Sleipner Fluid Dynamics*

(Fluid Dynamics of the Hydrostatic Offshore Conditions at the Sleipner Site [Buoyant Behavior of CO_2])

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Key Point

The pressure gradients are the main driving force for CO_2 migration under hydrostatic, and therefore buoyant, conditions.

References

Dake, L.P., 1978, Fundamentals of Reservoir Engineering: Elsevier, 443 p.

Duan, Z. and R. Sun, 2003, An improved model calculating CO2 solubility in pure water and aqueous NaCl solutions from 273 to 533 K and from 0 to 2000 bar: Chemical Geology, v. 193, p. 257-271.

IPCC, 2005, Special Report on Carbon Dioxide Capture and Storage: Cambridge University Press, 431 p.

Span, R. and Wagner, W., 1996, A new equation of state for carbon dioxide covering the fluid region from the triple point temperature to 1000 K at Pressures up to 800 MPa: Journal Physical Chemistry, Reference Data, 1996, v. 25/6, p.1509-1596.

Sleipner Fluid Dynamics

AAPG Workshop on CCS, Golden, Aug. 10-12, 2010

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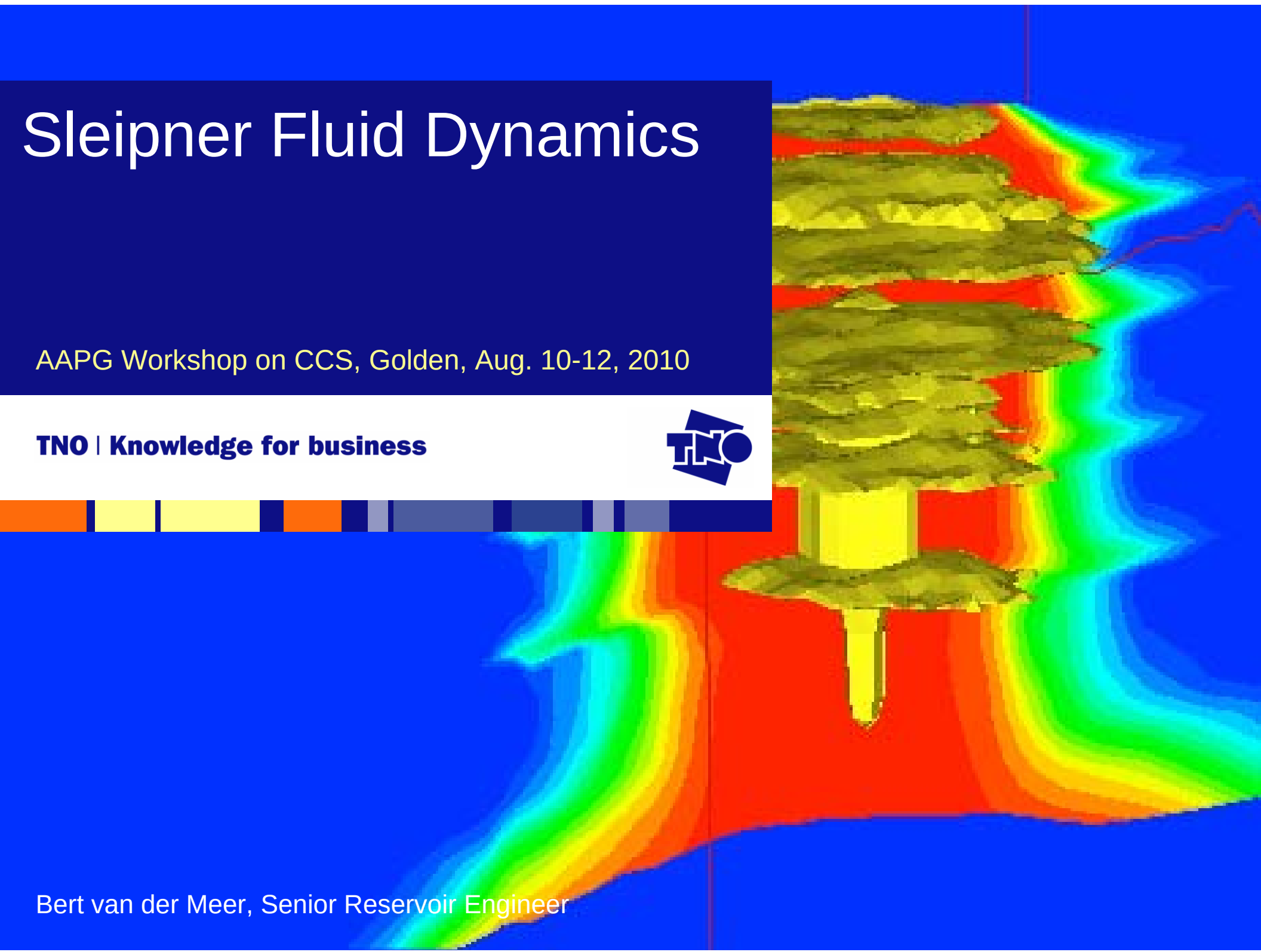
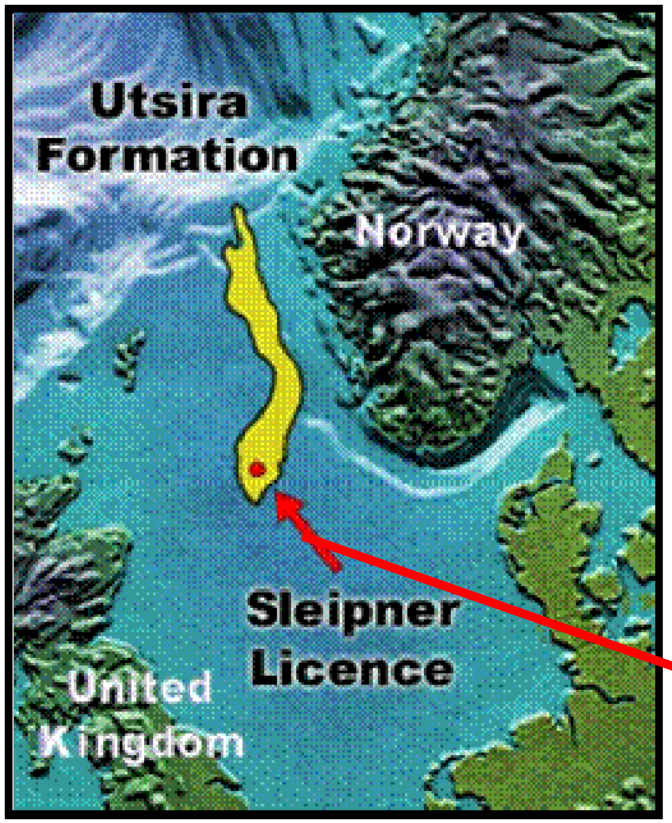
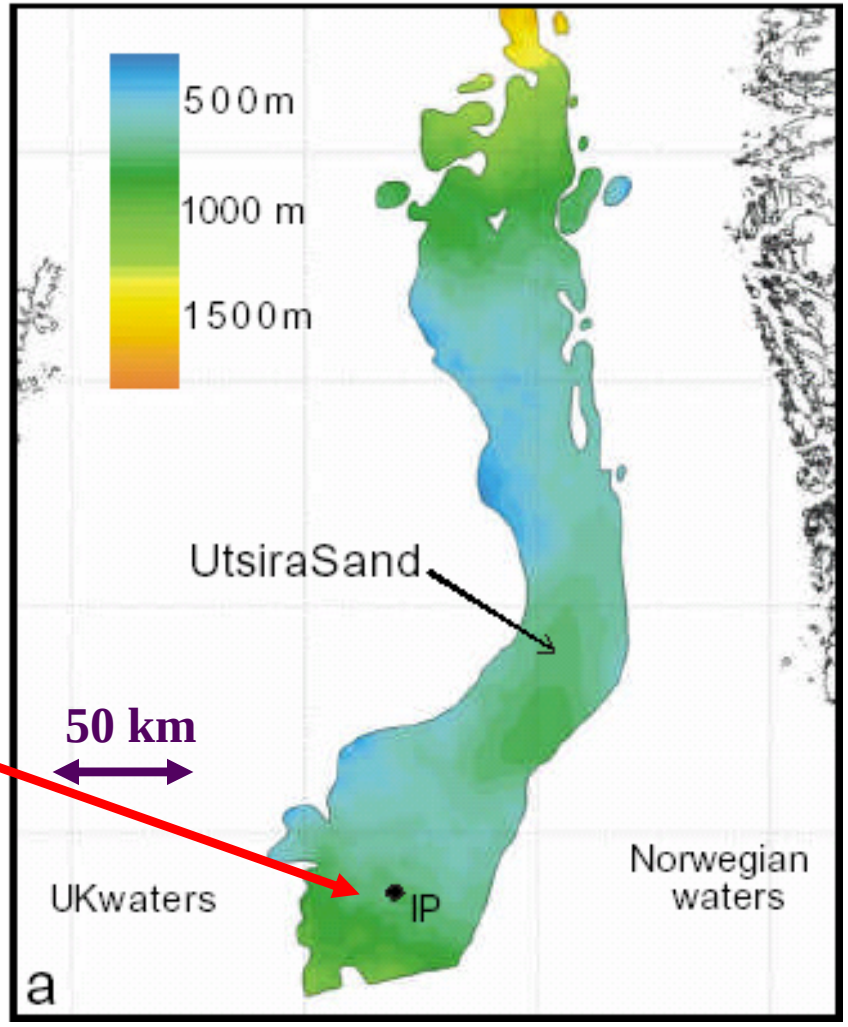


Bert van der Meer, Senior Reservoir Engineer

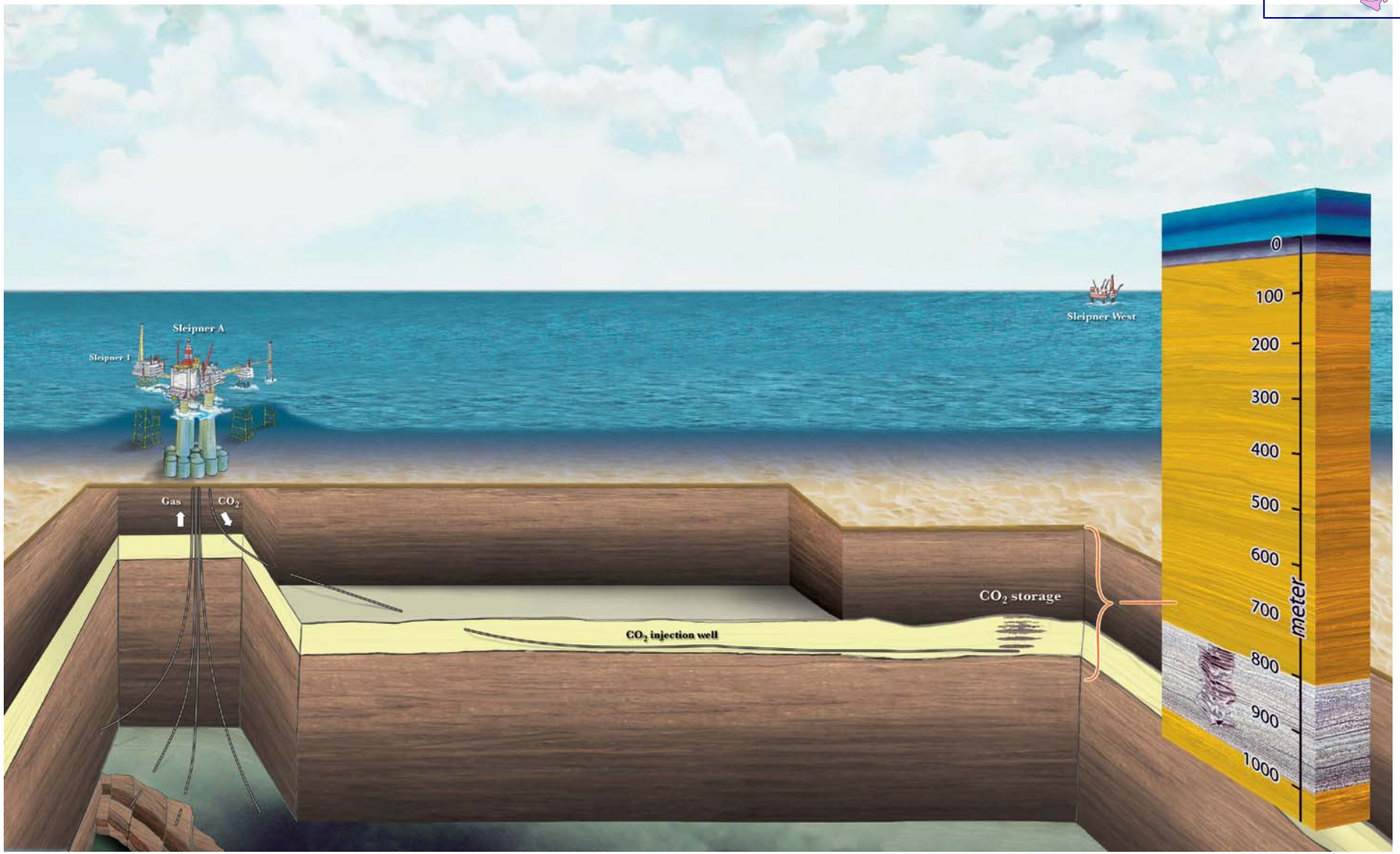
Utsira Sandstone Order of Magnitude





Total surface 26.000 km^2

Sleipner Site



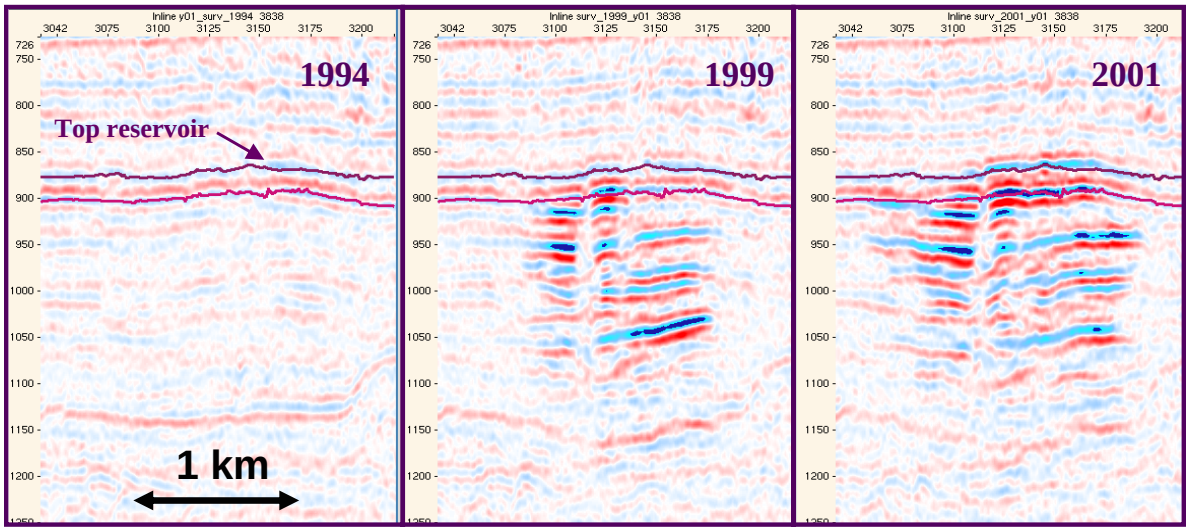
Courtesy StatoilHydro

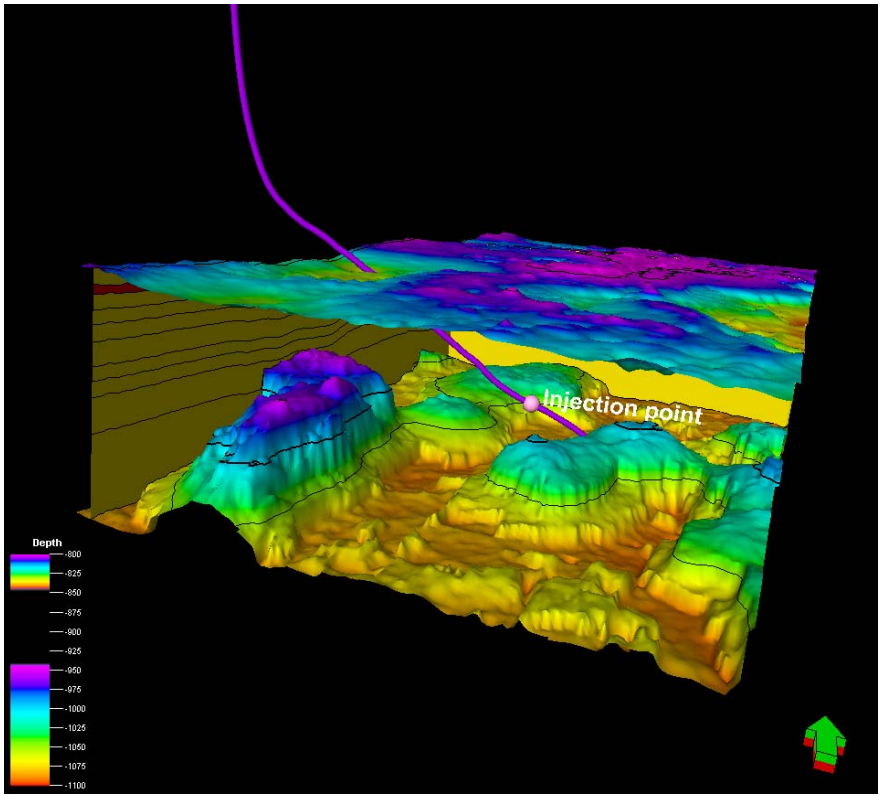
Introduction (Sleipner)

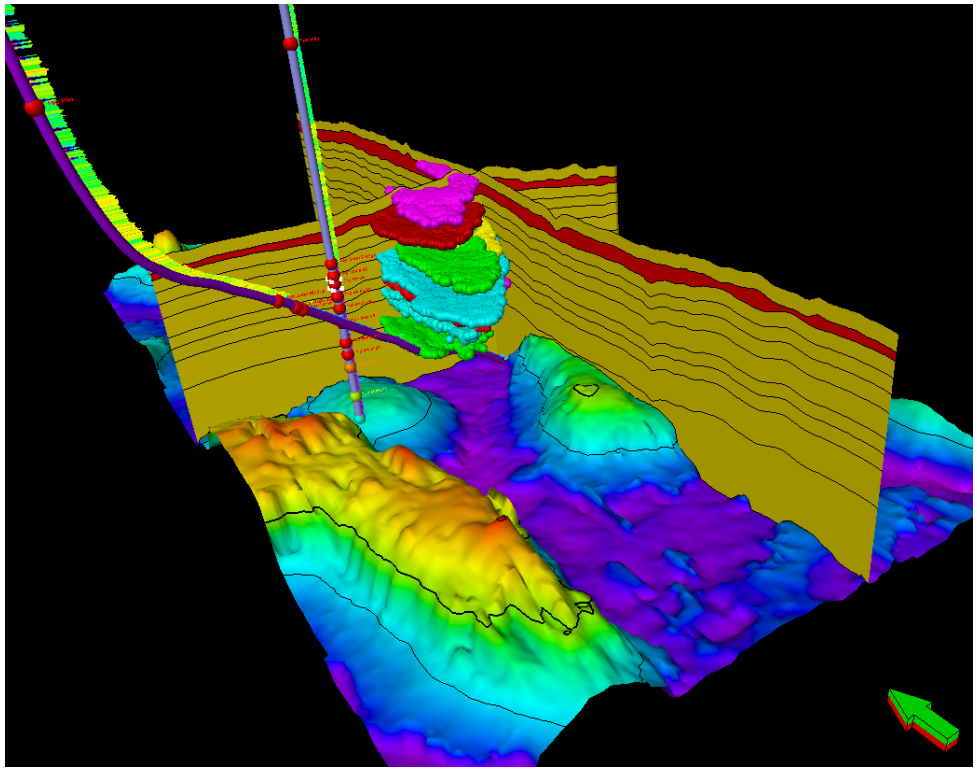
Basic Data

- Aquifer
- shallow (800 m SS)
- Thickness 200-250 m
- Temperature ~40 ^{o}C
- Hydrostatic (80 bar)
- High permeable (D)
- Extremely large (26,000 Km^2)
- Restricted test site
- Injection ~ 1Mt/y so far ~11 Mt
- Injection on temperature control

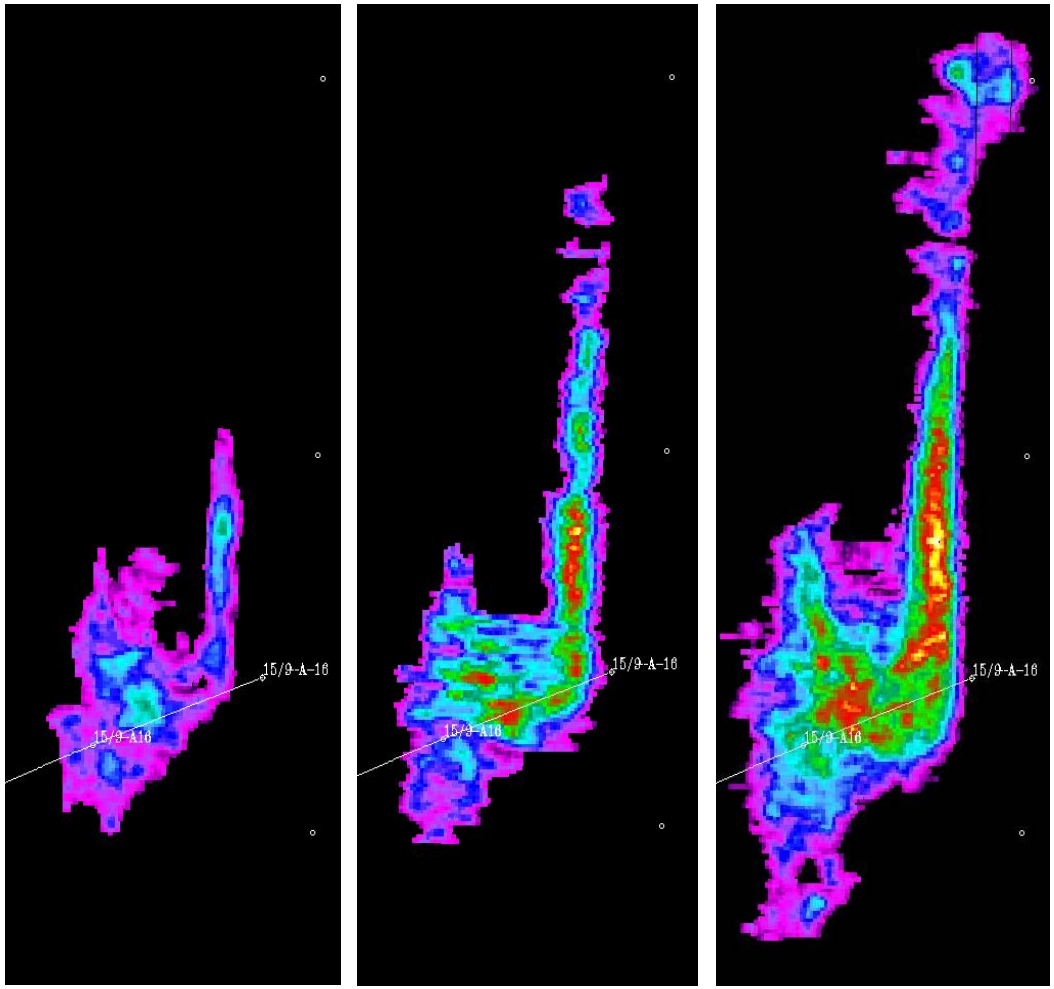
Sleipner 4D seismic monitoring







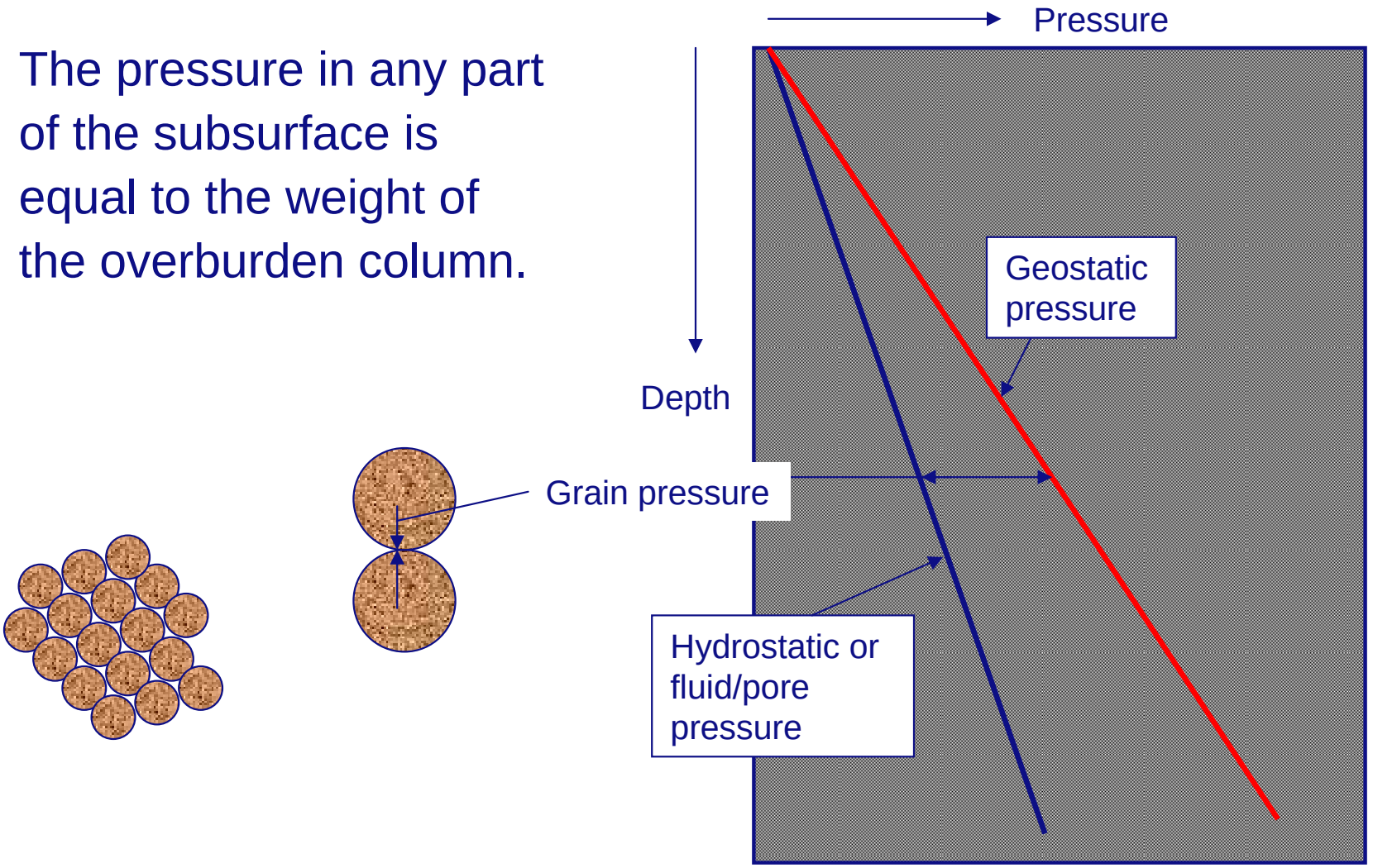
Seismic monitoring (4-D)



2001 2004 2006

Basic Rule - RE - pressure distribution

- The pressure in any part of the subsurface is equal to the weight of the overburden column.



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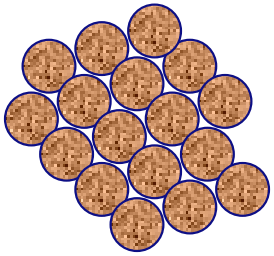

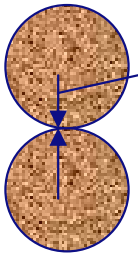

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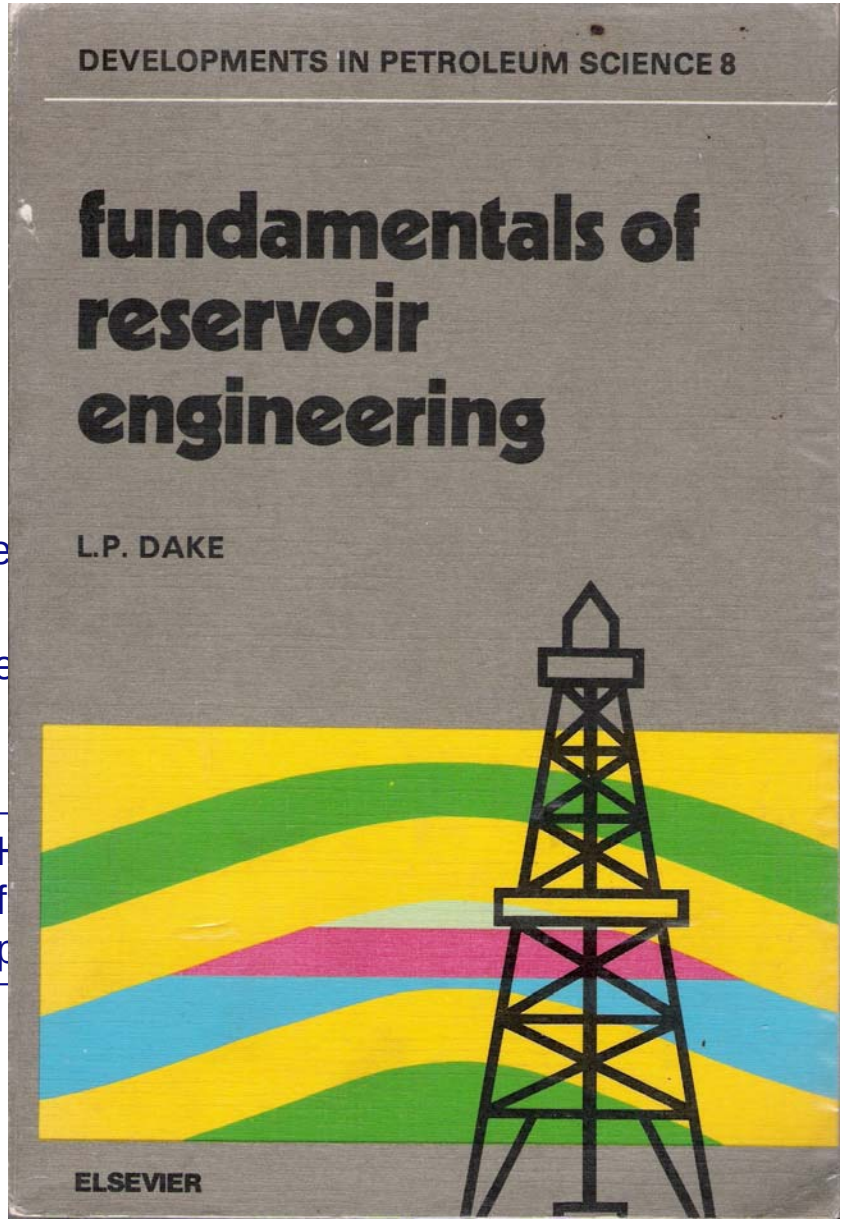
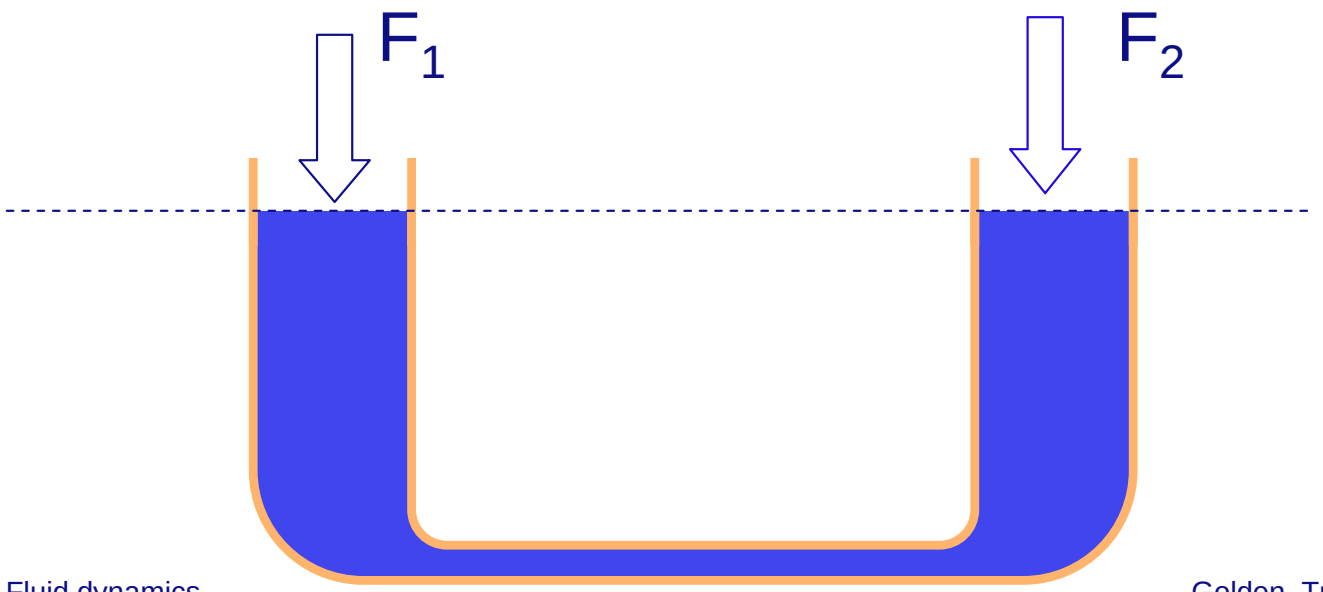


Pressure Status

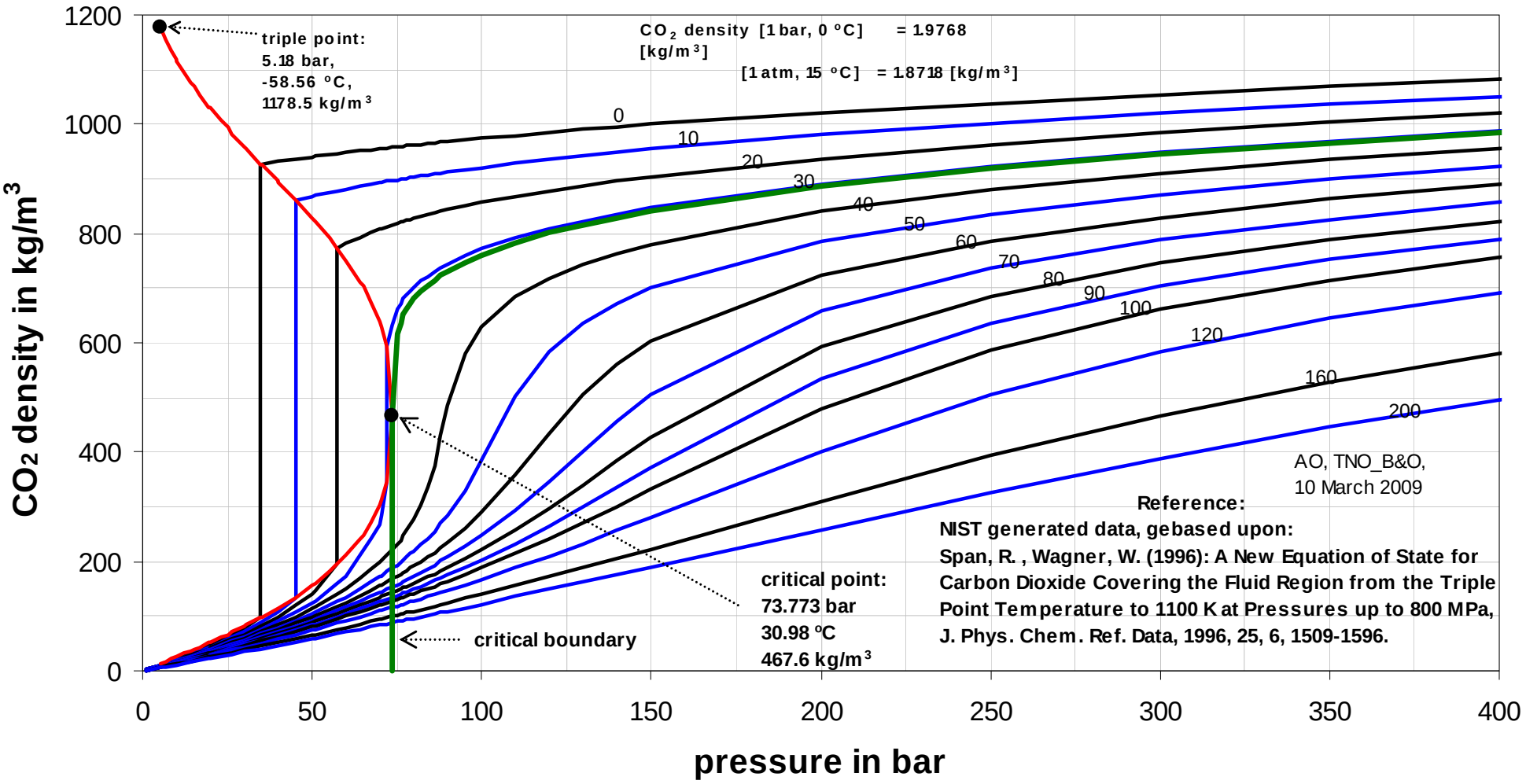
- Result : Hydrostatic in the whole formation

Vertical Equilibrium



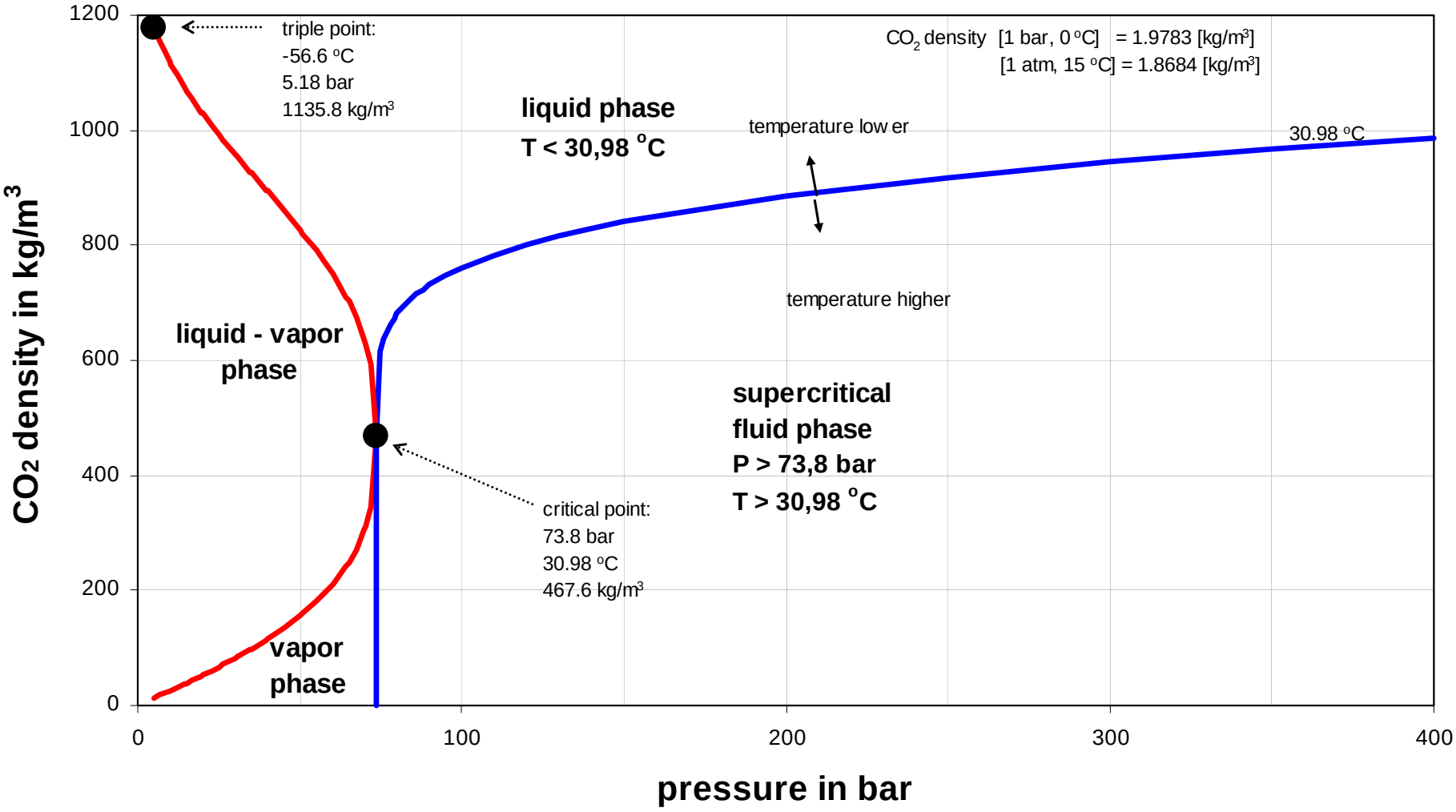
Carbon Dioxide

- **Density**



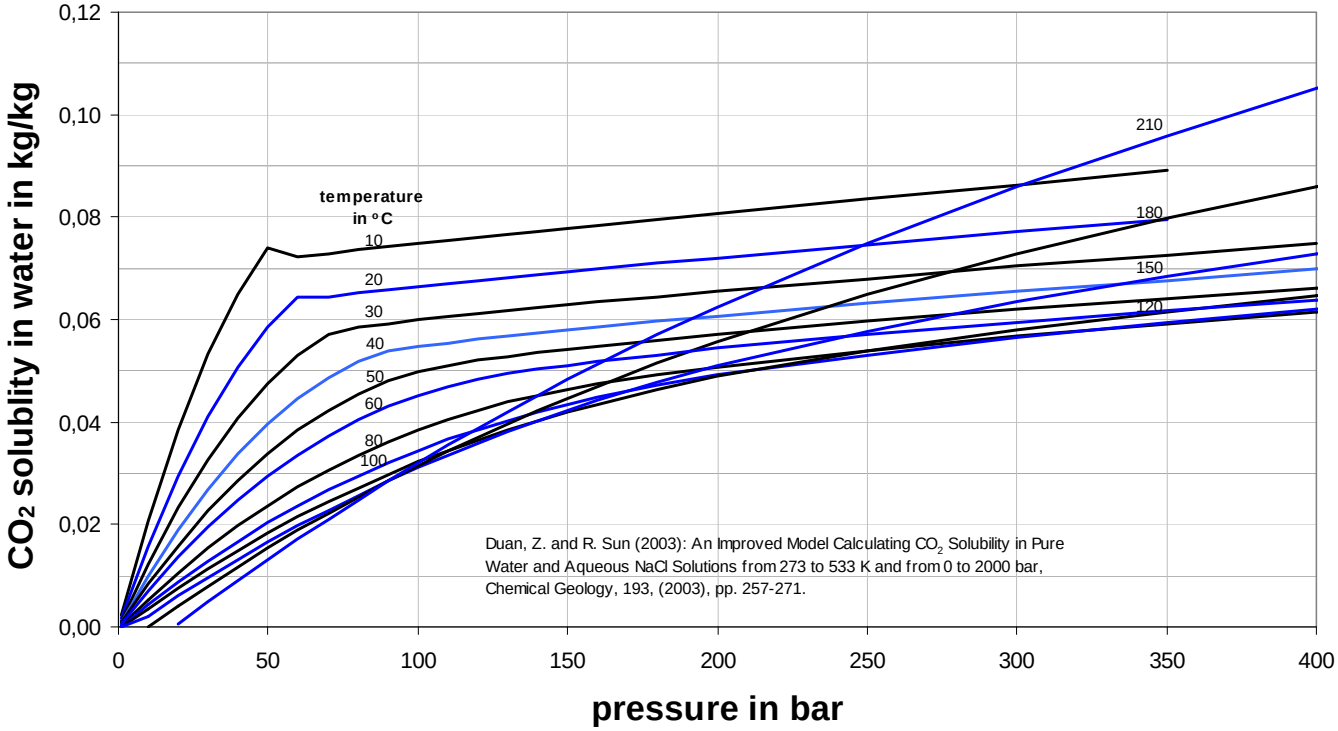
Carbon Dioxide

- **Critical phases and density**



Carbon Dioxide

- **Solubility in water**

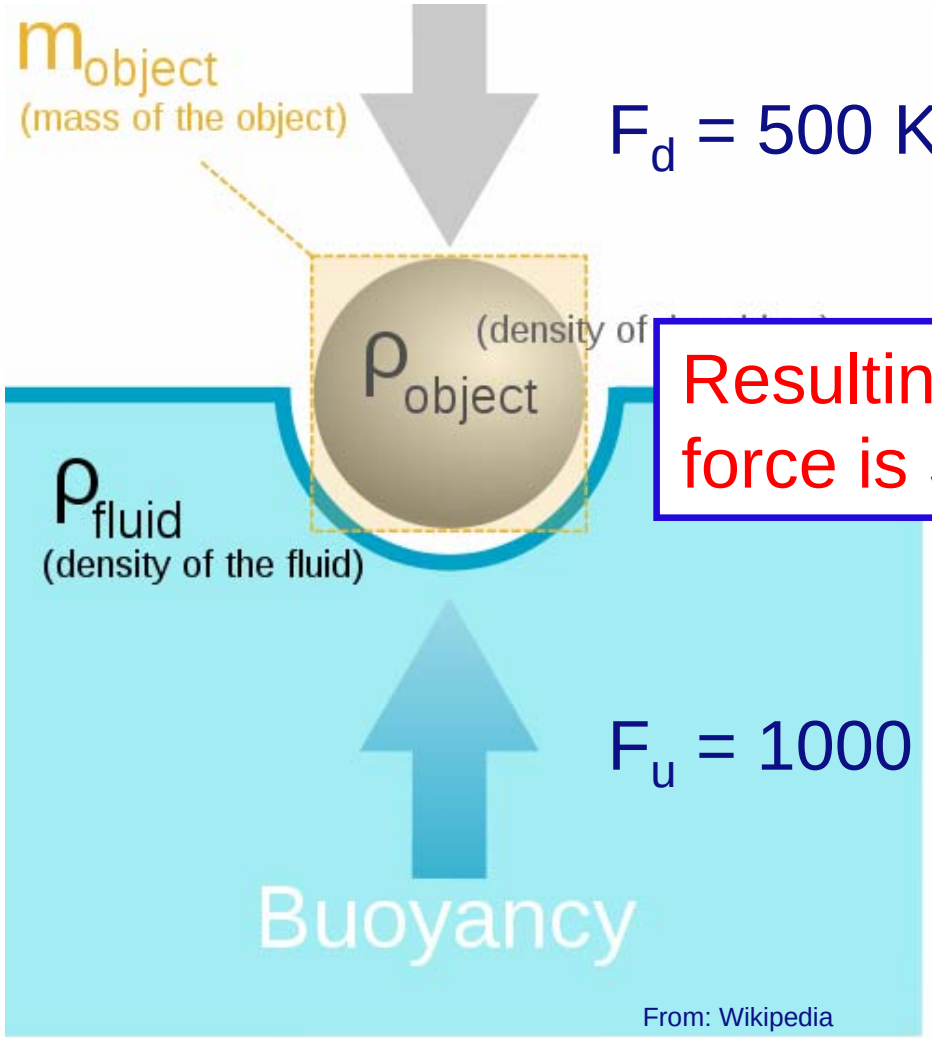


water salinity in NaCl percentage	solubility fraction compared with pure water	standard deviation due to P-T-variation
0 1	.000	0.000
5 0	.838	0.012
10 0	.709	0.020
15 0	.609	0.032
20 0	.525	0.031
25 0	.453	0.045

Reduction of solubility of CO_2 into saline water

Archimedes principle

- Buoyancy=weight of displaced fluid



$F_d = 500\ Kg/m^3 * 1\ m^3$

Resulting UPWARDS force is 500 kg

$F_u = 1000\ Kg/m^3 * 1\ m^3$

Archimedes principle

- Total effect =

Gravity segregation

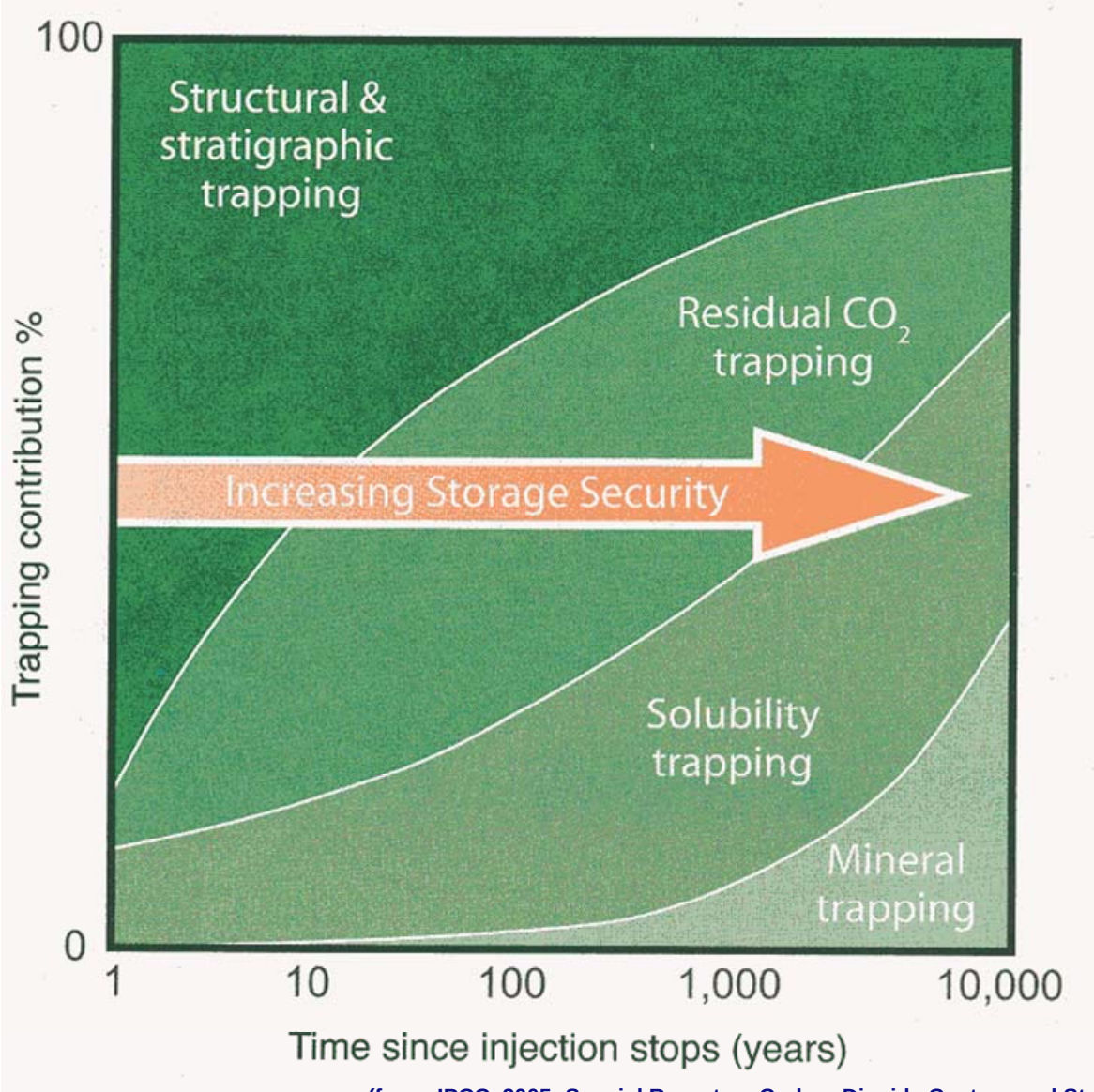
Natural Gas

CO2

Oil

Water

Carbon Dioxide

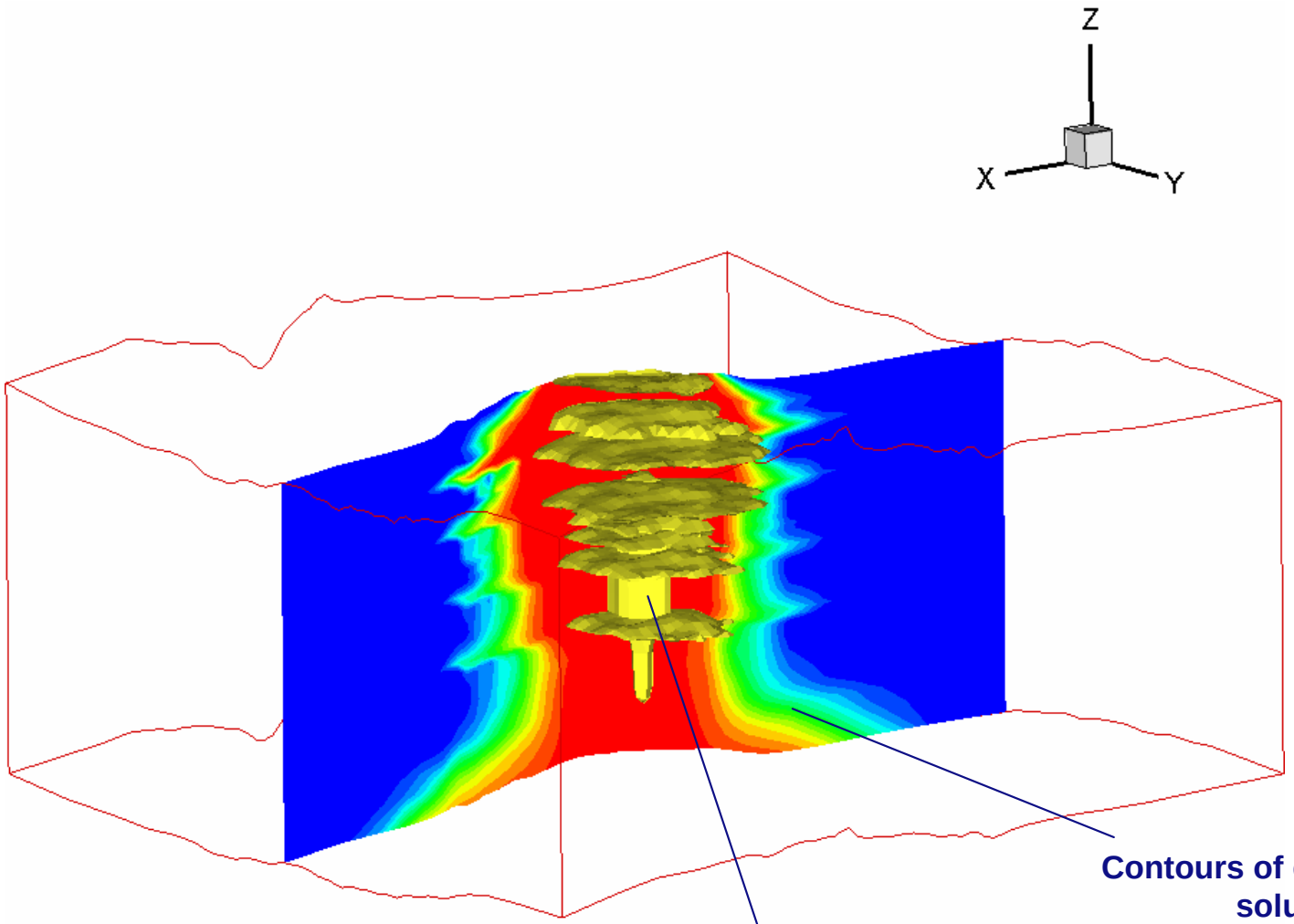


(from: IPCC, 2005: Special Report on Carbon Dioxide Capture and Storage.)

Carbon Dioxide in Sleipner

- Store deeper than 800 m (>80 bar, ~35 ^{o}C, Density ~700 Kg/m^{3})
- CO_2 super-critical (as a gas with a liquid density)
- Lighter than formation water (strong buoyancy forces)
  - Sleipner clearly upwards movement of CO_2
- CO_2 soluble in water
- Water soluble in CO_2

Sleipner CO_2 Storage Result



Questions

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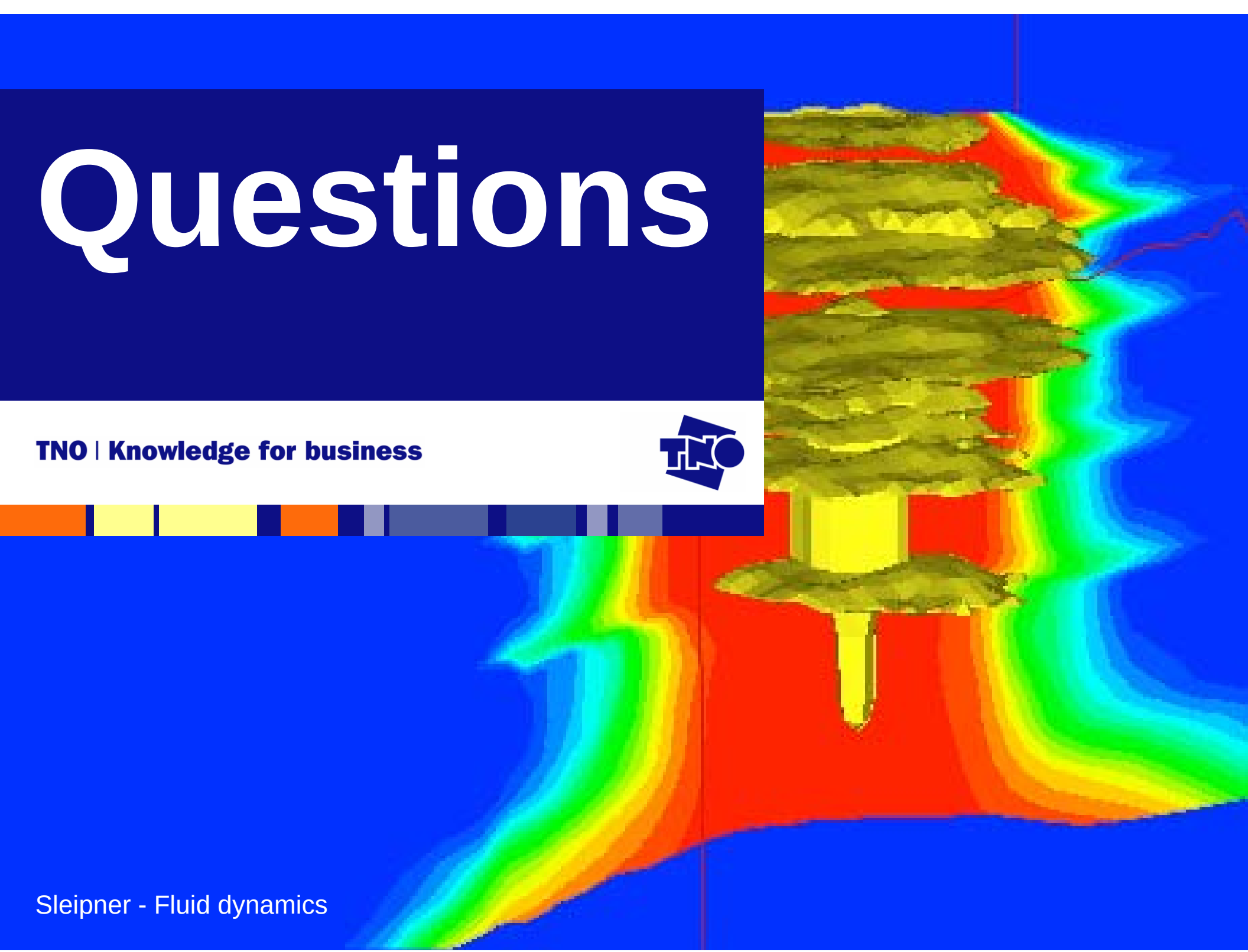

Sleipner - Fluid dynamics