Storage of CO_2 below the Seabed

Leakage Potential and Environmental Risks

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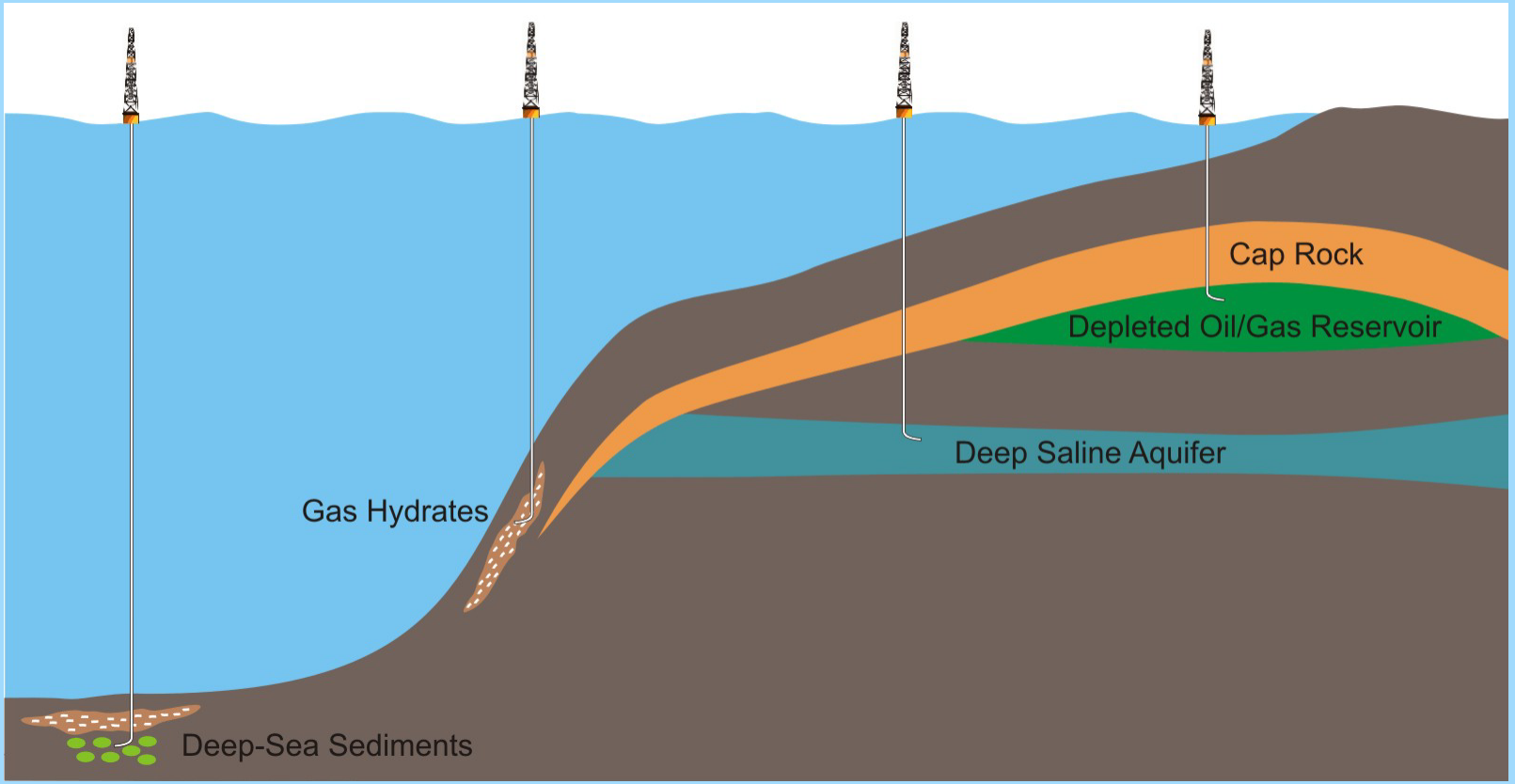
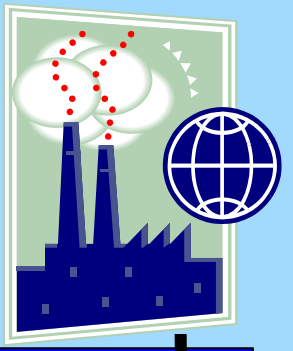
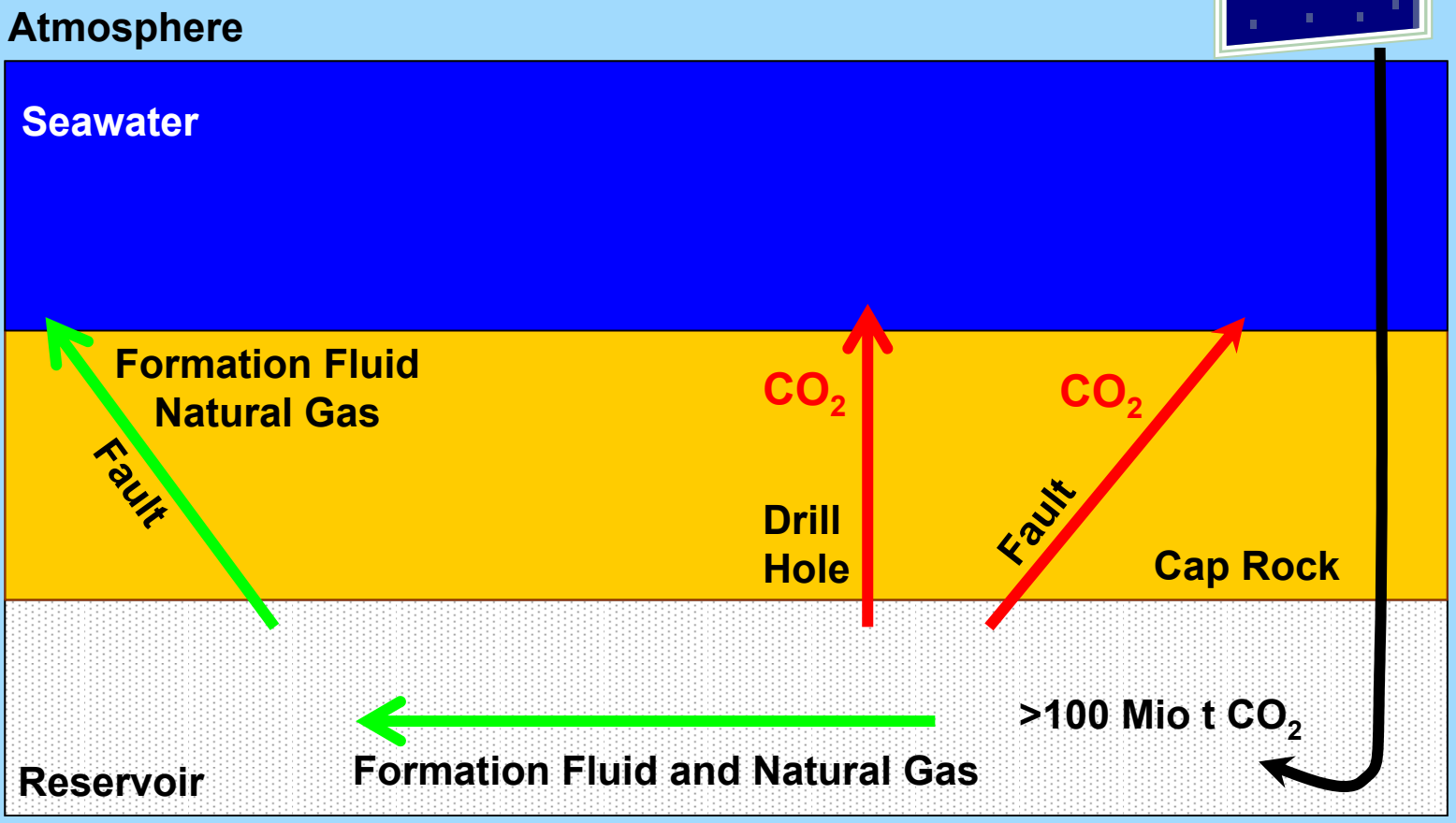
Storage of CO_2 below the Seabed



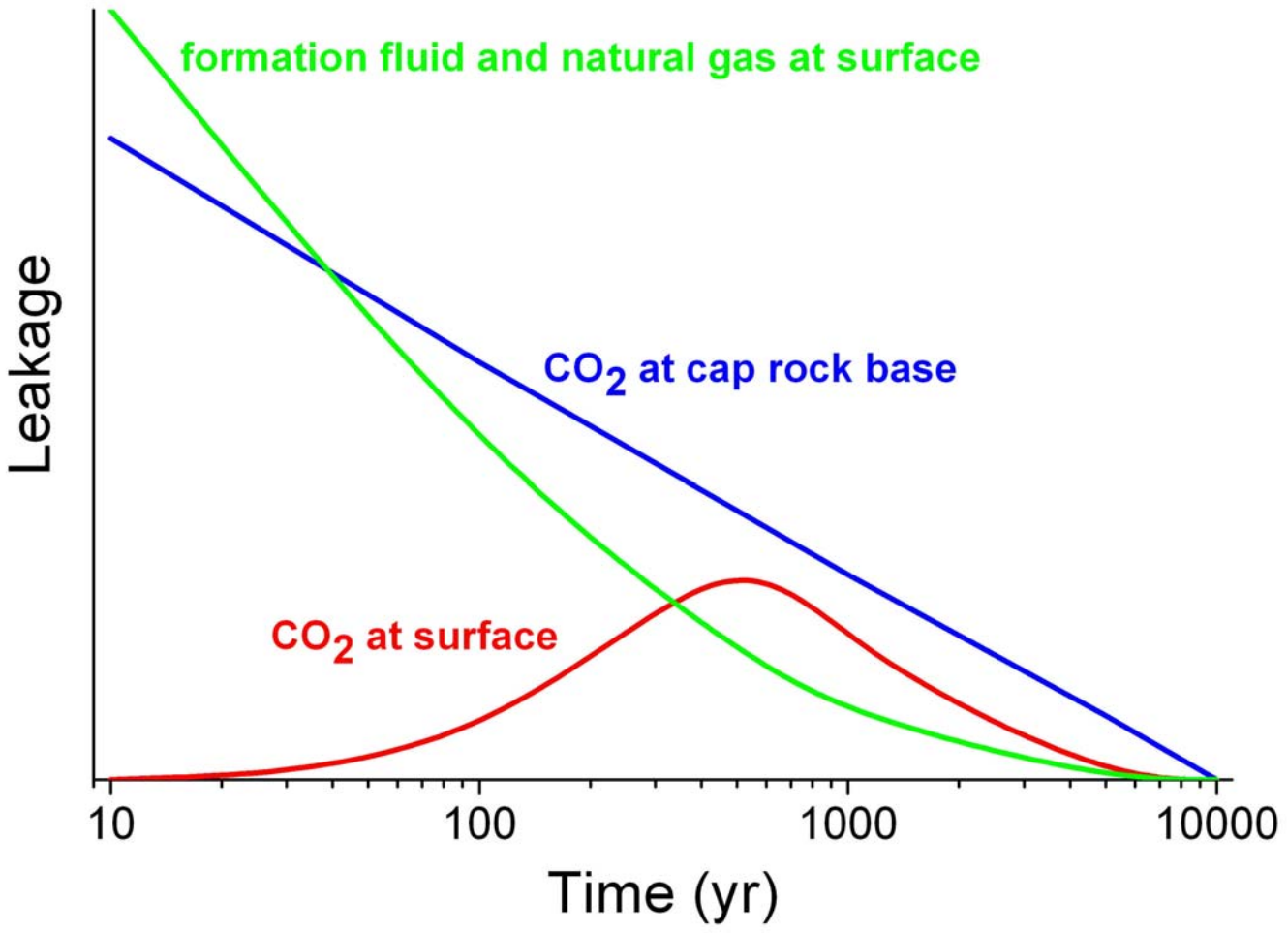
Safety, Costs

Leakage

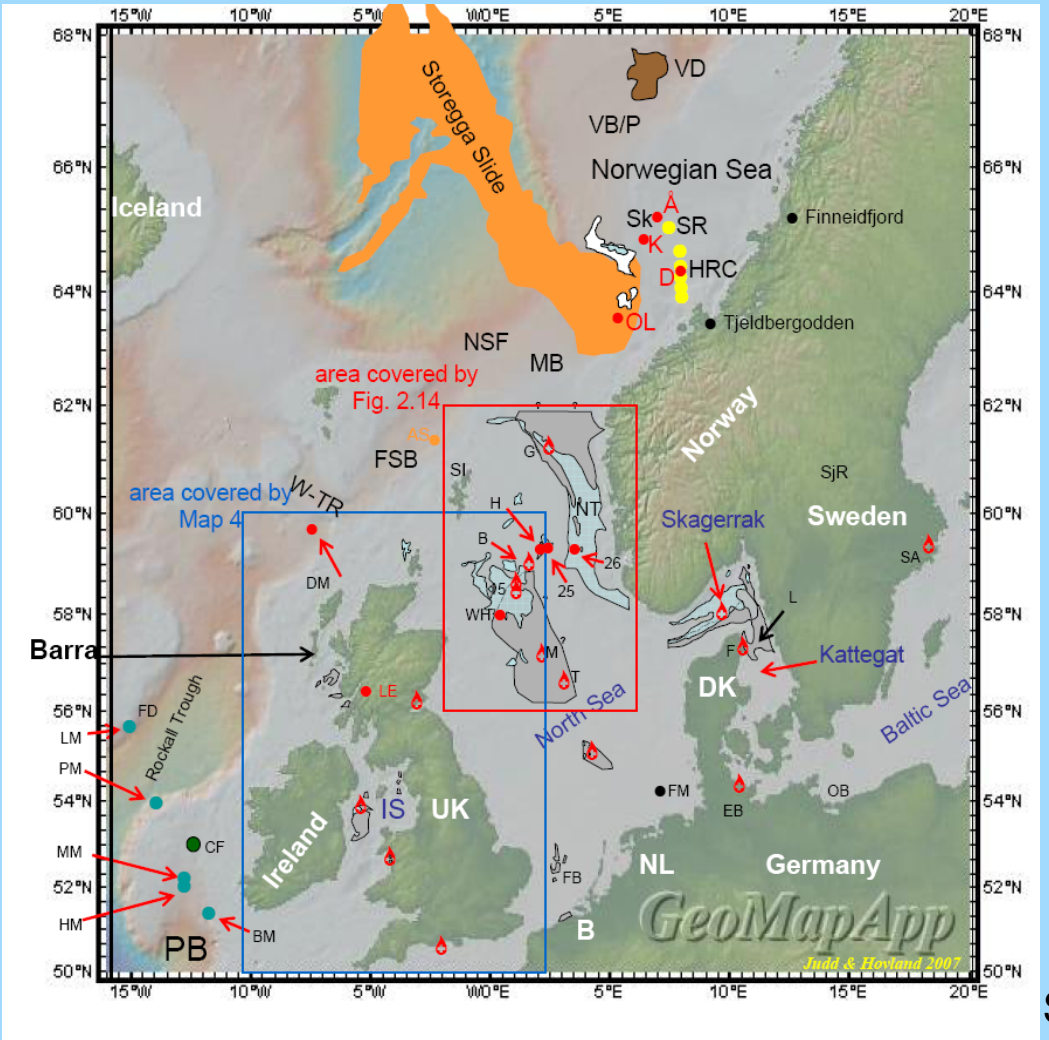



Atmosphere
Seawater
Formation Fluid
Natural Gas
Fault
CO_2
Drill
Hole
CO_2
Fault
Cap Rock
>100 Mio t CO_2
Formation Fluid and Natural Gas
Reservoir

Leakage over Time



Natural Seepage at the Seafloor
-North Sea-



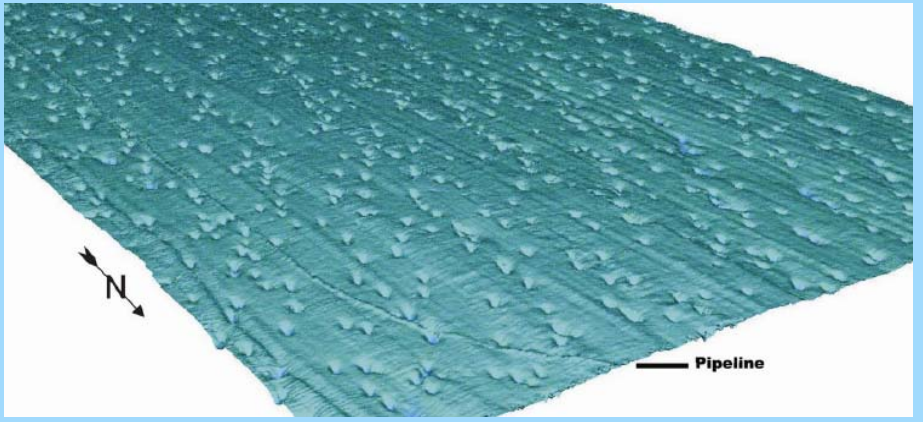
Legend

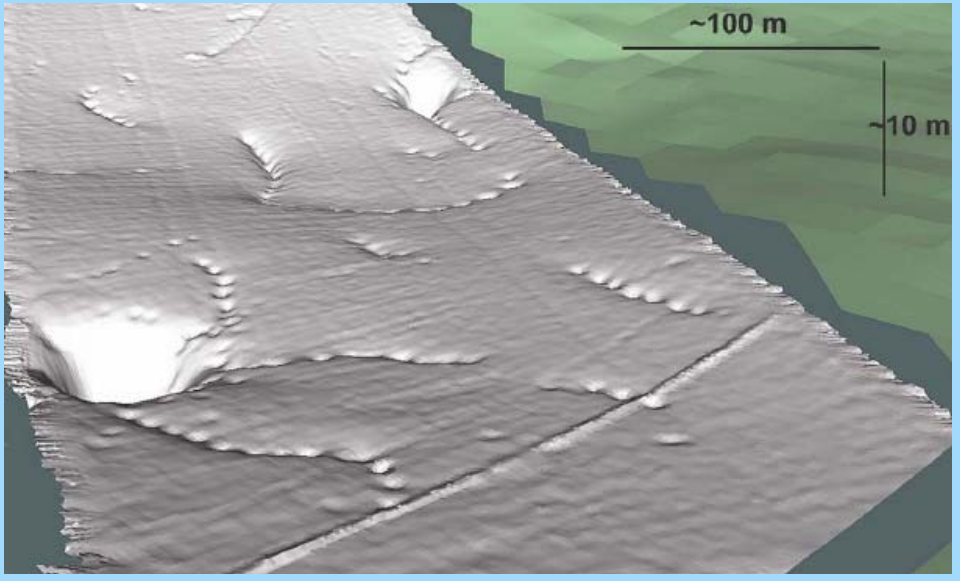
Seep areas

Pockmark areas

Source: Judd & Hovland (2007)

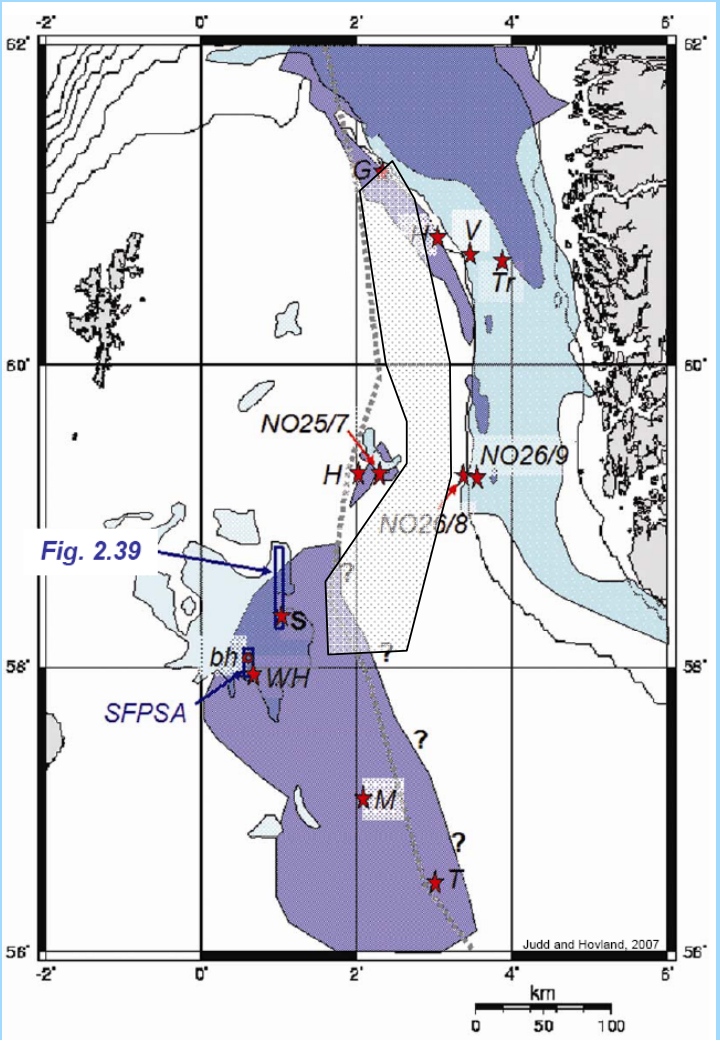
Natural Seepage at the Seafloor
-North Sea Pockmarks-





Source: Judd & Hovland (2007)

Natural Seepage at the Seafloor
-North Sea off Norway-

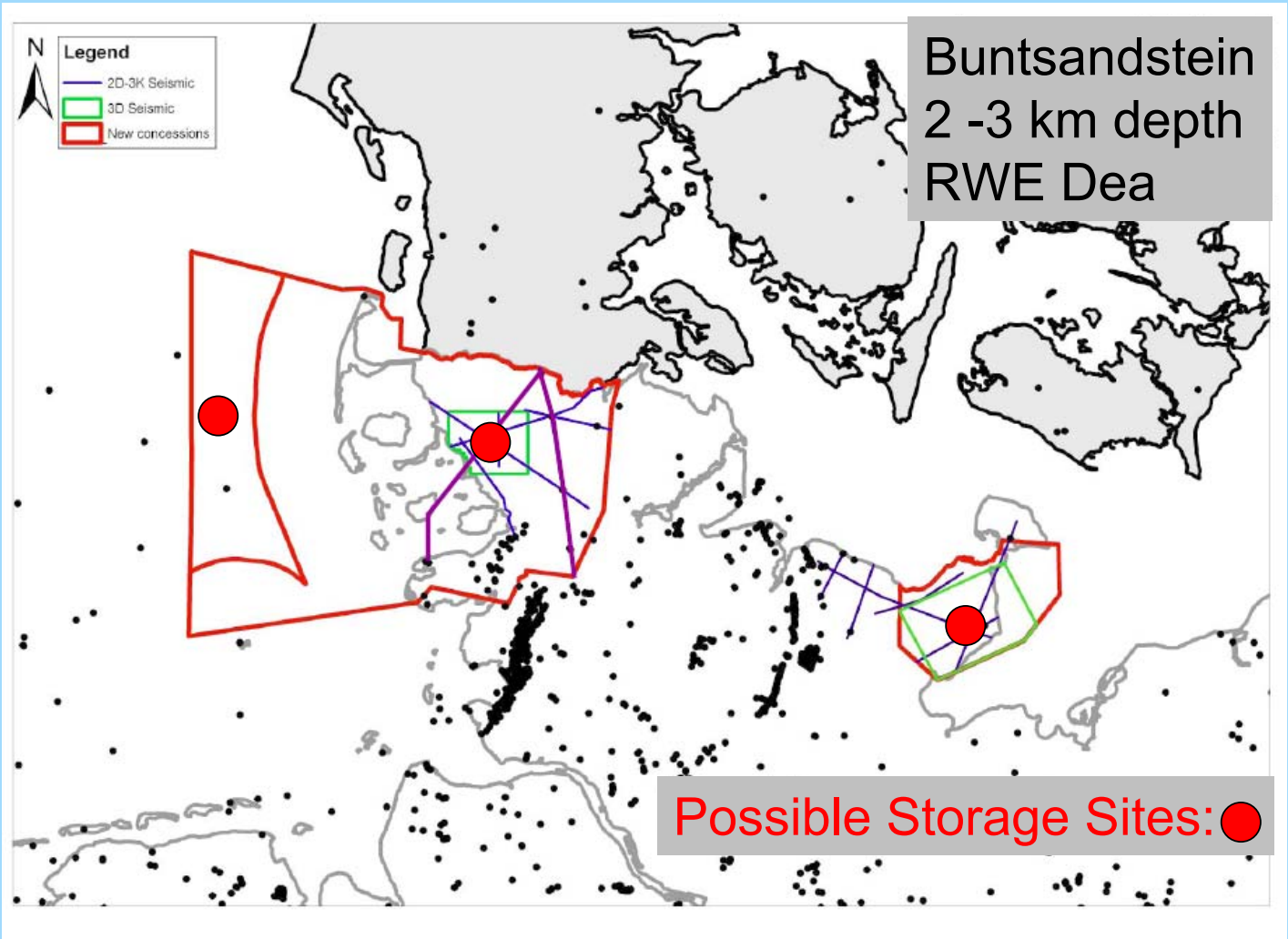


Legend

- Seeps
- Shallow gas
- Pockmark areas
- Utsira Sand

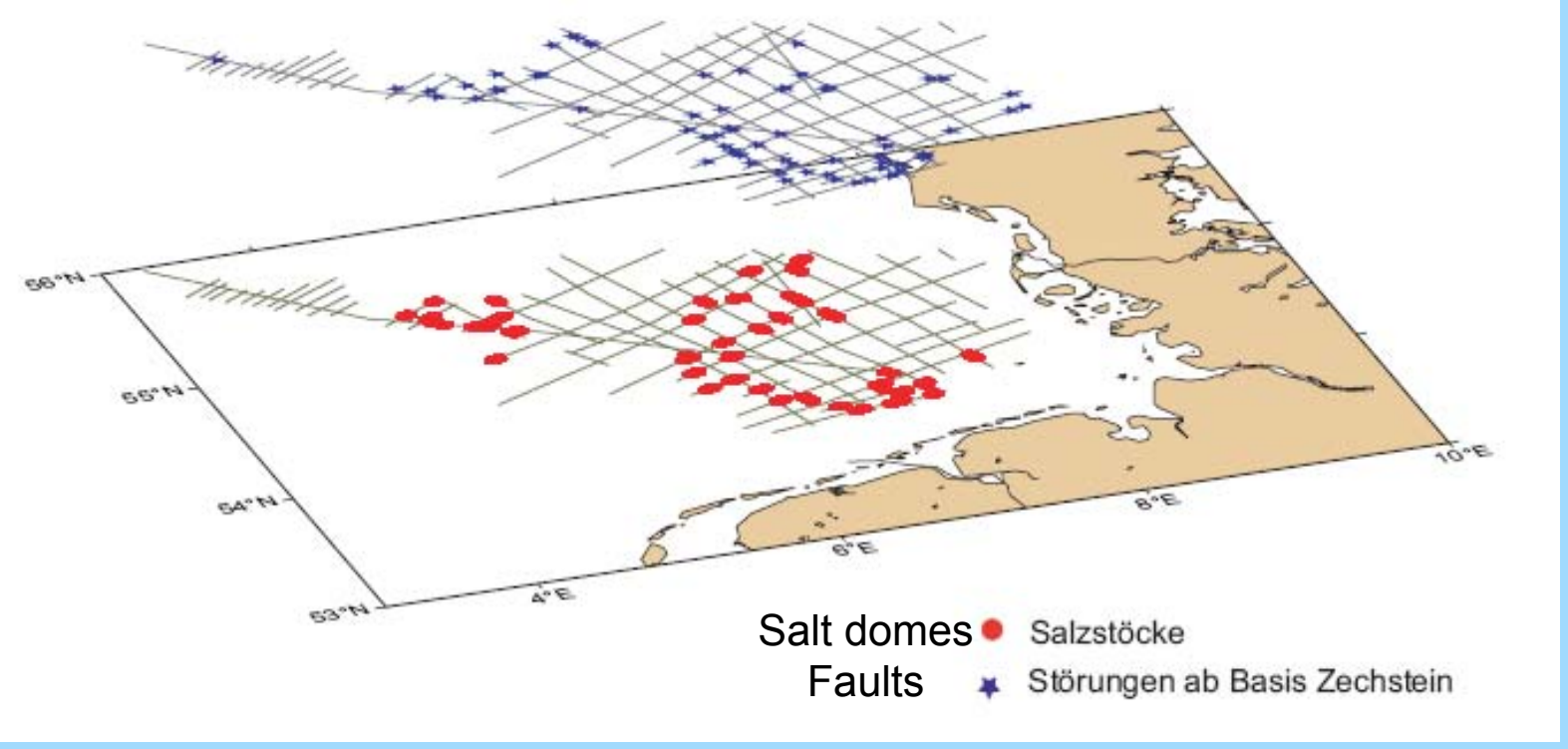
Source: Judd & Hovland (2007)

Proposed CO_2-Storage in Northern Germany



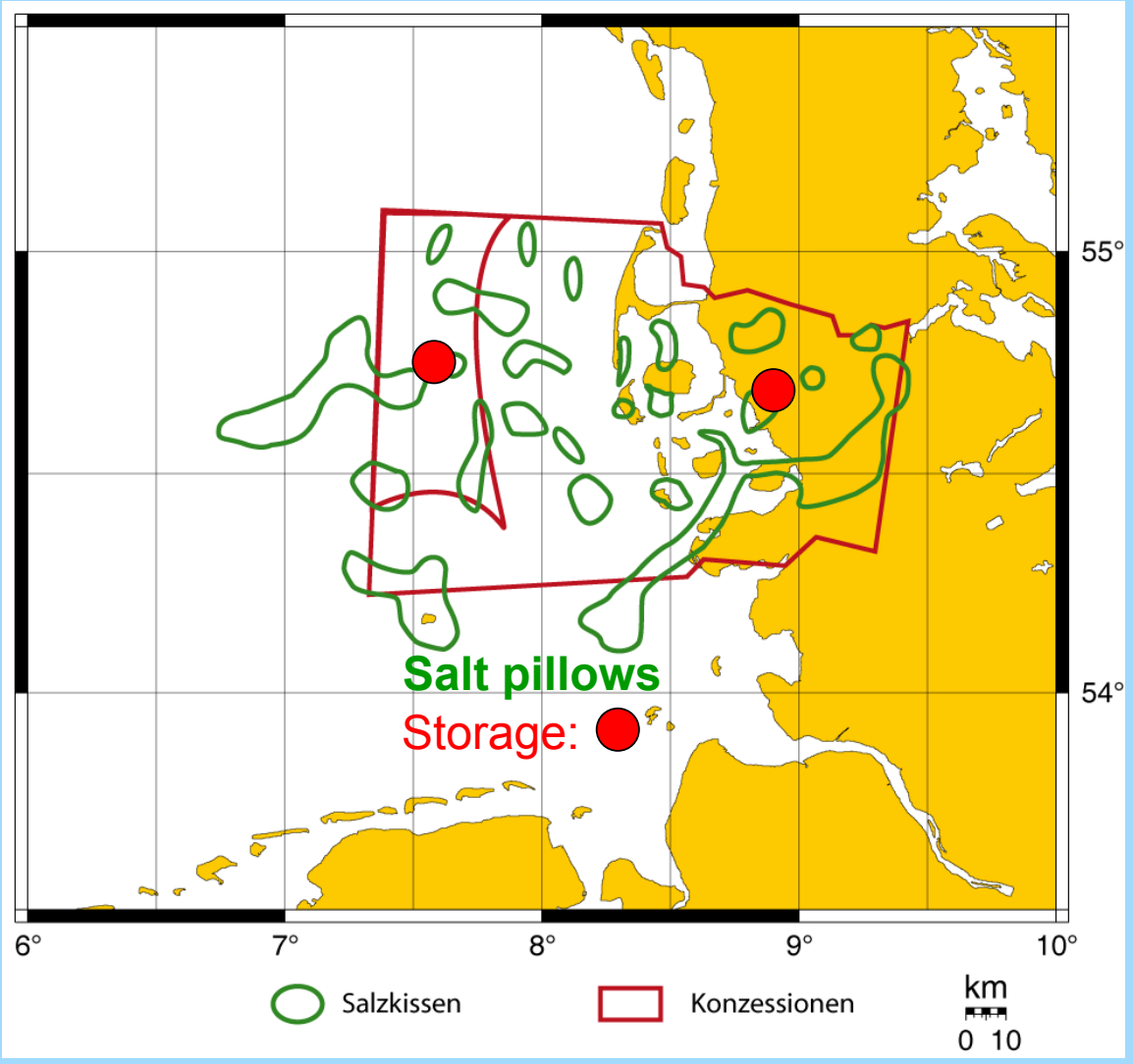
Source: RWE Dea (2008)

Salt Diapirs and Faults
-North Sea off Germany-

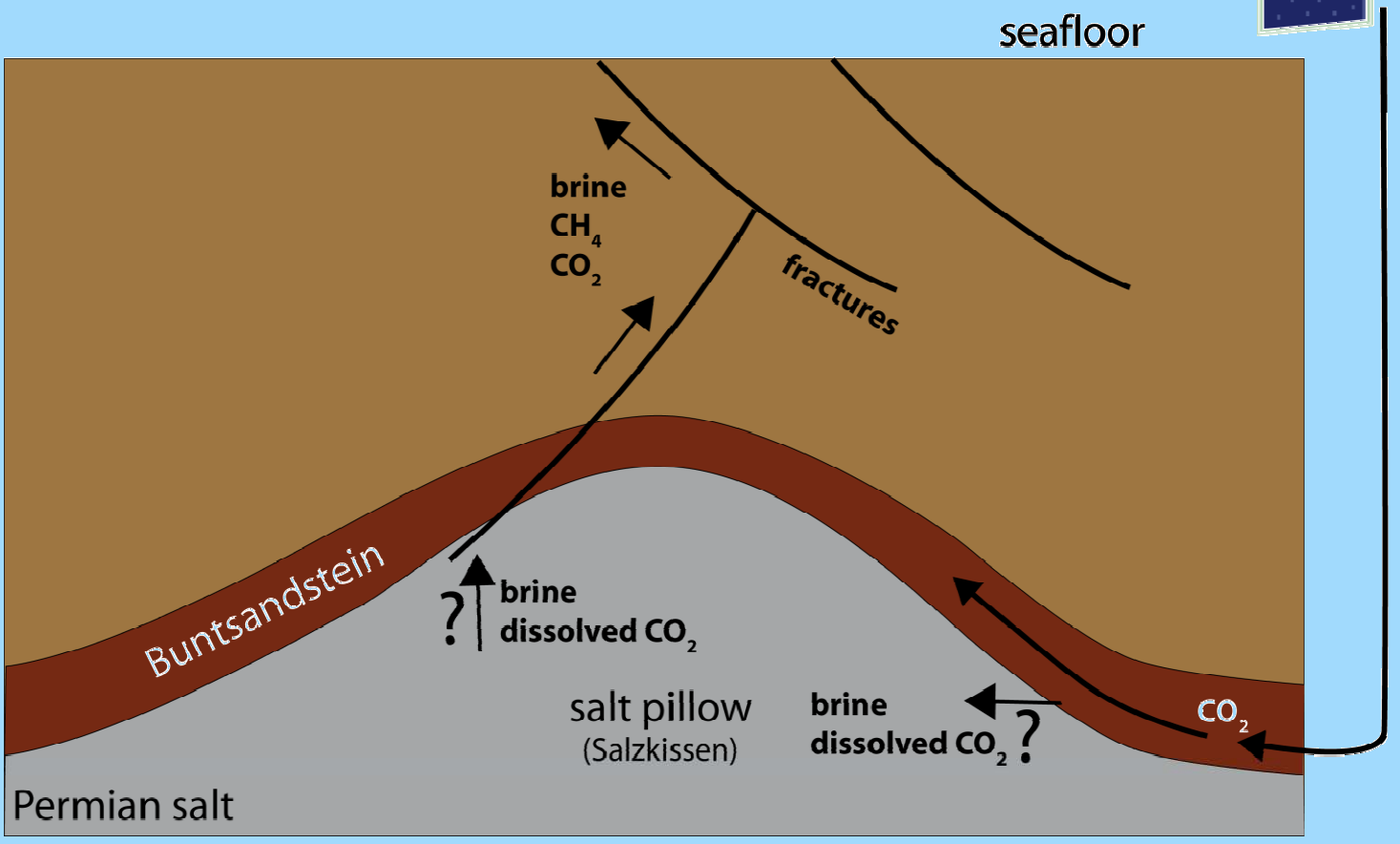


Source: Schlesinger (2006)

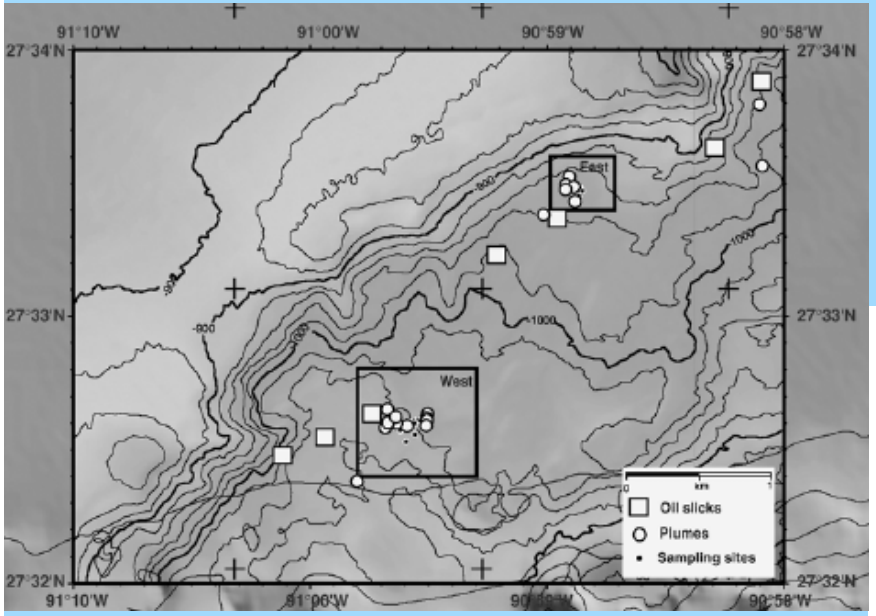
Proposed CO_2-Storage in Northern Germany

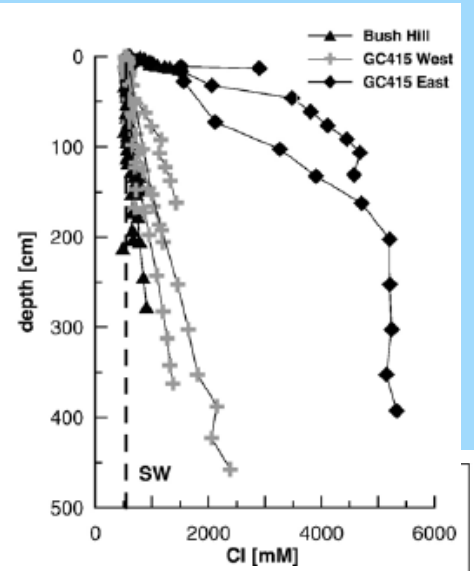


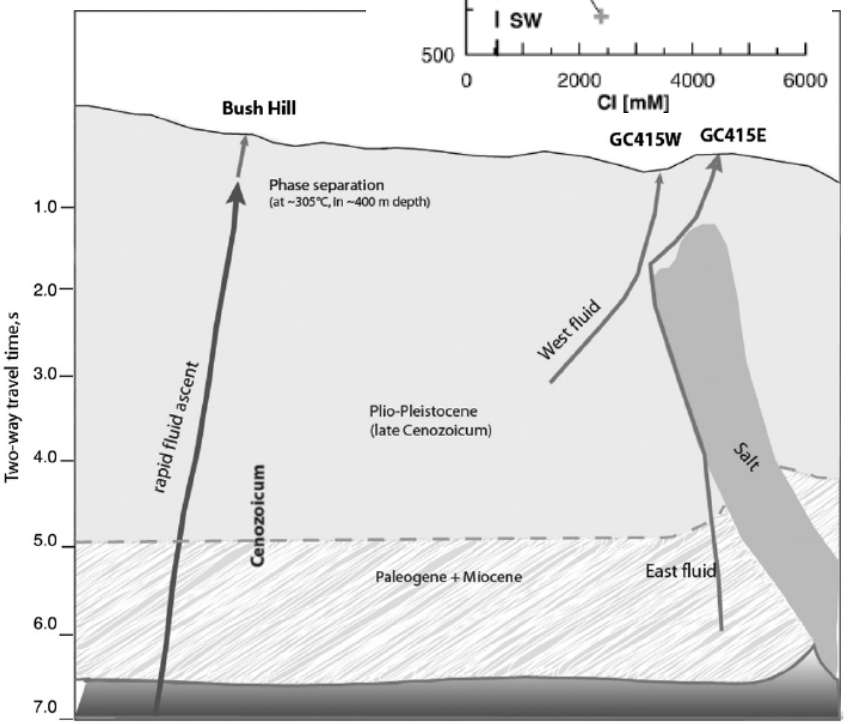
Potential Pathways for Leakage from the German Buntsandstein



Natural Seepage at the Seafloor
-Salt Diapirs, Gulf of Mexico-

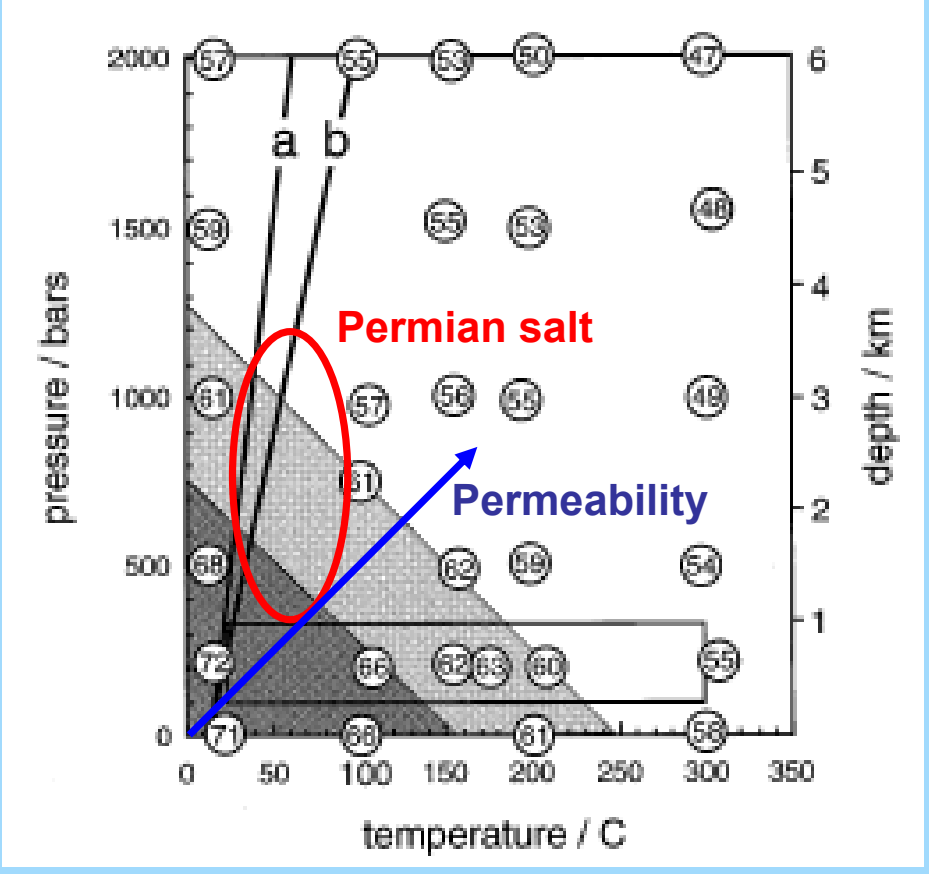






Source: Reitz et al. (2007)

Dihedral Angles of Halite in Brine

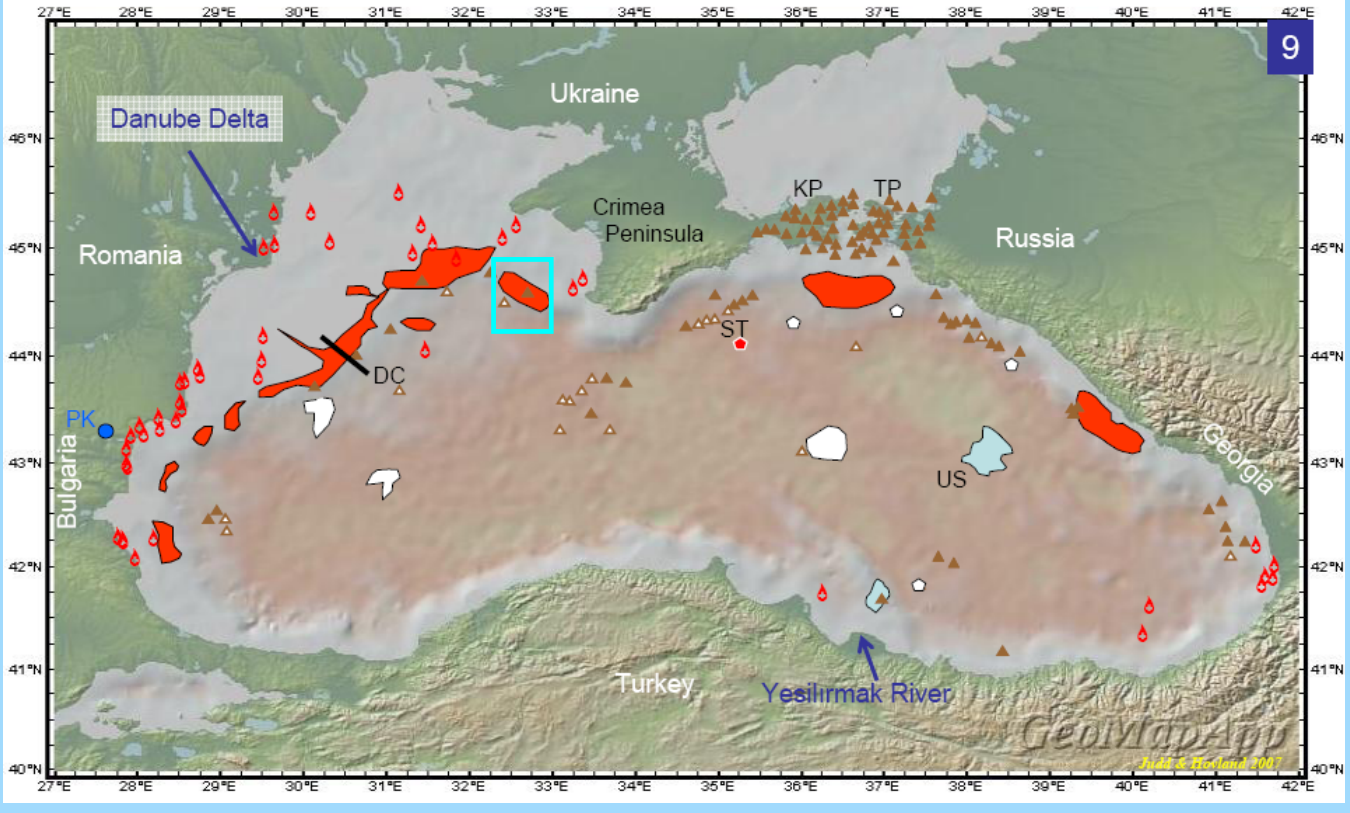


Halite permeability for water and brine

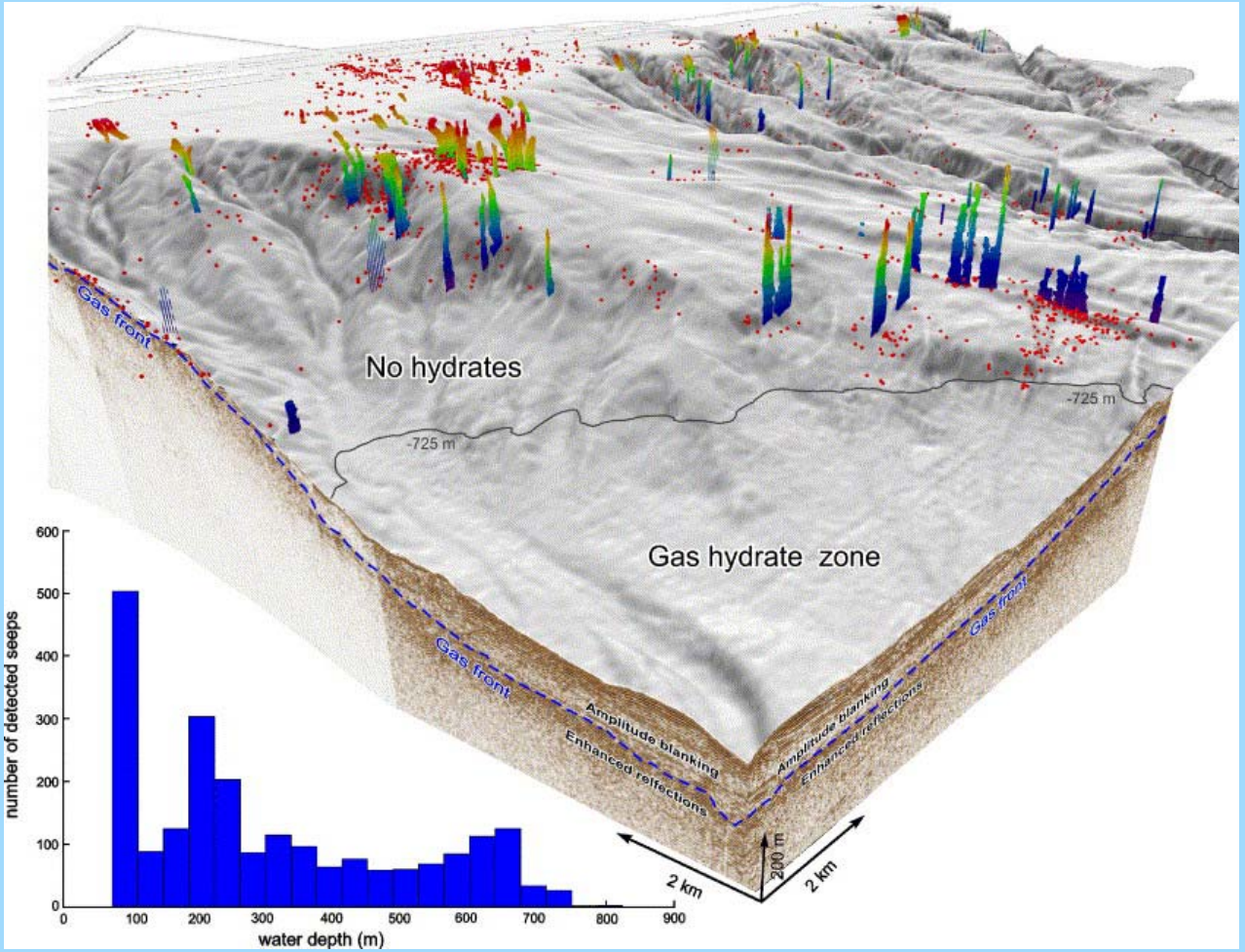
Permeability
high
medium
low

Source: Lewis & Holness (1996)

Natural Seepage at the Seafloor
-Black Sea-

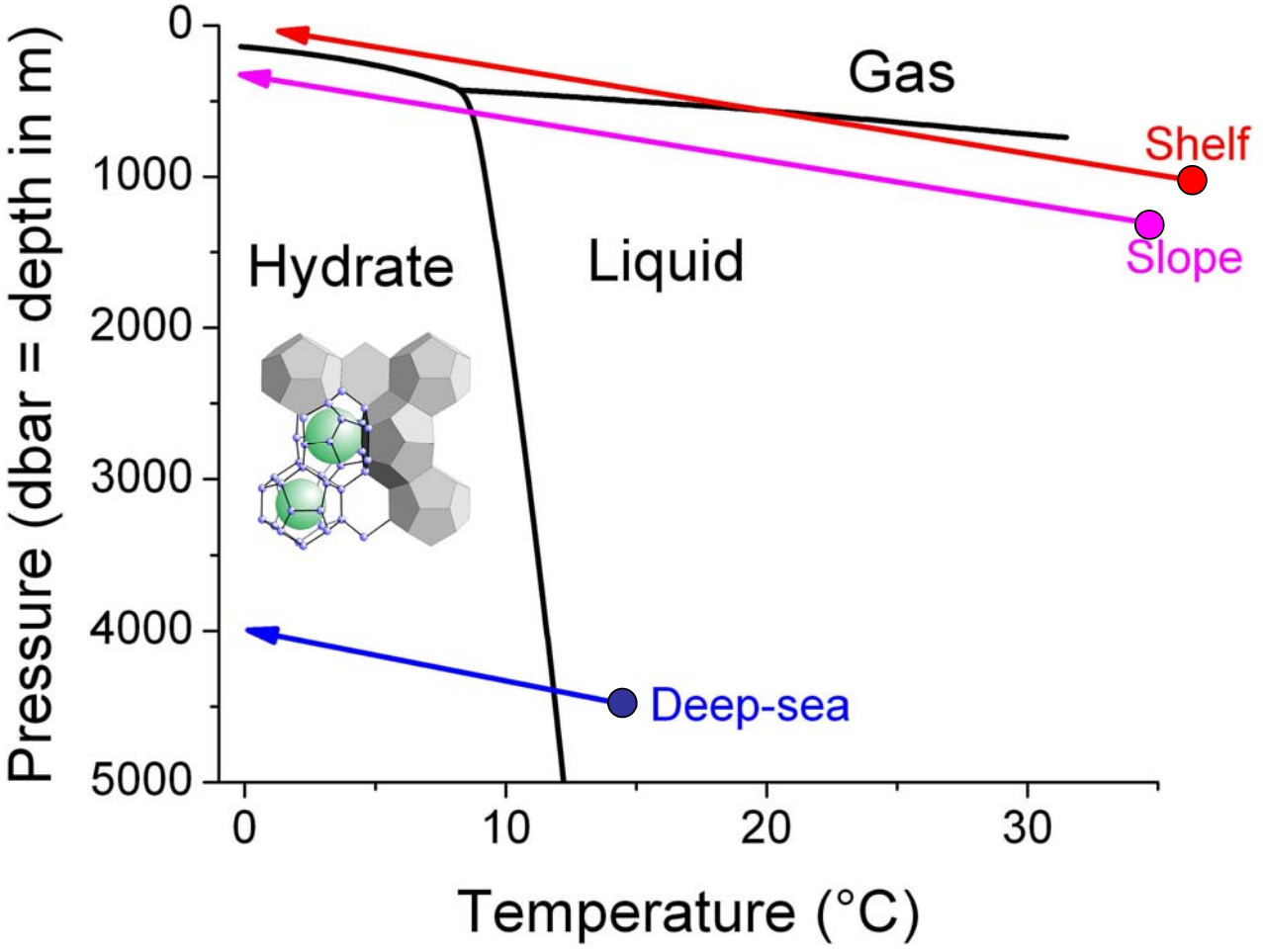


Natural Seepage at the Seafloor
-Black Sea Gas Seeps-

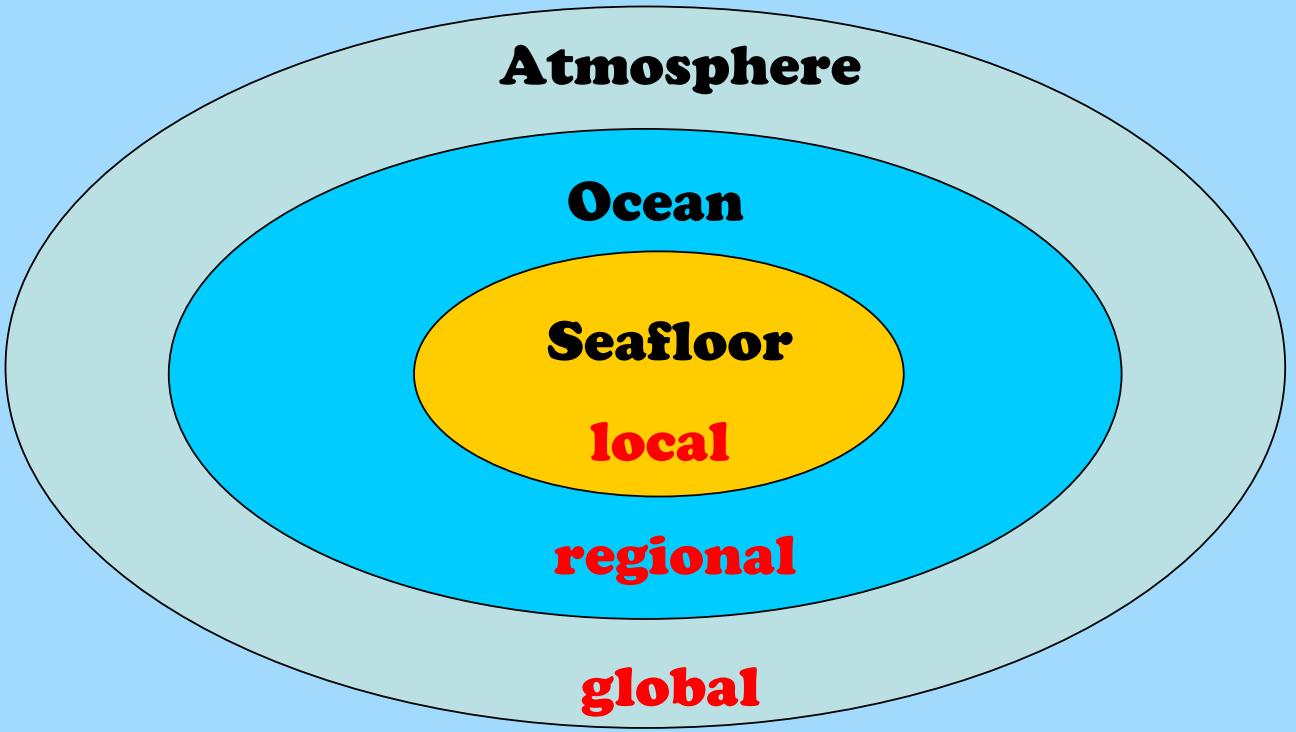


Source: Naudts et al. (2006)

Phase Diagram of CO_2



CO_2-Leakage at the Seafloor
-Environmental Impact-



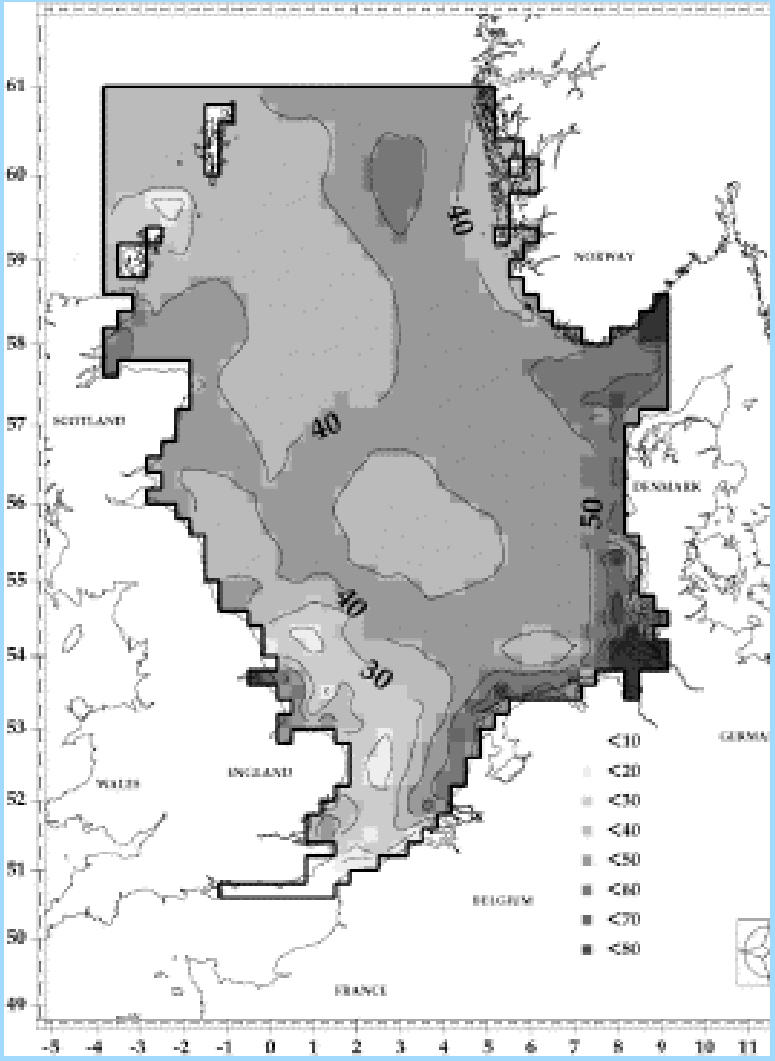
CO_2-Leakage at the Seafloor

Criteria for the maximum permissible CO_2 flux from submarine CO_2 disposal sites

CO_2-leakage should not affect:

- **Benthic ecosystems at the disposal site**
- **Pelagic ecosystems and seawater pH**
- **Global atmospheric pCO_2-values**

Natural CO_2-fluxes at the Seafloor



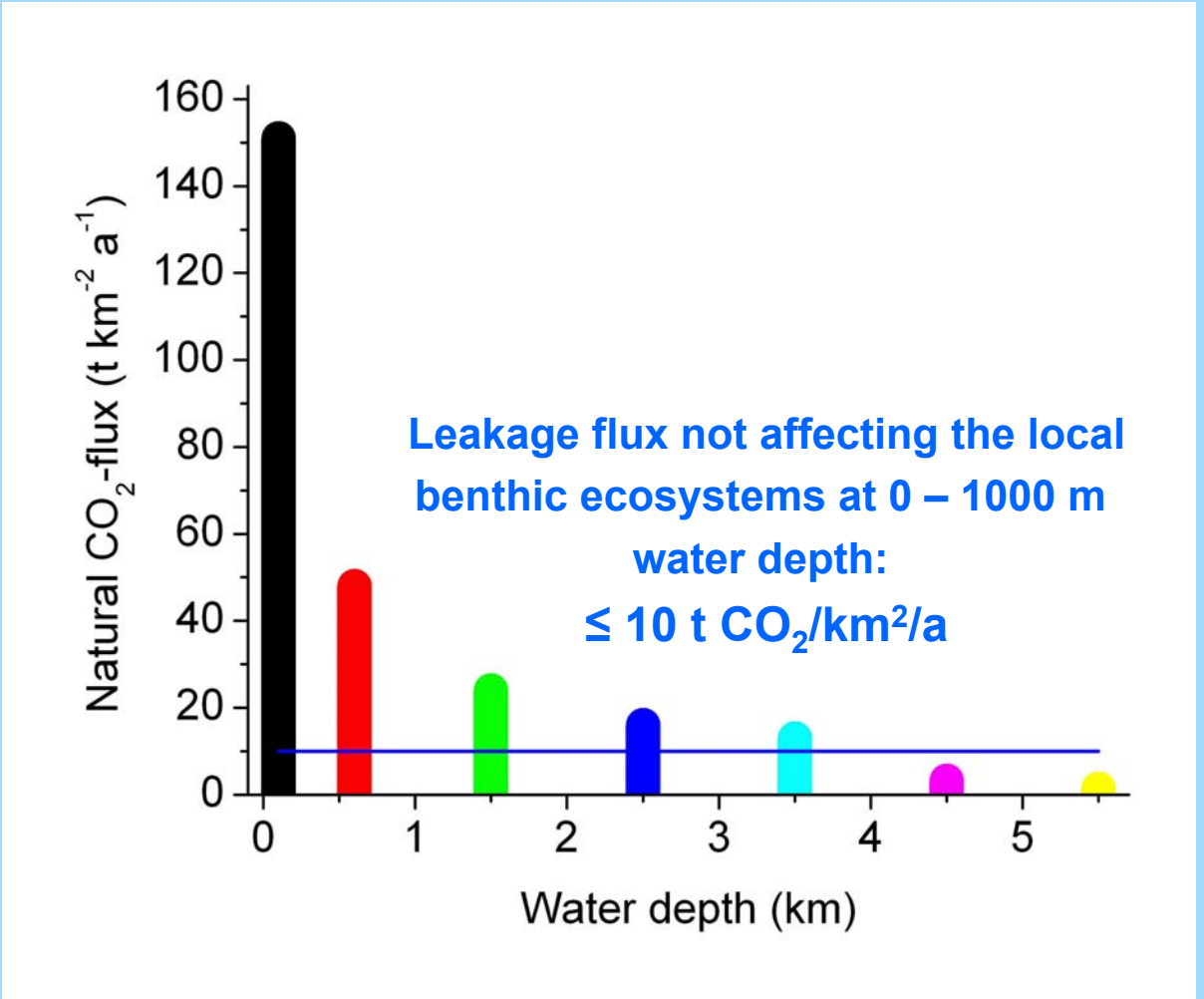
Benthic CO_2-fluxes in the North Sea induced by the degradation of particulat organic matter raining to the seafloor

Mean annual fluxes are given in g C m^{-2} a^{-1}

Annual flux averaged ove the entire North Sea:
~150 t CO_2 km^{-2} a^{-1}

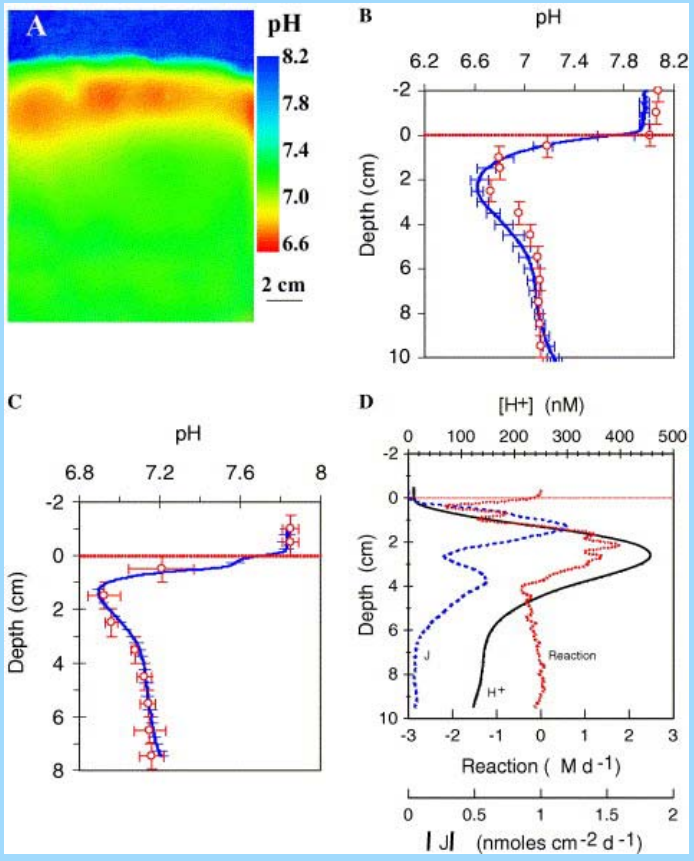
Source: Luff & Moll (2004)

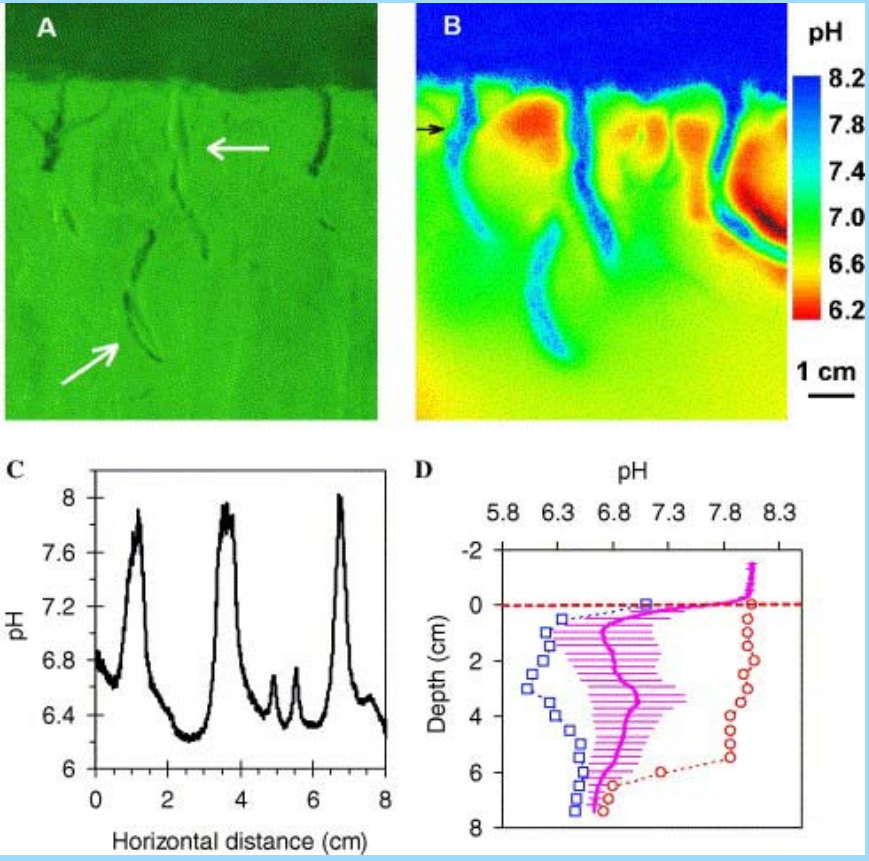
Natural CO_2-fluxes at the Seafloor



Global mean fluxes after Burdige (2007)

Natural pH Values in Shelf Surface Sediments

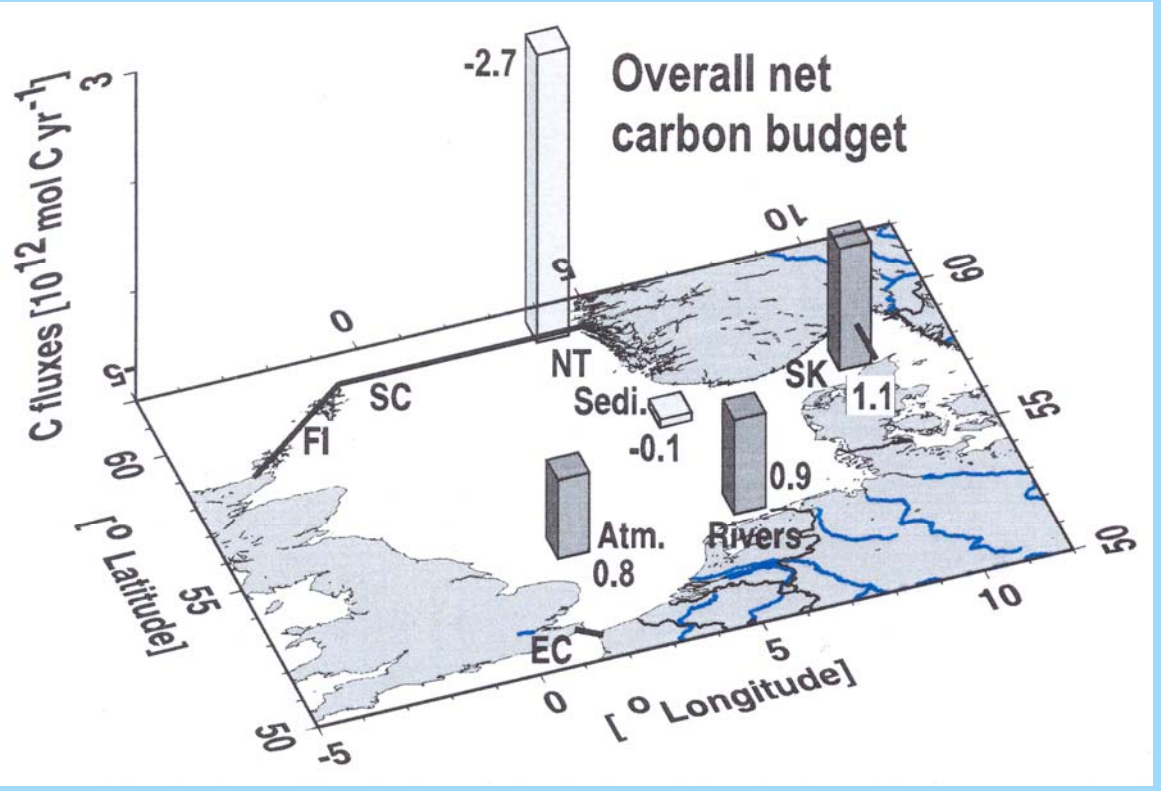




Source: Zhu et al. (2006)

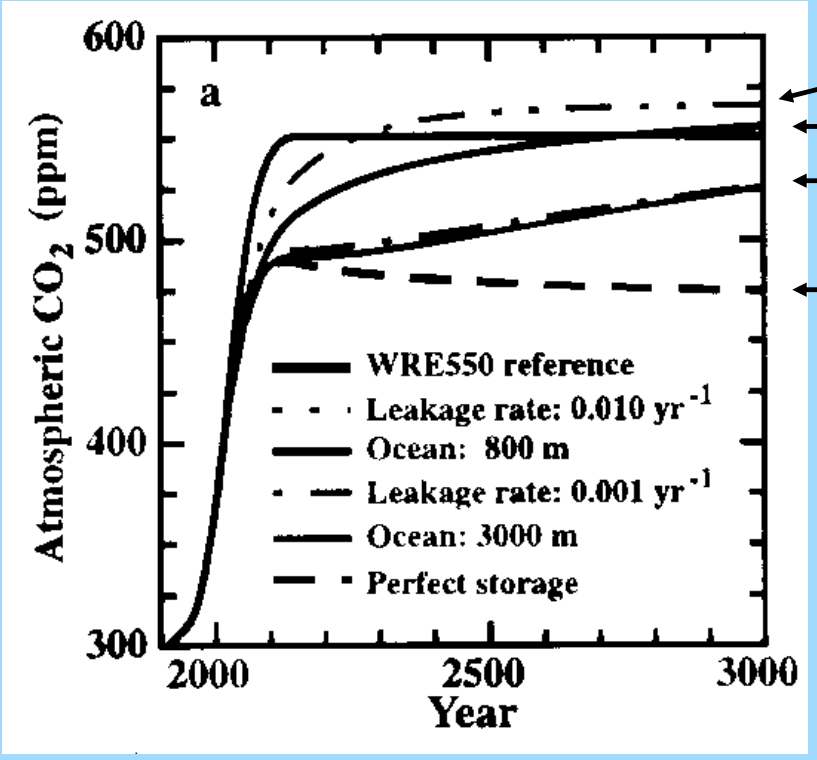
pH in CO_2-saturated solutions: 3.5 – 4.5

North Sea CO_2-Budget



Total CO_2-uptake: 123 Mt CO_2 a^{-1} or 214 t CO_2 km^{-2} a^{-1} (Thomas et al. 2005)

Effect of Leakage on Atmospheric pCO_2



1 % a^{-1}

no CCS

0.1 % a^{-1}

0 % a^{-1}

from Haugan & Joos (2004)

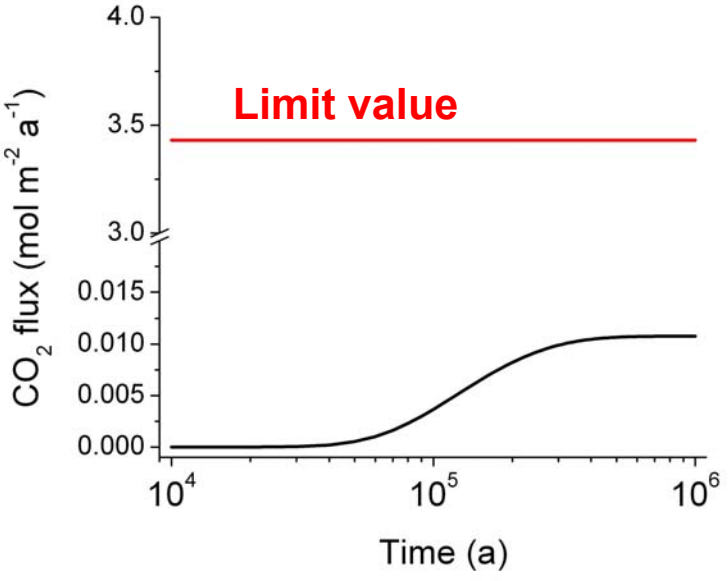
- Leakage rate should be <0.01%/a to achieve low pCO_2 values via CCS
- Inventory of submarine CO_2-disposal sites: ~1 – 10 Mt CO_2/km^2
- Leakage rate of 0.01 %/a corresponds to ~100 – 1000 t $CO_2/km^2/a$

Limit Value for CO_2-Leakage from Submarine Disposal sites

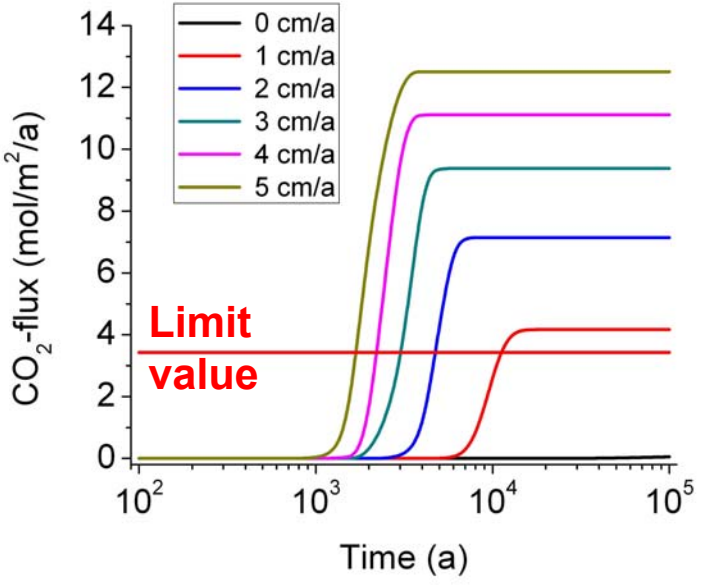
$\Rightarrow$ **CO_2-leakage flux of ≤10 t/km^2/a would not affect benthic and pelagic ecosystems and would allow for a significant reduction of atmospheric pCO_2 via CCS**

CO_2-leakage remains below the limit value in diffusion-controlled systems and at upward fluid flow velocities <1cm/a

Diffusion

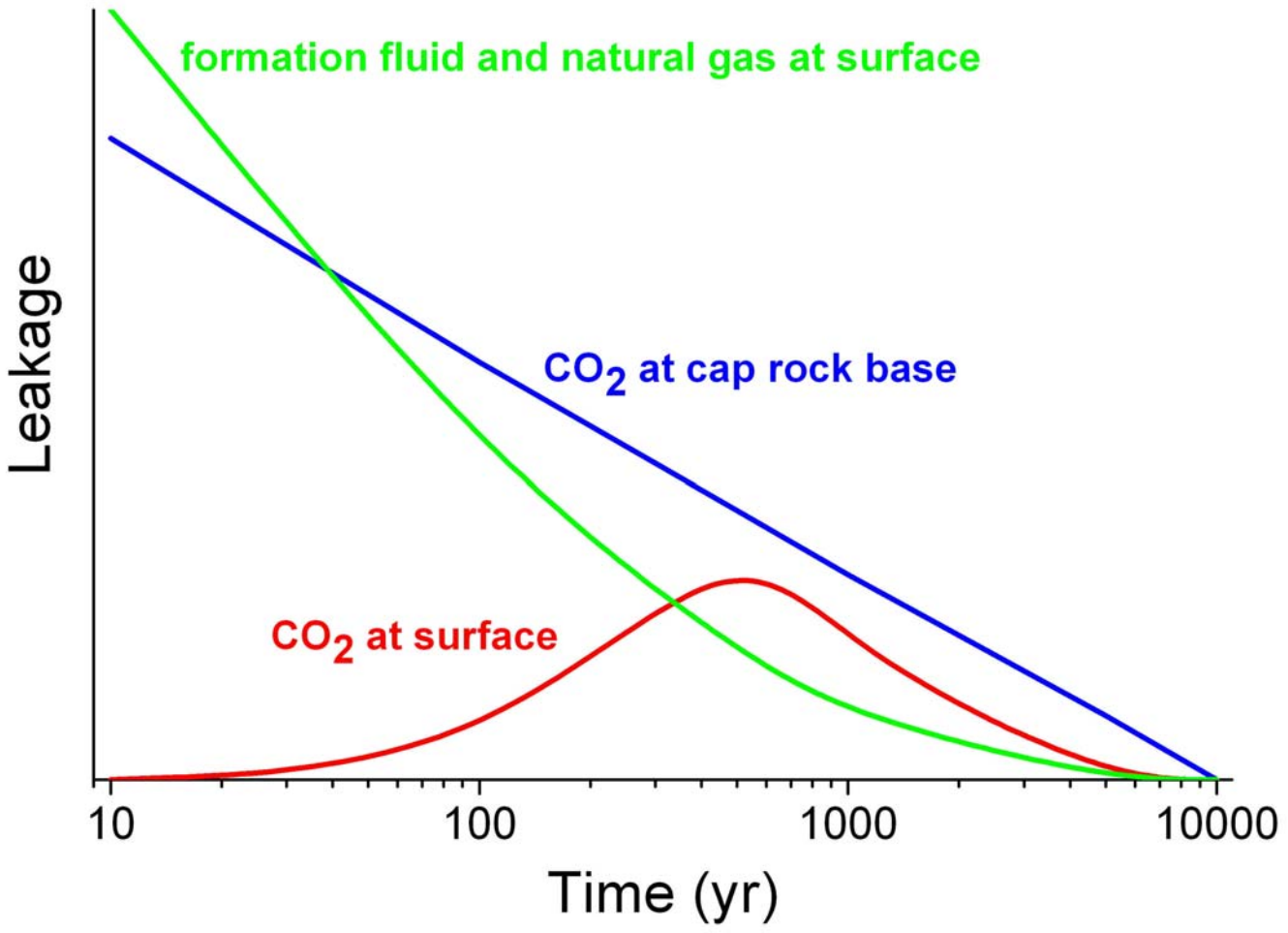


Advection



Advection at natural seeps: 1 – 1000 cm/a

Leakage over Time



Conclusions

- Negative effects on ocean ecosystems can be avoided at leakage rates ≤ 10 t CO_2 km^{-2} yr^{-1} and fluid ascent velocities < 1 cm/a.

- CO_2-leakage from storage sites should only be charged if the flux is larger than 10 t of CO_2 km^{-2} yr^{-1}.

- Leakage of natural gas (methane) induced by CO_2-storage has to be monitored and should be charged in a similar way as CO_2-leakage.

Conclusions

- During the operation period of a storage site, monitoring should focus on subsurface CO_2 imaging and on the seepage of formation fluids and natural gas at the seafloor.
- With this approach, monitoring during the operation period will greatly help to constrain the magnitude of future CO_2 emissions at the surface.
- Financial securities should be defined according to the monitoring results obtained during the operation phase.