Underpressures in the Barents Sea and Svalbard

Observations and possible implications for the petroleum systems

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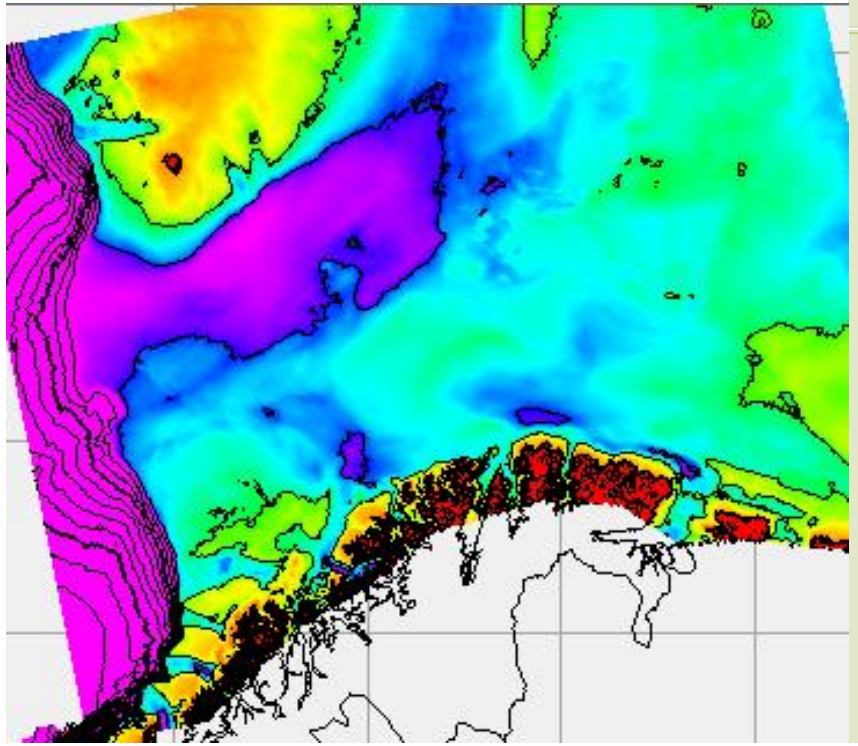
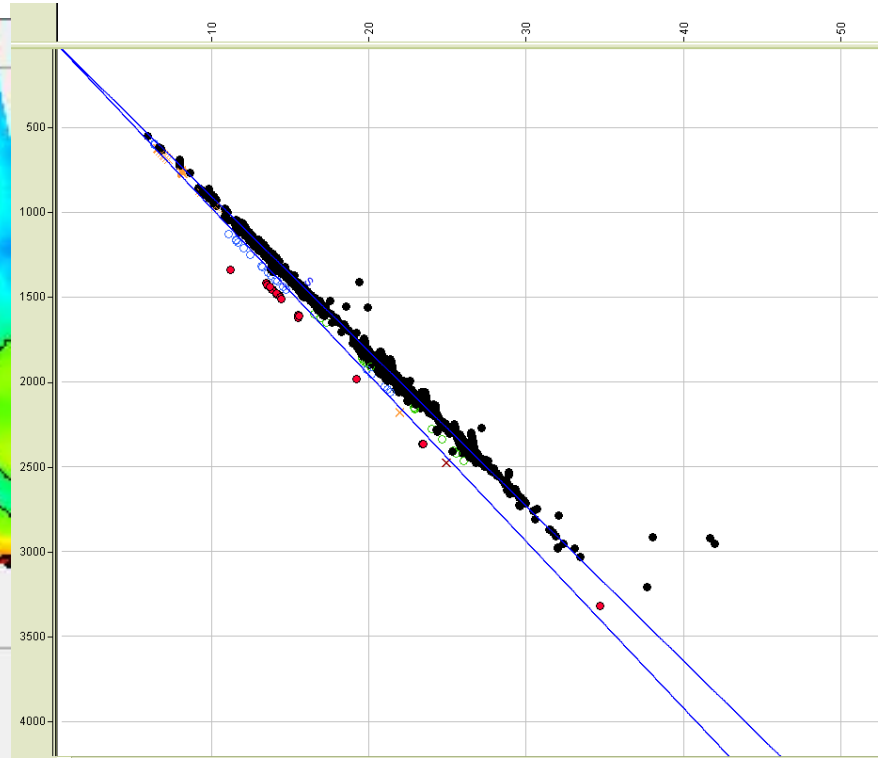
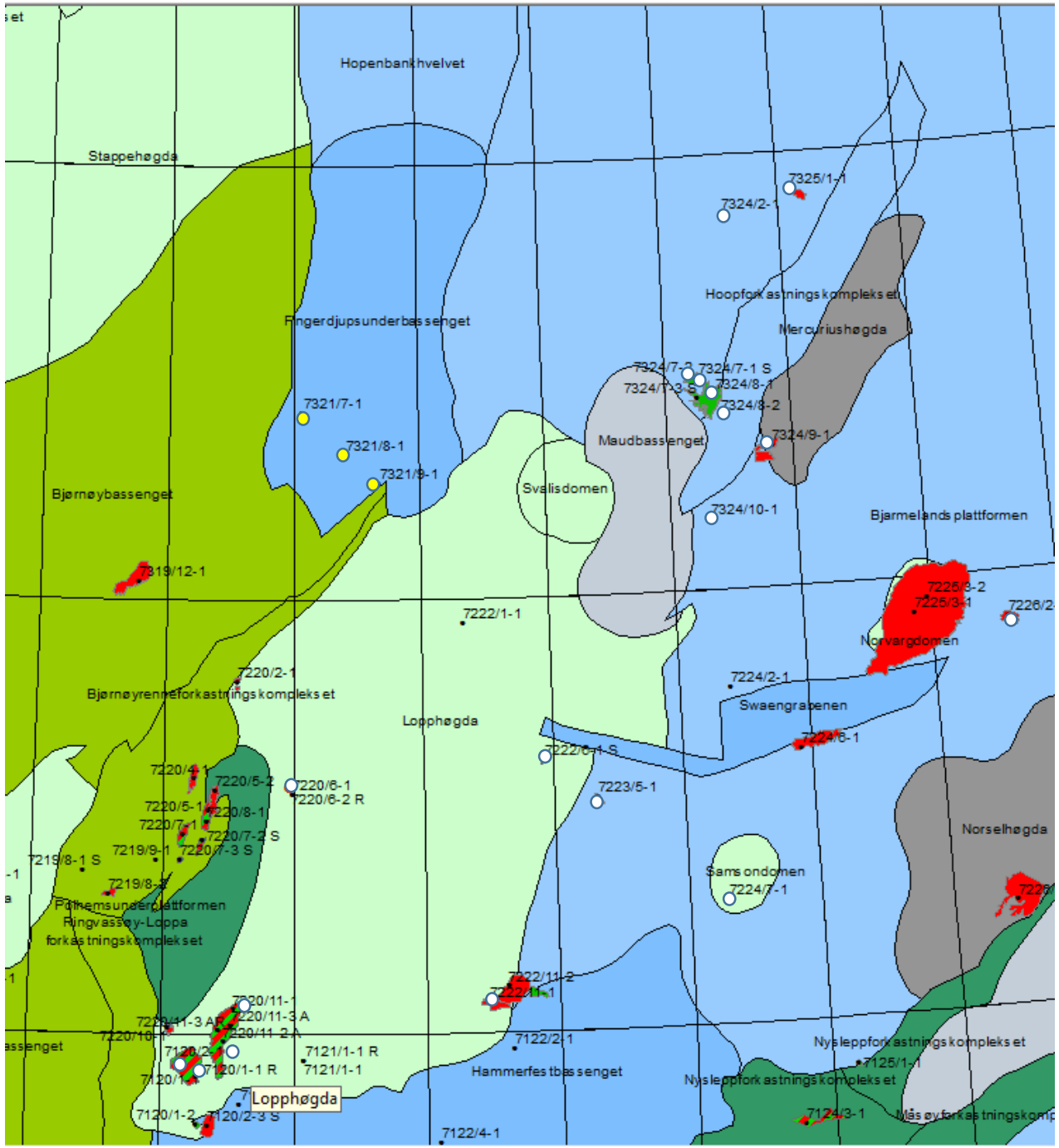






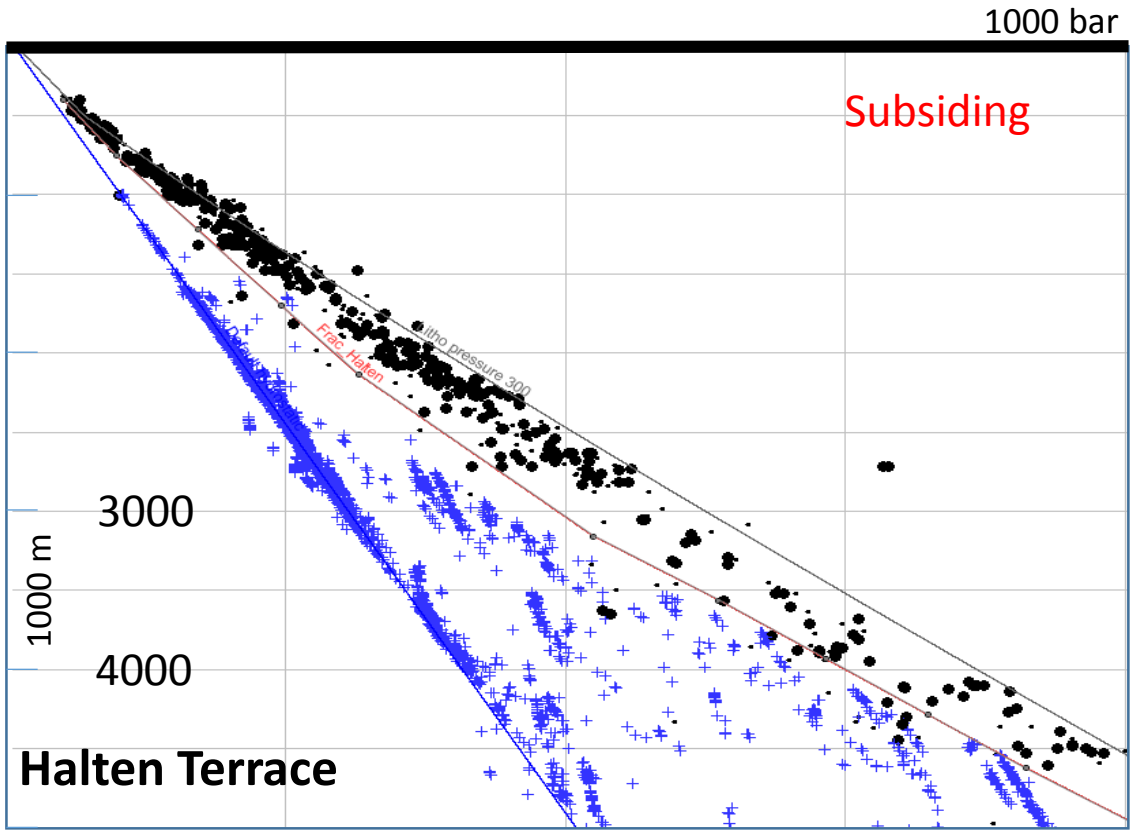
Introduction

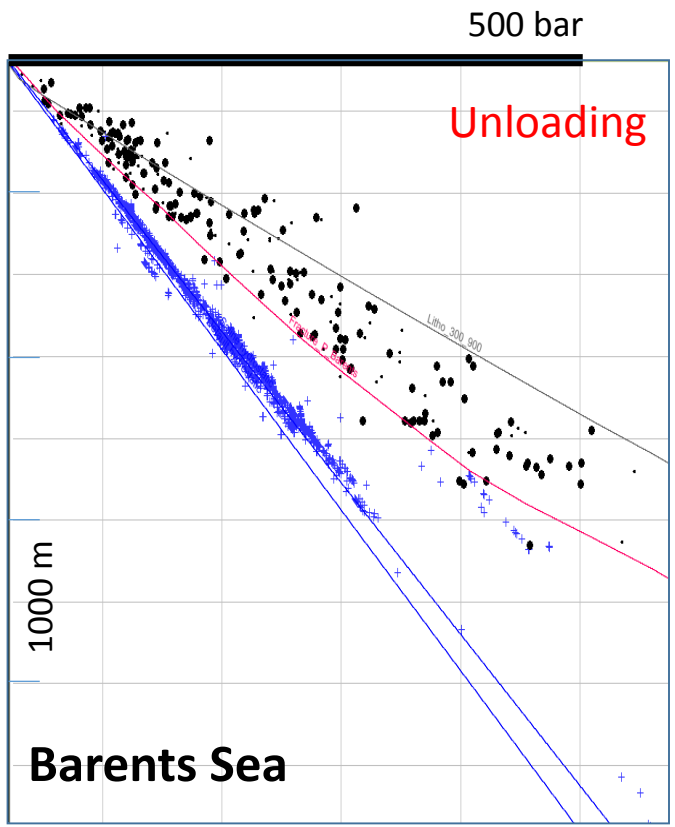
Yellow circles: Underpressured wells in the Fingerdjupet subbasin drilled 1988

White circles: Released wells in the Loppa High, Bjarmeland Platform and Maud Basin area

Relevance: Drilling hazards, basin modelling

Observation: Halten Terrace overpressure, Barents Sea hydrostatic and underpressures

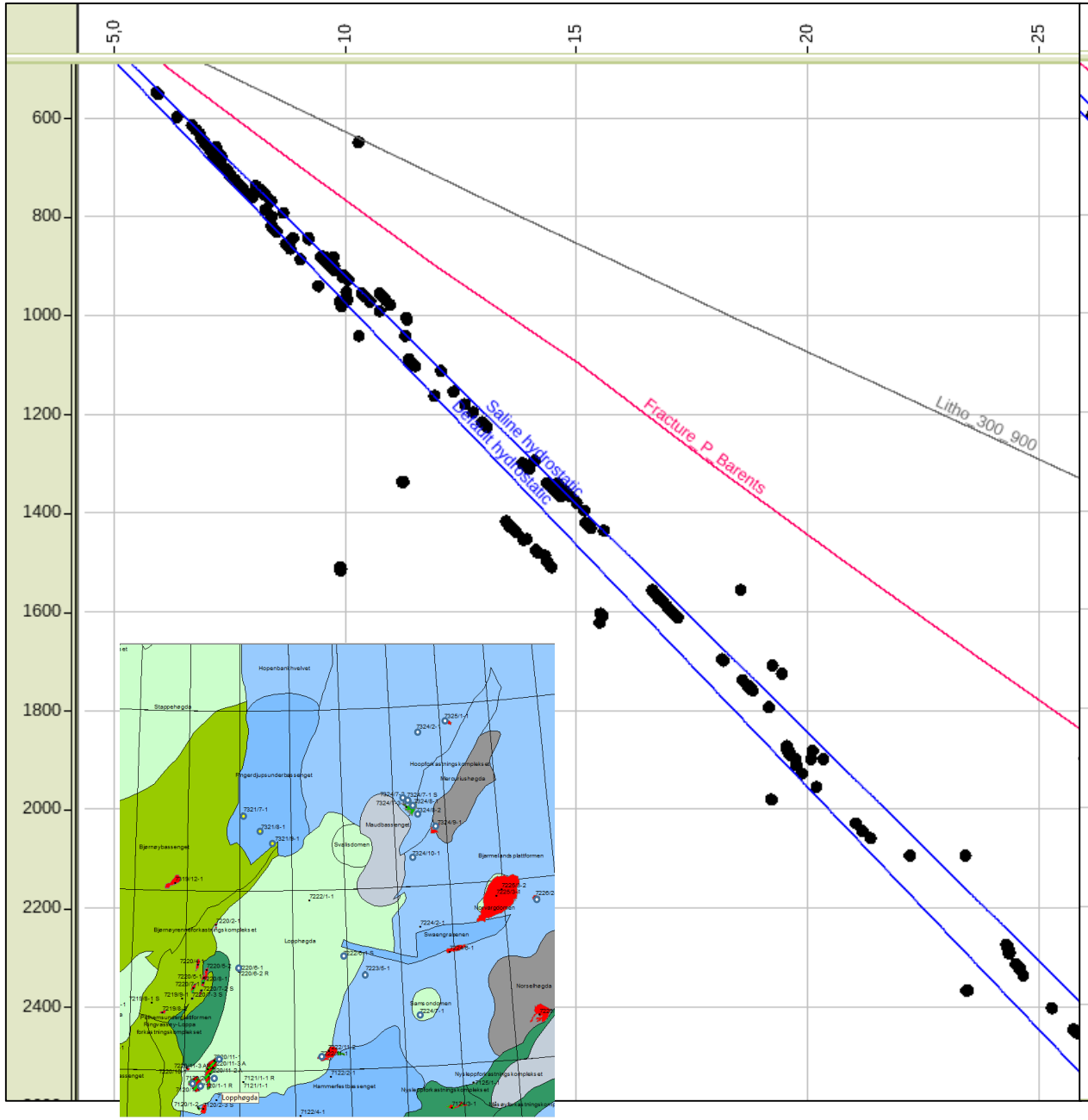


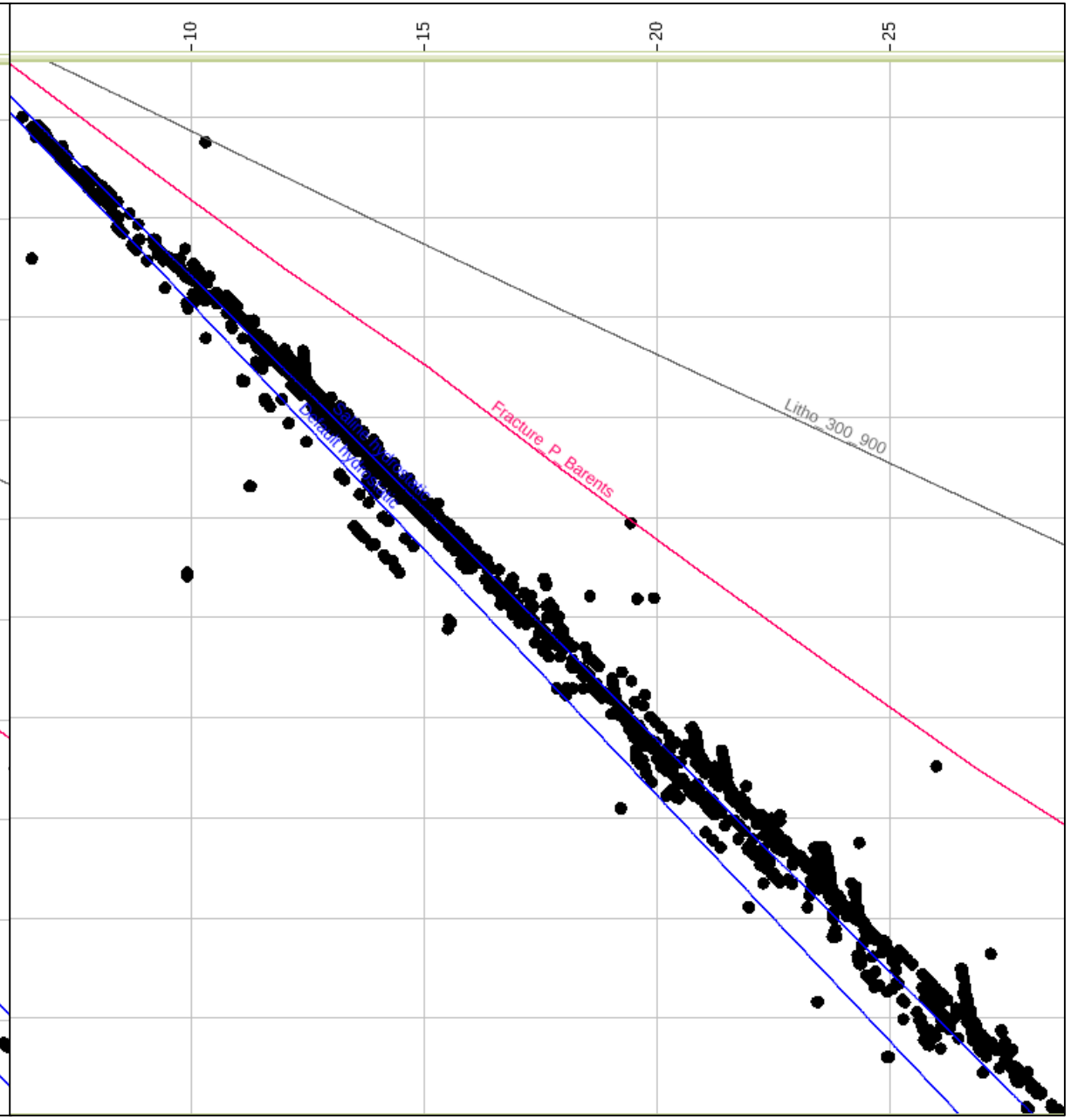


Pore pressure measurements (blue) and leak-off pressures (black) from the Halten Terrace and the Barents Sea. Calculated lithostatic pressures for 300 m water depth is shown by gray and interpreted regional fracture pressure gradients by red lines.

The blue lines show hydrostatic pressure gradients with sea water and high salinity water in the Barents Sea.

In subsidence, overpressures are formed because pore space is reduced by compaction of rock and fluid volumes increase because of temperature increase and by formation of hydrocarbons
In unloading, it can be argued that some of these processes are reversed. A tendency for small underpressures is observed



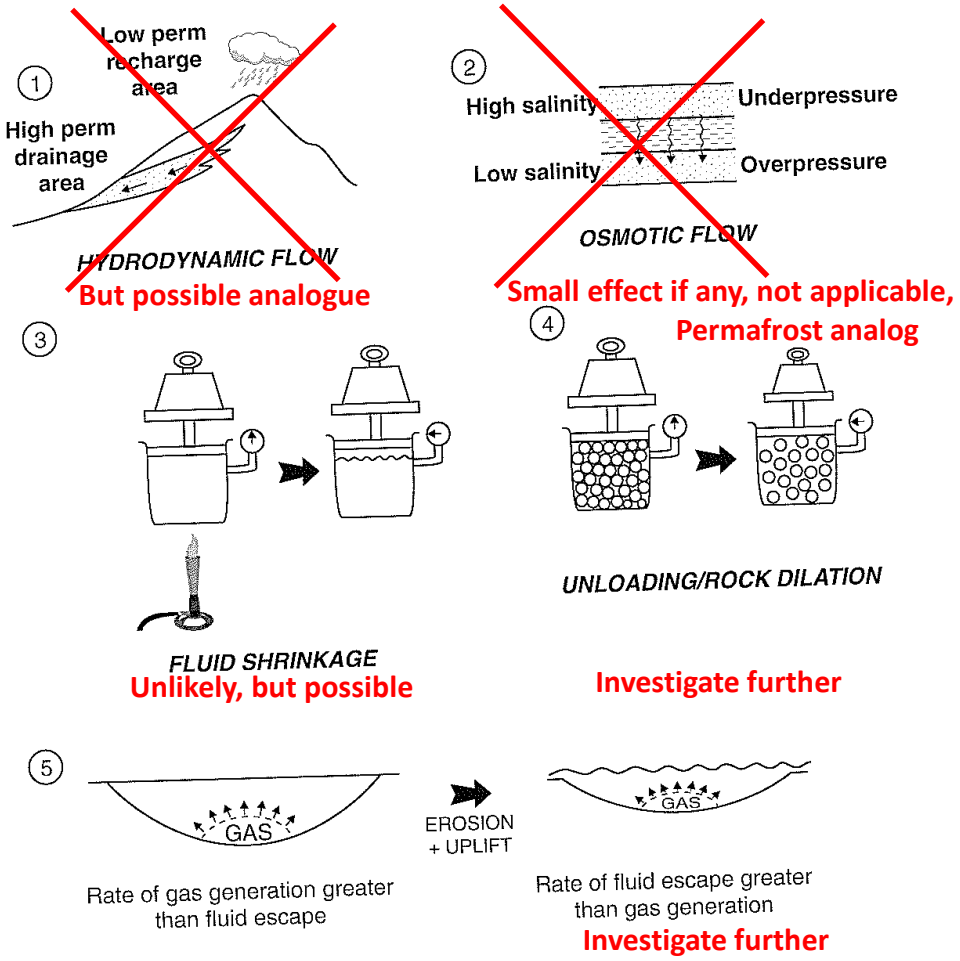


All white wells in the figure. Two groups. Small/low permeable aquifers

All Barents Sea pressures

Why underpressures - why do they form?

Underpressures are reported from eroded basins, e.g. Alberta, Songliao



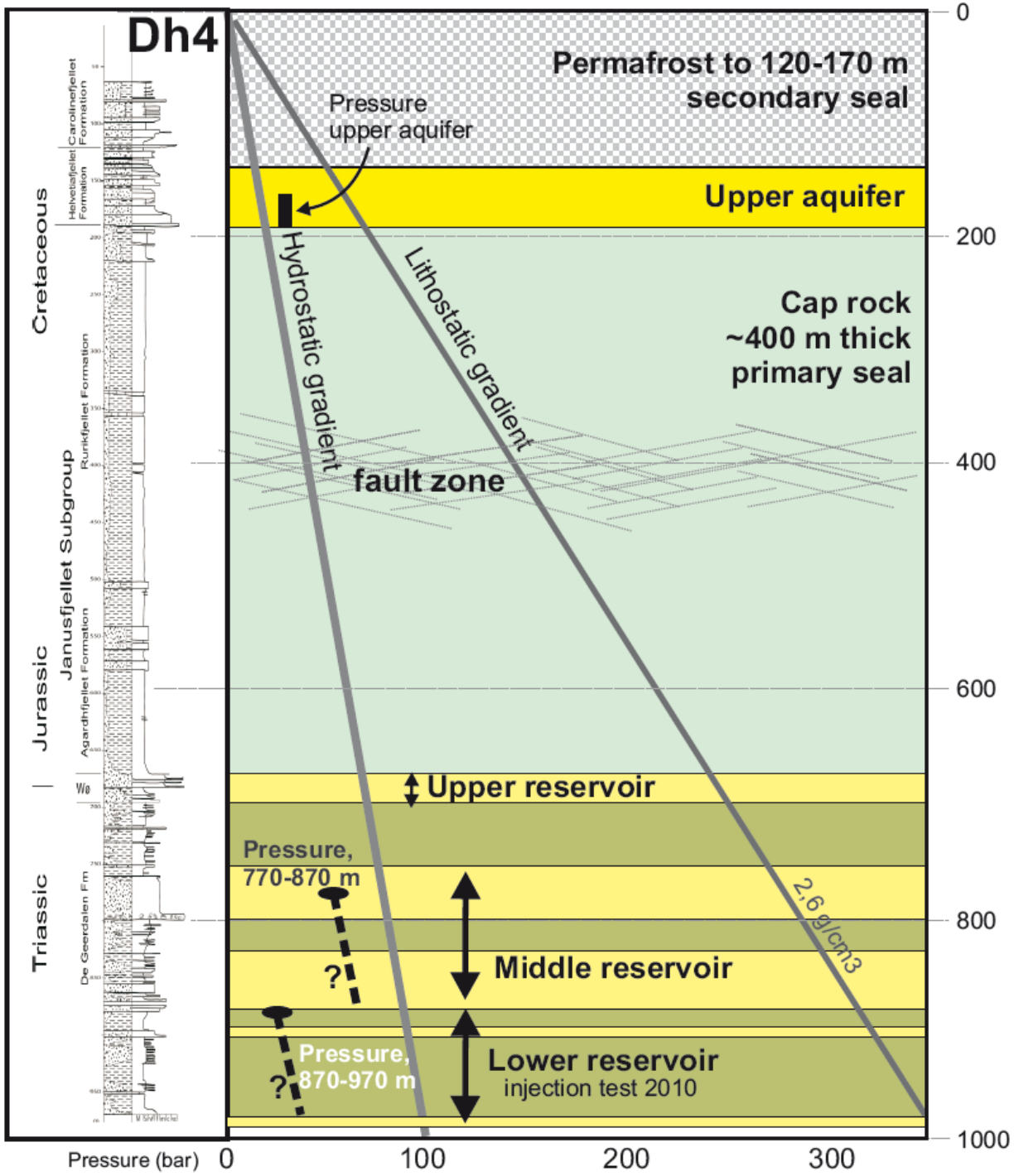
Swarbrick and Osborne 1998, AAPG Mem 70

Volume of fluid decreases relative to pore volume

Static
Shrinkage of water/fluid 3
Dilation of pores (clay) 4

Dynamic
Leakage (of gas) out of the system 5
Fluid flow out of the system 1, 2

Uplift and cooling will cause fluid shrinkage because the thermal shrinkage is larger than the expansion by depressurisation. The question is what happens to the pore volume. In the Barents Sea we observe a few wells with overpressures, indicating that fluid shrinkage is not the main cause for underpressuring



Longyearbyen CO2 lab pressure observations

18-23 bar overpressure

The extremely low pressure was surprising.

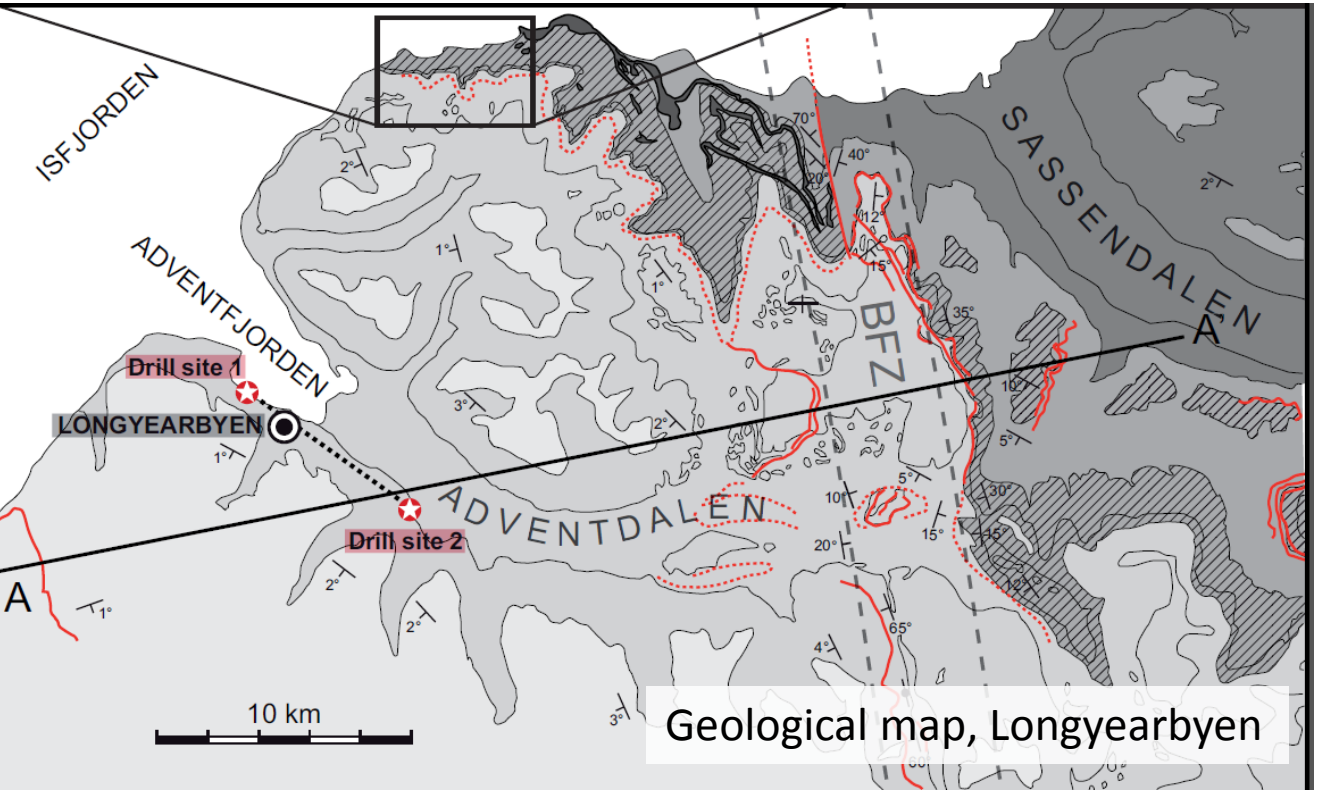
Good news: Proves good seal
Bad news: Could create unexpected problems for CO2 storage because CO2 may stay in gas phase

What pressure should be predicted away from the site?

Several explanations were provided along the lines presented above

>50 bar underpressure

Braathen et al NGT 2010



Geological map, Longyearbyen

Drilling overpressured water close to a pingo (photo for illustration purposes)

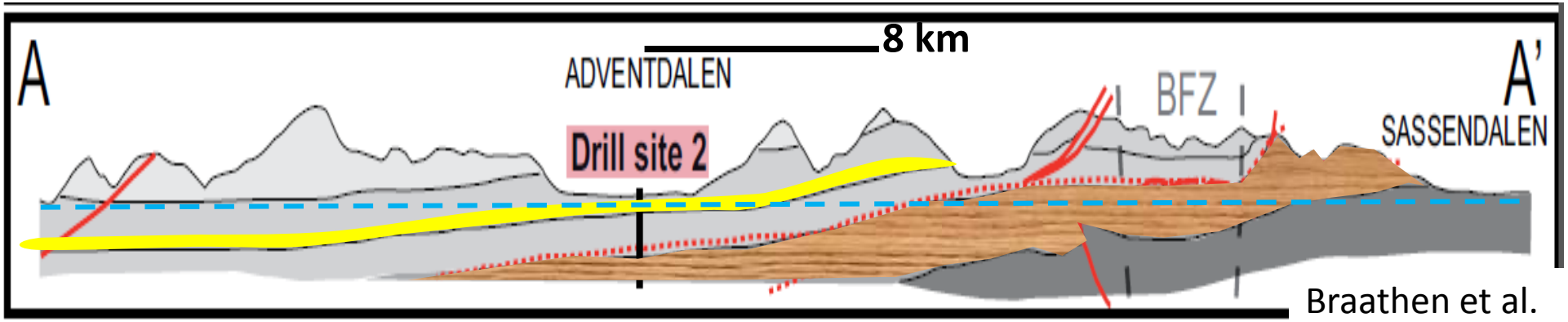
Longyearbyen wells:

50 bar underpressure below Jurassic seal.

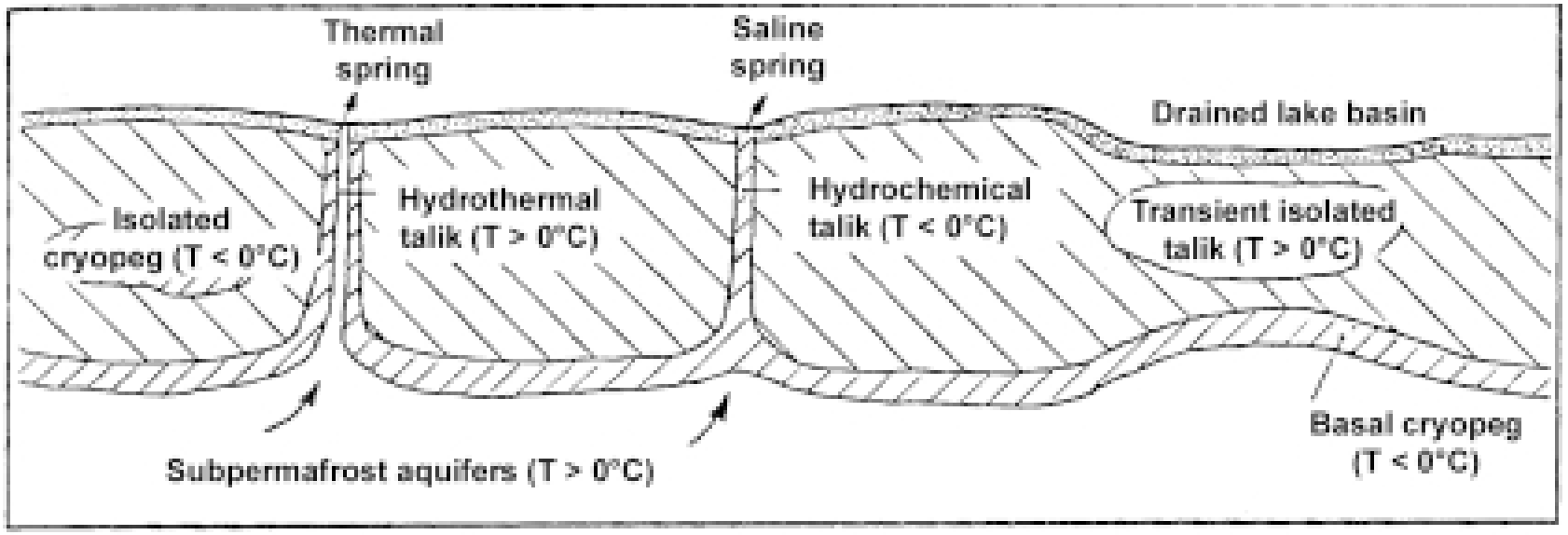
Observation: Permafrost can be associated with overpressures (pingos) and underpressures.

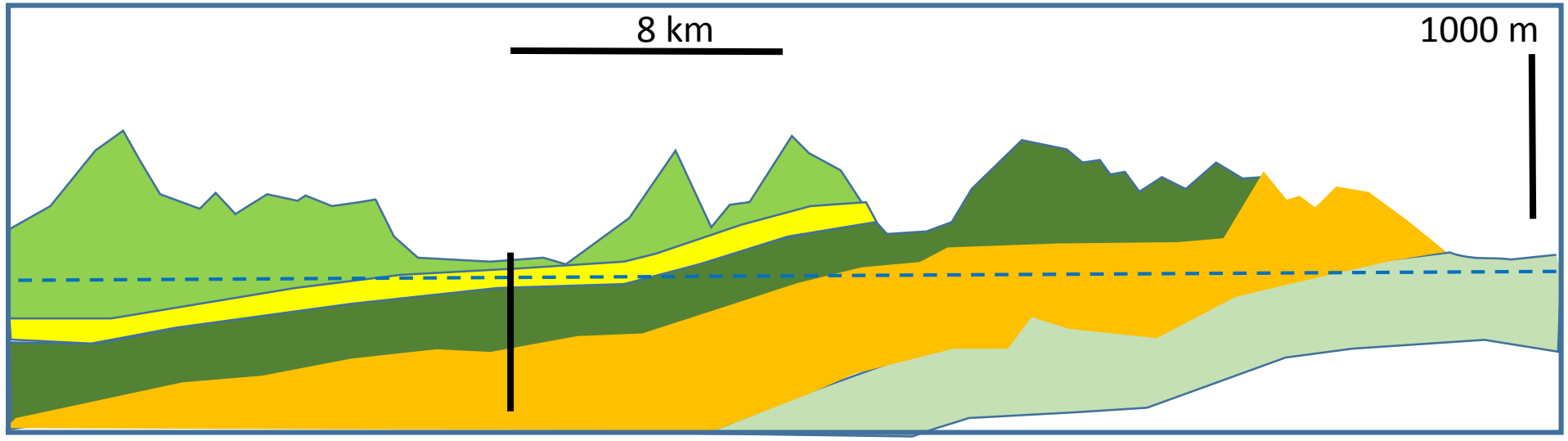
Water expands 6 % when freezing to ice

LYB drillsites: Low permeability, fractured reservoir below permafrost.
50 bar underpressure



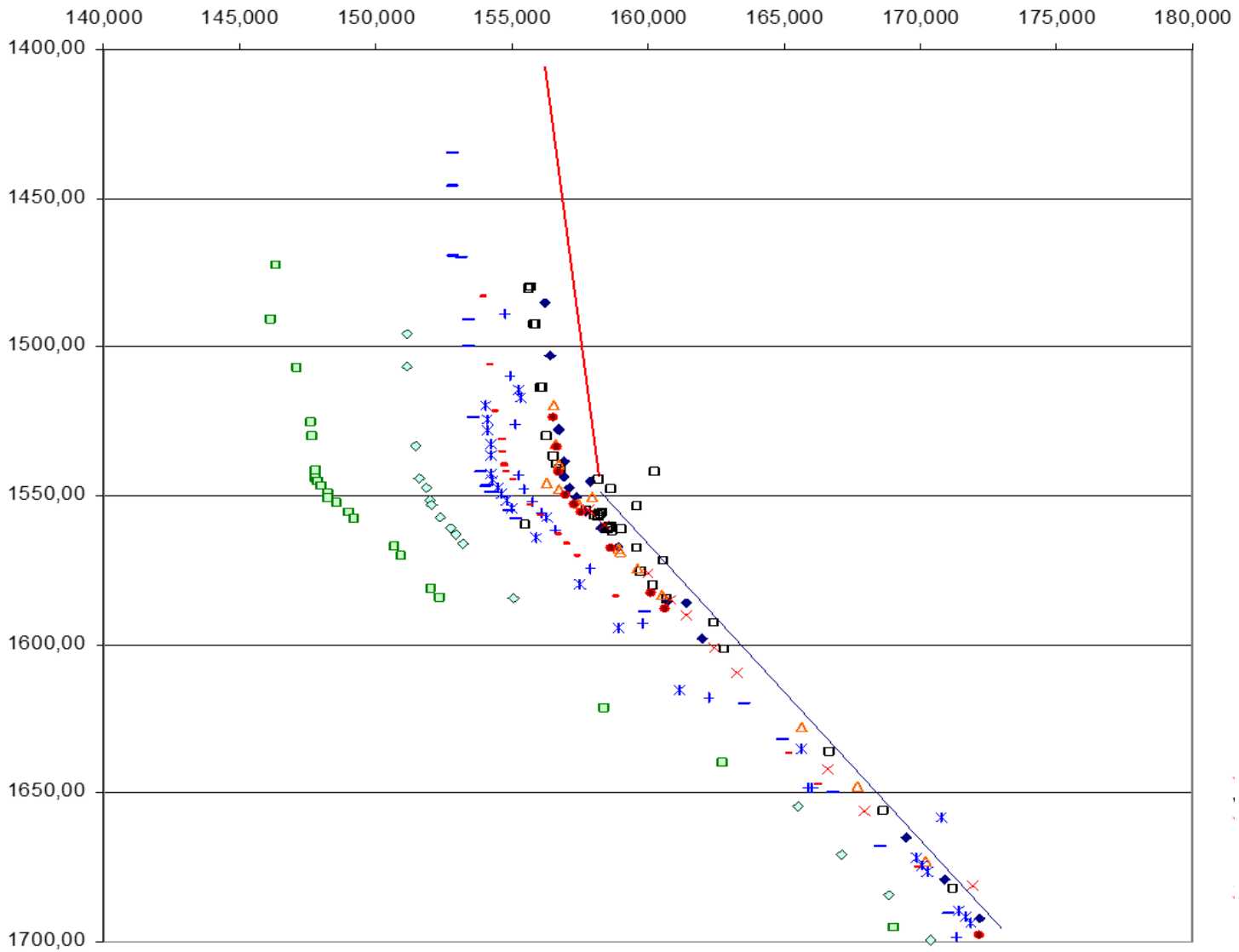
Braathen et al.





The aquifer is sealed by a shale caprock above and permafrost laterally. The permafrost is thicker below the mountains. Gas and gas hydrates may occur related to the thick organic rich Upper Jurassic shales which have generated hydrocarbons. The extreme pressure differences are not likely to survive for long periods of geological time. Conclusion: Add permafrost and gas hydrates to Swarbrick's list.

Pressure depletion caused by oil and gas production. Troll example



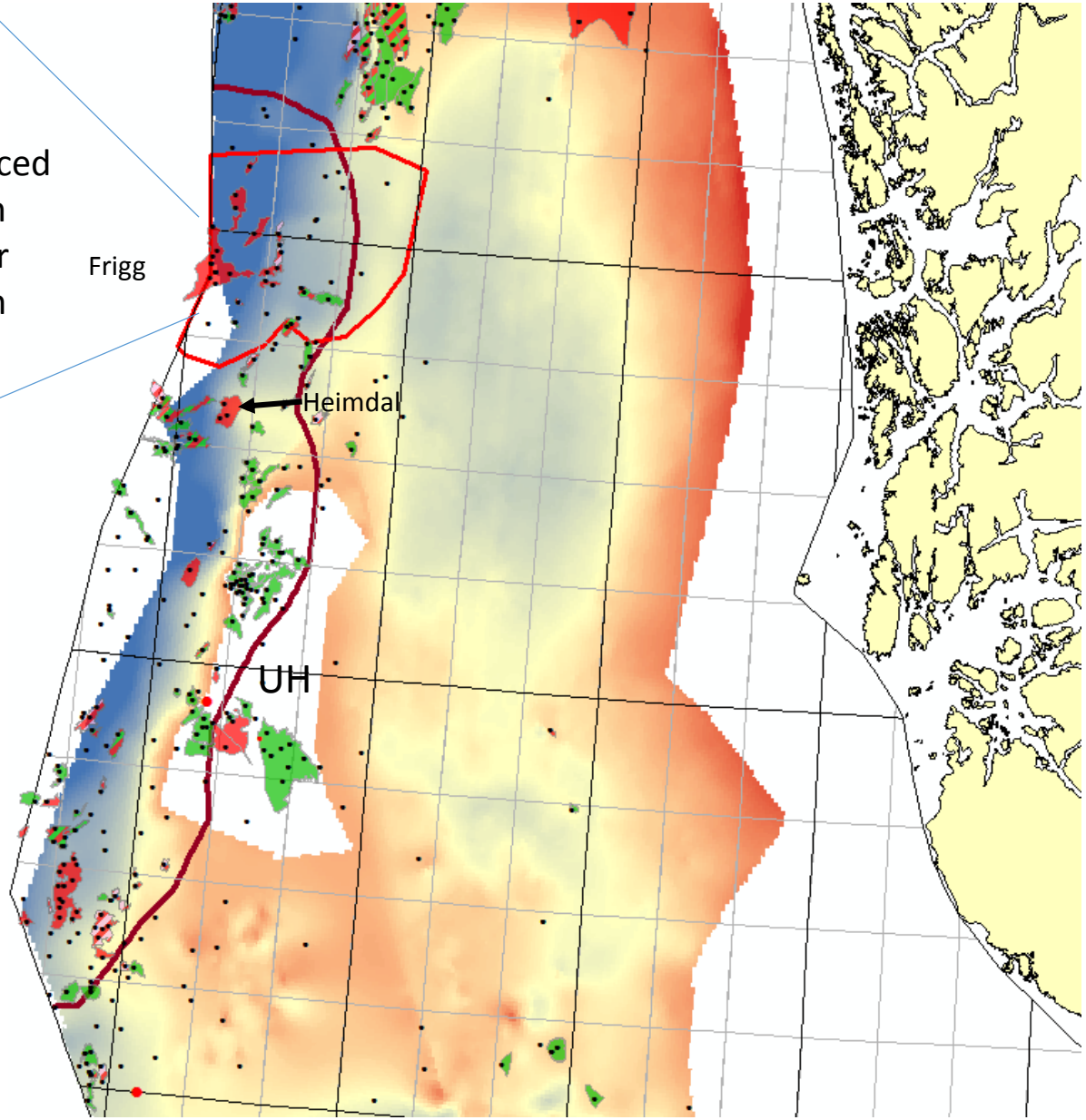
Fluid production analog

Underpressure is created in the aquifer when oil and gas production rate is greater than injection

Pressure depletion,Troll Field production wells. Red line: Initial gas pressure, black line: Initial water pressure. Plot of pore pressures from several wells drilled from 1 to 5 years after production started, green wells are the most recent. Most depletion (10 bar after 5 years) takes place in the uppermost formation.

The Frigg-Heimdal aquifer is depleted by gas production in Frigg-Heimdal and Sleipner East

The largest volume of gas was produced from the Frigg Field. Production from other fields like Heimdal and Sleipner East has contributed to the depletion



Frigg Fm outline

Heimdal Fm outline

Colors: Mid Jurassic depth

UH Utsira High

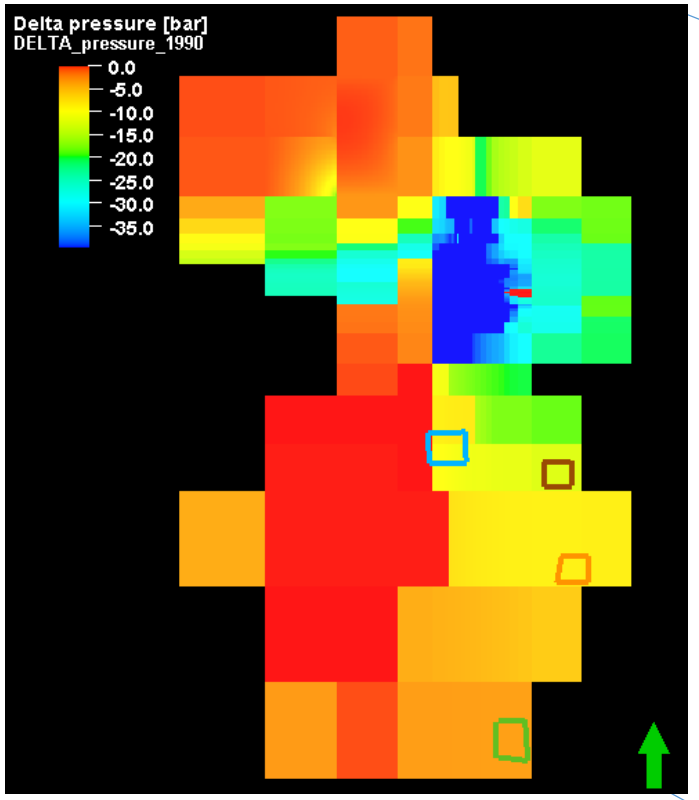
Aquifer includes
Frigg Formation
Balder Formation
Hermod Formation
Heimdal Formation
Ty Formation

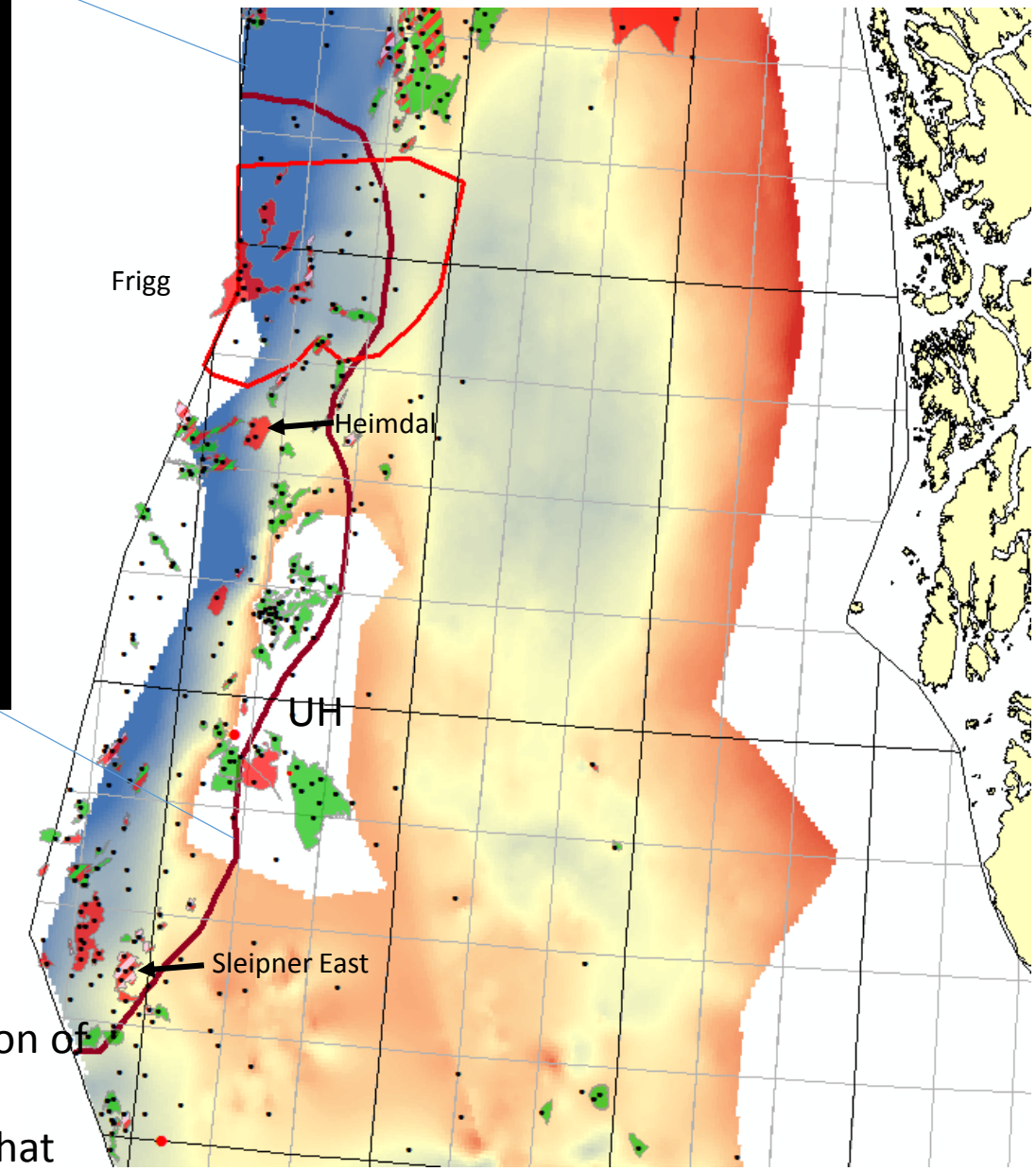
100 km

Modelling

Aquifer includes

Frigg Formation
Balder Formation
Hermod Formation
Heimdal Formation
Ty Formation





Frigg Fm outline

Heimdal Fm outline

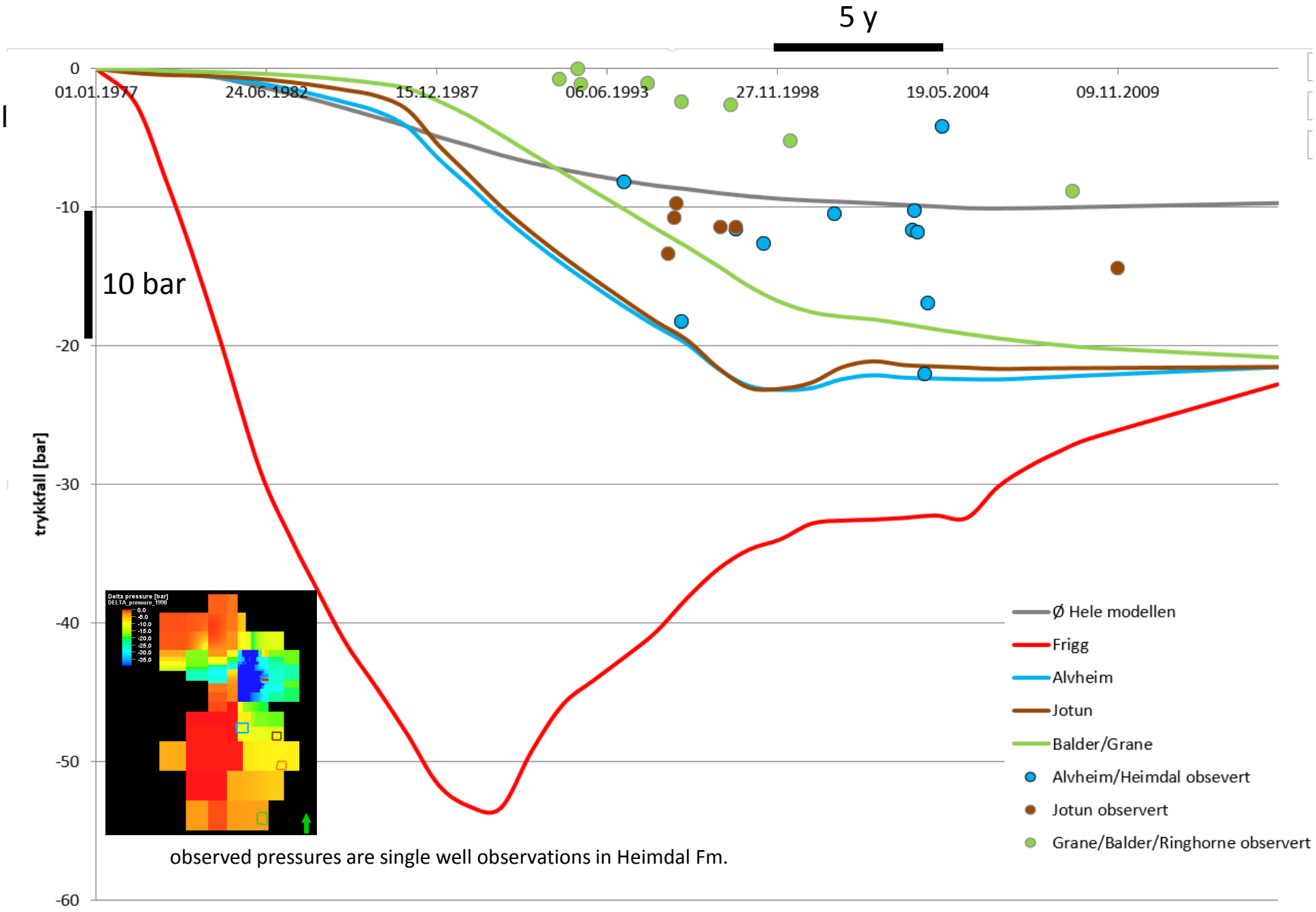
Colors: Mid Jurassic depth
UH Utsira High

Coarse aquifer model. Amount of depletion is a function of pore voluem, water and rock compressibility
Observations follow the modelled trend but indicate that the model volume is too small. 100 bar depletion will result from 0.5 -1 % voidage in a closed system.

Observations of aquifer pressure depletion through time from 1977 (onset of Frigg production)

Dots:
Observed well pressures,

Lines:
modelled pressures



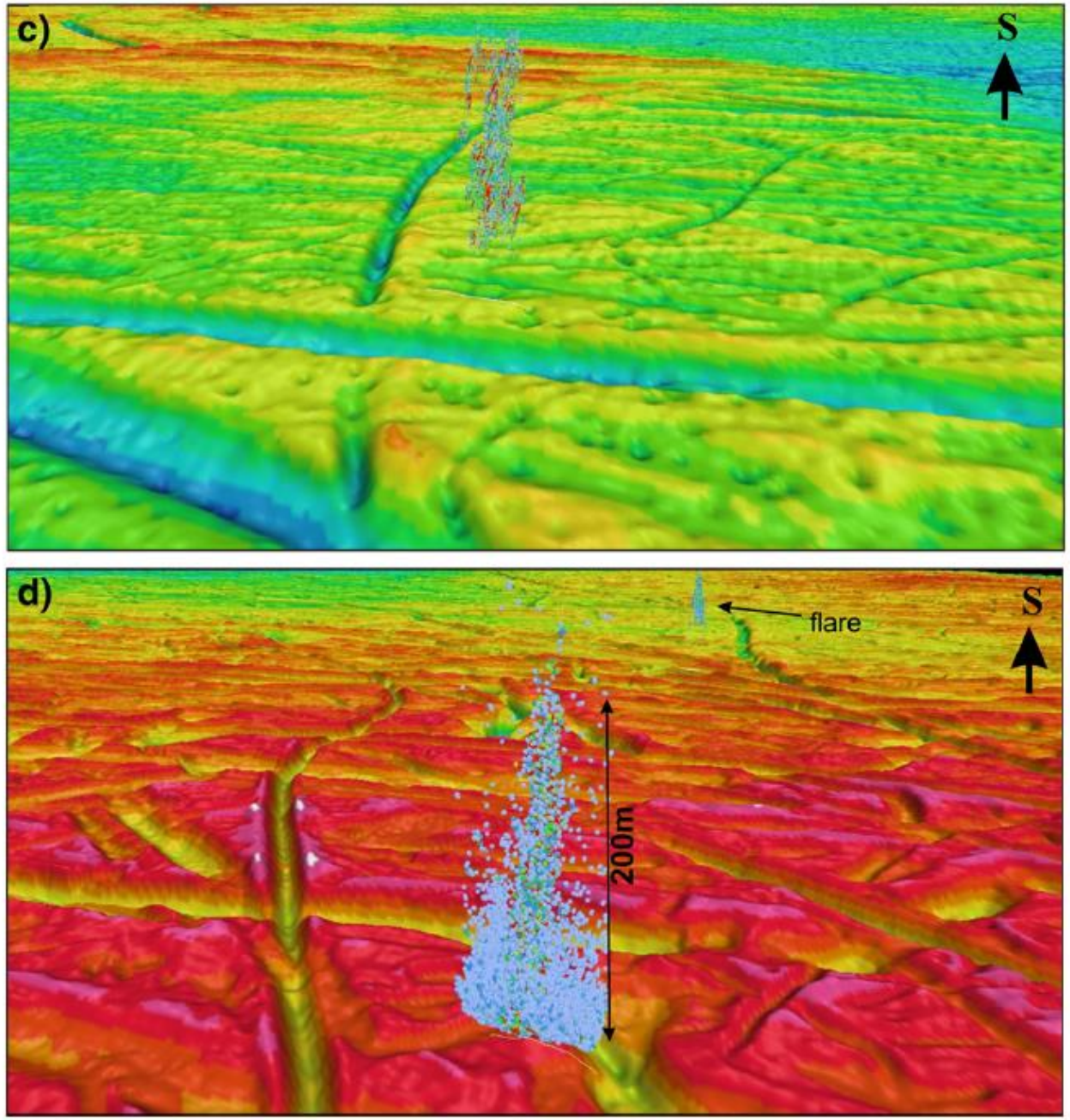
Can natural gas leakage lead to pressure depletion?

Natural seepage and leakage do not have open hole to the sea floor.
How large underpressures could reasonably be expected as a consequence of gas leakage?

Active natural seeps are typically in dynamic equilibrium, not catastrophic

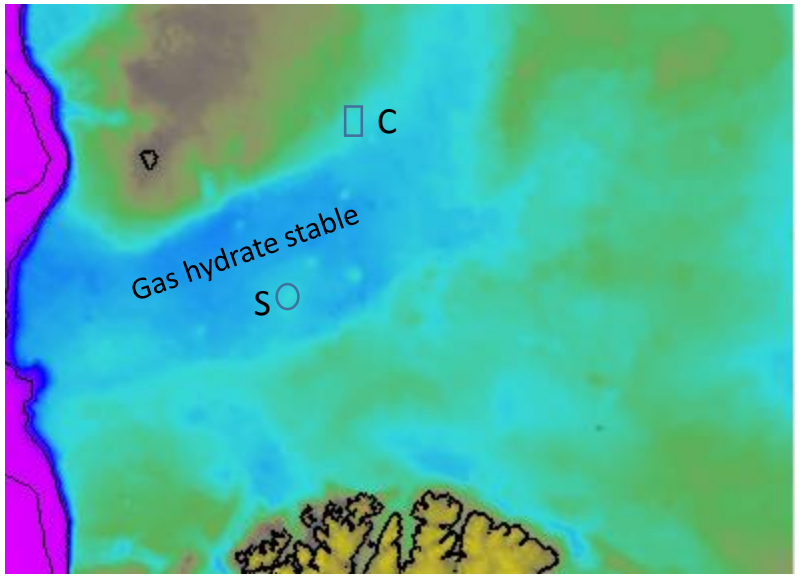
Leakage of hydrocarbons. Timing and mechanisms. Pipes, volcanoes and fracturing

Barents Sea gas seeps

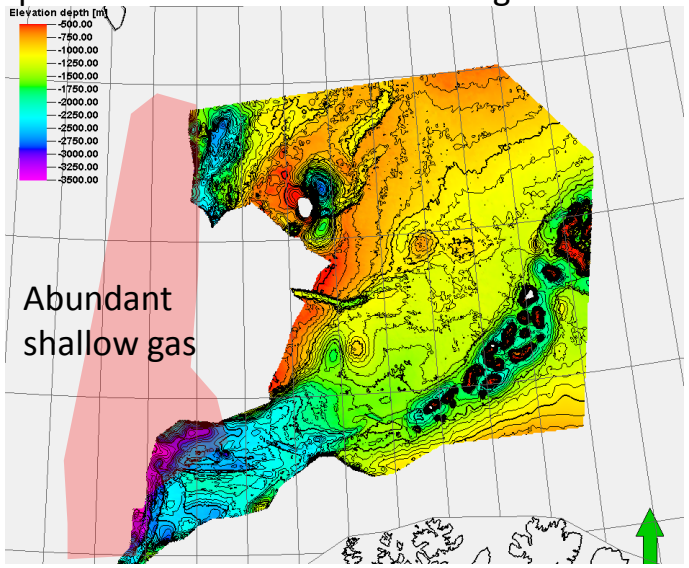


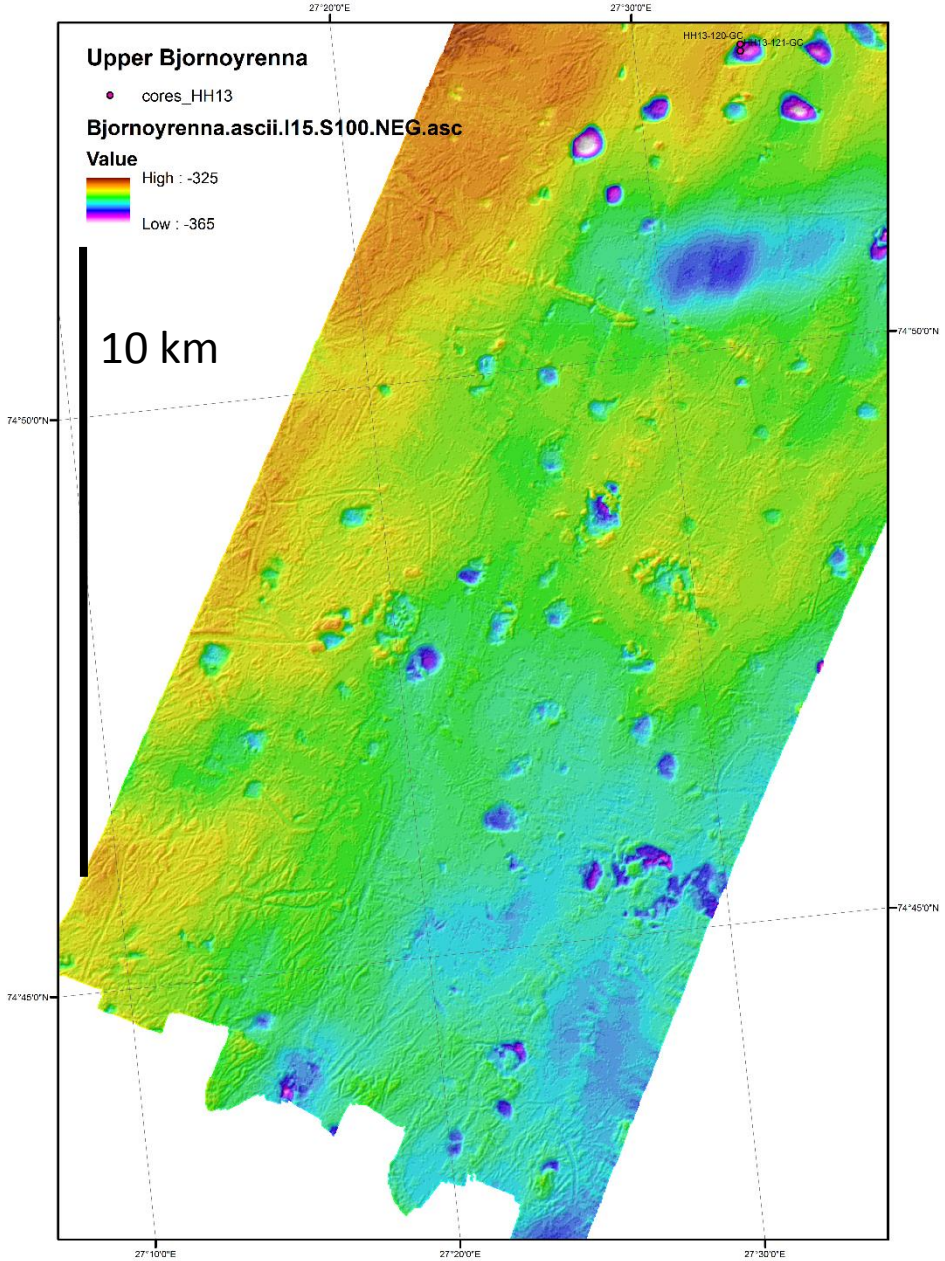
Chand et al. 2012

Fig. 3. a) Bathymetry and b) backscatter datasets showing the structure and backscatter properties of pockmarks and depressions. Notice the occurrence of pockmarks within depressions. Gas flares from c) pockmark area and d) non pockmark area shown on shaded relief bathymetry. Notice that the flares occur from iceberg plough marks. See Fig. 2 for location.



Gas flares and gas hydrate to the west correlate with active petroleum systems. Bjørnøyrenna is an area where abundant gas hydrates have occurred and are now under decomposition. C area shown to the right

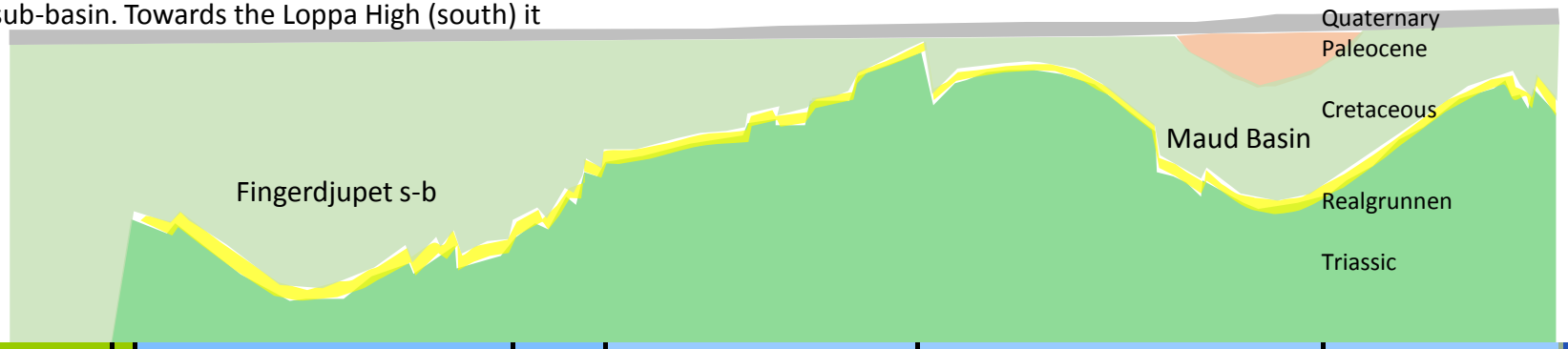


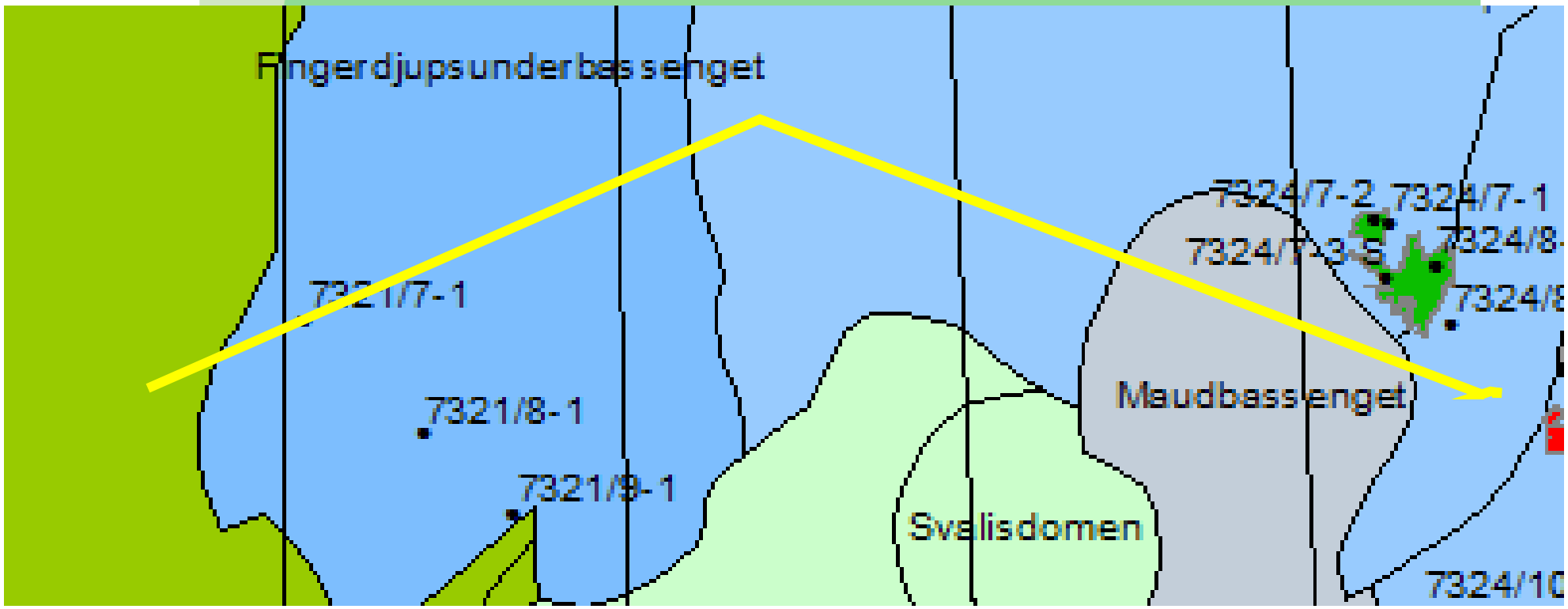


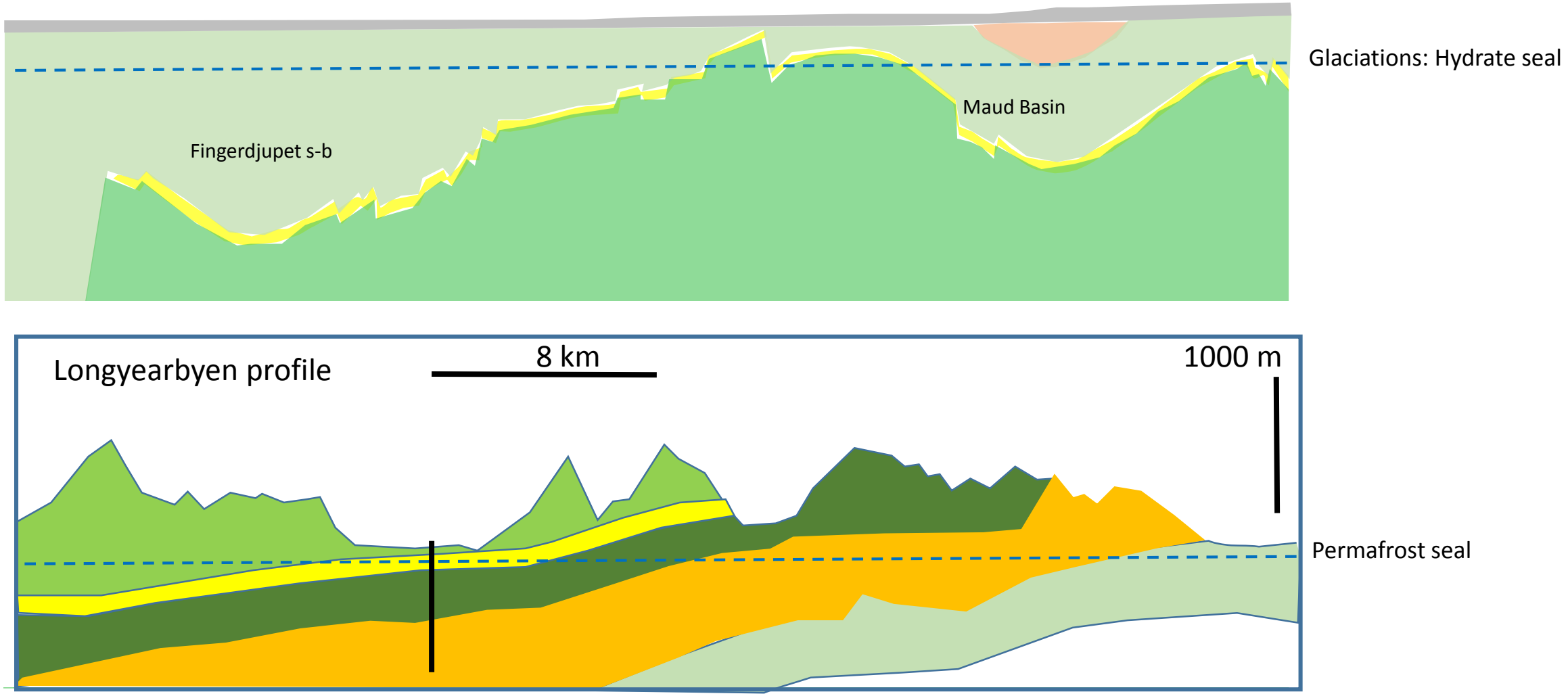
Bathymetry of «Crater» area in Bjørnøyrenna probably related to decomposition of gas hydrate. (Andreassen et al. submitted 2016)

Regional profile and map of Realgrunnen aquifer

The Realgrunnen aquifer (yellow) lies within the gas hydrate stability area east and north of the underpressured wells in the Fingerdjupet sub-basin. Towards the Loppa High (south) it is sealed by faults

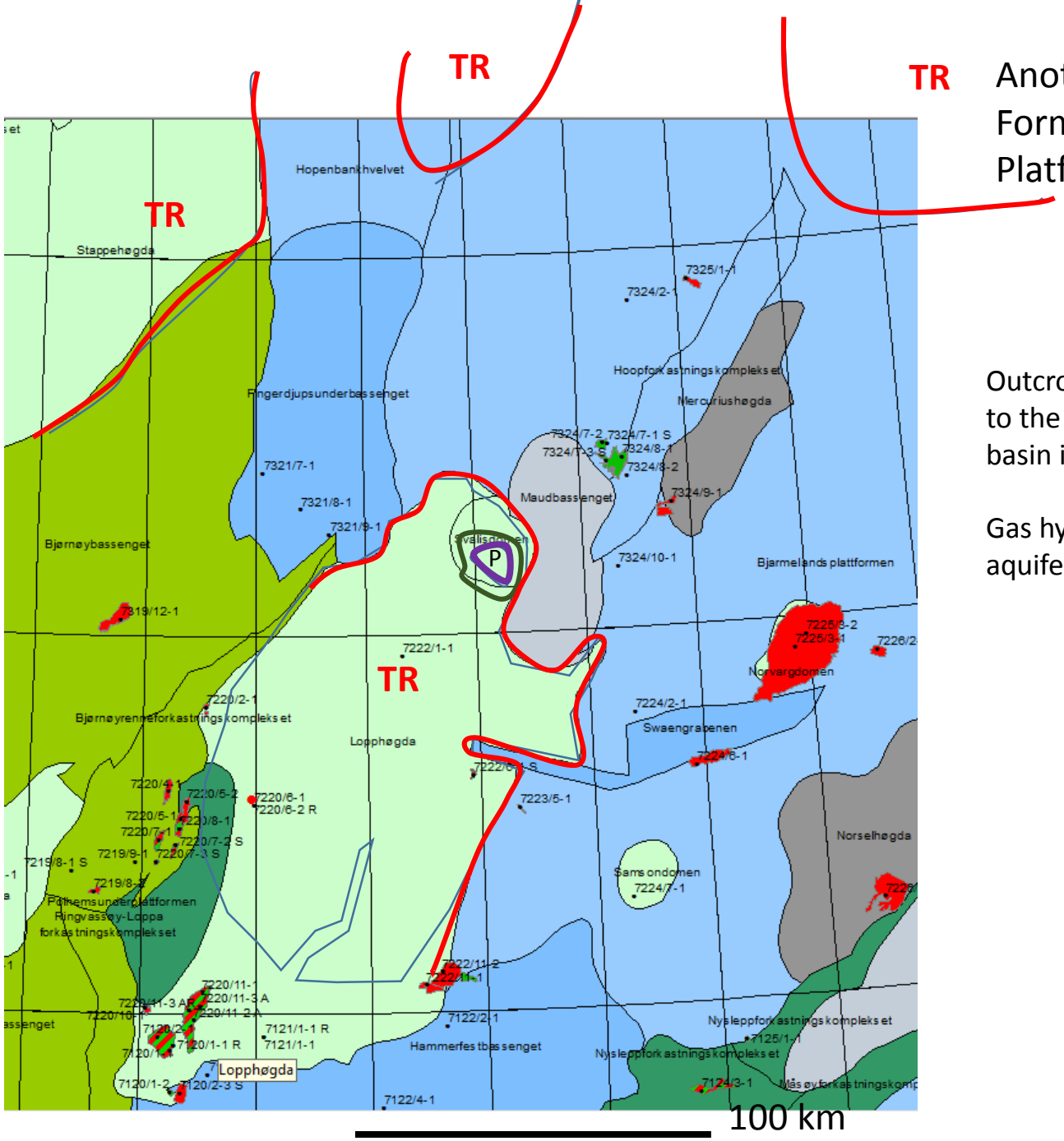






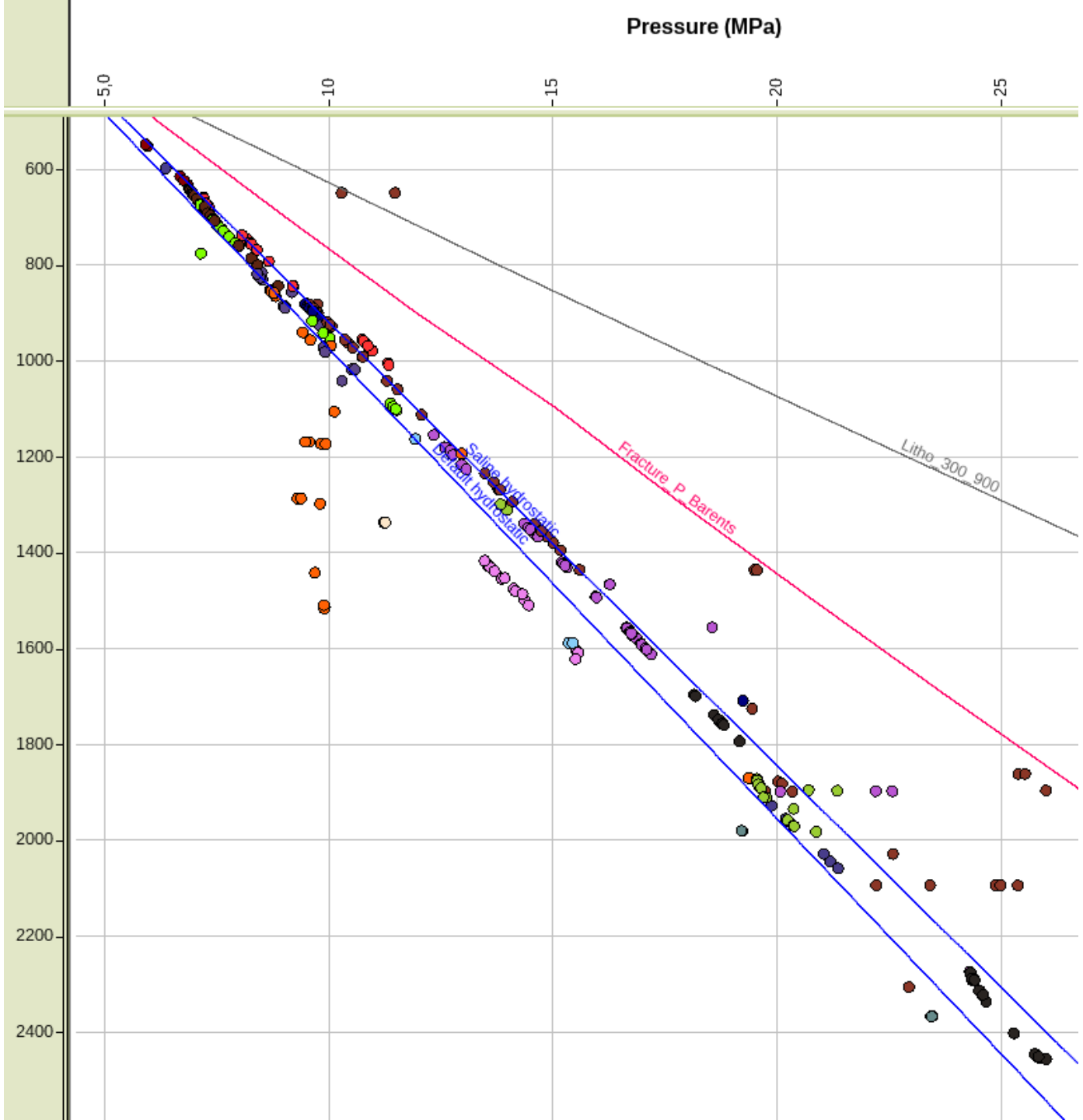
In a hypothetical situation when the Jurassic aquifer is closed by gas hydrate, there is an analogy between the Bjørnøya Trough and the Longyearbyen profiles.

Another analog: Underpressures in the Snadd Formation in the Maud Basin-Bjarmeland Platform



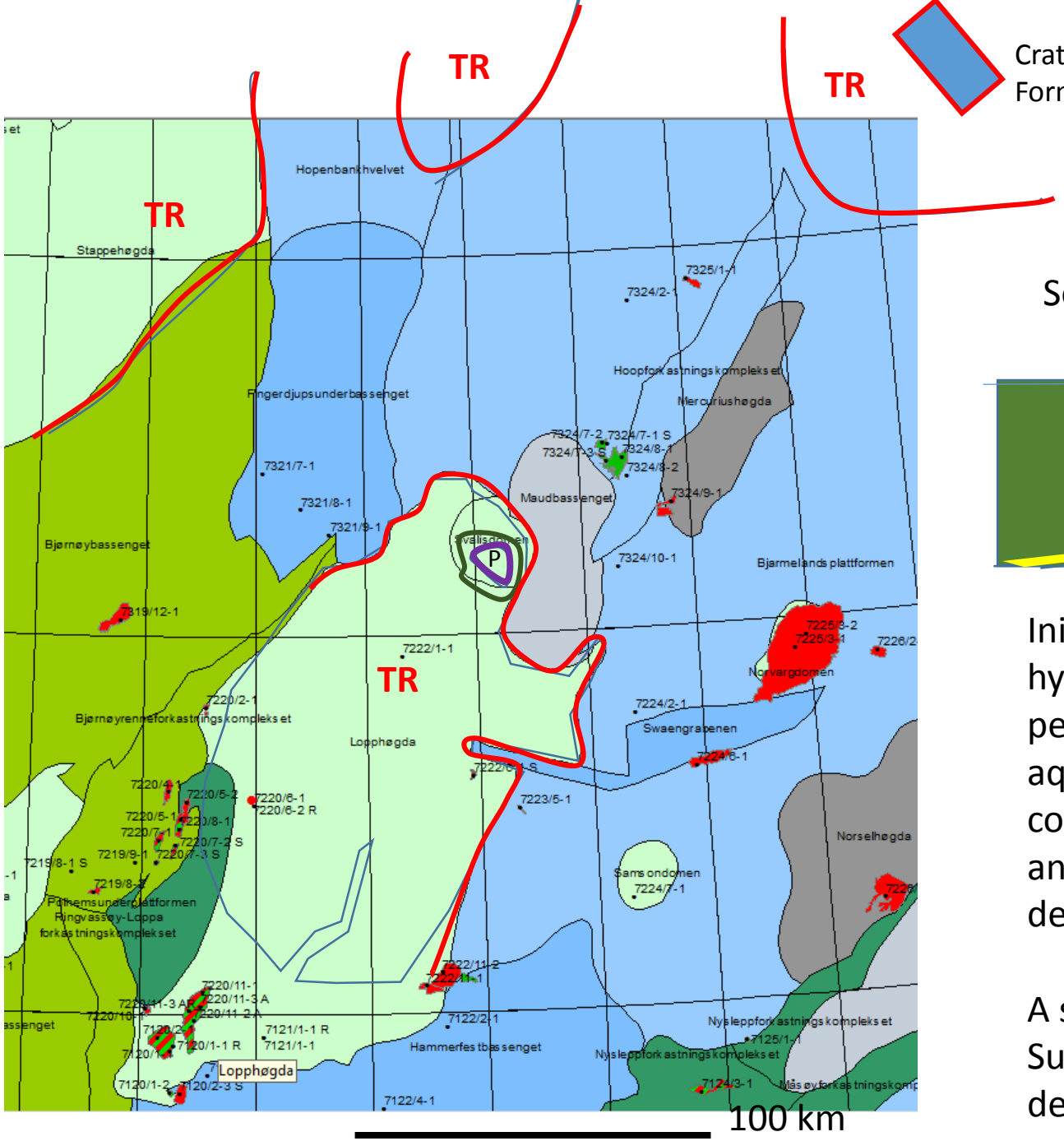
Outcrop map. Red boundary shows outcrop of Realgrunnen aquifer to the sea floor The southern boundary of the Fingerdjupet Sub-basin is a major fault .

Gas hydrate seals could have been formed in Jurassic and Triassic aquifers along these boundaries.



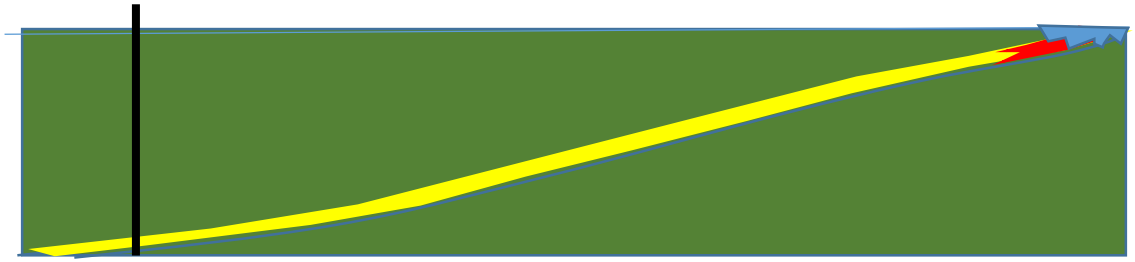
Pressure data from released wells in the Maud Basin, Fingerdjupet sub-basin and western Bjarmeland Platform (each well has its own colour.) Location of wells in slide 2 (white dots)

All white wells with individual colors



Crater area – evidence of large post-glacial gas release. Lower Snadd Formation subcrops at the sea floor in the crater area.

Setting of underpressures in lower Snadd sandstone



Initial stable situation with gas trapped beneath gas hydrate. Large stability area of gas hydrate in periods of glaciation. Gas hydrate depletes the aquifer, which has a relatively small volume of connected sands. Decomposition of gas hydrates and blow-out of gas may have caused further depletion of the aquifer.

A similar history could apply to the Fingerdjupet Sub-basin. Look for features caused by hydrate decomposition.

Conclusions

The problem is not yet solved, but two main hypotheses for underpressures in the Barents Sea are suggested.

- Underpressures or tendency for underpressuring in the order of a few bar are caused by net leakage of gas out of traps where the connected aquifer volumes is small or where the aquifer has low permeability

- Large underpressures, more than 10 bar, occur in a few low permeable aquifers which could have been depleted by formation of gas hydrate and/or rapid gas leakage after the last glacial maximum.