for natural gas
	CO_2 Capture and Storage (CCS)	
6. Capture CO_2 at baseload power plant	Introduce CCS at 800 GW coal or 1600 GW natural gas (compared with 1060 GW coal in 1999)	Technology already in use for H_2 production
7. Capture CO_2 at H_2 plant	Introduce CCS at plants producing 250 MtH_2/year from coal or 500 MtH_2/year from natural gas (compared with 40 MtH_2/year today from all sources)	H_2 safety, infrastructure
8. Capture CO_2 at coal-to-synfuels plant	Introduce CCS at synfuels plants producing 30 million barrels a day from coal (200 times Sasol), if half of feedstock carbon is available for capture	Increased CO_2 emissions, if synfuels are produced without CCS
Geological storage	Create 3500 Sleipners	Durable storage, successful permitting
	Nuclear fission	
9. Nuclear power for coal power	Add 700 GW (twice the current capacity)	Nuclear proliferation, terrorism, waste
	Renewable electricity and fuels	
10. Wind power for coal power	Add 2 million 1-MW-peak windmills (50 times the current capacity) "occupying" 30×10^6 ha, on land or offshore	Multiple uses of land because windmills are widely spaced
11. PV power for coal power	Add 2000 GW-peak PV (700 times the current capacity) on 2×10^6 ha	PV production cost
12. Wind H_2 in fuel-cell car for gasoline in hybrid car	Add 4 million 1-MW-peak windmills (100 times the current capacity)	H_2 safety, infrastructure
13. Biomass fuel for fossil fuel	Add 100 times the current Brazil or U.S. ethanol production, with the use of 250×10^6 ha (one-sixth of world cropland)	Biodiversity, competing land use
	Forests and agricultural soils	
14. Reduced deforestation, plus reforestation, afforestation, and new plantations.	Decrease tropical deforestation to zero instead of 0.5 GtC/year, and establish 300 Mha of new tree plantations (twice the current rate)	Land demands of agriculture, benefits to biodiversity from reduced deforestation
15. Conservation tillage	Apply to all cropland (10 times the current usage)	Reversibility, verification

15 strategies to achieve a reduction of 1 Gt C / a in 50 years

Potential stabilization wedges (= 25 Gt C)

Pacala & Socolow (2004)