Naturally Occurring Underpressure — A Global Perspective*

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Abstract

Underpressure is defined as any pore-pressure below hydrostatic i.e., the pressure exerted by a column of water. Correspondingly, overpressure is defined as any pressure in excess of hydrostatic and is more widely documented in literature. Understanding the distribution and implications of underpressure is important for drilling safety, hydrocarbon exploration and the potential to miss pay. The injection of gas, such as carbon dioxide, can be complicated by underpressure as it influences storage capacity and fluid phase. Underpressures of up to 1000 psi are common in sedimentary basins of North America, China, Russia and the Norwegian Barents Shelf and Svalbard. Whilst they are geologically distinct, all have undergone recent uplift. A number of mechanisms have been hypothesized as main drivers of underpressure but fundamentally the phenomenon must relate to either reduction in fluid volume or an increase in connected pore volume. We investigate all potential mechanisms including the most widely cited of differential hydraulic flow, rock dilation, thermal effects, and differential gas flow. Differential hydraulic flow is proposed to occur where a dipping reservoir has lower rates of meteoric recharge in up-dip areas than discharges from the system down-dip. Thermal effects include fluid volume reduction due to cooling. Differential gas flow occurs where initially overpressured gas accumulations displace water in tight formations which subsequently become underpressured during uplift. Rock dilation occurs due to unloading and subsequent elastic rebound, and we also investigate the influence of fractures as recent studies in Svalbard indicate they may play an important role. In addition to our synthesis we investigate the present day and historical hydrostatic gradients and their implications. Most of these causal mechanisms are inferred from basins in North America. Other basins possessing underpressure have geological differences which enables us to rule out certain mechanisms. For example, on the Barents Shelf and Svalbard differential flow can be discarded as the entire underpressured target interval is subsea. We investigate the geological characteristics of 19 underpressured basins from around the world on a case by case basis. We identify and compare where specific underpressure causing mechanisms are likely to occur and where they are geologically unfeasible.

Naturally Occurring Underpressure – A Global Perspective

Tom Birchall, University Centre in Svalbard

AAPG ACE - Tuesday 21st May 2019

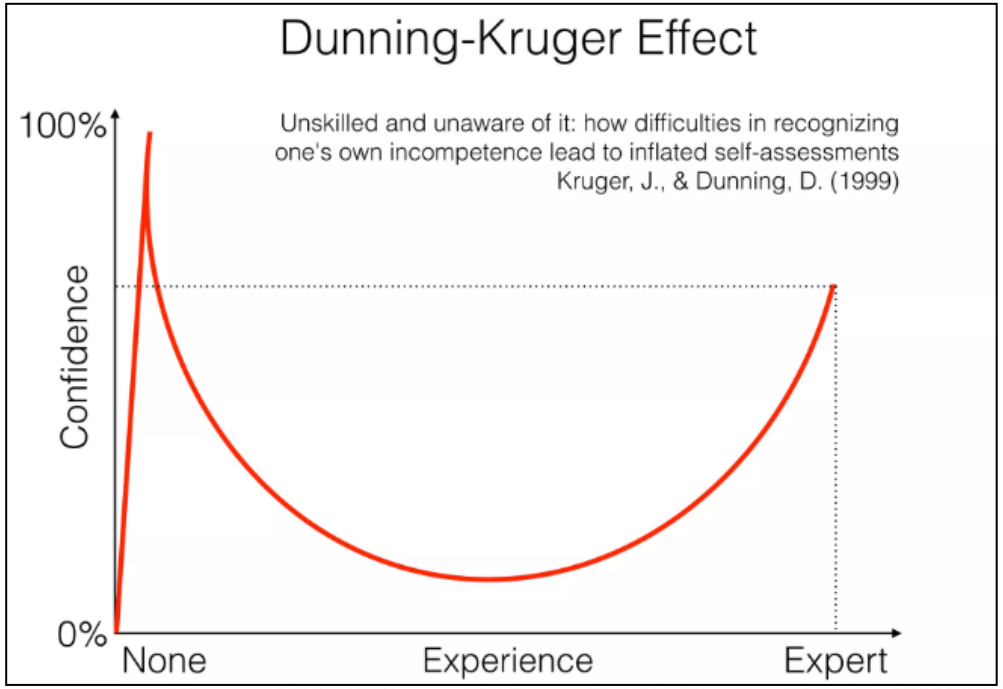
Who Am I?

- PhD Candidate with University of Oslo based at UNIS in Svalbard
- PhD focus on Pore-Pressure regimes in the Barents Sea

Durham University → ikon Science → 1495 UNIVERSITY OF ABERDEEN

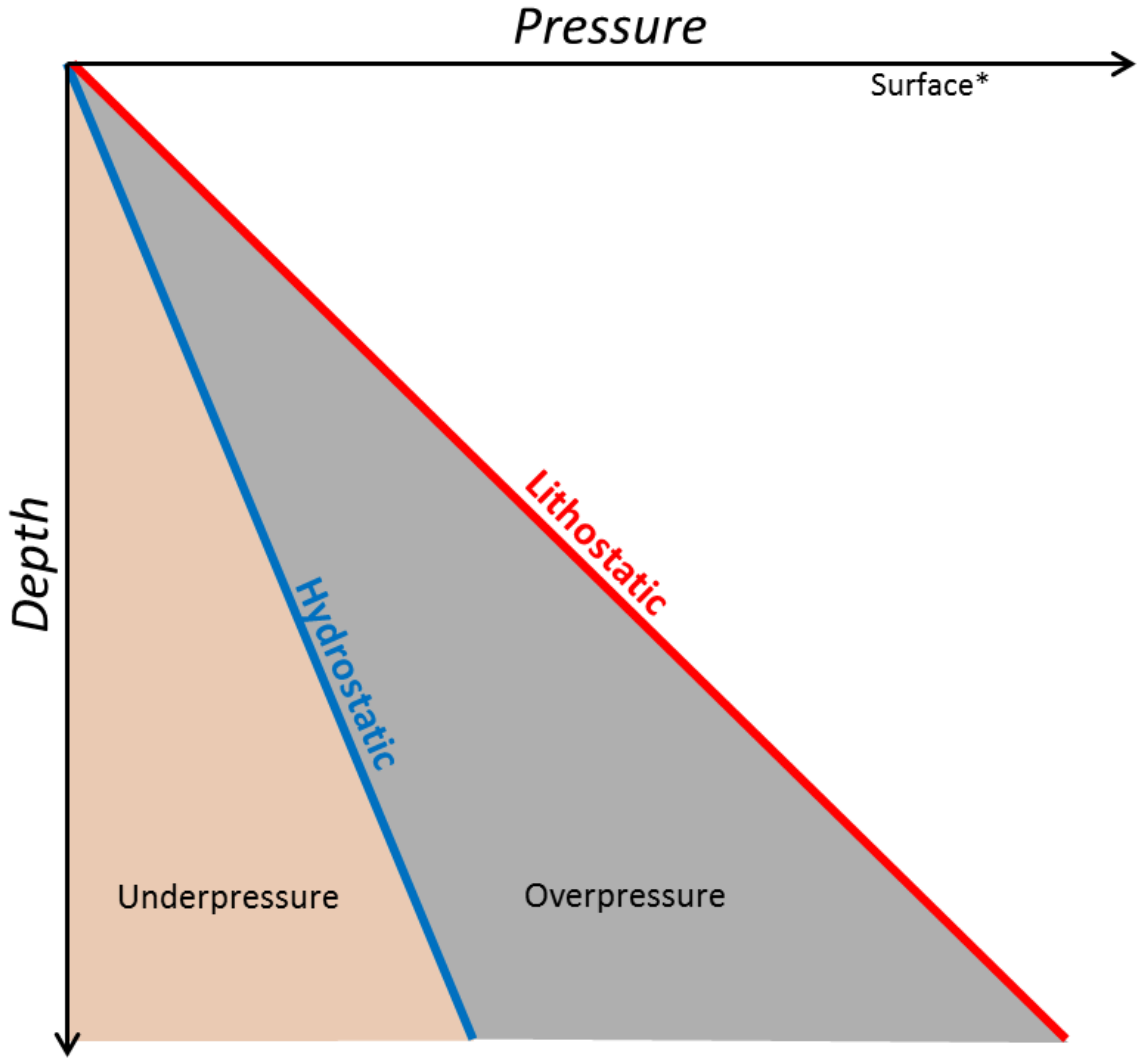
MAERSK OIL → UNIS

Source: Geology.com



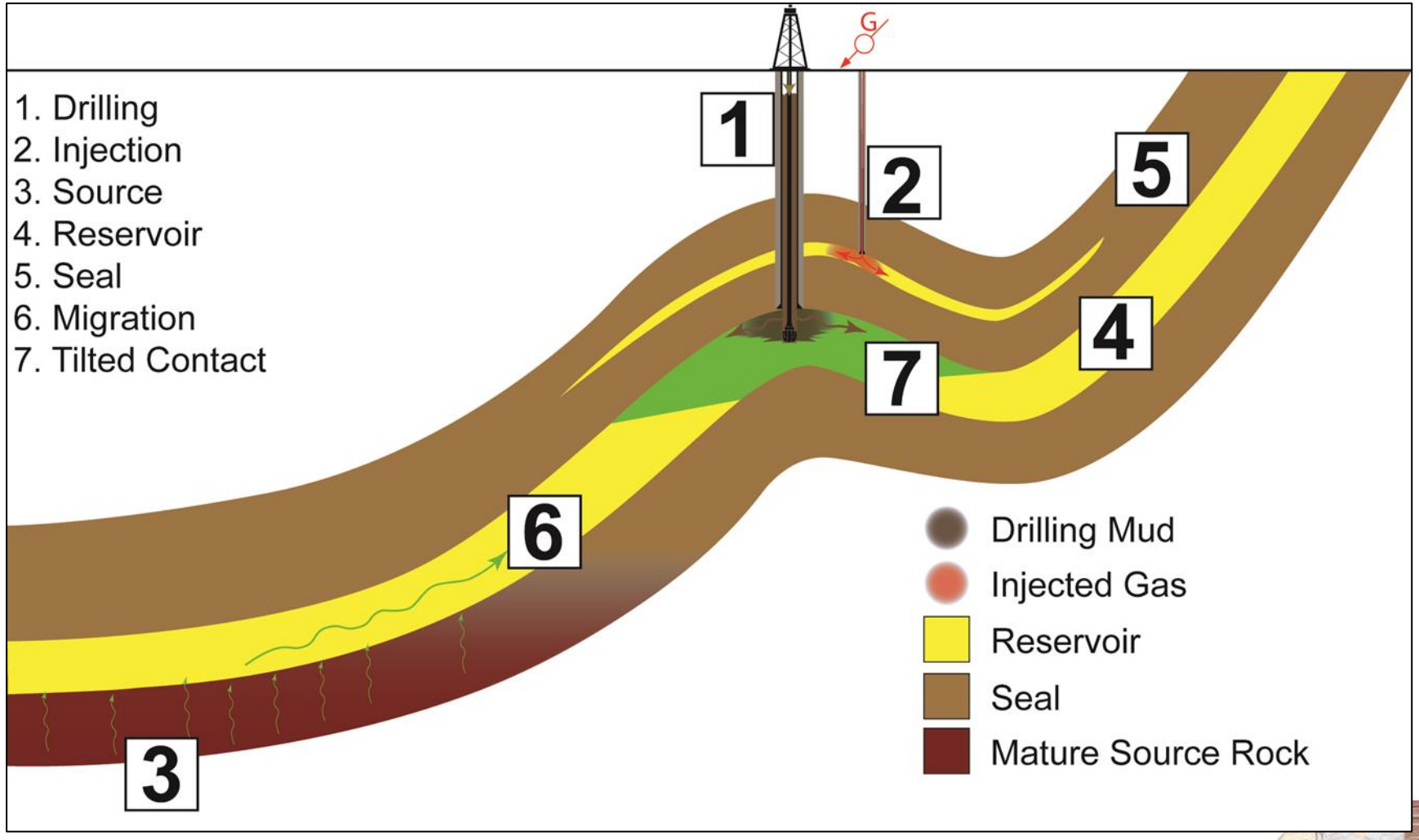
What is Underpressure?

- Pore Pressure – pressure of fluid in pores
- Lithostatic pressure - the pressure exerted by column of rock
- Hydrostatic pressure - pressure exerted by column of water*
- Underpressure is any pressure below hydrostatic



**Hydrostatic is anything but static!*

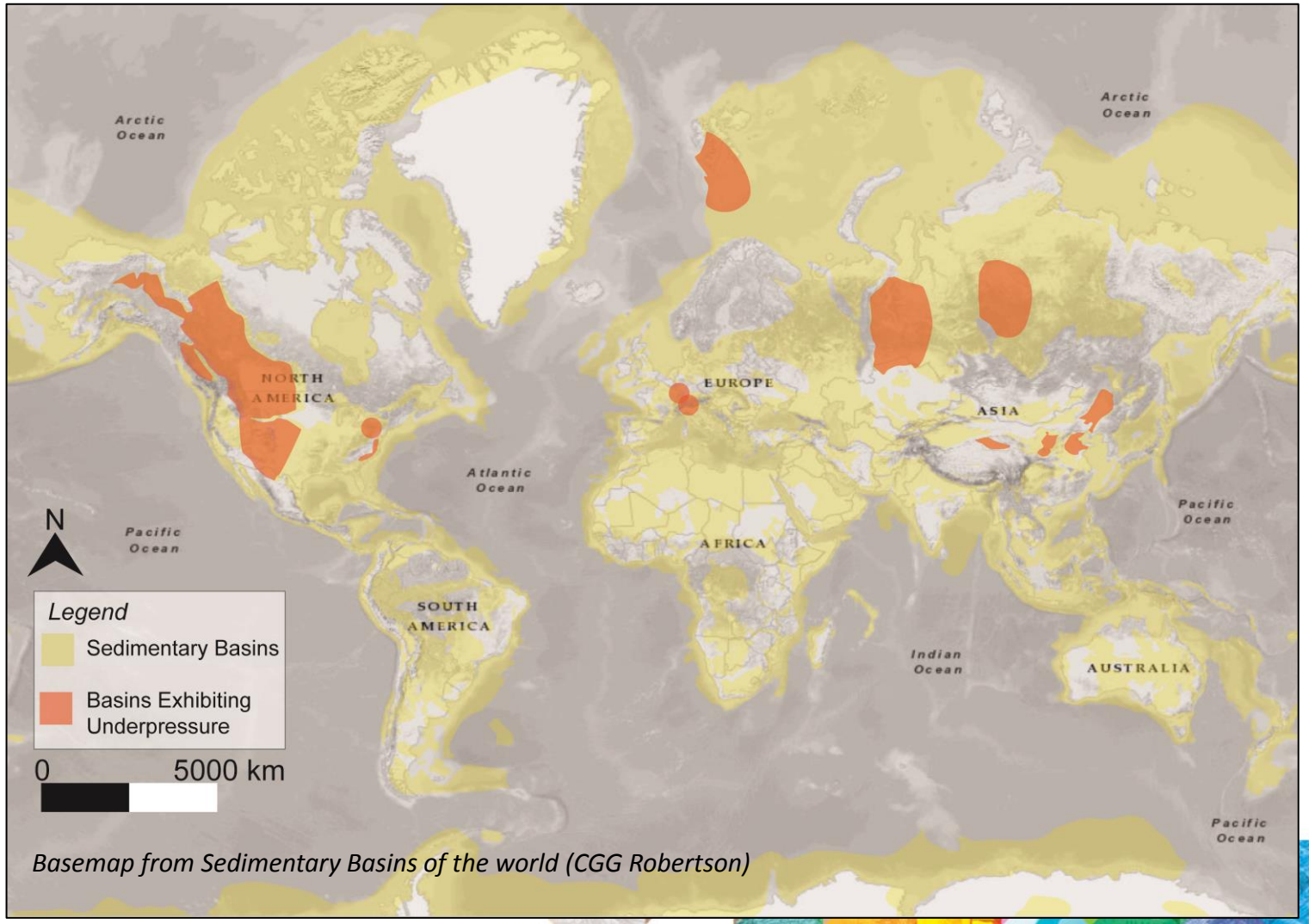
Why is underpressure important?



- Potentially serious consequences during drilling
- Impacts on all aspects of the risk elements
- Challenges to injection (e.g. CO2)
- Difficult to detect

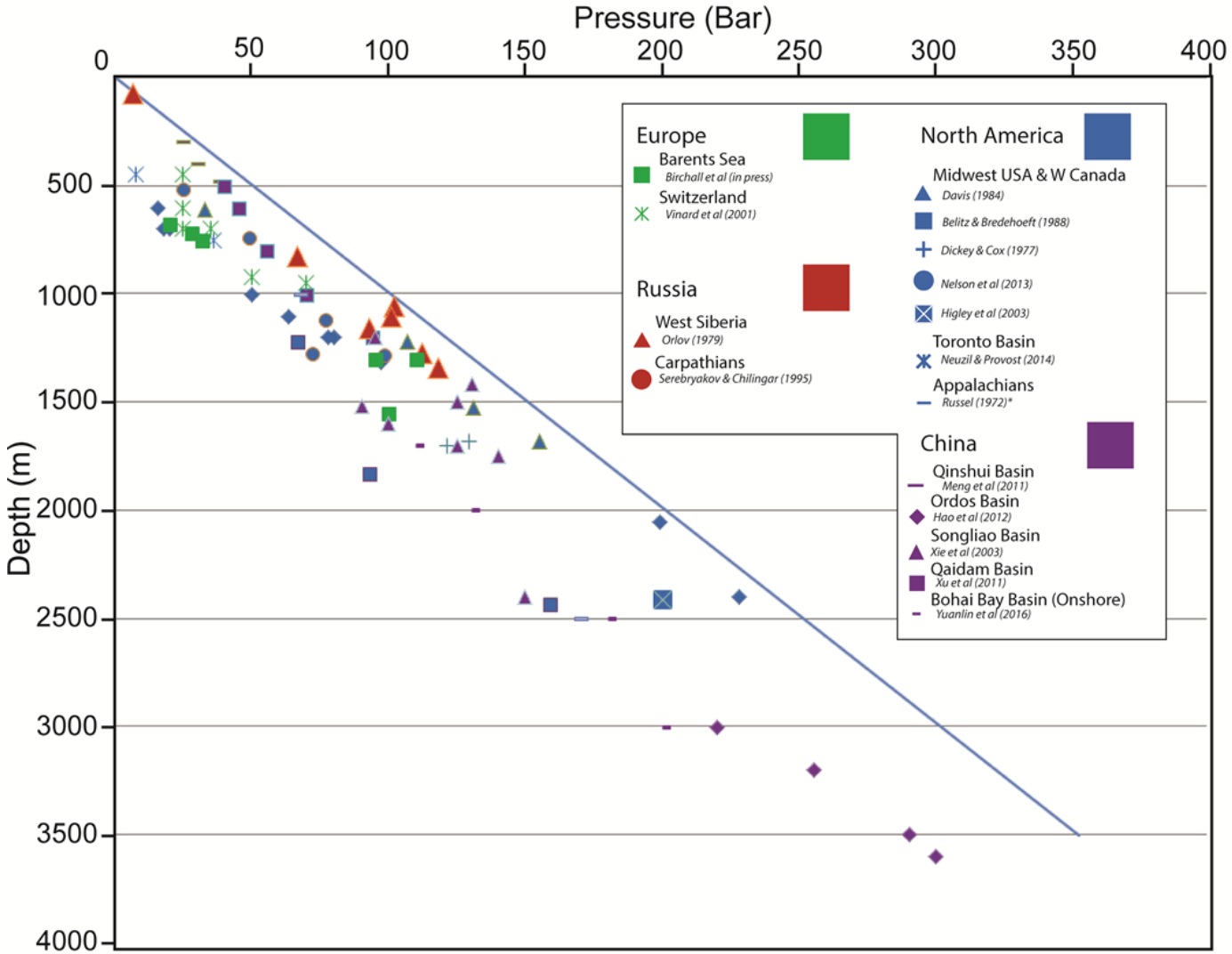
Where does natural underpressure occur?

- 20 basins/regions globally
- 9 Locations outside North America
- All areas associated with geologically recent uplift
- Barents Sea is only occurrence of offshore underpressure



Basemap from Sedimentary Basins of the world (CGG Robertson)

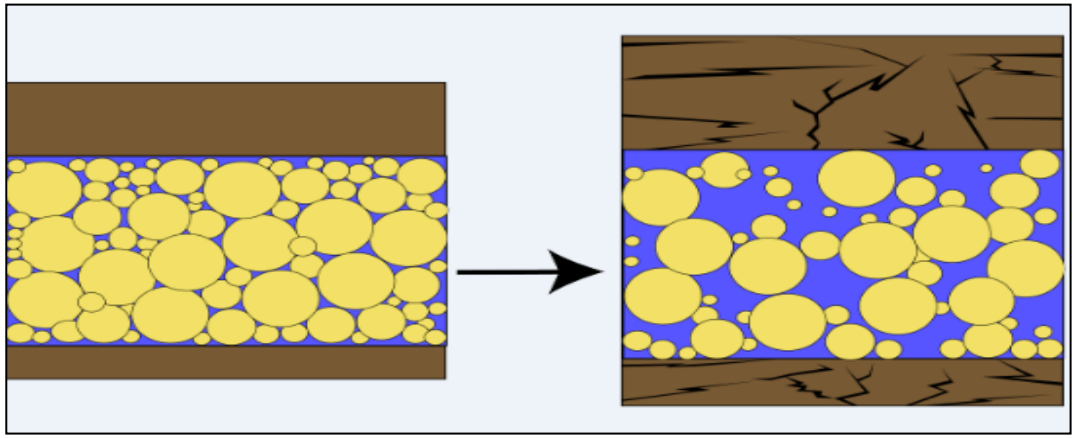
Magnitudes of Underpressure



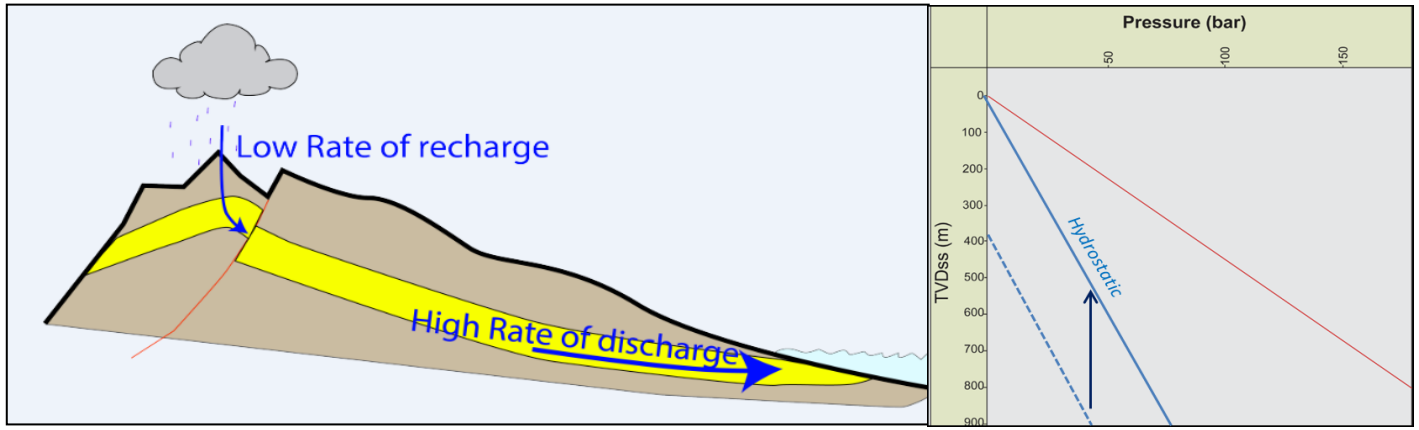
- Magnitudes of underpressure surprisingly similar
- Most occurrences see maximum underpressure of circa 50 bar (725 psi) with no observations exceeding 100 bar (1450 psi)
- Most occurrences are relatively shallow
- Most commonly observed in poor quality reservoirs

Causes of Underpressure

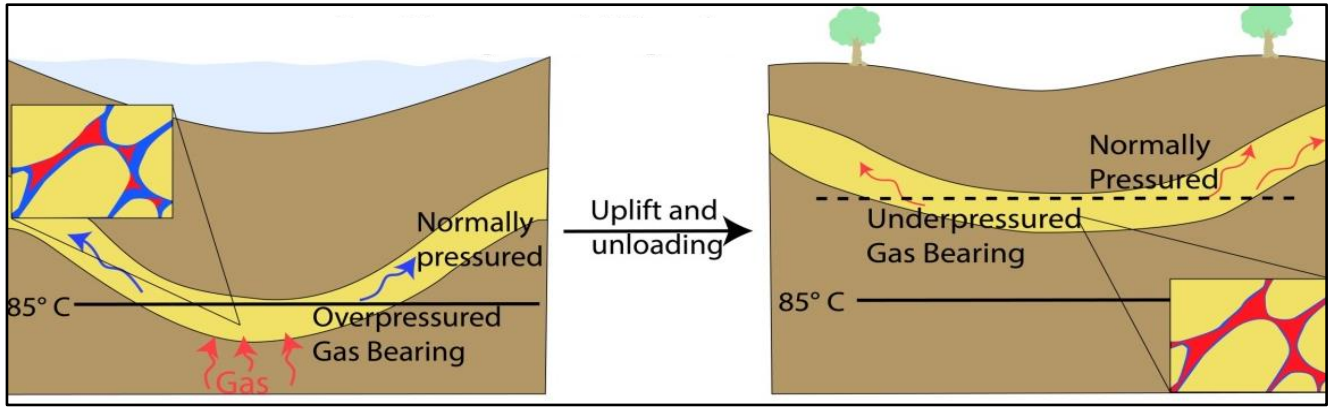
Decompaction



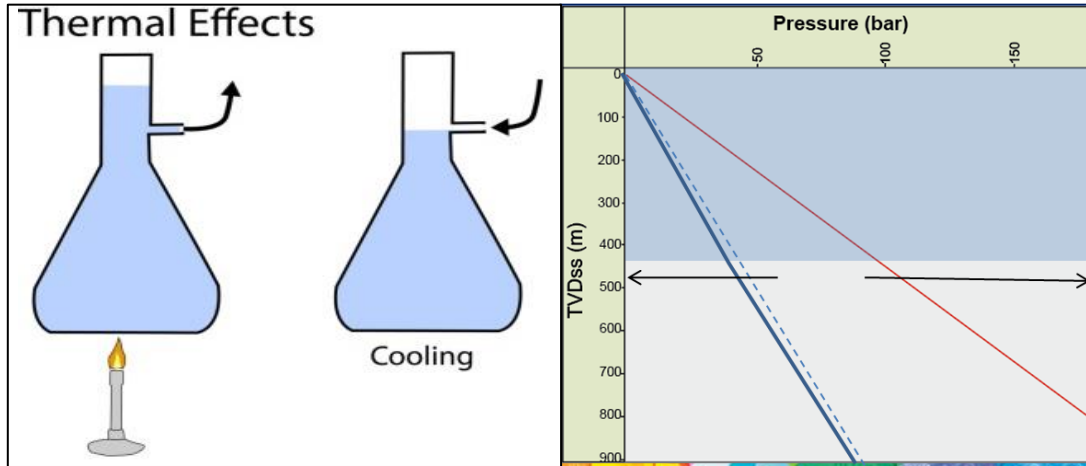
Hydraulic Regime Change



Basin Centred Gas

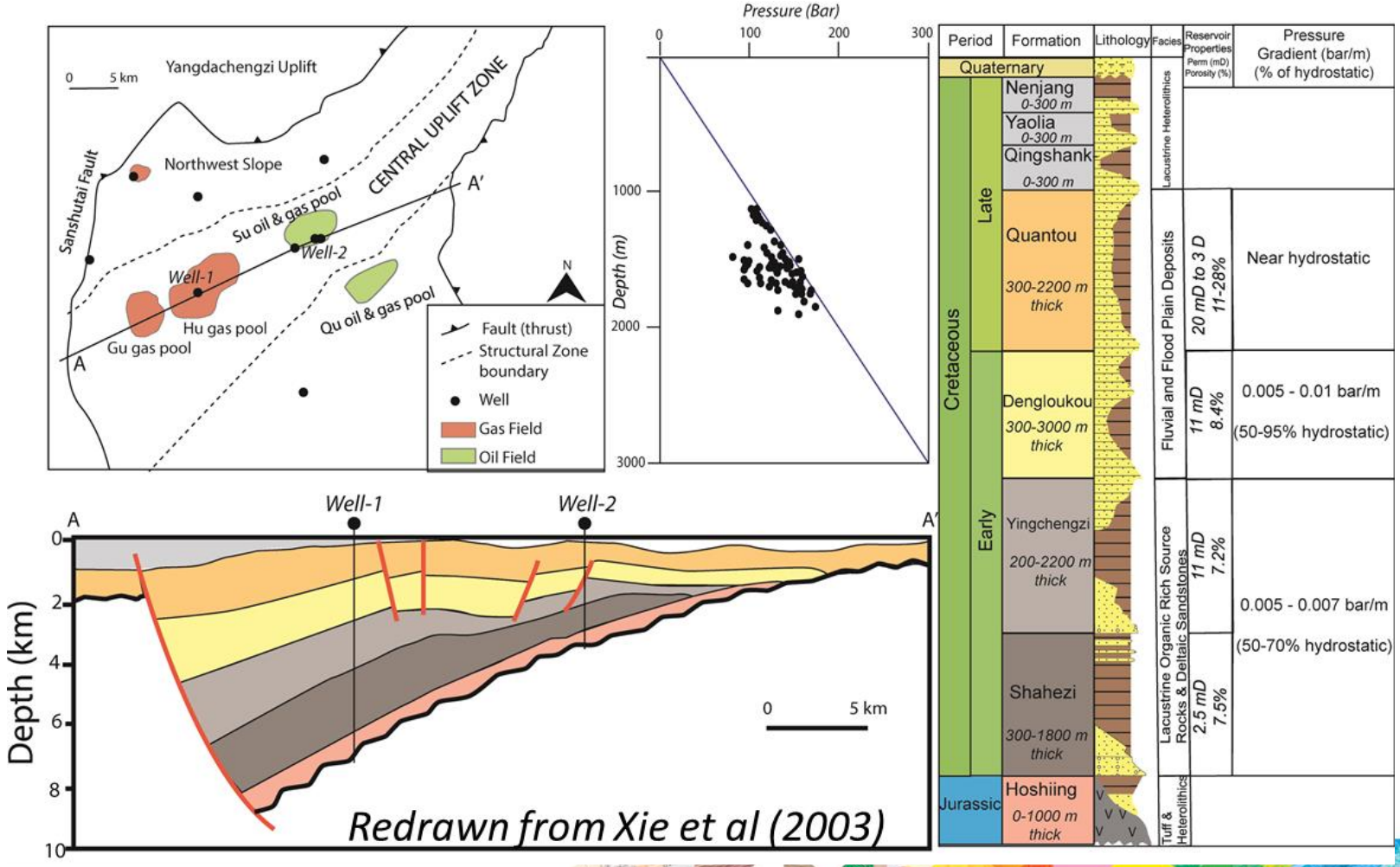


Fluid Shrinkage



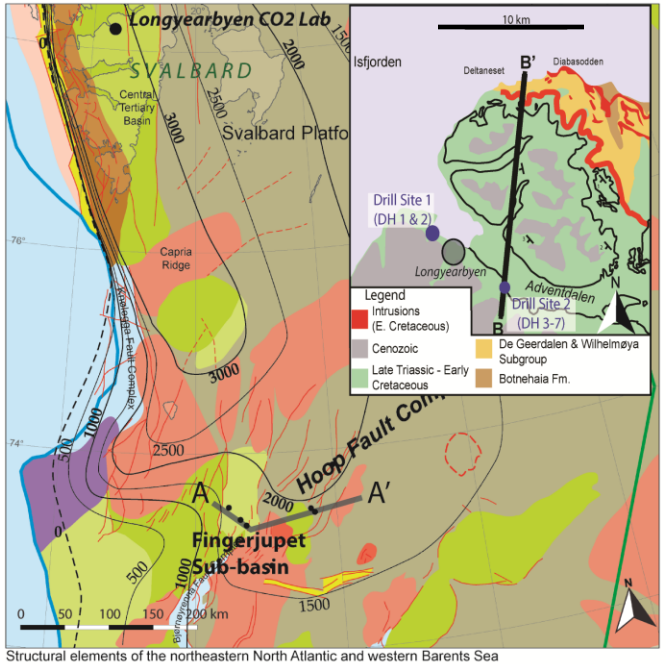
Case Study 1 – Songliao Basin, China

- Long term uplift throughout Cenozoic
- 400-1200 m (1300-4000 ft) of uplift and erosion
- Low permeability lacustrine reservoirs
- Underpressure in oil, gas and water



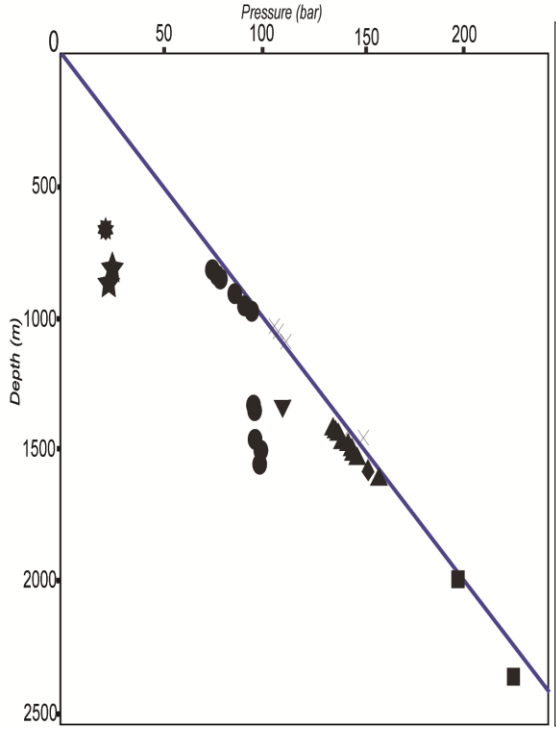
Case Study 2 – The Barents Shelf

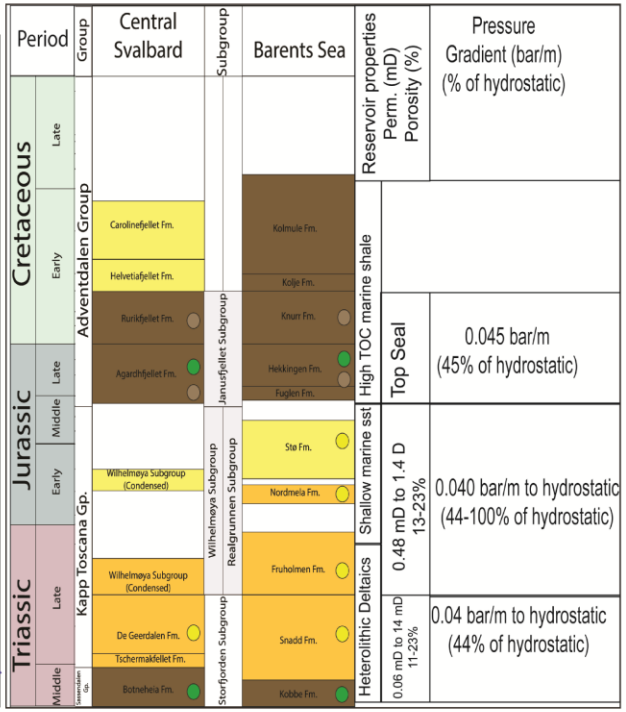
- Underpressure occurs offshore and onshore Svalbard
- Several km of uplift throughout Cenozoic
- Underpressure in water and gas accumulations

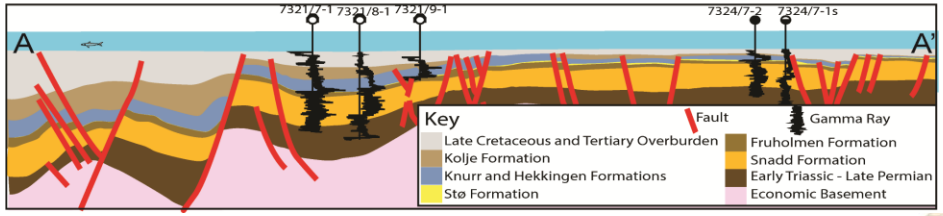


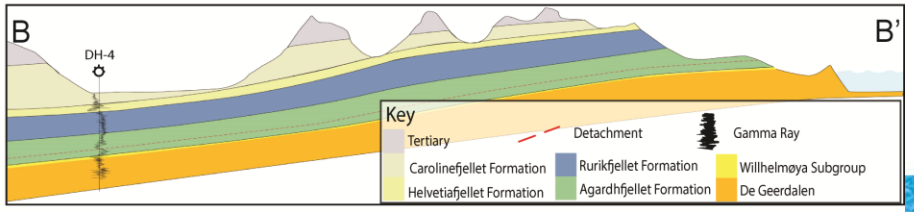
Structural elements of the northeastern North Atlantic and western Barents Sea
Compiled by Winfried K. Dallmann

Volcanic province
Continental shelf areas, undiff.
Fold belt (Cenozoic)
Graben (Cenozoic)
Structural basin (Cenozoic)
Dome structure (Cenozoic)
Structural high (Cenozoic)
Platform (Meso-/Cenozoic)
Major Faults
Cenozoic Uplift (Metres) From Henriksen et al (2011)
Underpressured Well

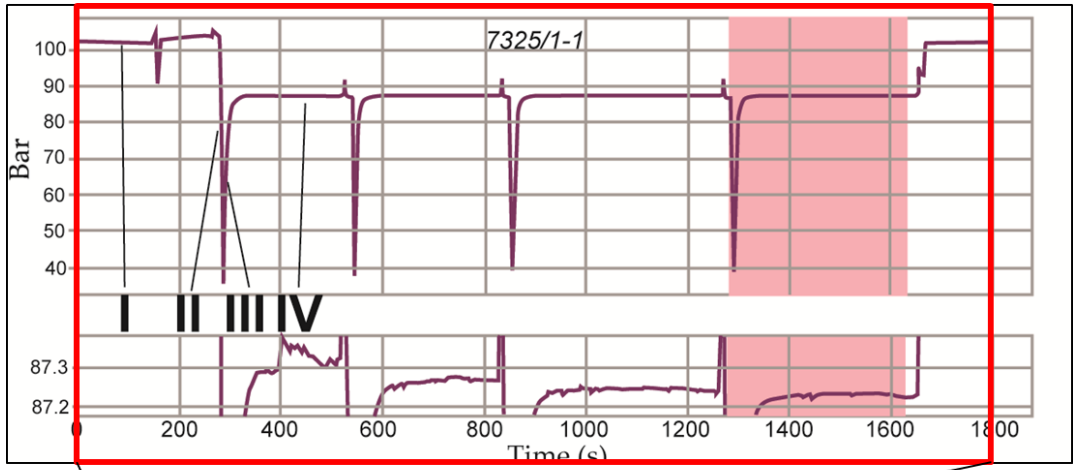


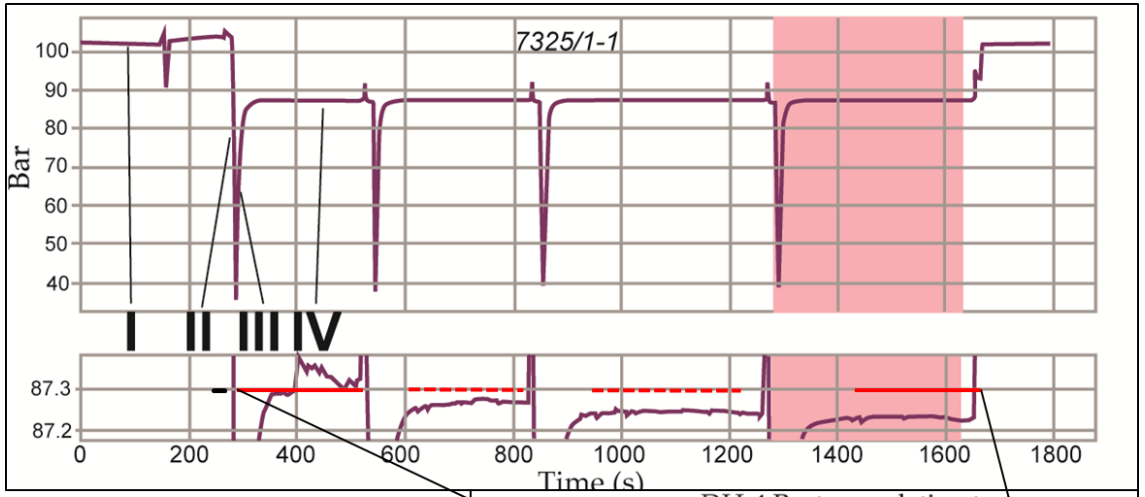


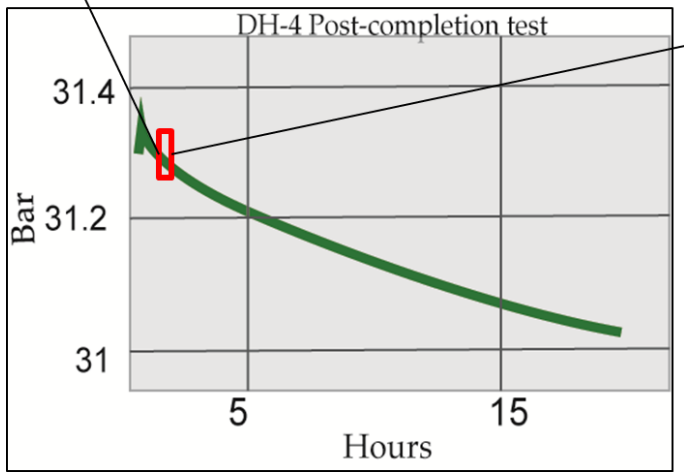


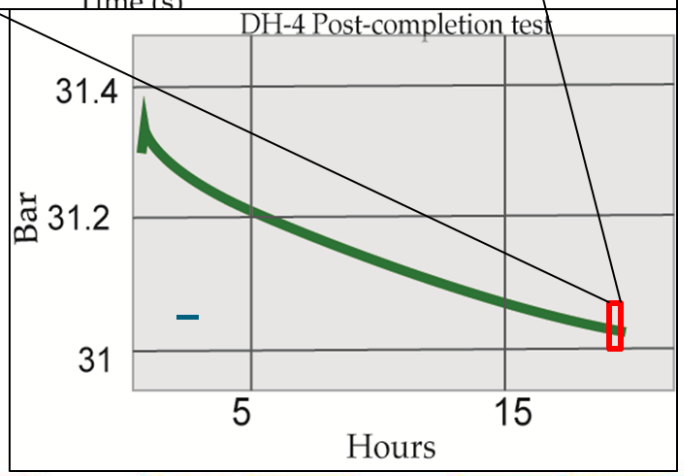


Case Study 2 – Long Term Tests



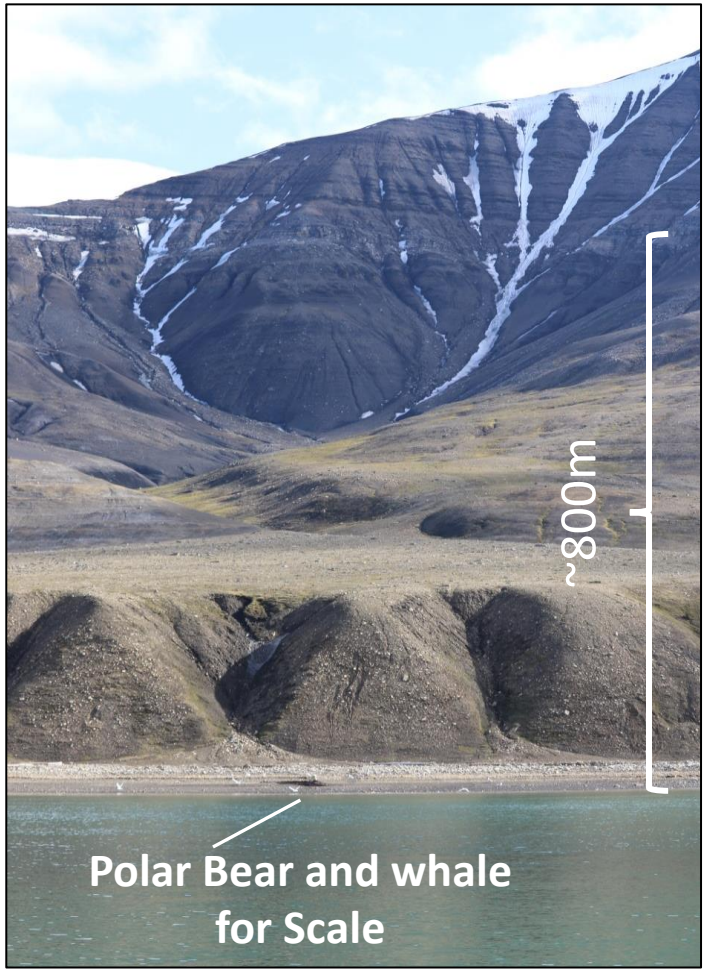




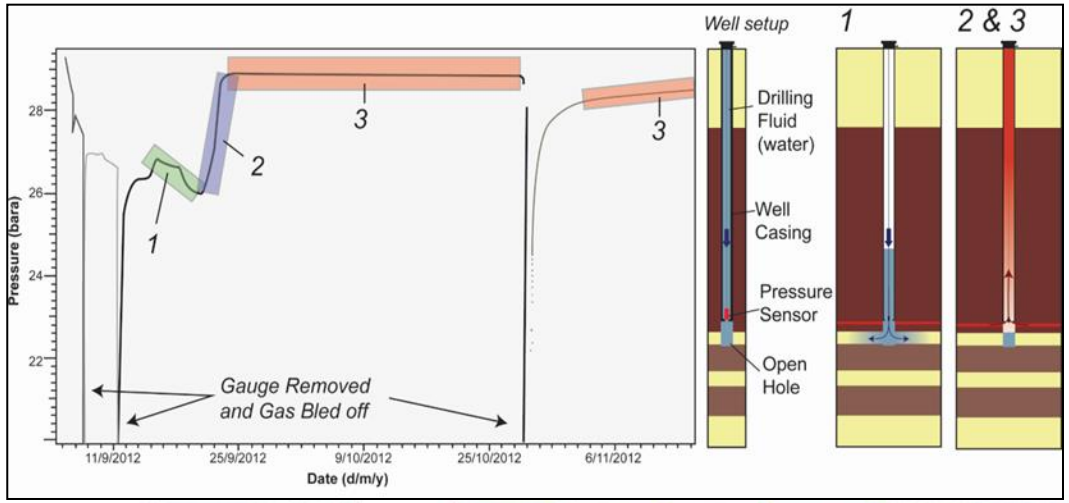


- How detectable is supercharging?
- DH-4 in Svalbard took three years to return to initial RP following injection tests

Case Study 2 – Underpressure in the Top Seal

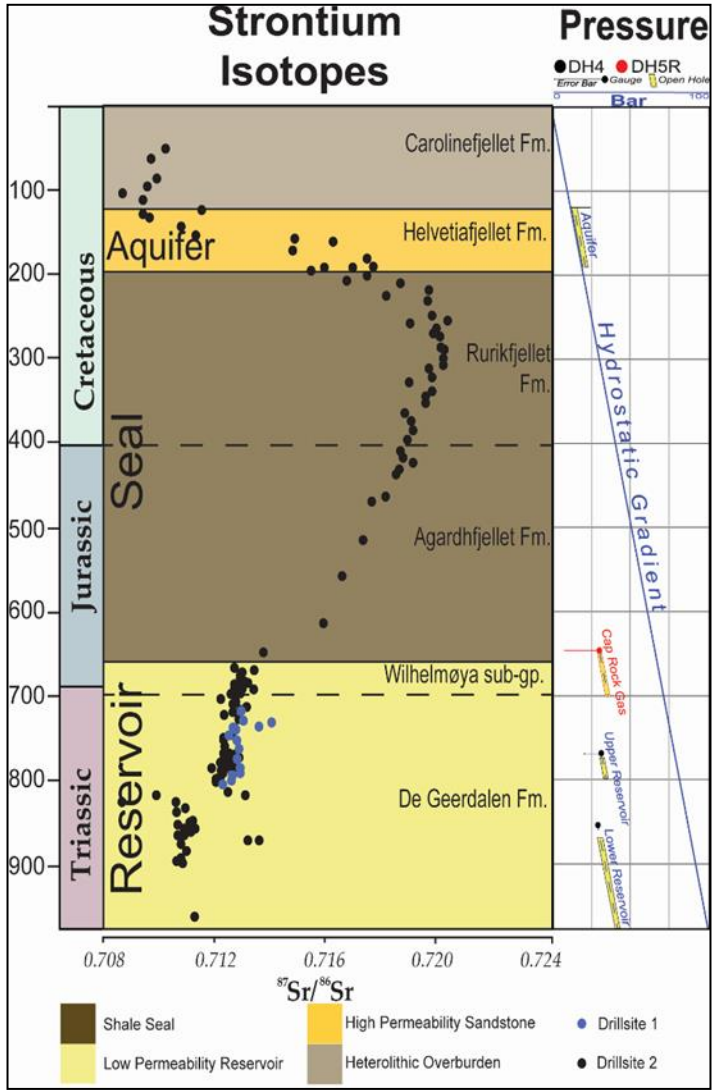


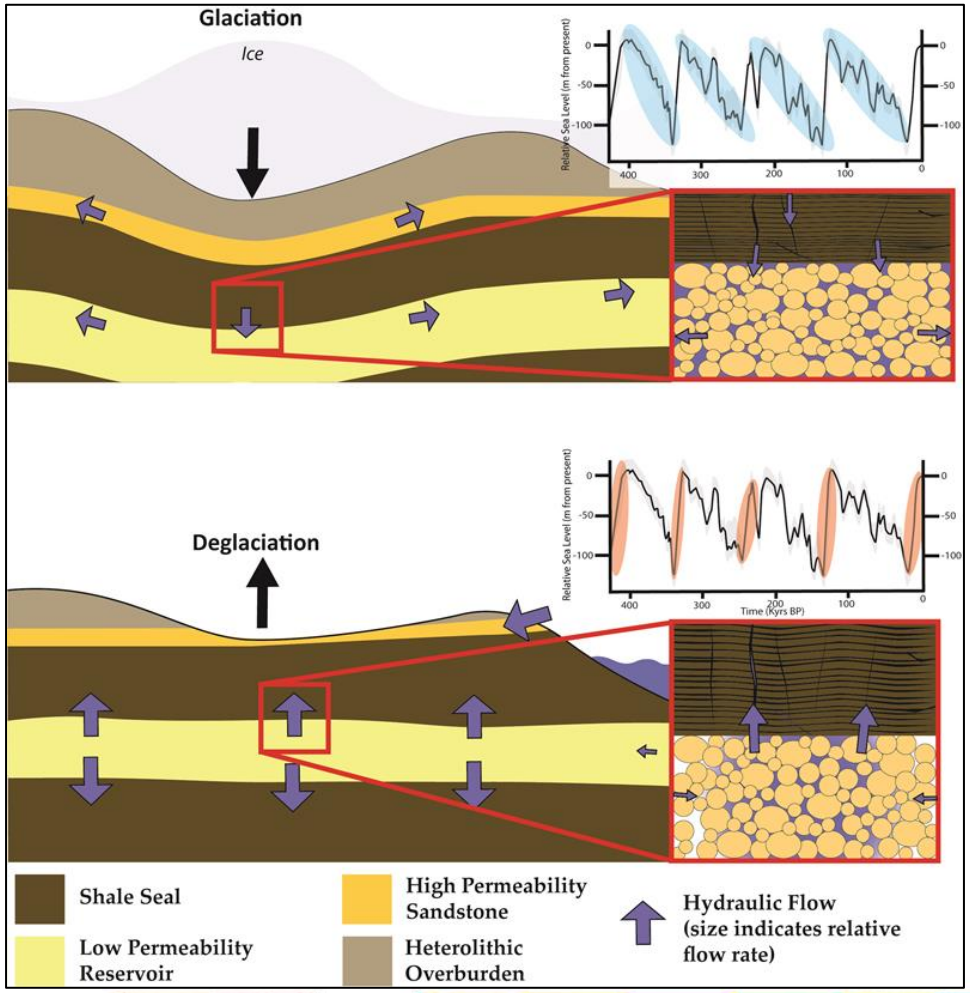
- Svalbard represents exhumed stratigraphy of the Barents Shelf
- A gas kick occured in monitoring well DH-5 during interference testing



Case Study 2 – Cause

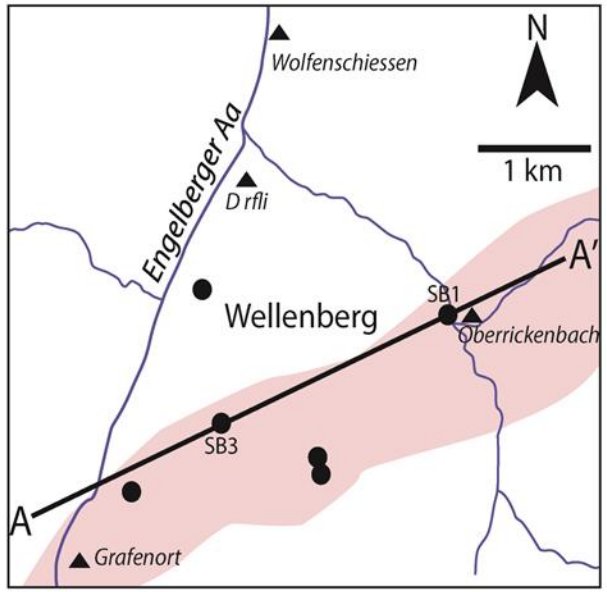
- Underpressure has been formed recently
- Underpressure exists in the top seal
- Isotope data indicates fluid mixing from reservoir to top seal

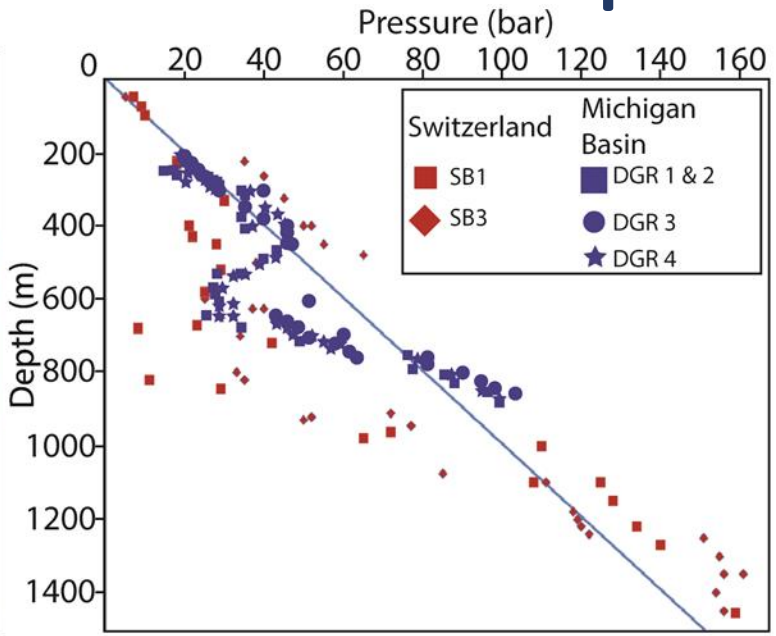


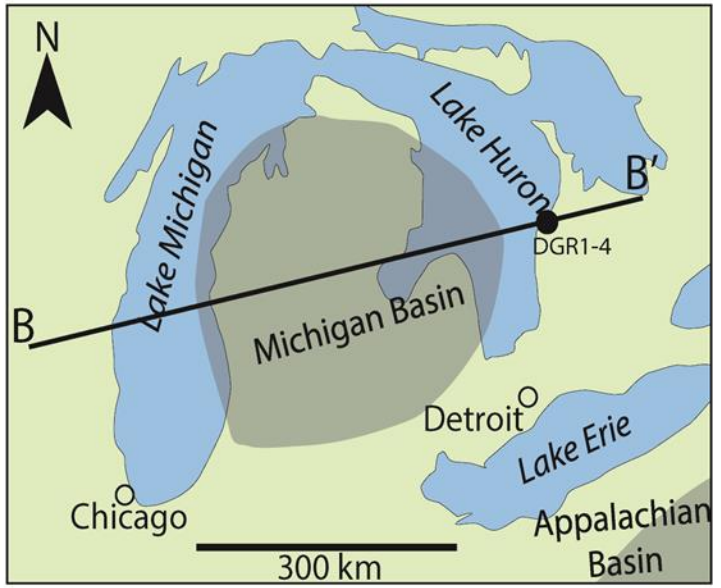


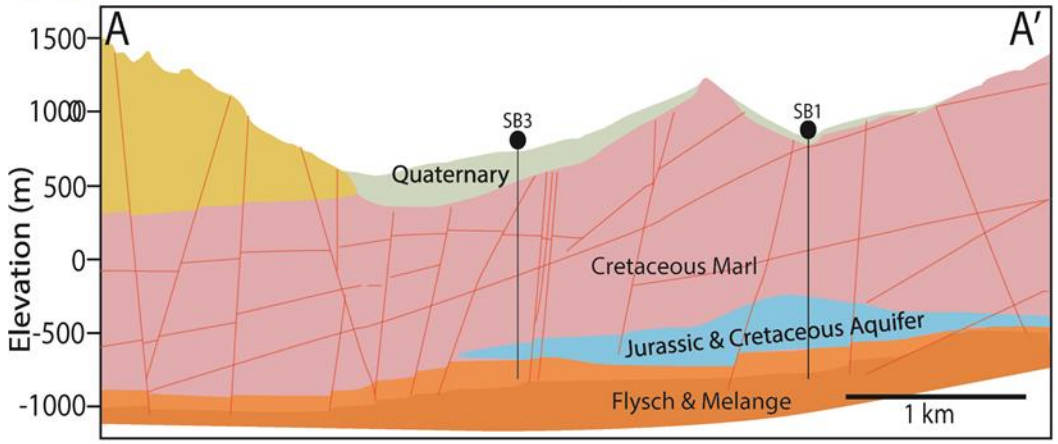
Case Study 3 – Nuclear Waste Disposal Sites

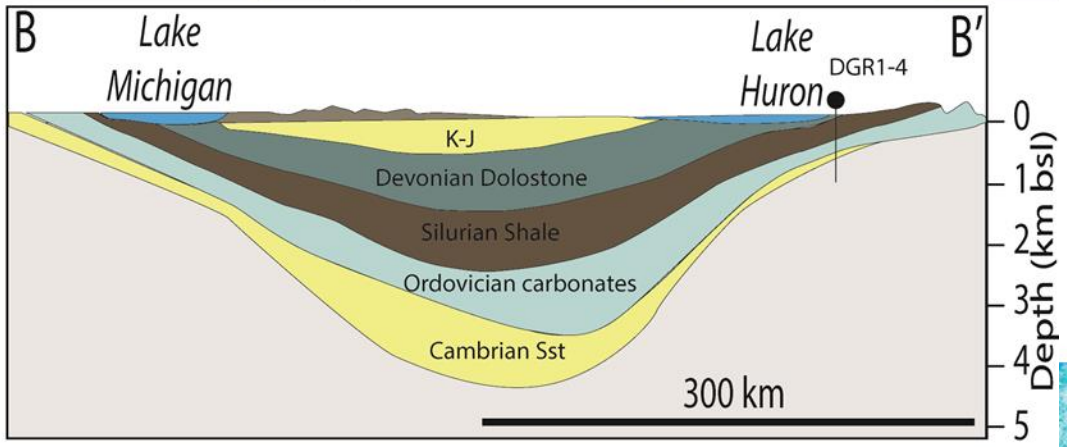
- Long term pressure tests
- Both experienced recent uplift
- Evidence of underpressure in mud rocks
- Reservoirs normally pressured











✓ Potential Cause

✗ Cannot Occur

● Can Contribute

Potential Mechanisms by Location

Location		Mechanism					
		Decompaction	Cooling (Fluid Shrinkage)	Phase Change (fluid shrinkage)	Hydrodynamic Flow	Sea Level Rise	Basin Centred Gas
China	Bohai Bay	✓	✓	✗	●	✗	●
	Qinshui	✓	✓	✗	✓	✗	?
	Ordos	✓	✓	✗	✓	✗	✗
	Songliao	✓	✓	✗	✗	✗	*✓
Russia/ Balkans	Siberia	✓	✓	●	✗	✗	?
	Carpathians	✓	✓	●	✗	✗	?
Barents Shelf	Svalbard	✓	✗	●	✗	●	✗
	Offshore	✓	● ✓	✗	✗	●	✗ ✓
Switzerland		✓	✗	●	✗	✗	✗
Michigan		✓	✗	●	✗	✗	✗

Multiple symbols indicate a mechinism may physically occur in isolated cases/wells

Conclusons/Summary

- Underpressure is closely associated with Cenozoic uplift
- Underpressure is observed in the Top Seal
- Underpressure can cause severe drilling problems and should be expected (even in potential sealing units)
- Underpressure formed recently in all locations
- Care should be taken when using formation pressure for long-term geological analysis (e.g. seal analysis)

Aknowledgements

UNIS CO_2 LAB

ARCEx
Research Centre for
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ikon
Science

OMV

Schlumberger

cegal