Storage efficiency factor – A wildcard for subsurface storage cost and safety

Harald Johansen, Kjersti Iden and Harry Hjelmseth
Institute for Energy Technology

Background

Sleipner-Utsira
Almost 15 Mt have been injected over 15 years without major problems!

This could be due to the **large** regional extent of the **pressure compartment** !?
But it could also be due to a high extent of water **dissolution** and **mineralization** ?!

Snøhvit: 23 Mt planned to be injected in Tubåen – Reservoir appears to be ″full″ after less than 1 Mt of injection !?

- **has the storage capacity been overestimated?**
- **has the connectivity of the reservoir been overestimated?**
- **is the reservoir full already?**
- **is it a pressure transmissivity problem?**

Reservoir scale **vertical connectivity** is commonly strongly overestimated !
Deep paleo-burial and high paleo-temperatures may have created **diagenetic barriers** to vertical fluid flow !?

One consequence of poor connectivity would be that **dissolution** and mineralization would also be strongly **delayed** or **inhibited**

Injection strategy: arrange for a maximum extent of dissolution and mineralization !

Johansen ??	2 - 2.5 km burial
Longyearbyen ??	3 - 3.5 km paleoburial

Theoretical storage capacity : abundant
Storage efficiency (SE) : limited and uncertain - pressure constraints

3 ways to succeed :

- Capacity >> quantity to be injected
- Concomittant water production
- **Inject in such a way that dissolution and mineralization is maximized**

Anyhow - imperative knowledge for SE assessment :

- **geohistory**
- **compartment structure**

of reservoir and surrounding basin

Water production as a way to increase storage efficiency ?

Expensive drilling and pumping !

Discharge of formation water with heavy metals and radioactivity !

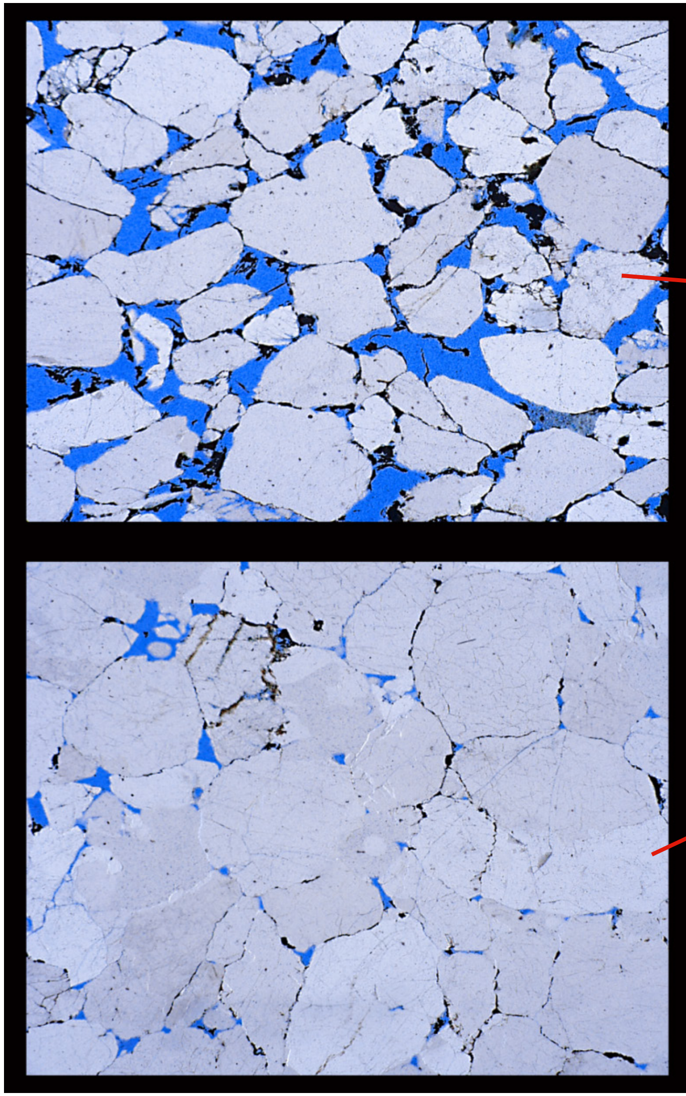
Production well(s) may be be long term leakage path(s)

Factors that affect Storage Efficiency :

Pressure and temperature gradients
Fluid compressibilities
Permeability distribution and anisotropy
Sediment compressibility or expandability
Size of pressure compartment (pressure transmission)
Size of flow compartment (displacitivity)
Water-CO_2 contact area and dissolution of CO_2 into water
Mineralization of CO_2

Diagenetic heterogeneities

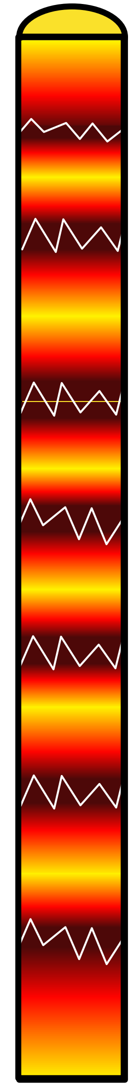
Stylolites



High permeability

Strong vertical permeability anisotropy

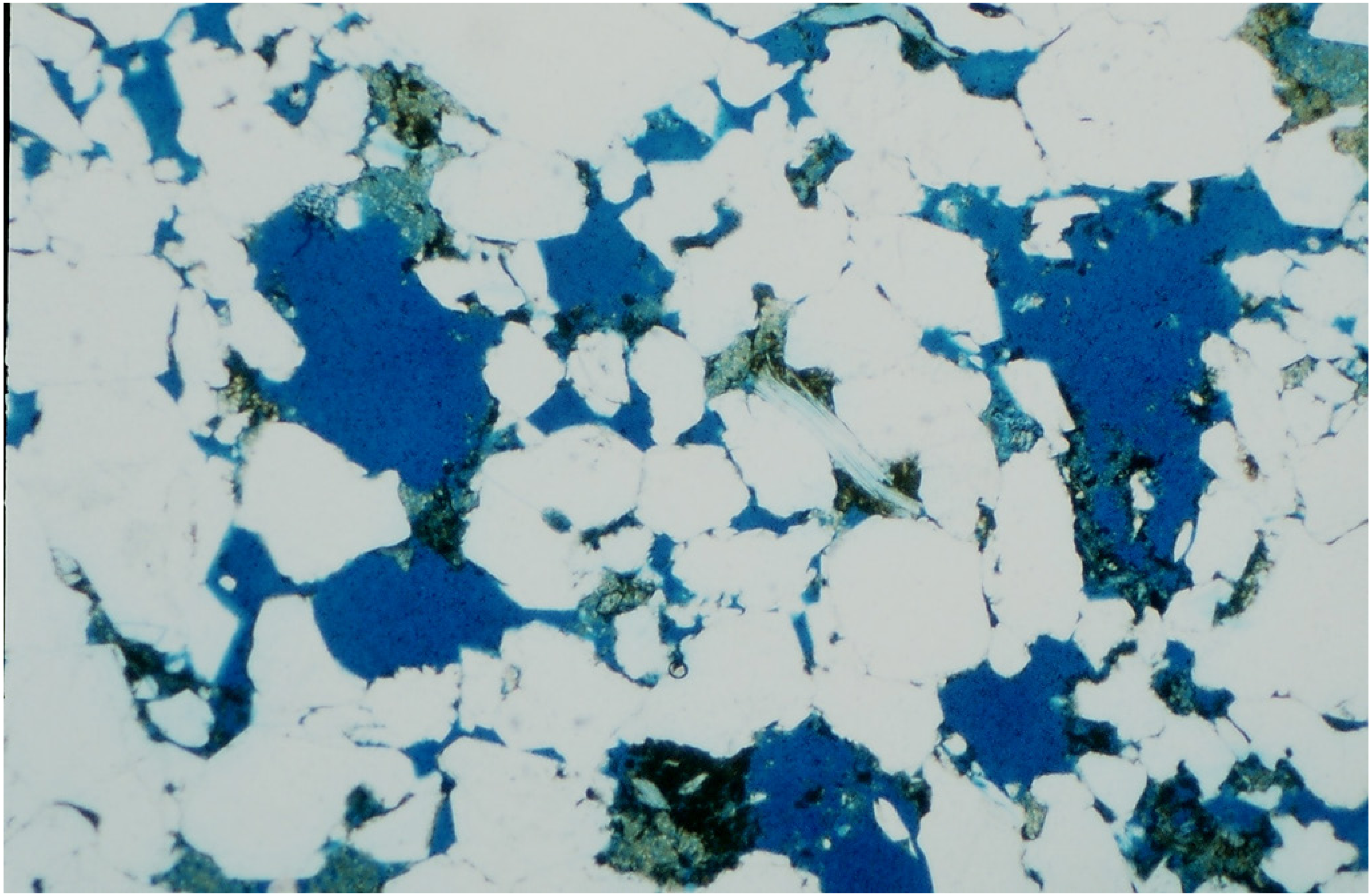
Low permeability



Weak cementation away from stylolites

Strong cementation close to stylolites

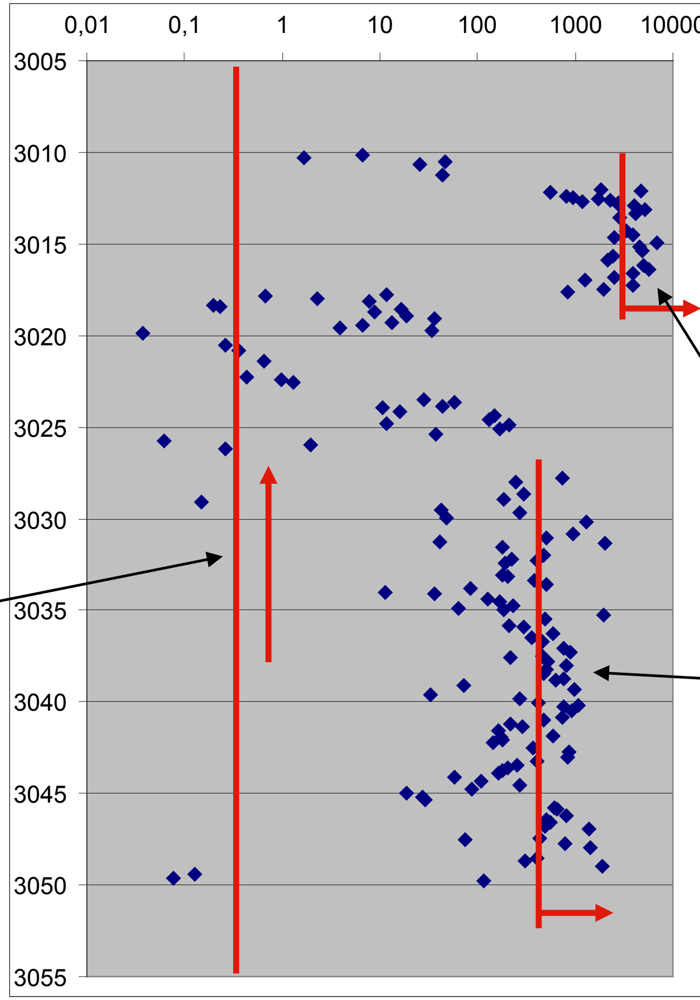
Deeply buried sandstone dominated by secondary porosity



CO_2 rise and water sinking ?

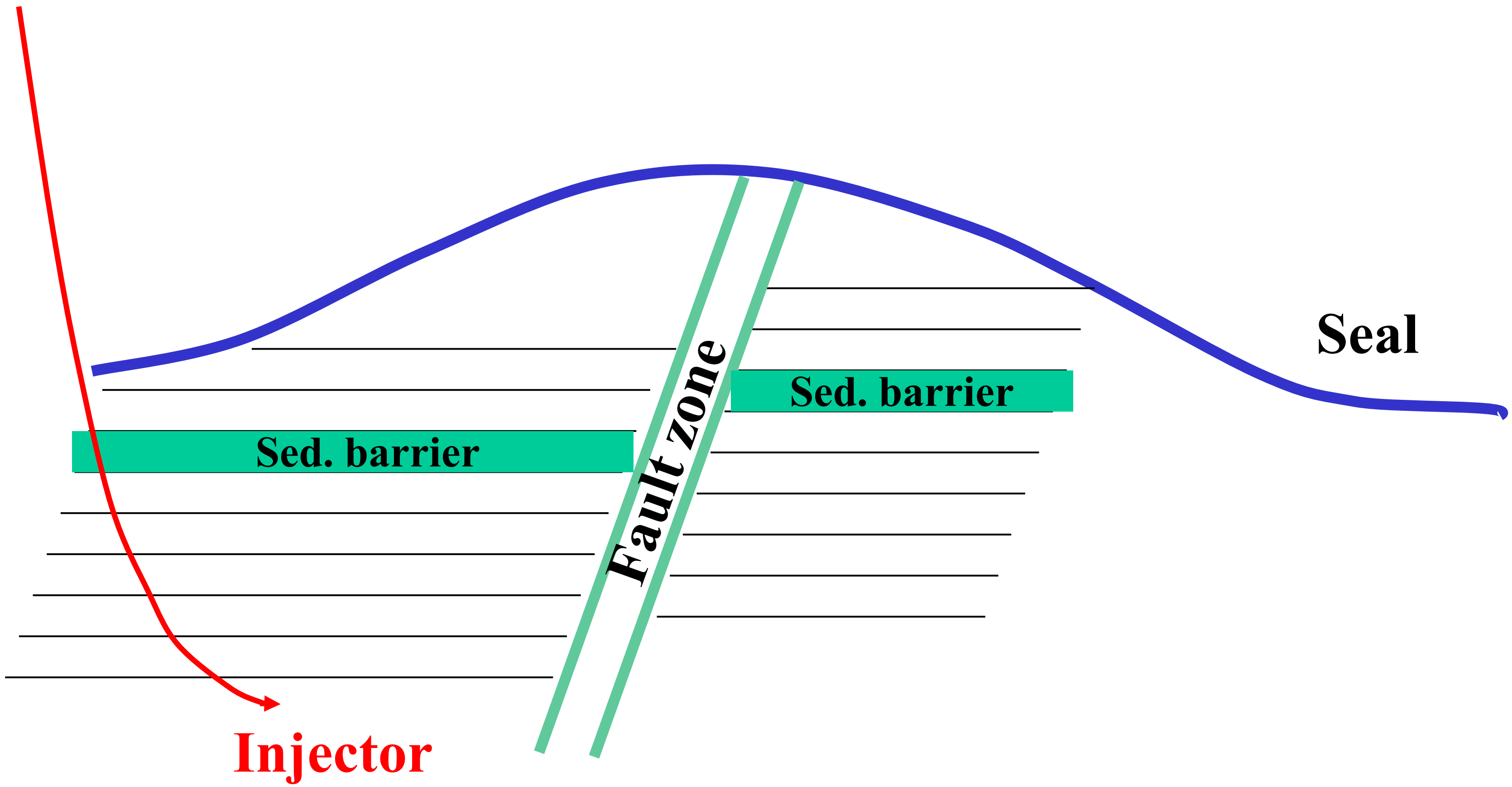
Permeability anisotropy, well 25/5-A1, Frøy Field

Calculated harmonic mean large scale vertical permeability, based on horisontal measurements, and $k_H = 5 \cdot k_V$

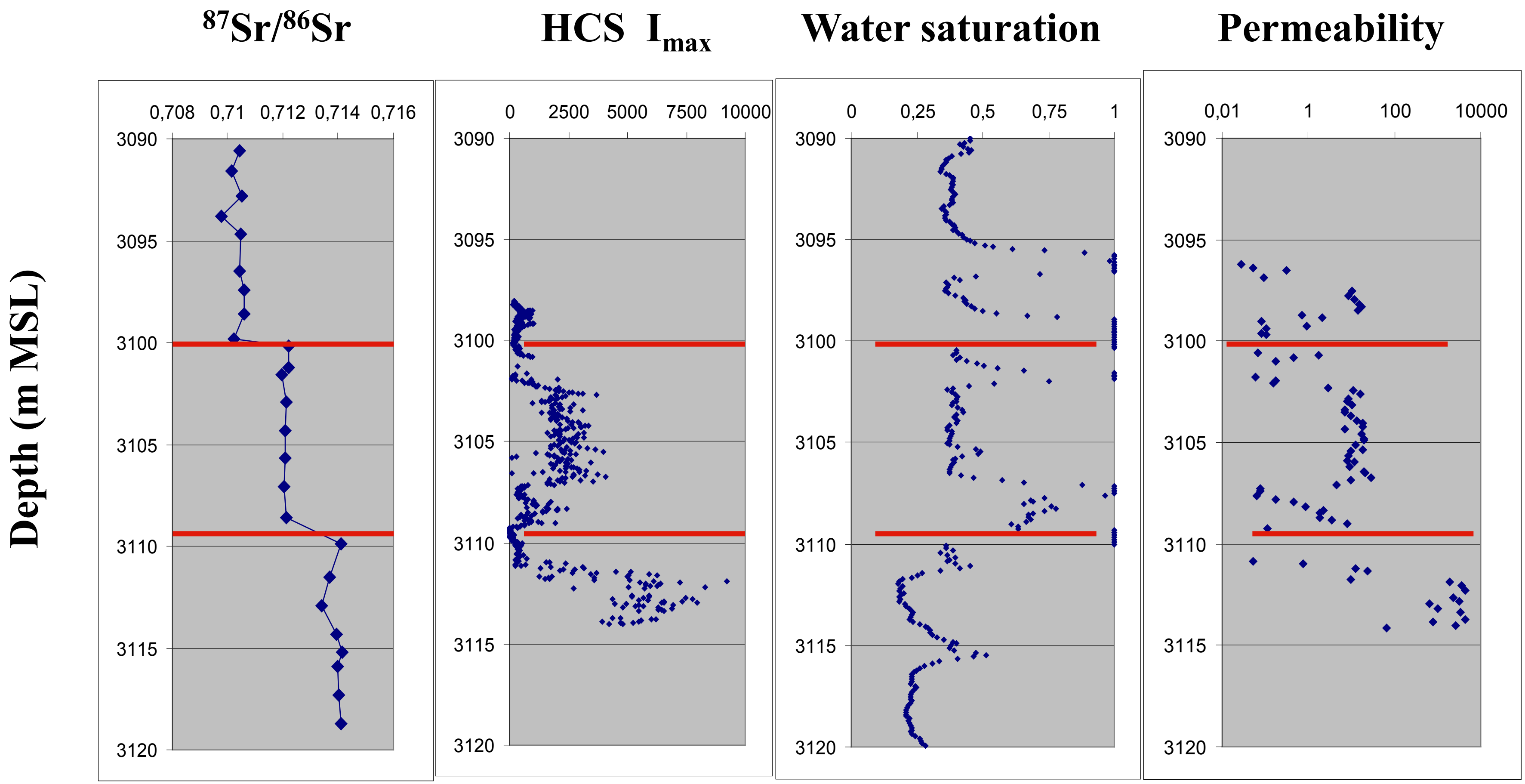


Measured horisontal permeabilities

Compartment structures

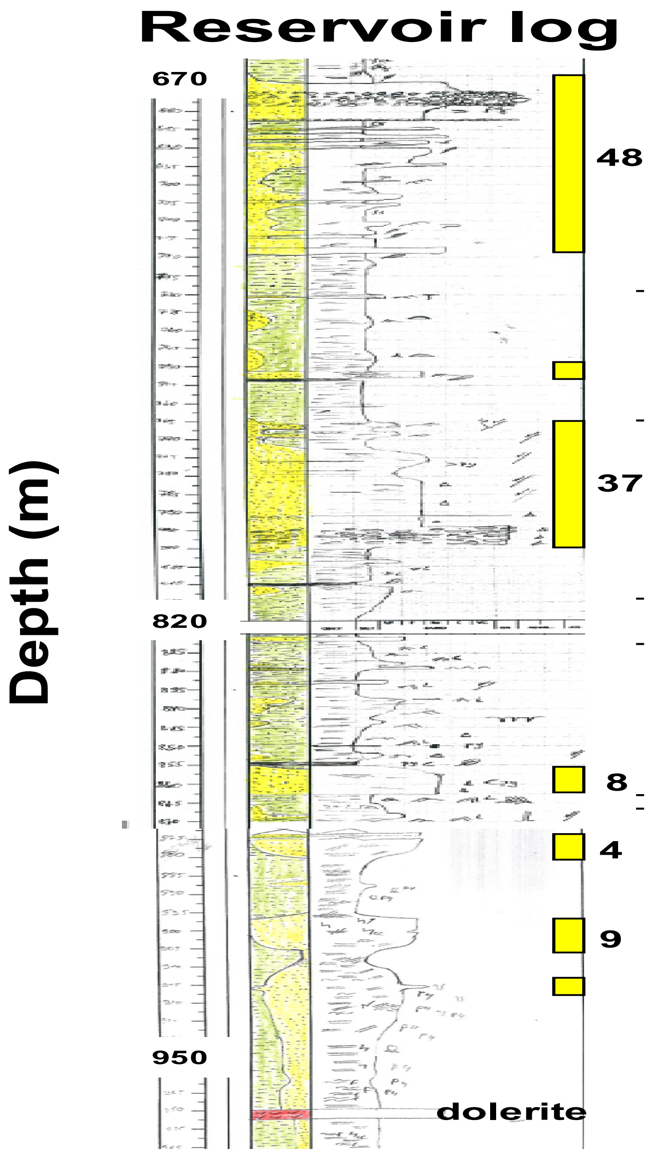


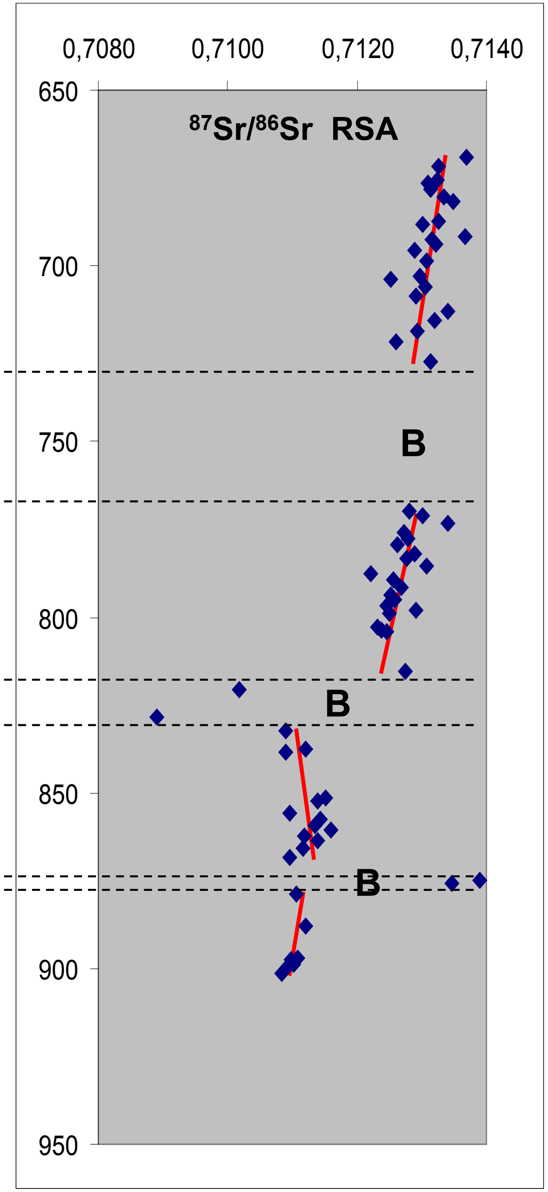
Reservoir heterogeneities – Frøy Field, North Sea



25/5-A7

Well Dh4 Longyearbyen





Tentative compartment structure:

4 main compartments

3 main barriers

Compartment analysis

Fluid geochemistry
- gas composition and isotope data
- oil geochemical data
- fluorescence
- pore water chemistrydata
- Sr isotope residual salt analysis
- isotope/chemistry analysis of diagenetic minerals

Pressure data

Log data

Petrophysical data

4D seismic or electromagnetic data

Seismic megacompartments

Sleipner-Utsira

No injection problems !

dissolution (mineralization) >> displacement ?

Snøhvit-Tubåen

Injection- and capacity problems !

Compartmentalization ?

Low vertical permeability ?

Stylolitization and quartz cementation (very low k_v) ?

displacement >> dissolution (mineralization) ?

Svalbard

???? **Deep paleoburial, strong uplift**

Johansen Fm

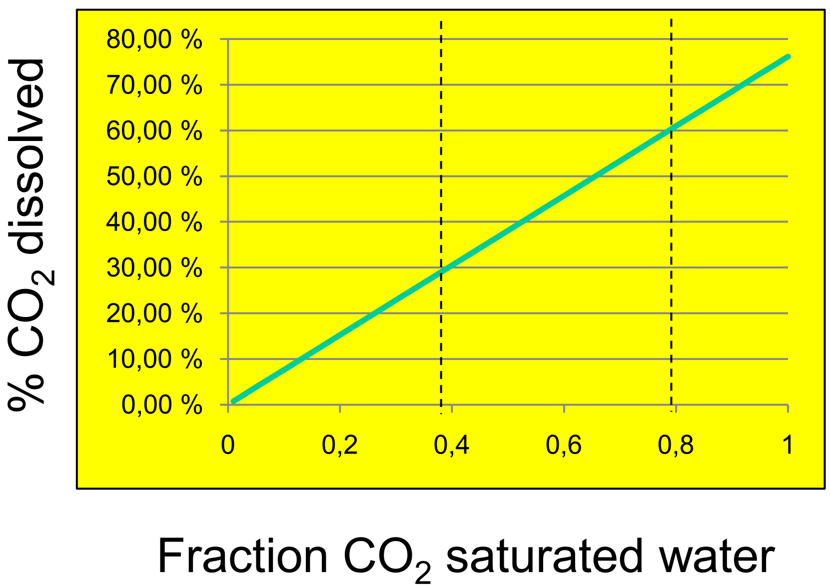
???? **Present burial 2.5-3 km**

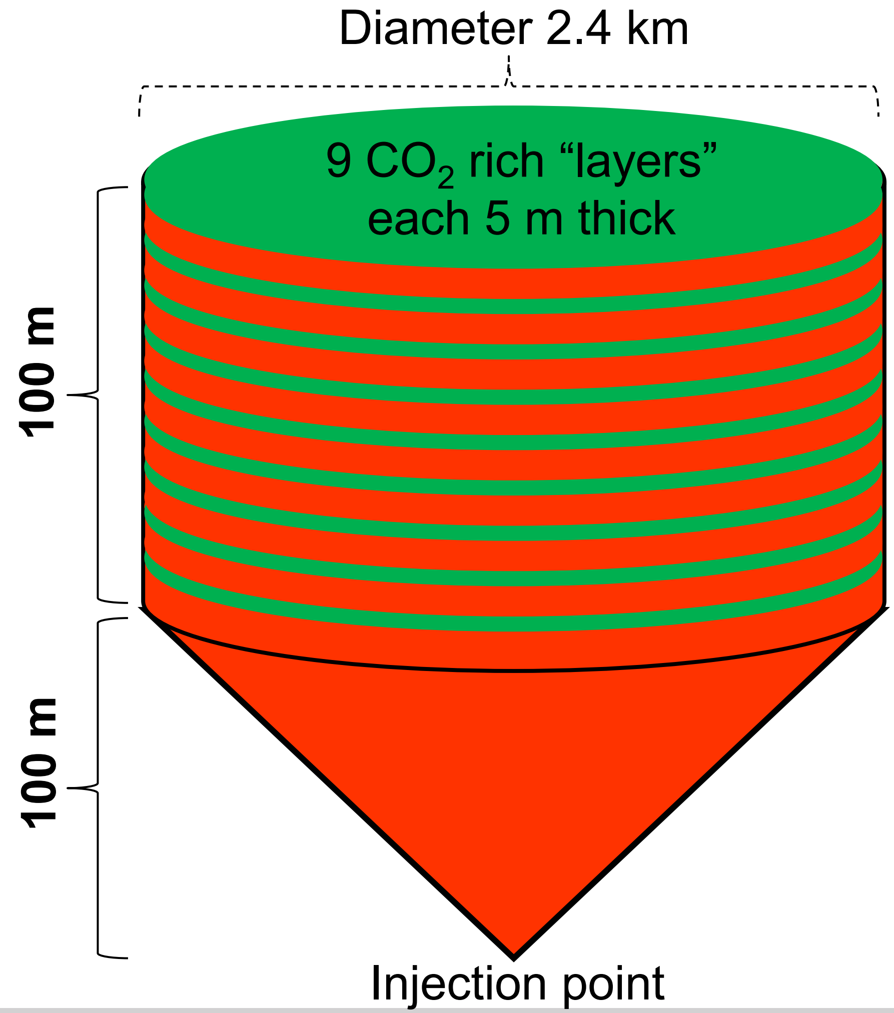
Sleipner example

Overall CO_2 saturation in cylindric + conical section:
0.08

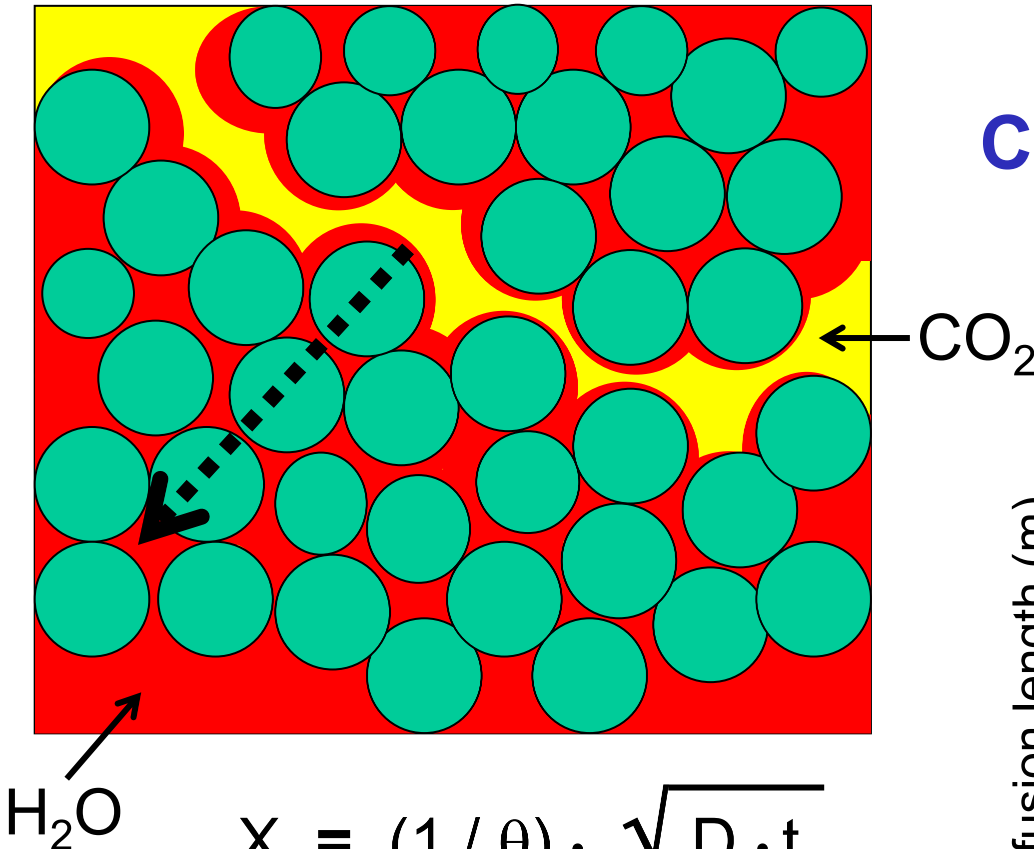
Overall CO_2 saturation in "rich" section:
0.25

Porosity 0.333
CO_2 density 0.72 ton/m^3
12 ton CO_2 injected





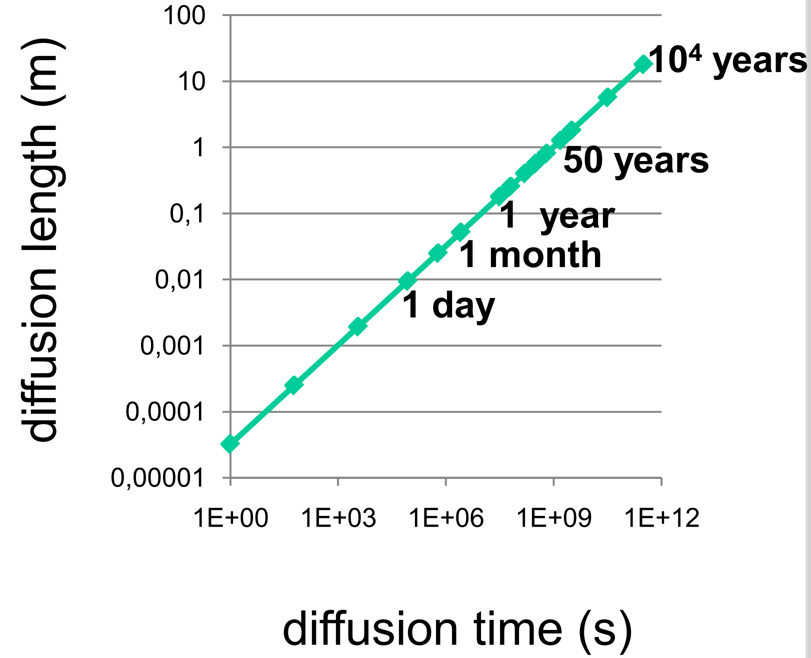
CO_2 dissolution time



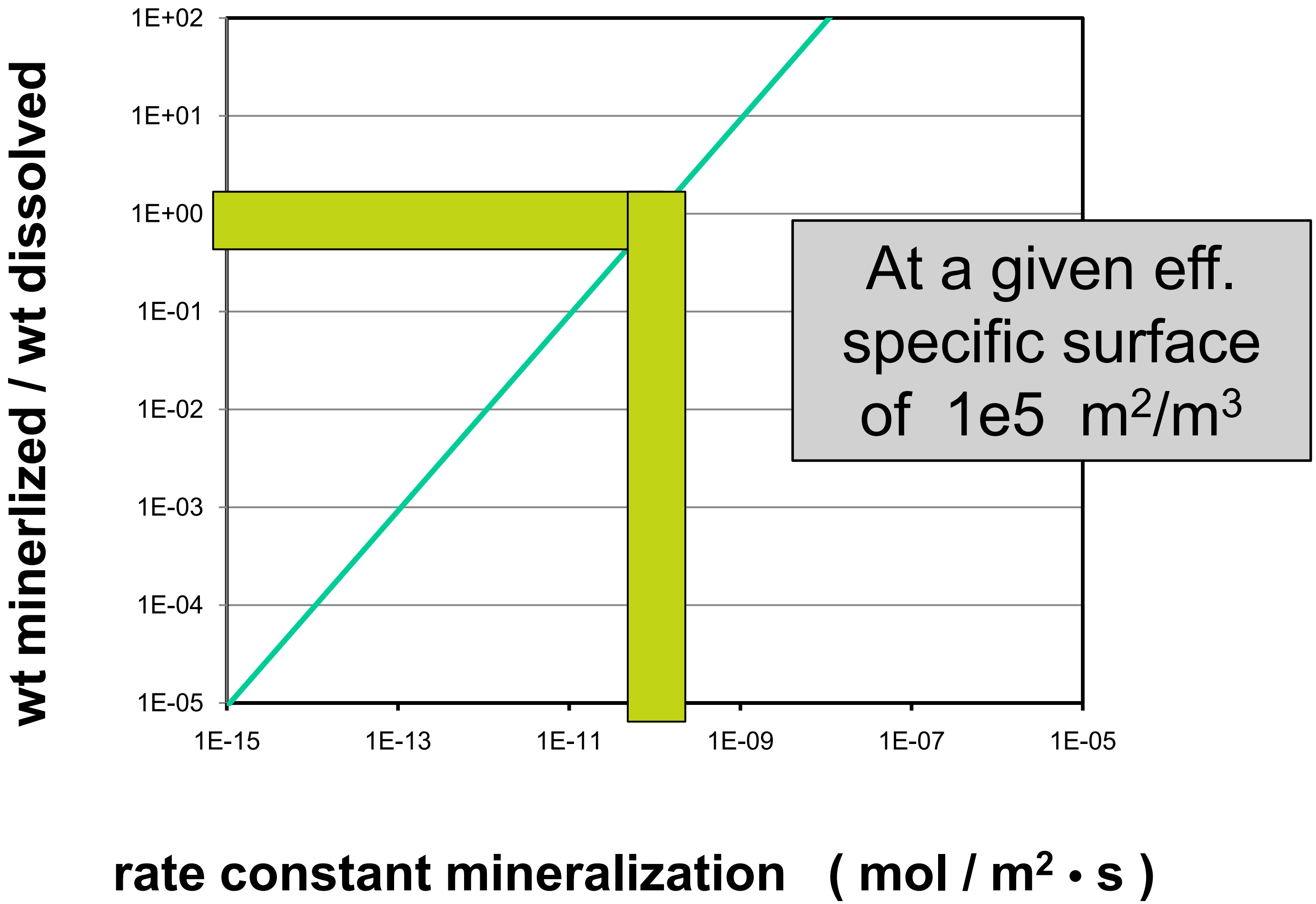
$$X = (1/\theta) \cdot \sqrt{D \cdot t}$$

X : diffusion length
D : diffusion constant
t : time
θ : tortuosity

D = 5e-9 m^2/s
θ = 2.2



Rate of mineralization vs rate of dissolution



Geohistory analysis - Burial history, block faulting, diagenesis

Deep burial

(+) tight and strong seal

(-) poorly connected secondary porosity (swapped for primary porosity); diagenetic barrieres (stylolites); large k_h/k_V ratios; compartmentalization; block faulting; small pressure cells

Shallow burial

(+) porous and permeable sands/sandstones; less rigid internal barriers; dominantly well connected primary porosity; poorly developed diagenesis; low k_h/k_V ratios; less severe compartment effects; less block faulting; larger pressure cells

(-) more porous and weaker seal; more risk for sediment fracturing or fludization

Uplifted reservoirs

overcompacted
stylolitization
may be underpressured

Conclusions

Sleipner	excess capacity, large pressure cell
Snøhvit	fairly deep burial, uplifted
Longyearbyen	extensive uplift
Johansen Fm.	fairly deep burial

Important factors:

- deep or shallow storages
- geohistory
- compartment effects

Diagenetic studies:

- important heterogeneities for deep or uplifted storages
- behaviour of the storage is recorded in the secondary minerals