Plugging and abandoning well strategies for storage development

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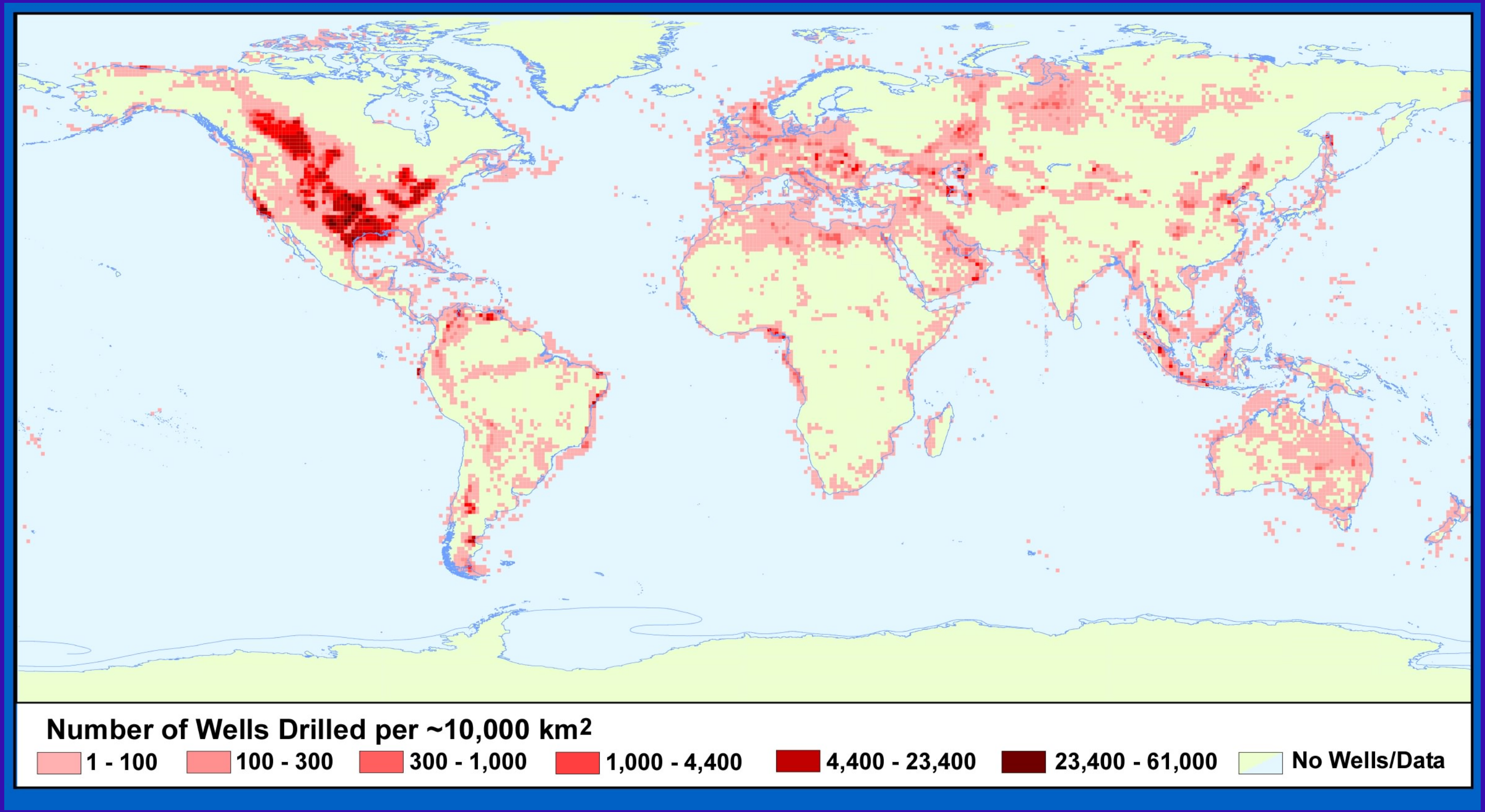
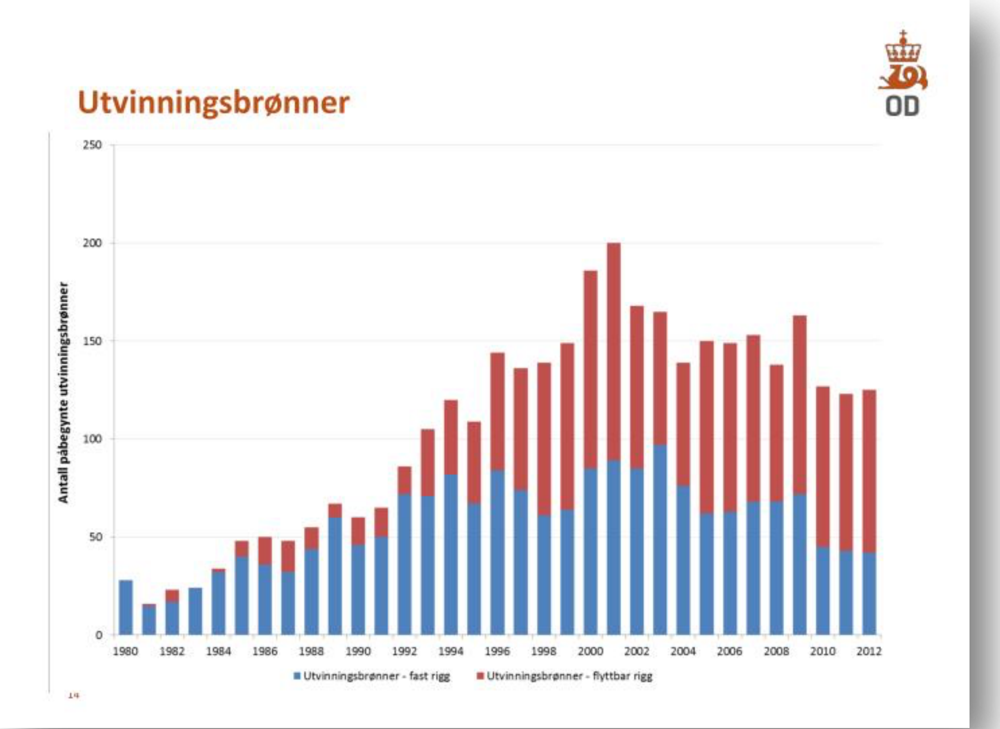
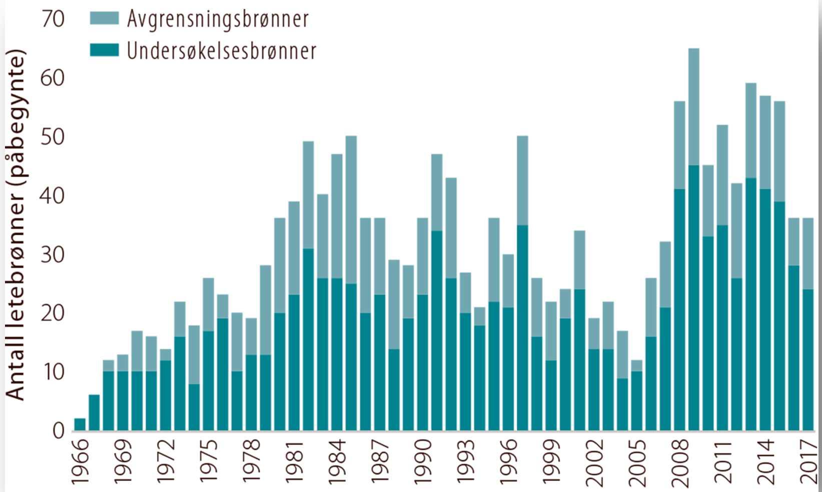
Global well infrastructure, 2005

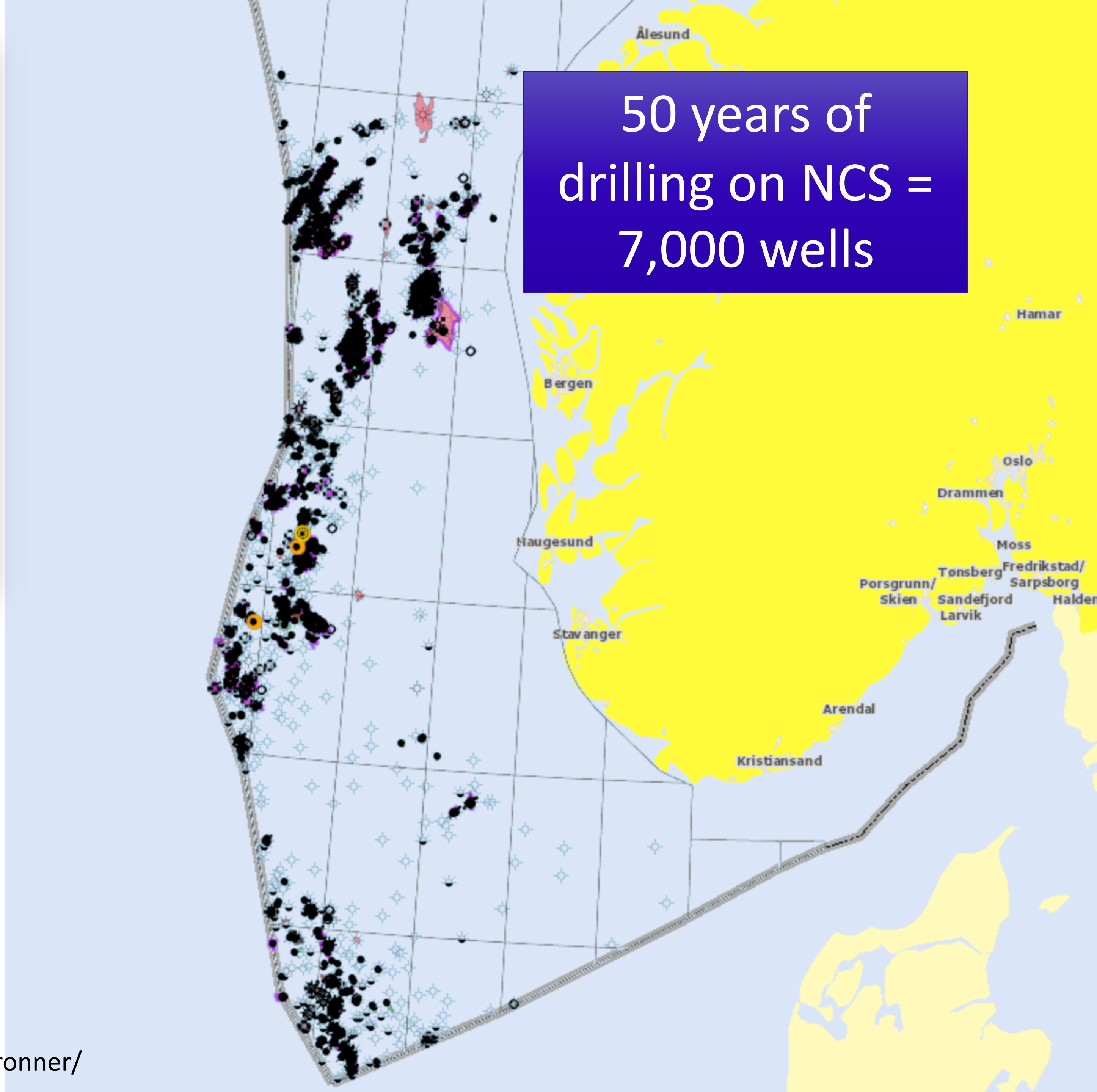
- Millions of wells worldwide (as of 2005)
- High density in regions of mature regions
- Designed for petroleum production and lifetime of max 50 years
- Many are still active
- All will be eventually abandoned
- IPCC 2005 data, already *outdated* because thousands of wells are drilled and abandoned each year!



IPCC, 2005 – Bert Metz, Ogunlade Davidson, Heleen de Coninck, Manuela Loos and Leo Meyer (Eds.) Cambridge University Press, UK.







50 years of drilling on NCS = 7,000 wells

Norwegian Petroleum Directorate (2020) https://www.npd.no/fakta/bronner/

Existing Wells in a Mature Sedimentary Basin

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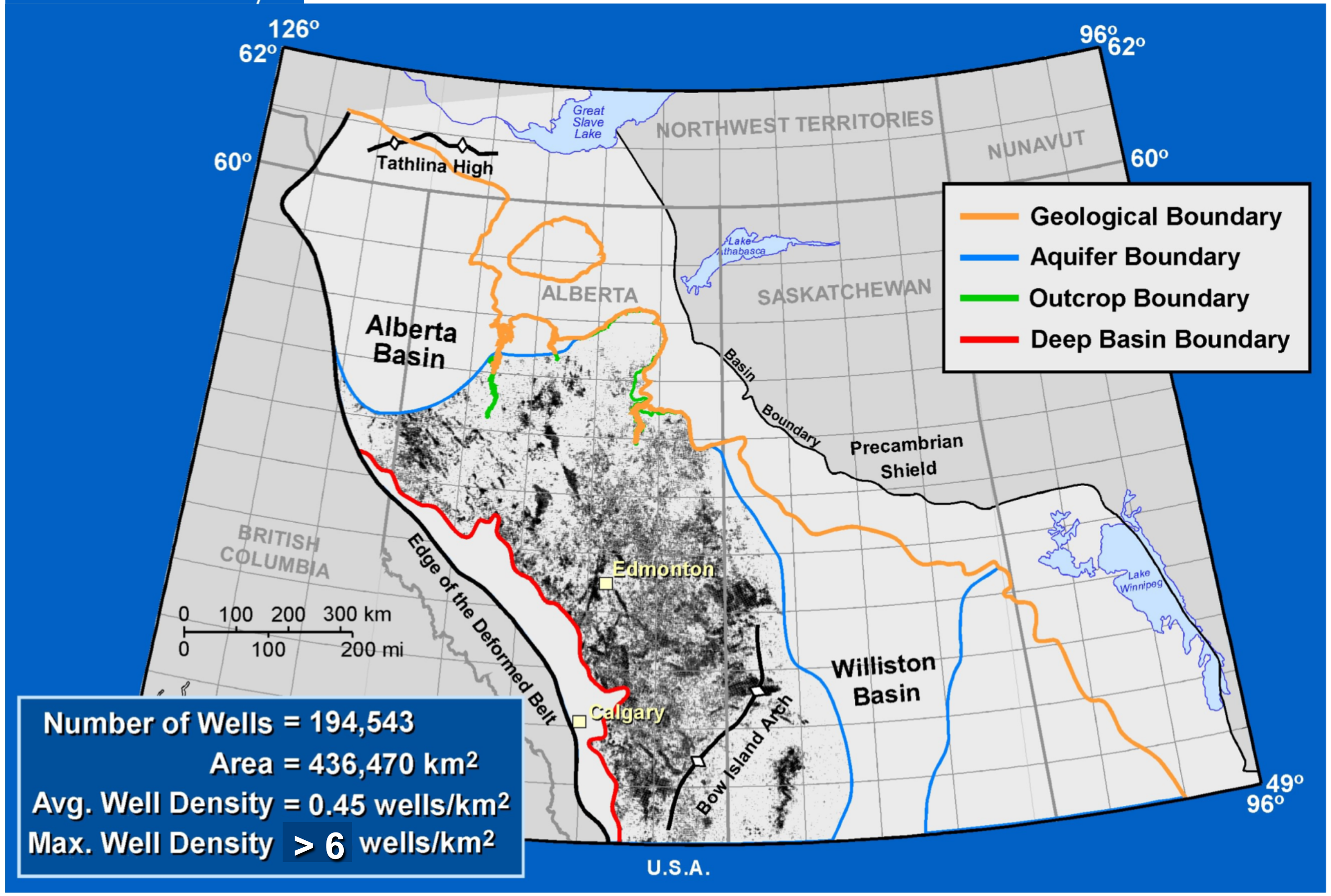
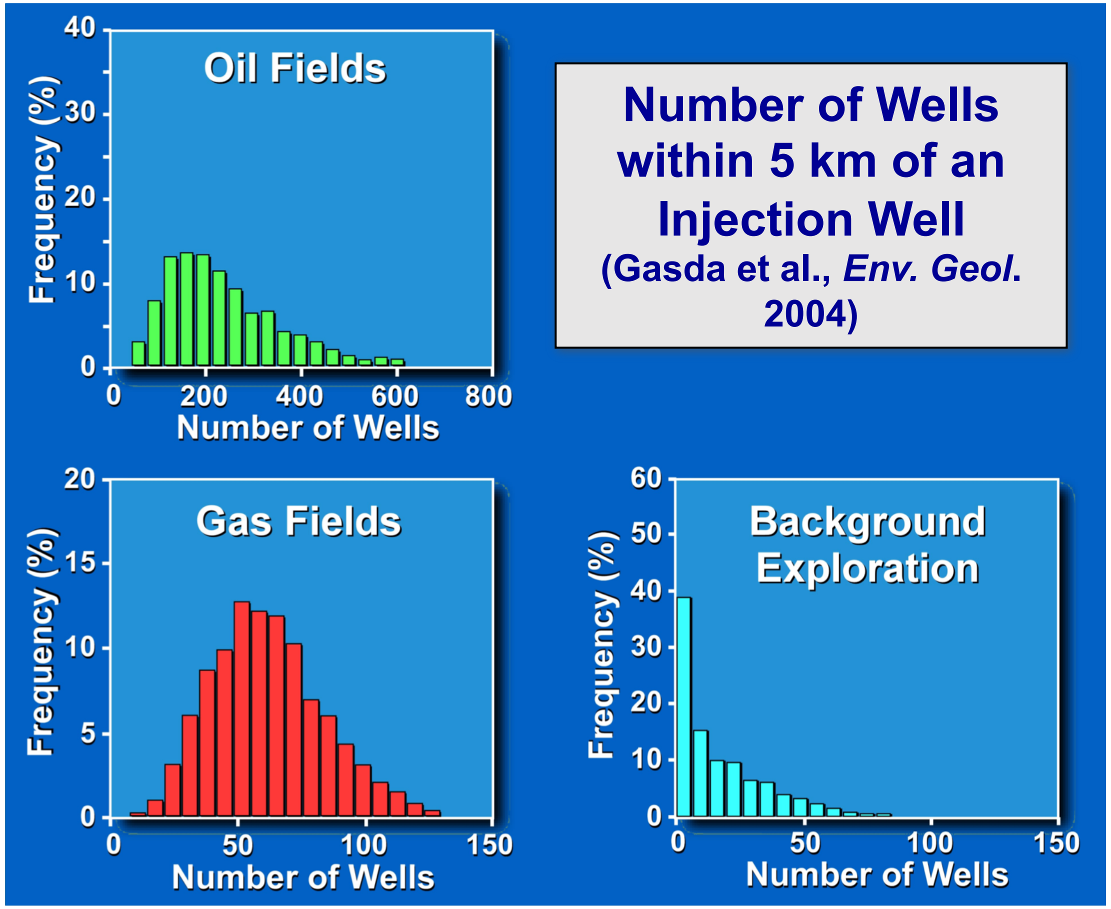
Total Wells in the Alberta Basin, Canada

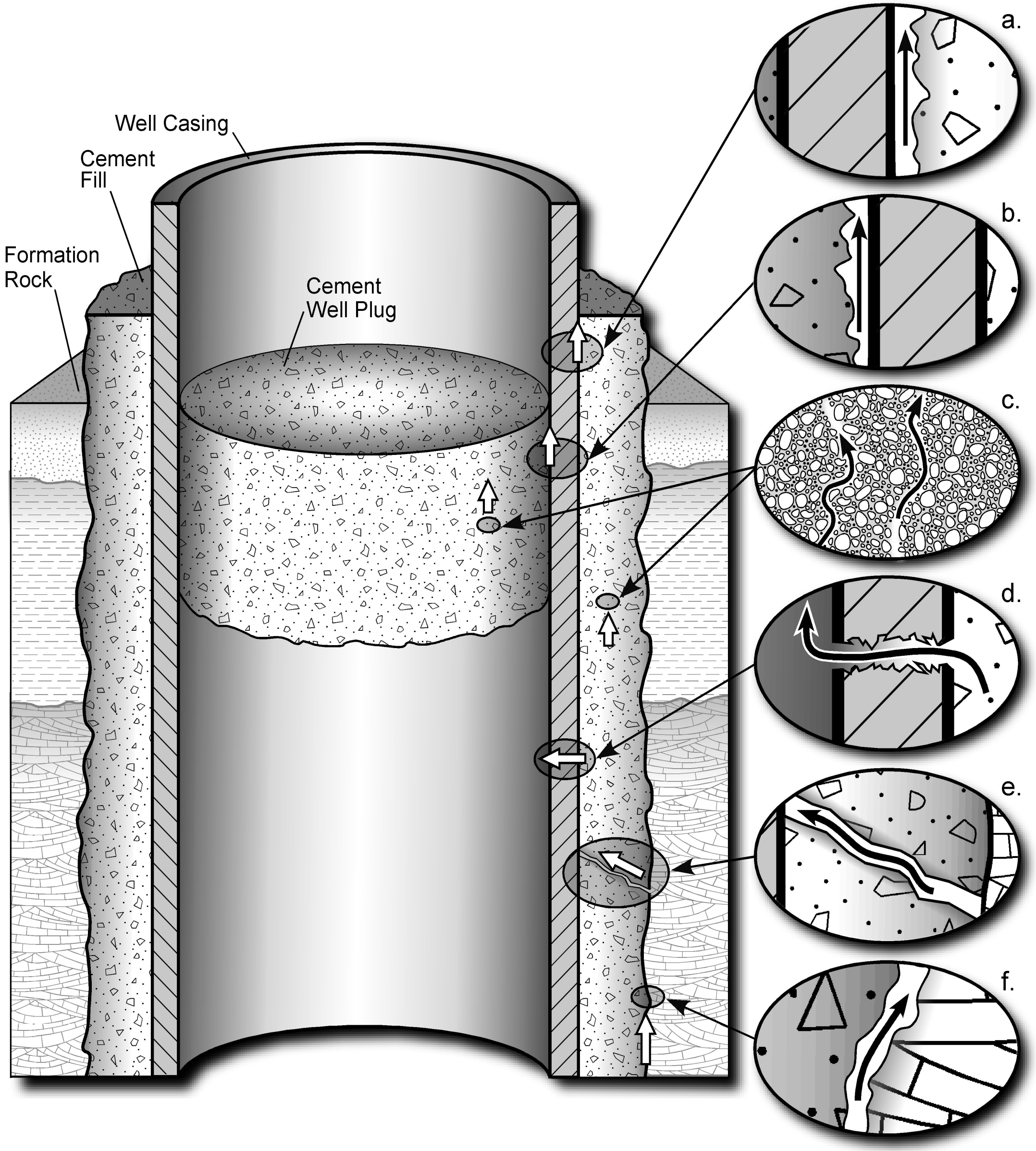


Neighboring wells in Alberta



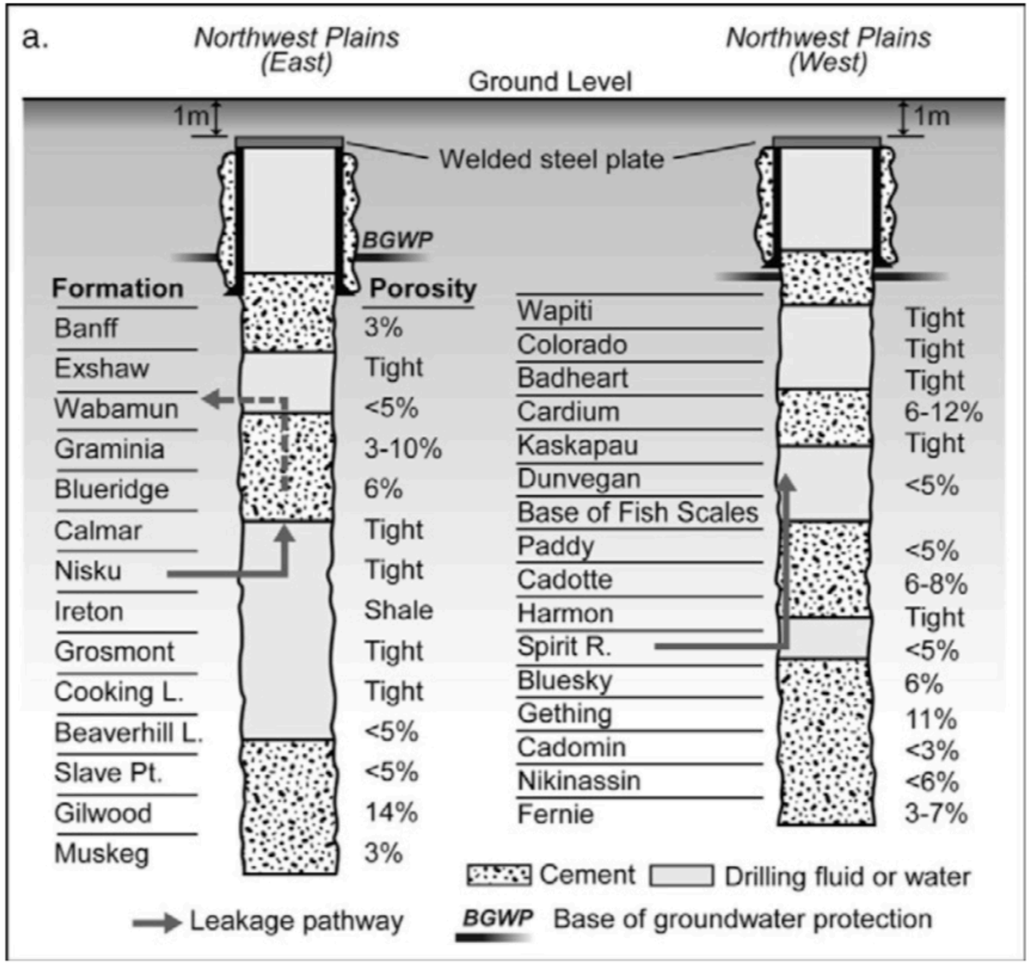
Wellbore Integrity

- All wells are eventually plugged and abandoned
- Integrity is dependent as much on initial well completion as abandonment procedure
  - Neither is always perfect
- Plug can be cement or bridge
  - Type and quality of the plug is important
- Initial state is important before added impact of chemical attack or mechanical fatigue



Gasda et al. *Env. Geol*. 2004

Plugging & Abandonment in Canada



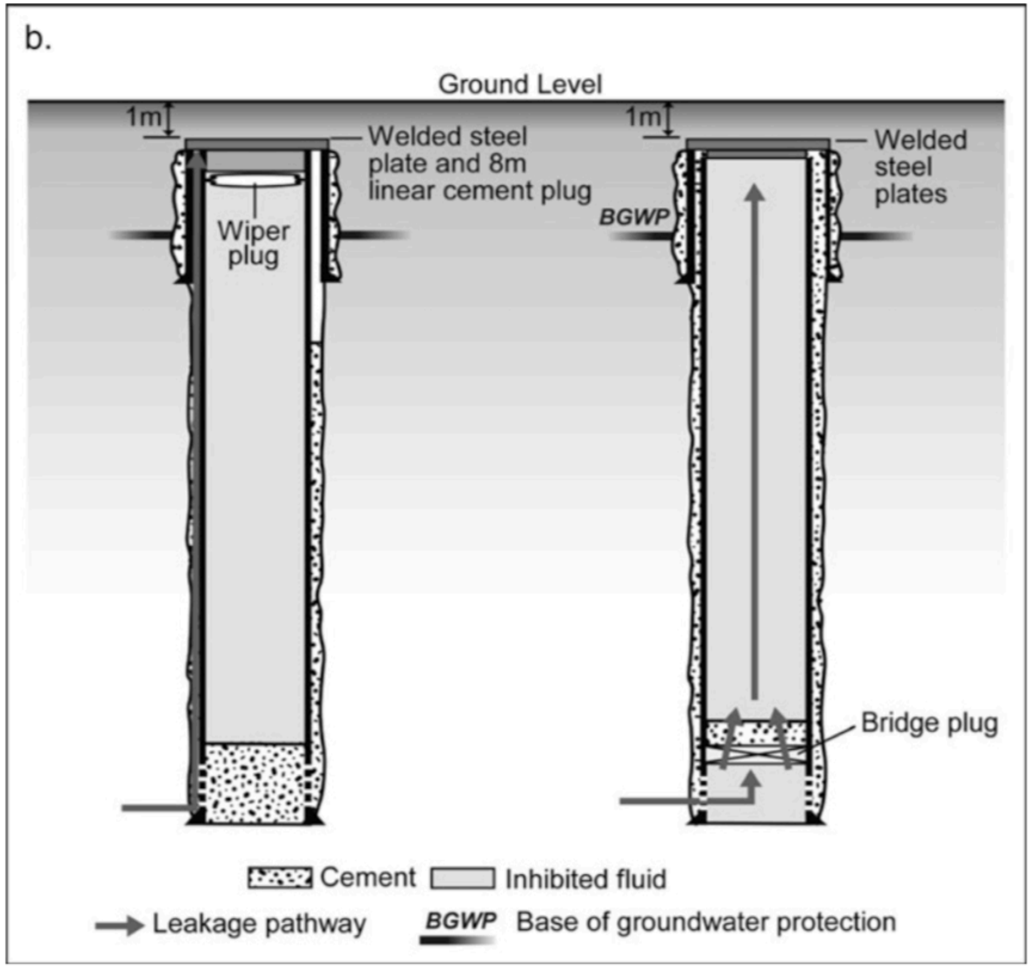


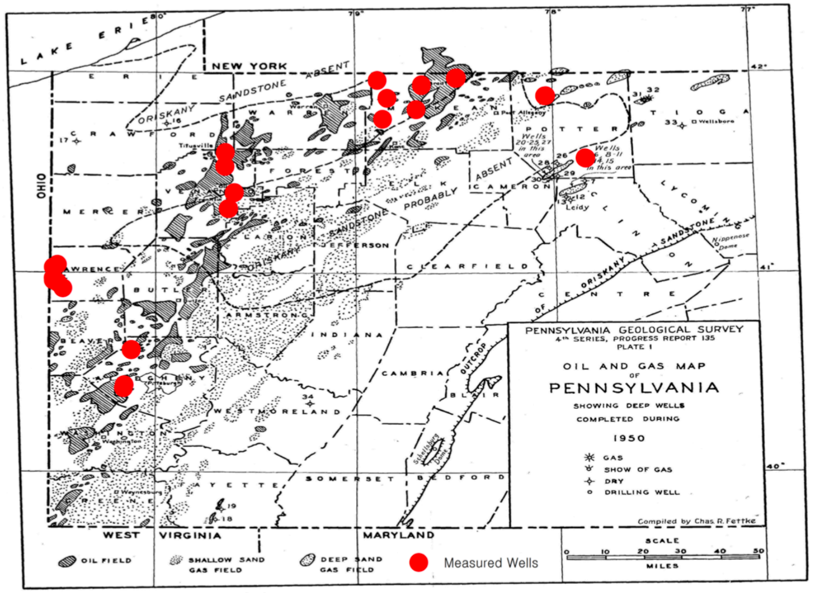
Fig. 1—Typical well abandonments in Alberta, Canada: (a) drilled and abandoned open hole; (b) cased, completed, and abandoned.

Watson and Bachu, SPE 106817, 2009

Legacy well leakage

- Field evidence that legacy wells can leak.
- Well documented cases in N. America
  - Surface casing vent flow (SCVF) in Alberta; monitoring required by regulations (*Watson and Bachu, SPE 106817*)
  - Sustained casing pressure (SC) in US (*Lackey et al. ES&T 2017*)
- Measurement campaigns have documented methane leaks from old wells in Pennsylvania
  - 100 yr-old oil wells in USA in western PA
  - *Kang et al., Proc. Natl. Acad. Sci. 2014*

Watson and Bachu, SPE 106817, 2009



Kang et al., Proc. Natl. Acad. Sci. 2014

Legacy well leakage

Data are important for evaluating potential for leakage in CO_2 storage

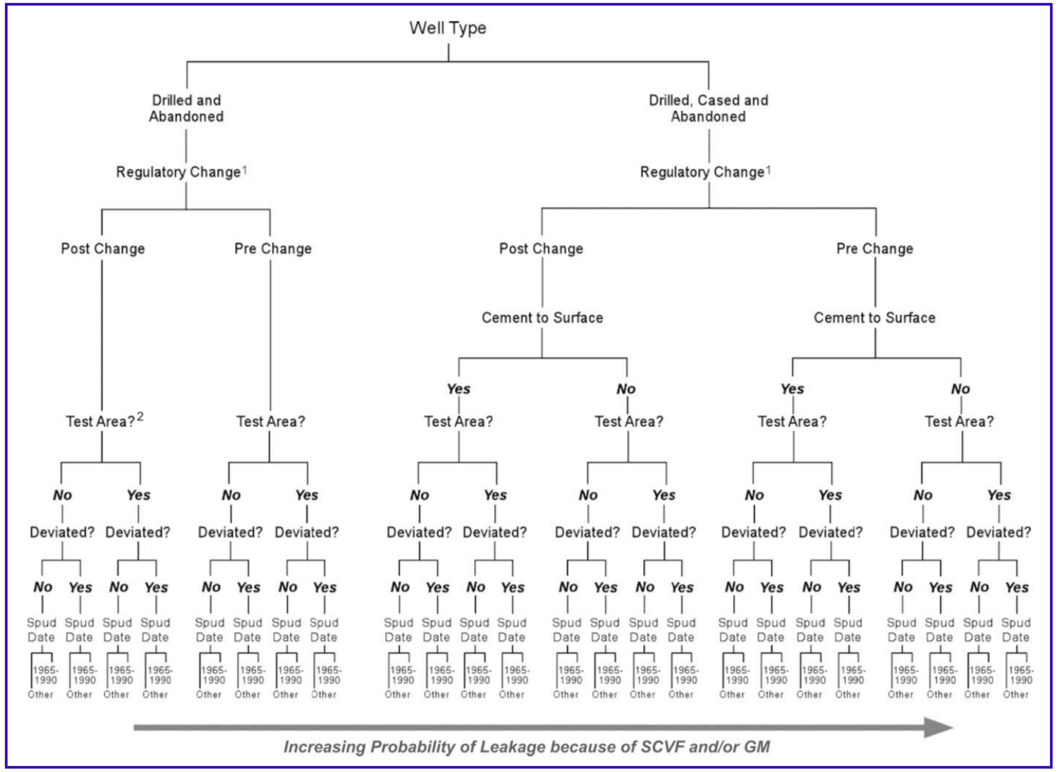
Type of abandonment (regulations) has a high impact on leakage

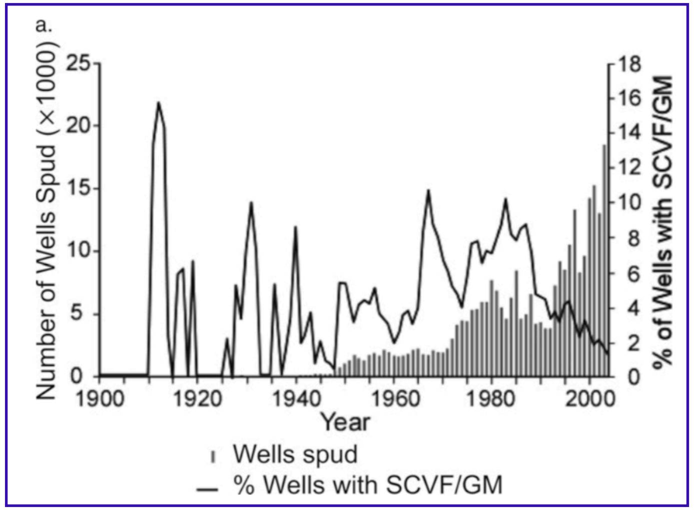
Cased holes are more likely to leak

Leakage is from shallower zones than the original completion depth.

Minority of wells are problematic

Only 5% of well infrastructure have recorded leaks in Alberta





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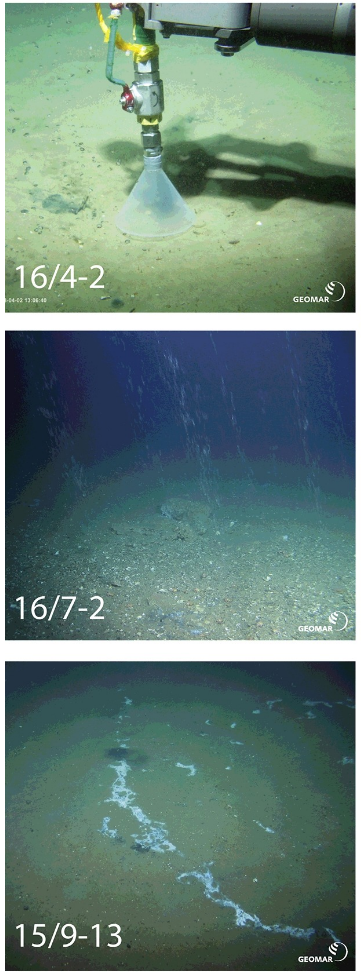
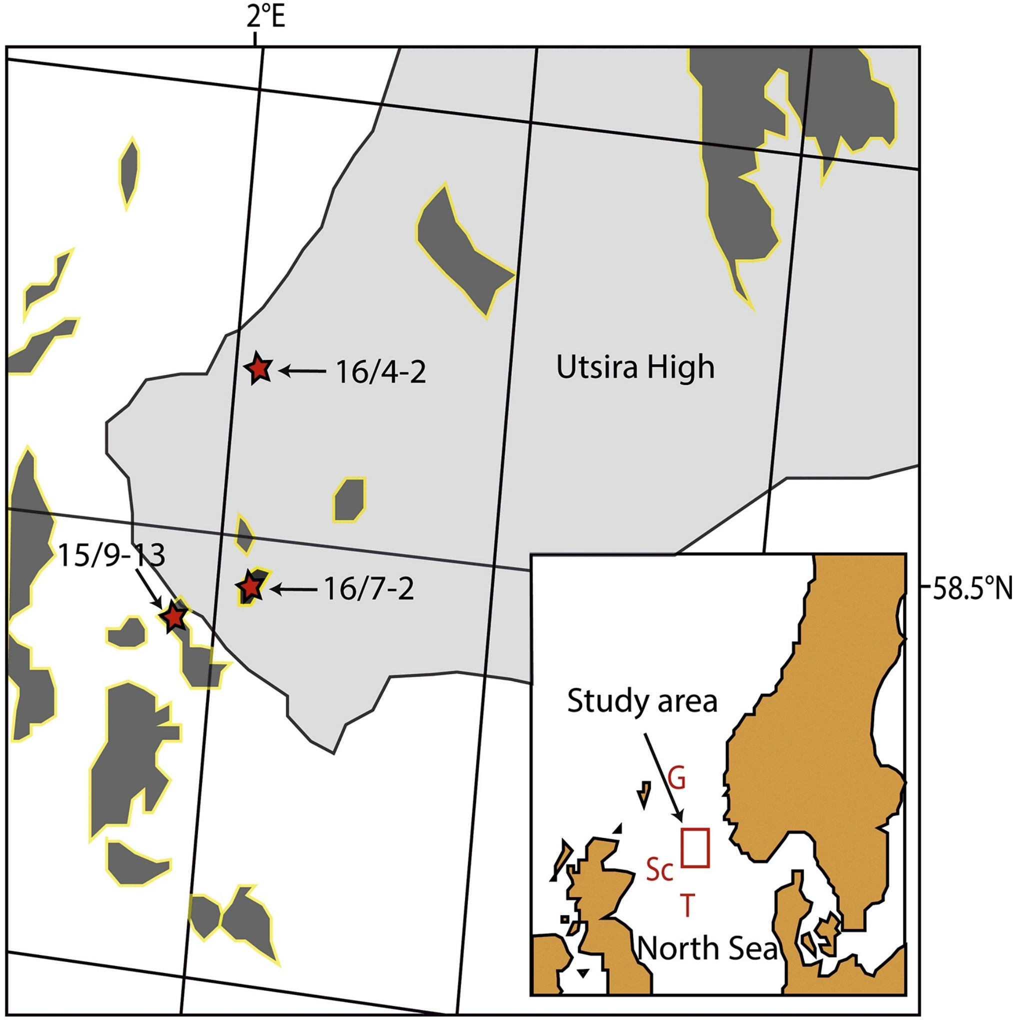
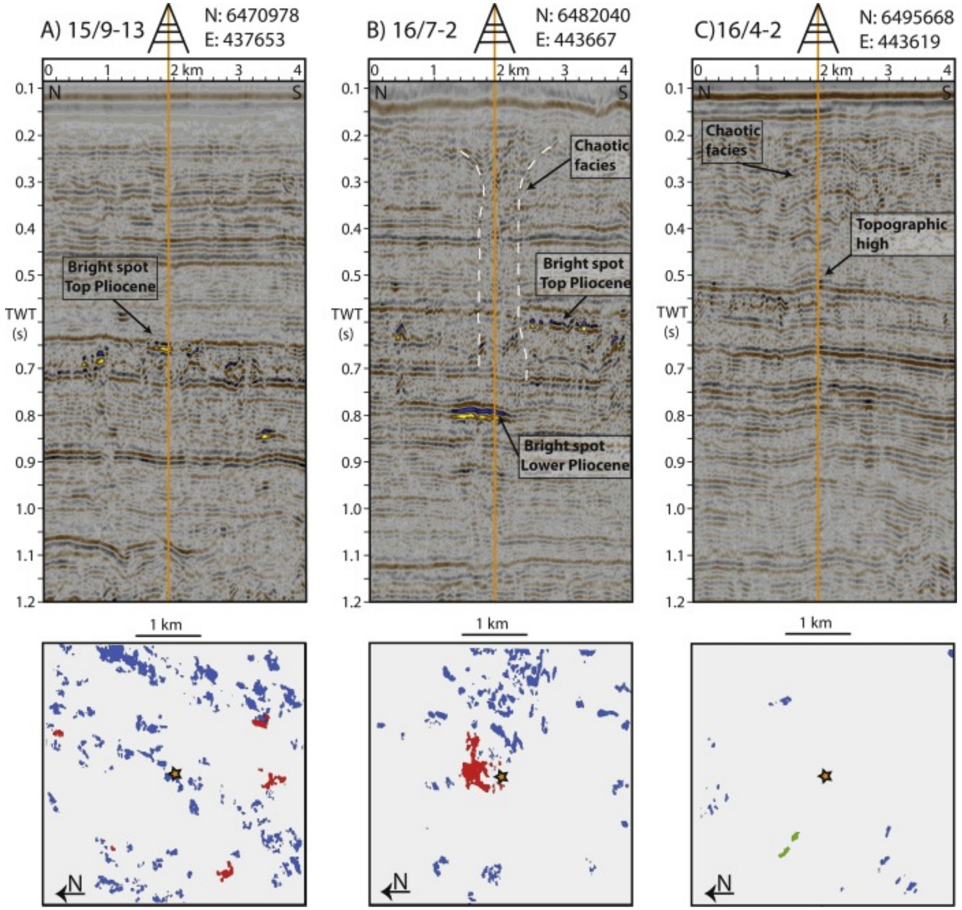
Central North Sea measurements



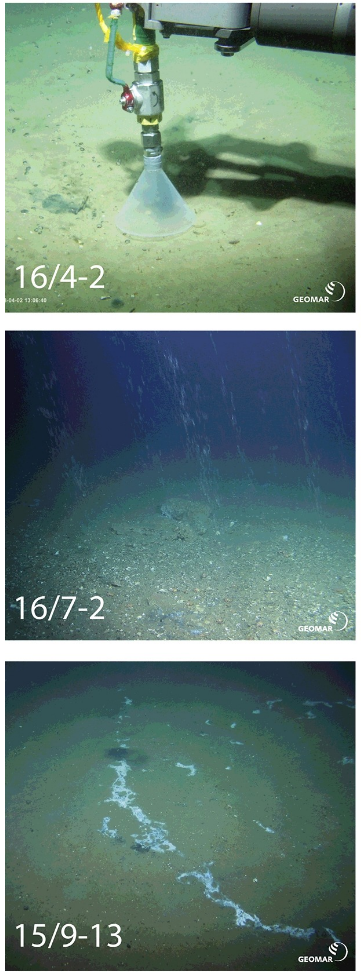


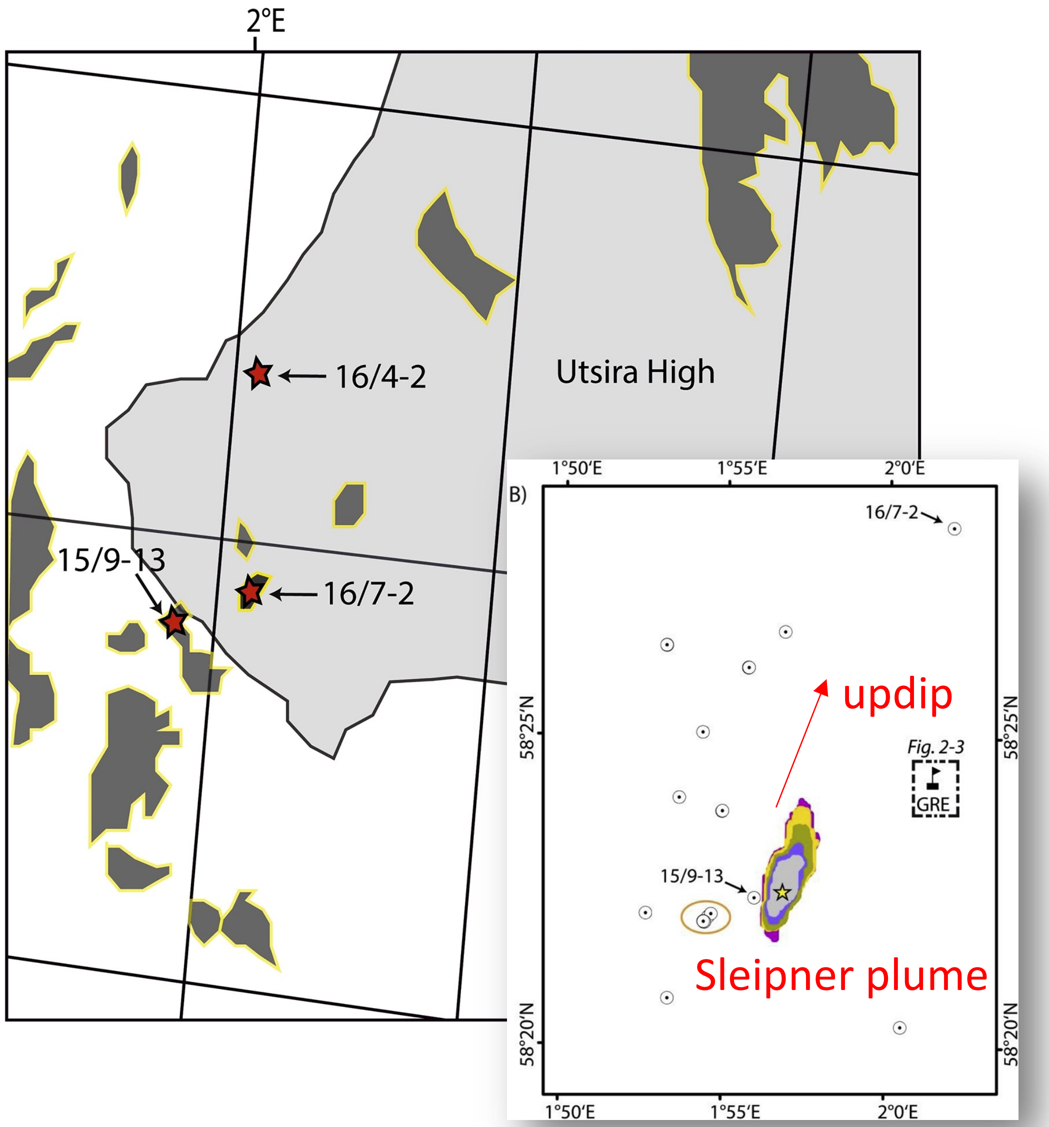


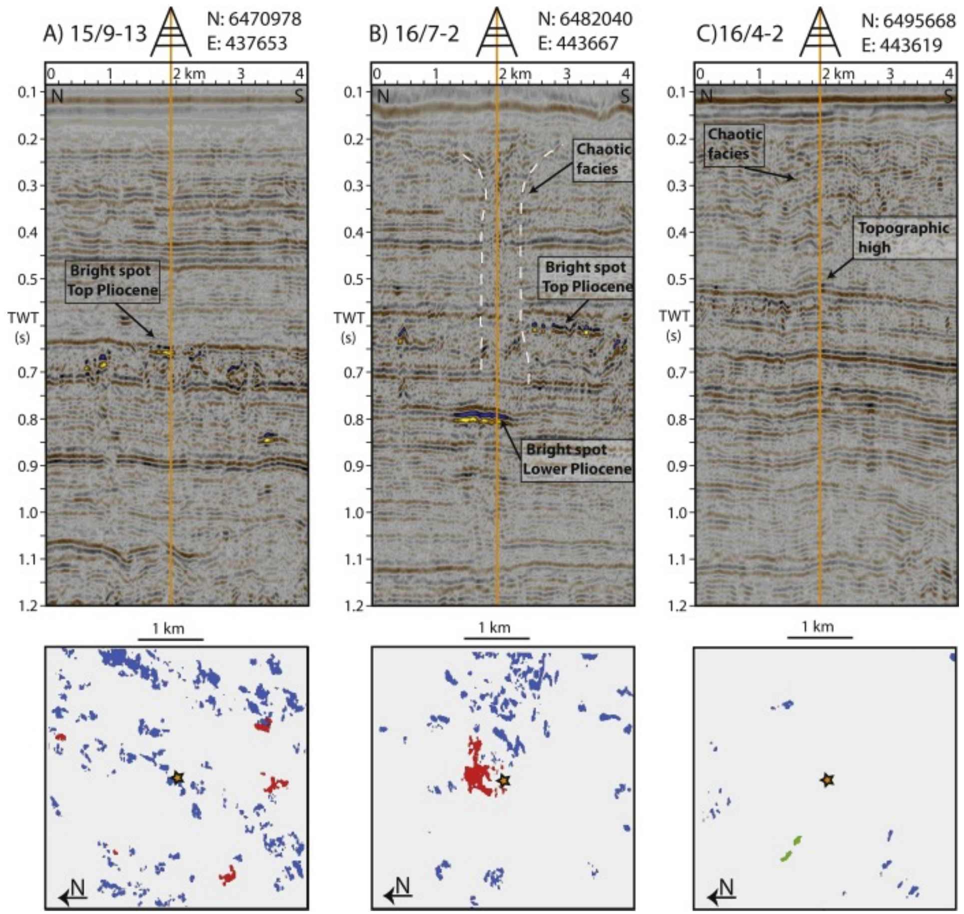
Measurement campaign at 3 wells in 2015
First public study to quantify methane leaks
Max rate 0.15 L/min
Geochemical, bubble sampling, video

L. Vielstädte et al./Marine and Petroleum Geology 68 (2015)

Central North Sea measurements







Wells in vicinity of Sleipner, but not related

Source zone is shallow depth

Gas origin is biogenic

Leakage rate is comparable to natural seeps

L. Vielstädte et al./Marine and Petroleum Geology 68 (2015)

From natural seeps to CO_2 storage

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- Leakage is interesting, but tells only part of the story
- Well properties (and not the leakage itself) are needed to predict impact on CO_2 storage
- Efforts to estimate hydraulic properties
  - Direct testing of legacy wells by down-hole intervention (VIT)
  - Indirect estimation from leakage rates at surface
- Both methods give estimates that can be used to further to constrain potential for leakage for CO_2 storage development

Integrity test of a CO_2 producer

Well History

Drilled and completed — 1976

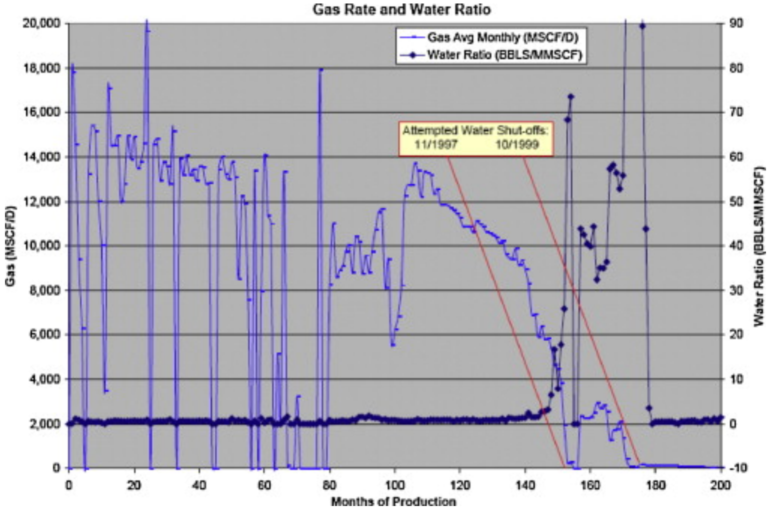
Begin production — 1986

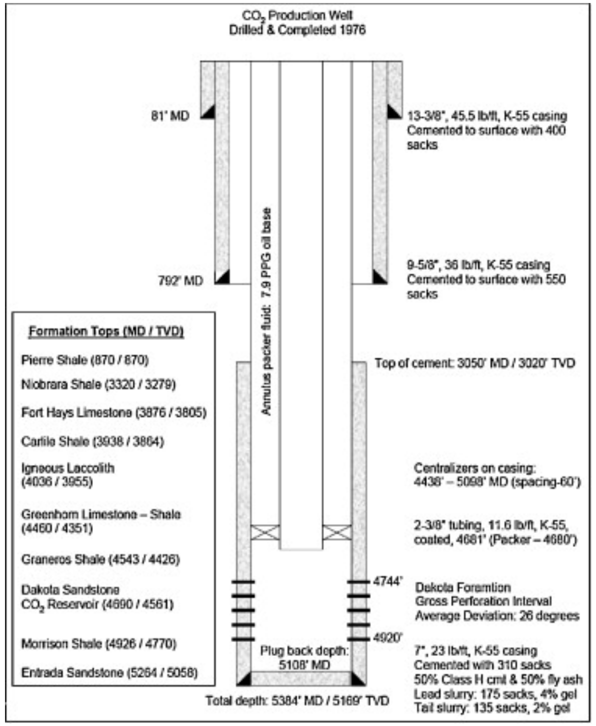
Field survey and abandonment — 2006/07

30-year well life
producing from a CO_2 reservoir

Field Survey

- Evaluate barrier system
  - Mechanical integrity (caliper)
  - Cement bond log/ultrasonic scanner tools
  - Vertical Interference Test
- Detect signs alteration by CO_2 migration.
  - Fluid/gas samples
  - Sidewall cores through the casing





Crow et al., Wellbore integrity of a CO_2 producer, *IJGGC, (2010)*

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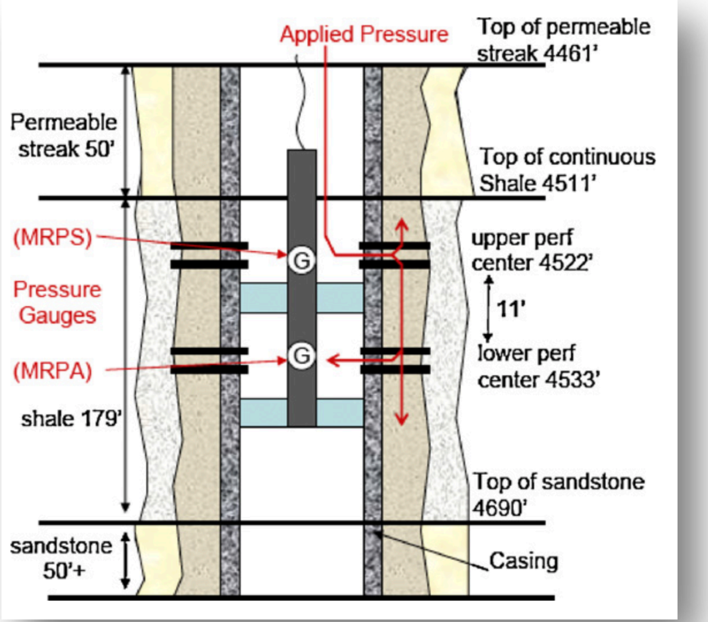
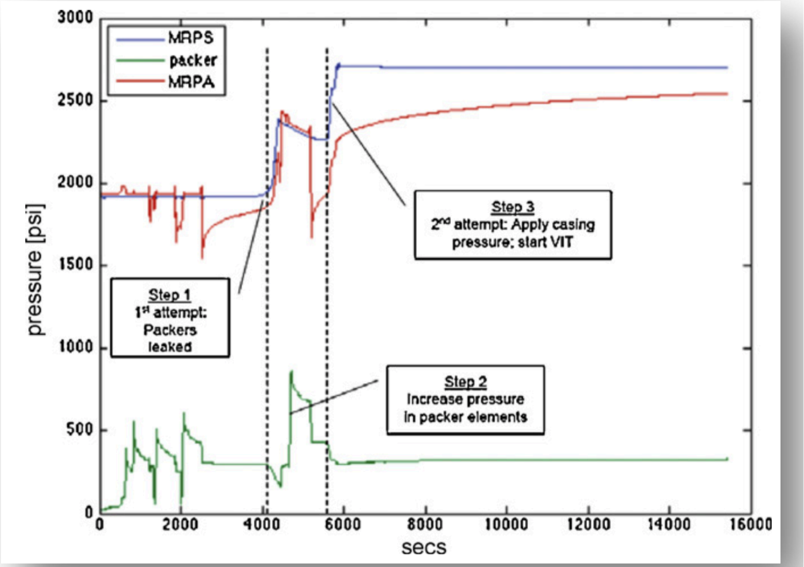




Crow et al., Wellbore integrity of a CO_2 producer, *IJGGC, (2010)*

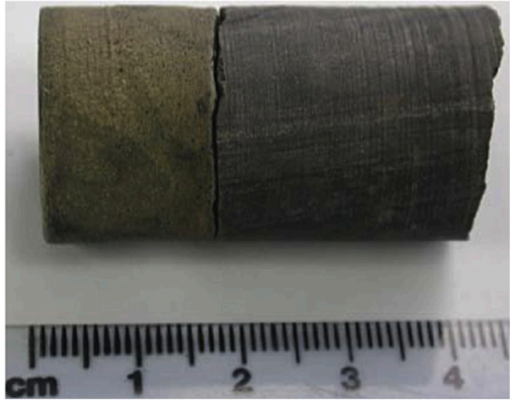
Integrity test results

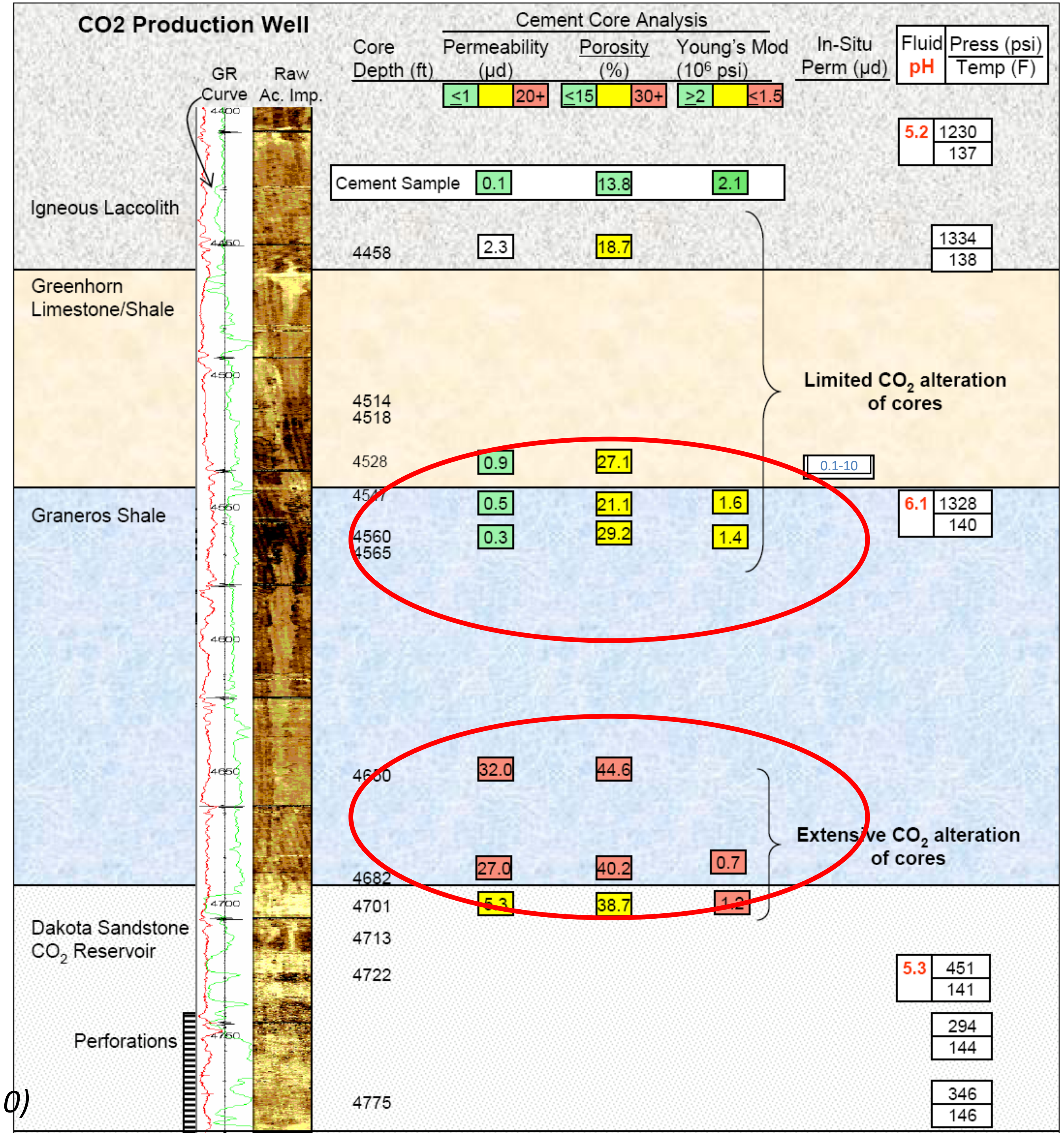
No visual signs of cement degradation from sidewall cores.

- CO_2 has altered cement barrier system along the caprock to varying degrees.

  Higher amounts of calcium carbonate near CO_2 reservoir.

  Carbonation effect is evident in fluid/gas analyses.





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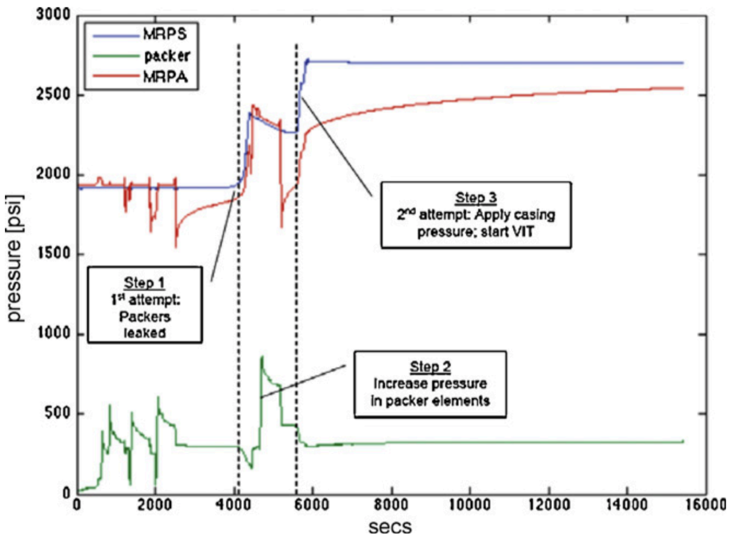
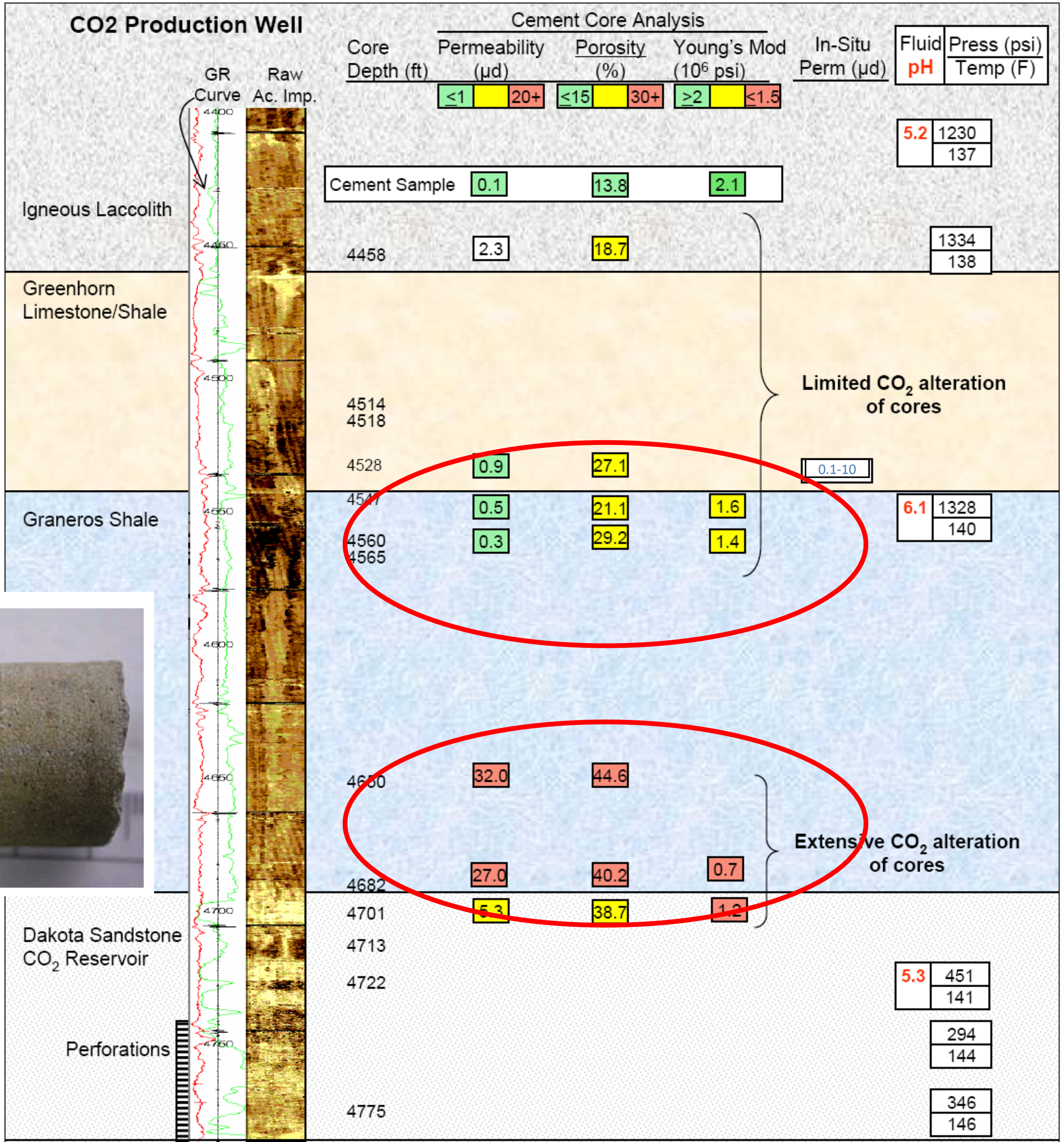
Integrity test results

Permeability measurements indicate that interfaces are primary flow pathway.

- Lab analysis of cement perm are in the microD range.
- Lowest VIT estimate of effective perm is 0.1 milliD.





Crow et al., Wellbore integrity of a CO2 producer, *IJGGC, (2010)*

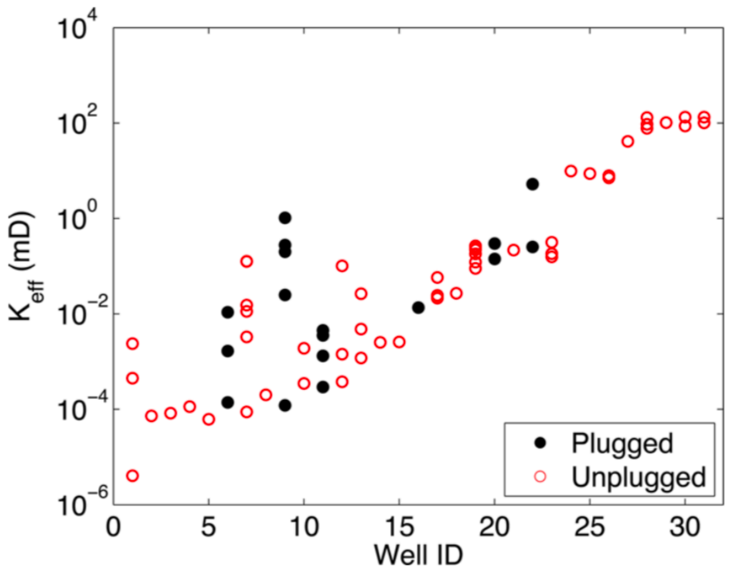
Field test summary: Effective permeability vs cement permeability

Reported VIT data	Estimated Wellbore permeability	Measured Cement permeability
CCP	1.7 mD	0.1 – 32 microD
TPX	170 mD	0.1 – 449 microD
CC1	25 mD	0.001 – 4.63 mD
Hypothetical VIT data		
CCP upper bound	100 D	--
CCP lower bound	0.01 mD	--
Unreported VIT data		
3 datasets	6 mD – 3 D	--

Source: *Gasda, et al., Energy Procedia 37 (2013); Crow et al., IJGGC, (2010); Duguid et al., Greenhouse Gases: Science and Technology (2017)*

Surface leakage measurements and wellbore permeability estimates

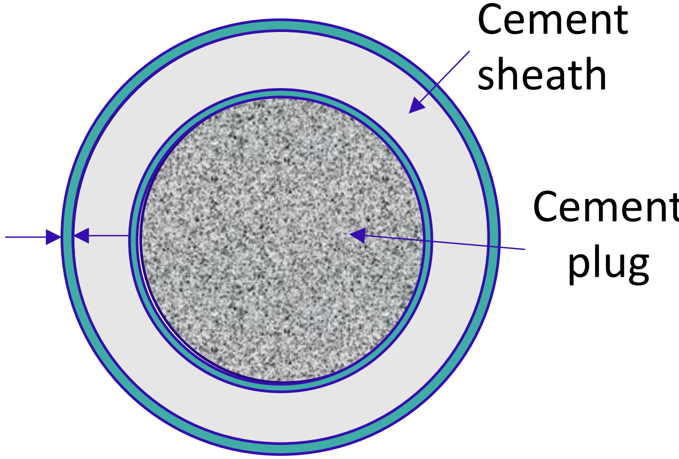
- Direct measurements of leaked volumes in time can be used to estimate permeability
- Uncertainty of source depth and other parameters
- No wells greater than 1 Darcy permeability



[2]*Kang et al., ES&T 2015*

Location	Number of wells	Wellbore permeability
British Columbia[1]	736	10 μD – 10 mD
Pennsylvania[2]	42	1 nD -- 100 mD
Central North Sea**	1	100 mD – 1 D

- Cubic law for annular aperture
  - 5 μm (1mD) to 0.2 mm (100 Darcy)

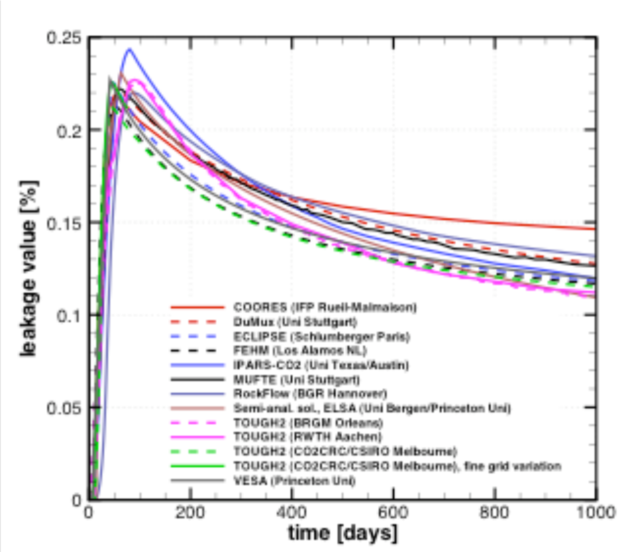


Annular spaces of cased well

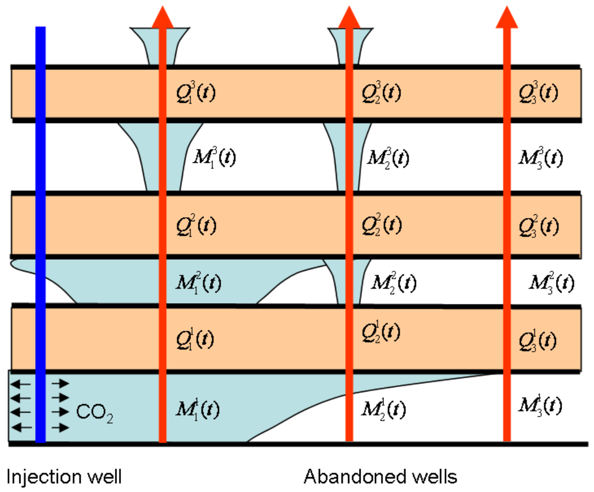
[1]Tao, Q.; Bryant, S. L. Well permeability estimation and CO2 leakage rates. Int. J. Greenhouse Gas Control 2014, 22, 77–87
**approximation by S. Gasda

From parameters to prediction

- Simulation technology can be used to understand the potential for leakage in prospective CO_2 storage regions
- Advances in modeling gives very accurate simulation of wellbore flow over many wells in real geological system with multiple strata
- ”Elevator effect” with CO2 flow into thief zones dampens eventual leakage to surface



Class et al., Comp Geosci, 2009



Case study: Well leakage in Alberta

1146 total wells in 30 x 30 km area

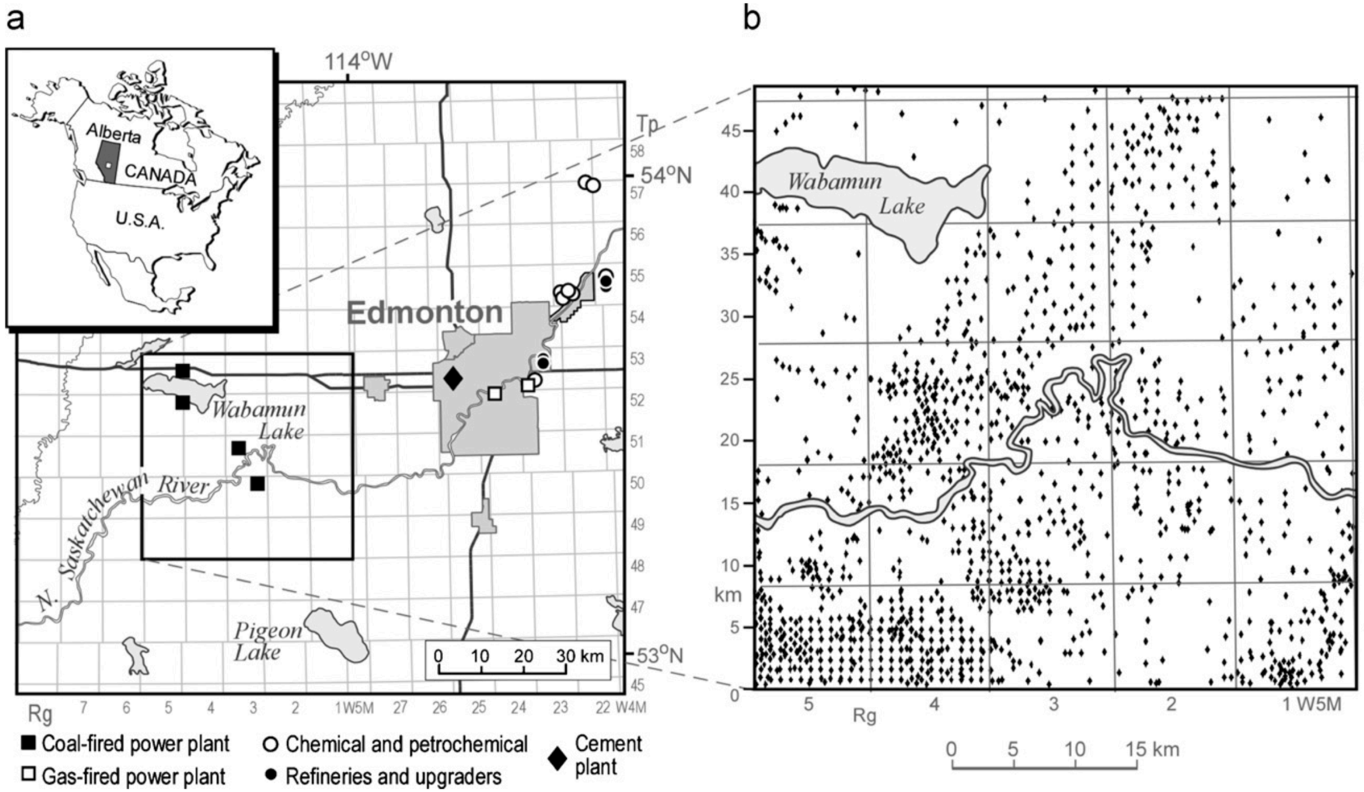
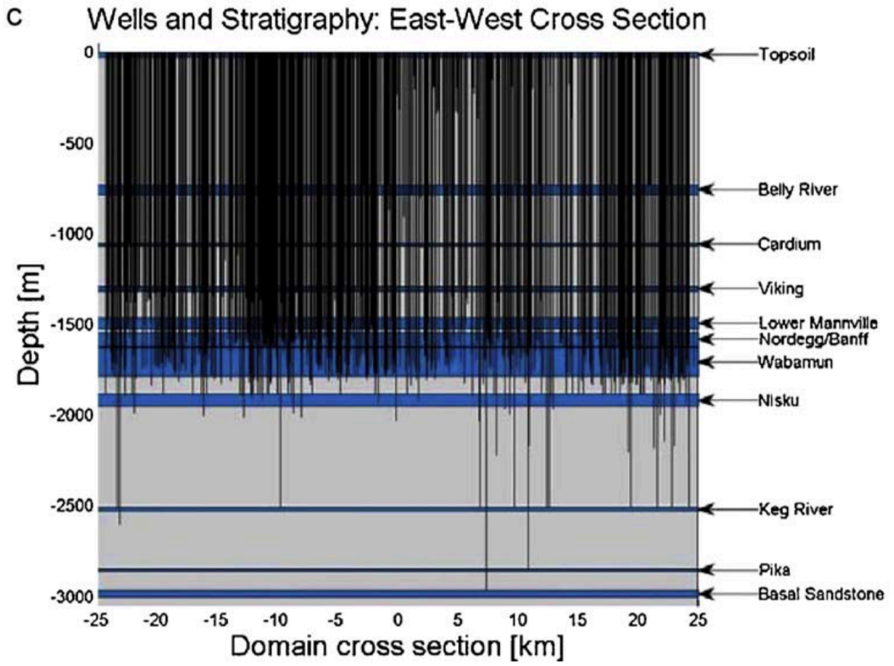
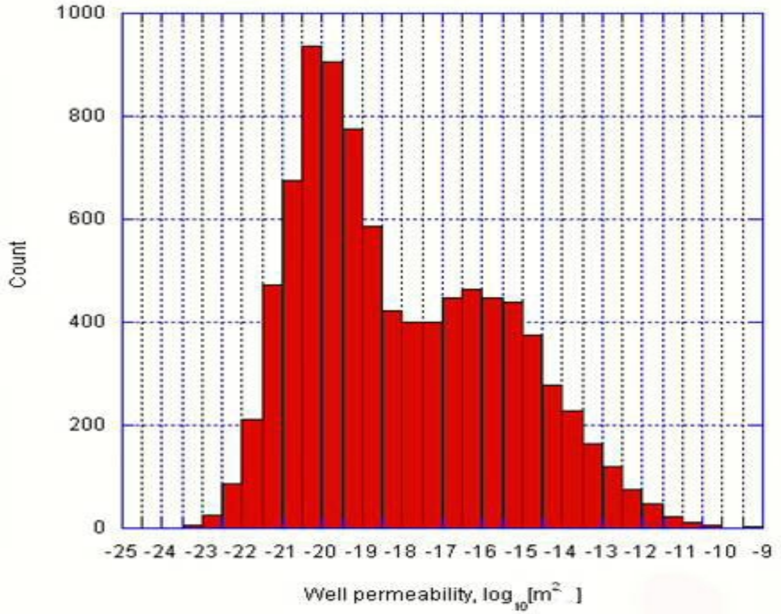
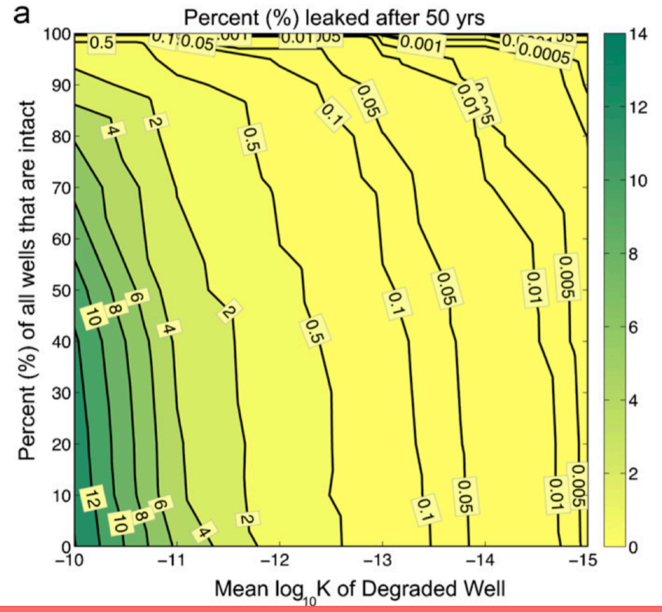


Fig. 1. (a) Location of major CO_2 sources in central Alberta, Canada. (b) Areal view of the Wabamun Lake study area showing all of the 1146 existing wells in the system.

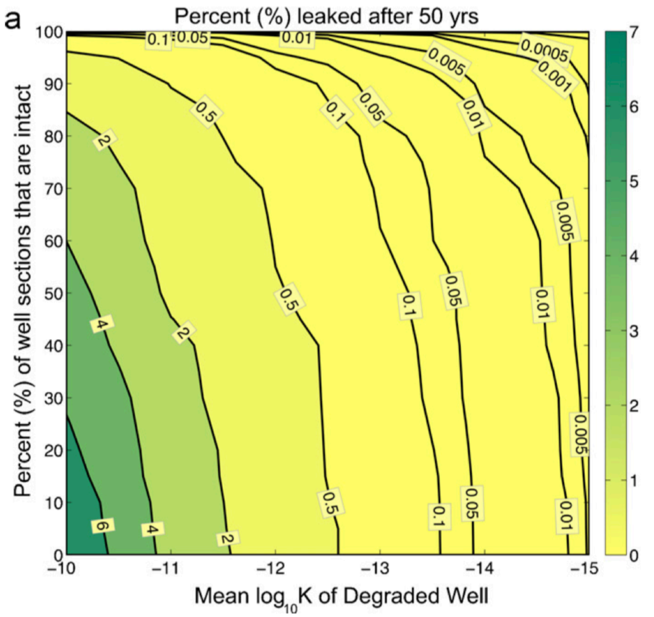


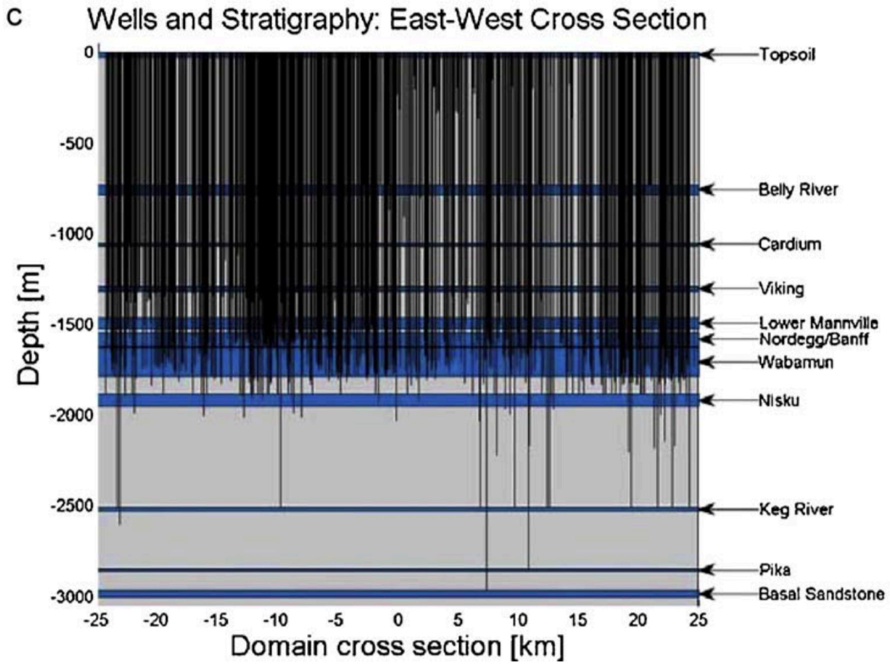


Nogues et al., A methodology to estimate maximum probable leakage along old wells in a geological sequestration operation, IJGGC 2012



Leakage out of injection aquifer (2000 m)





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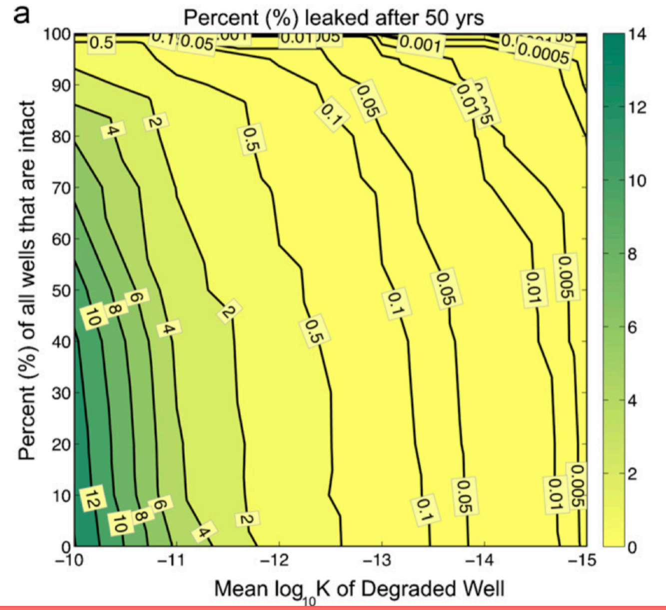
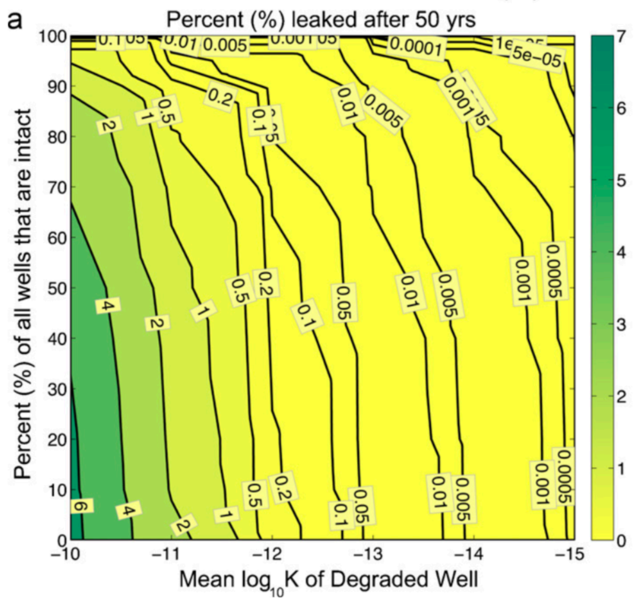
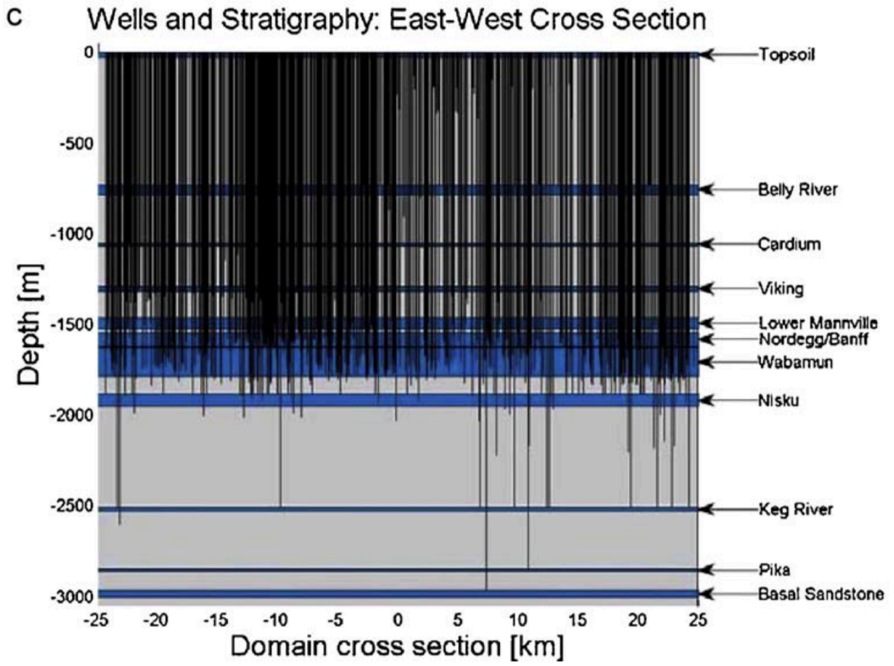
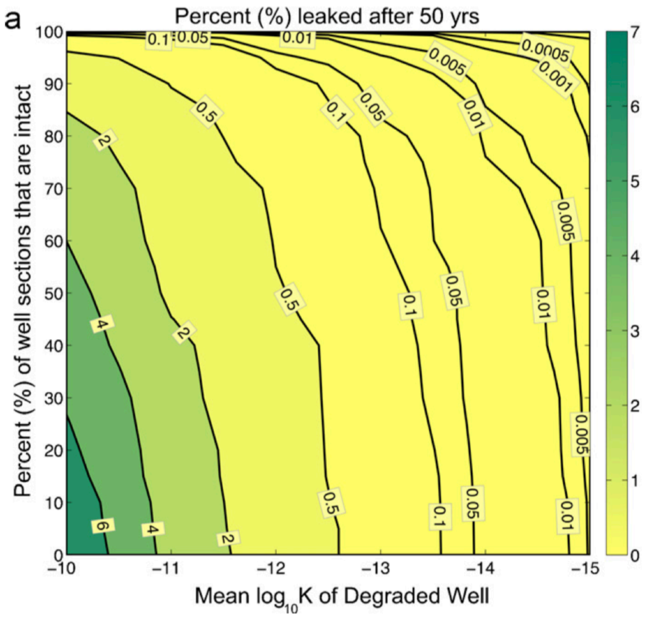


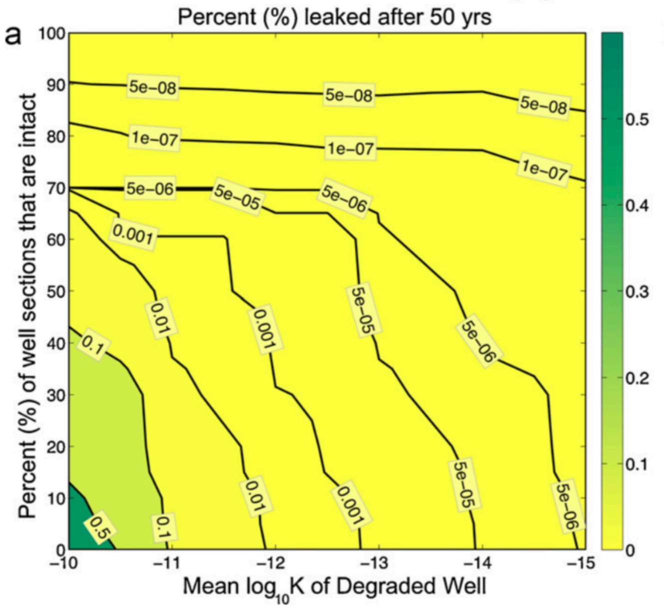




Leakage out of injection aquifer (2000 m)

Leakage into top two aquifers (<750 m)





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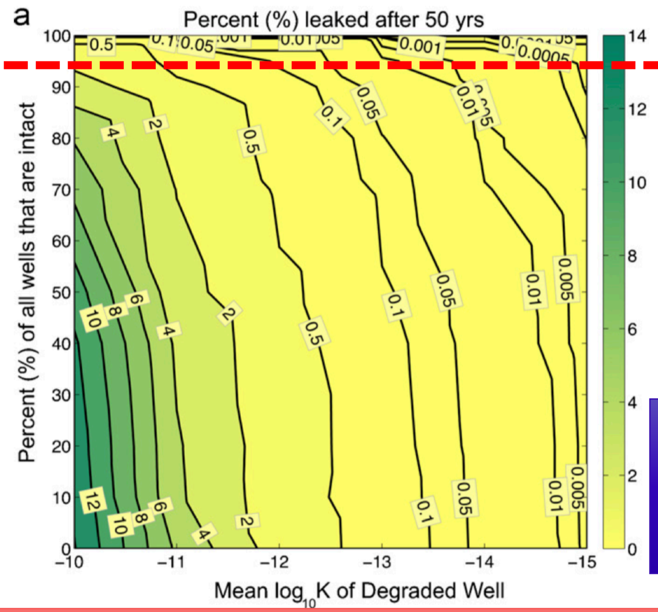
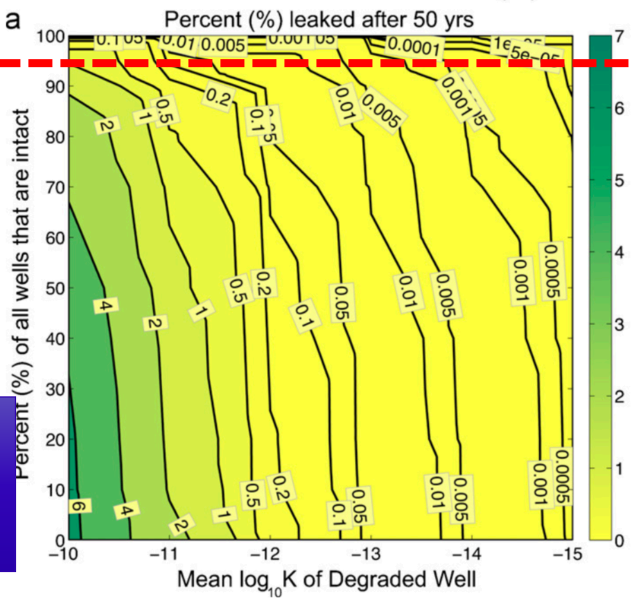
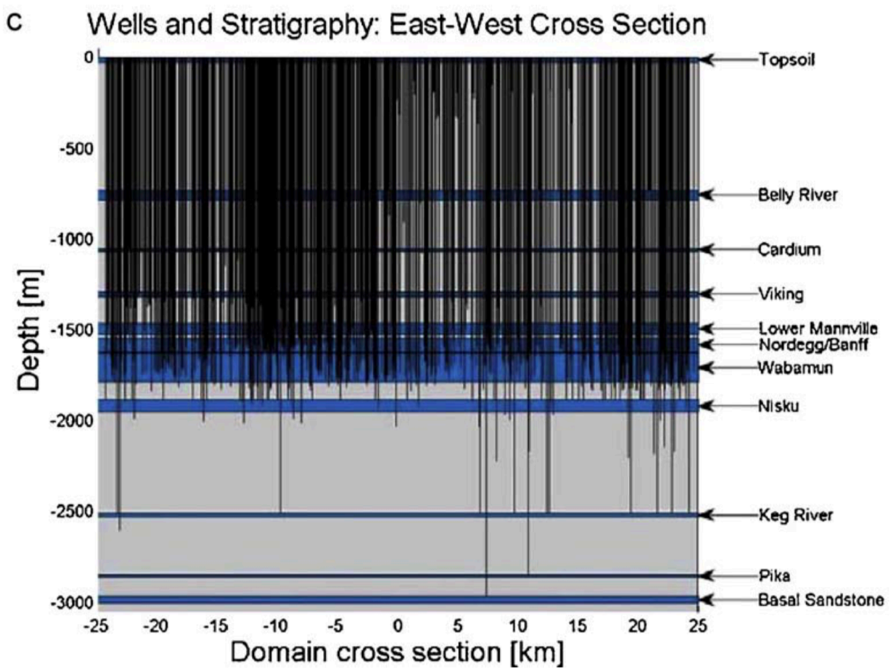


95% good wells





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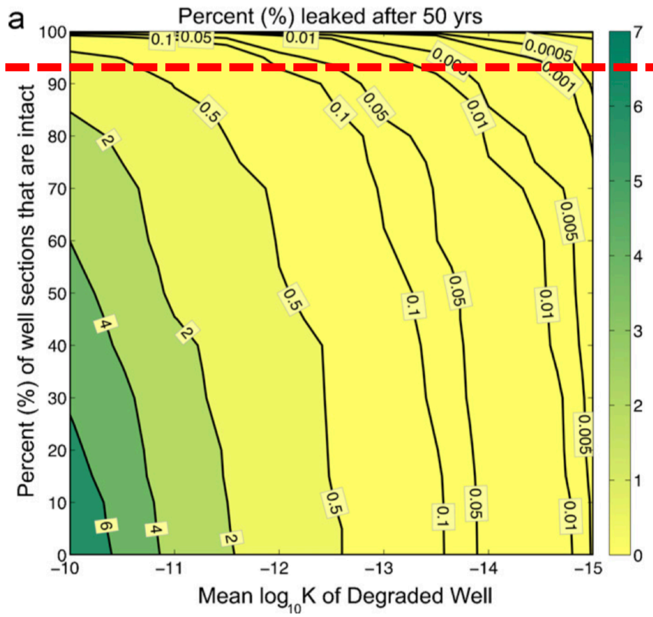

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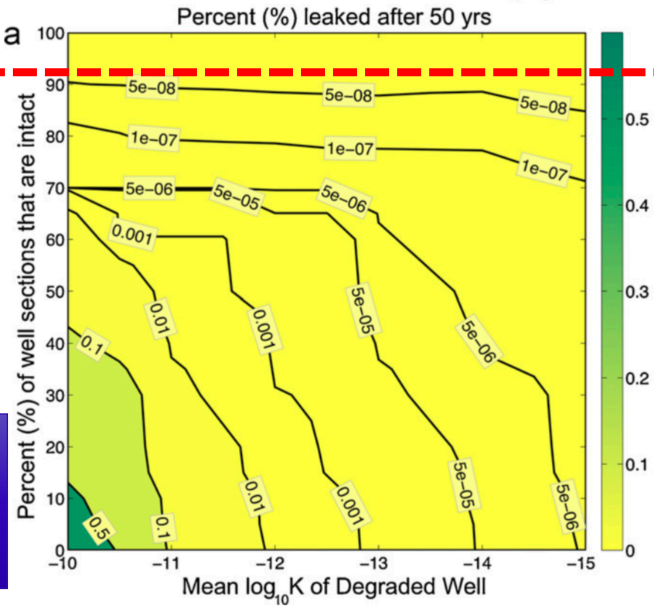
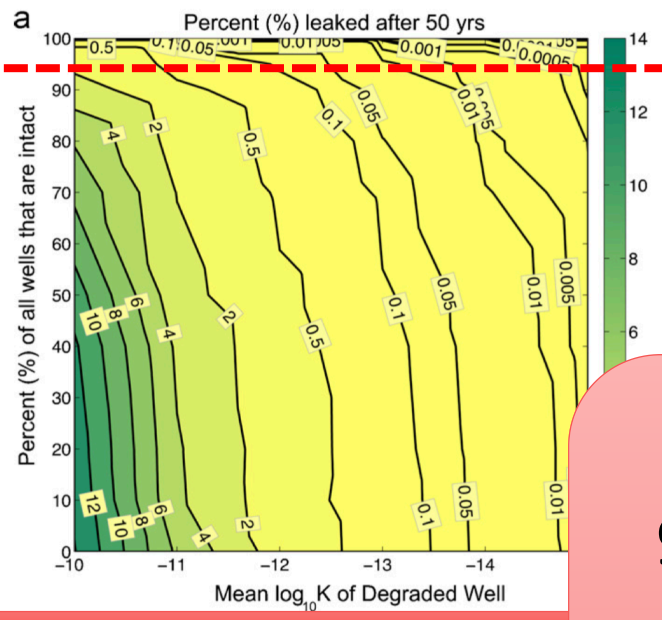


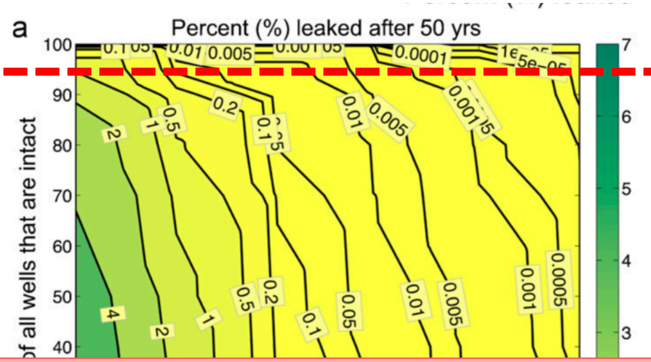
Most leakage is within acceptable bounds for climate change

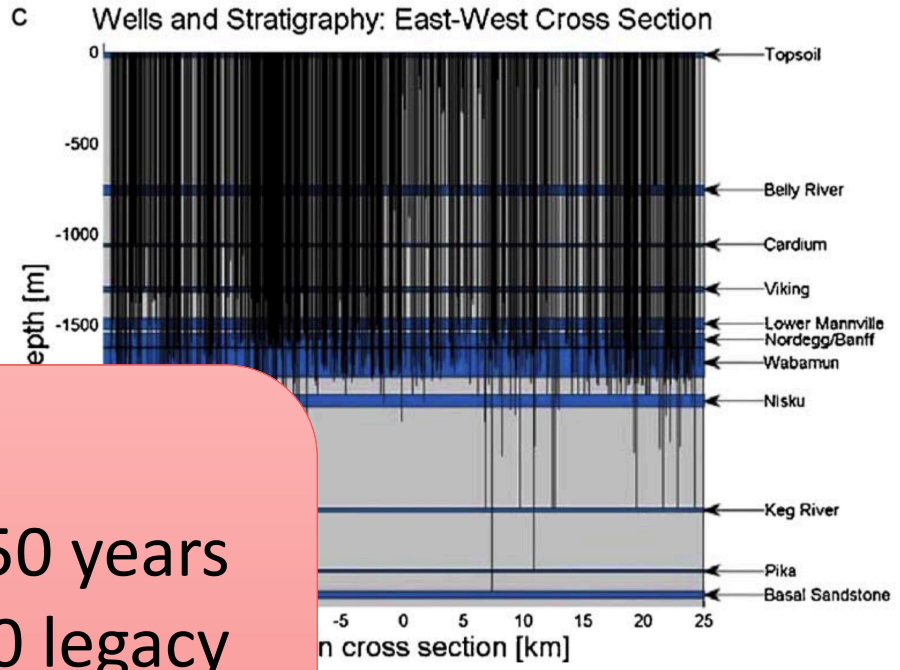
Measured wells < 1 Darcy produces < 0.1% leakage after 50 years

Very difficult to produce significant leakage through degraded wells

Nogues et al., IJGGC 2012

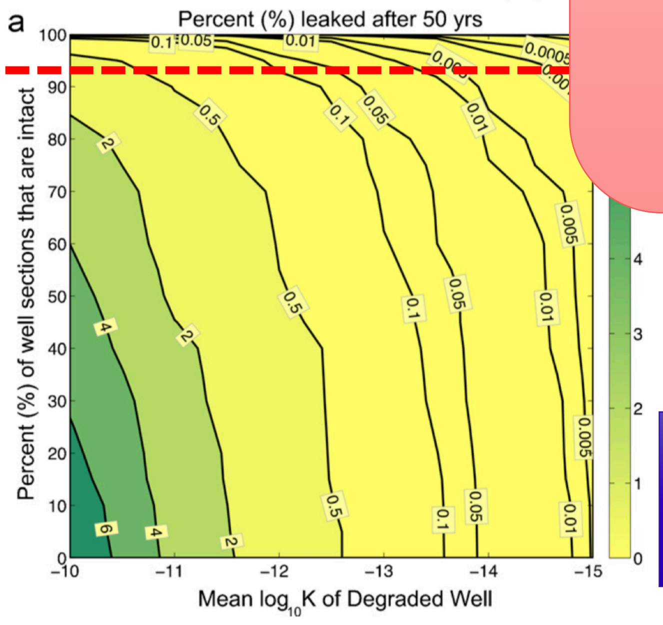






Leakage out of injection aquifer (20

99.9% retention of CO_2 after 50 years with leakage from 5% of 1,000 legacy wells



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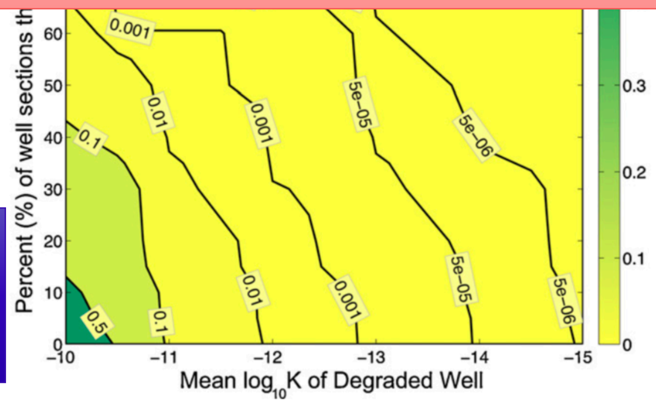

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Future of P&A offshore

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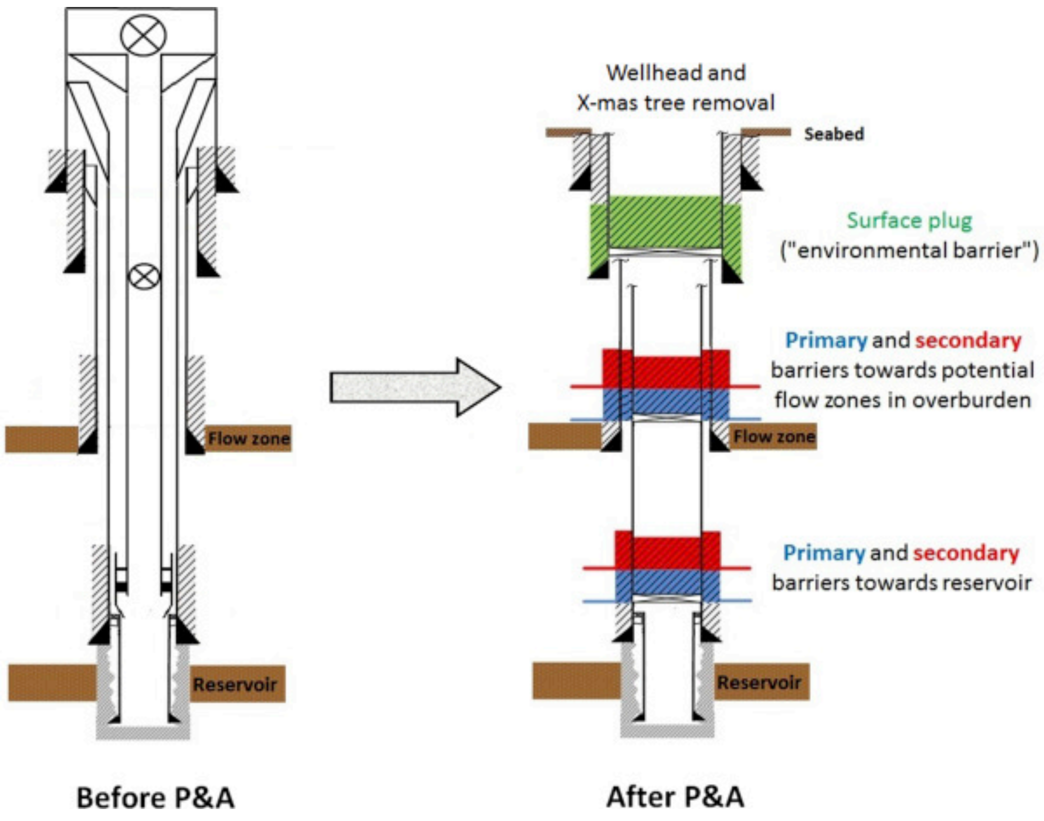
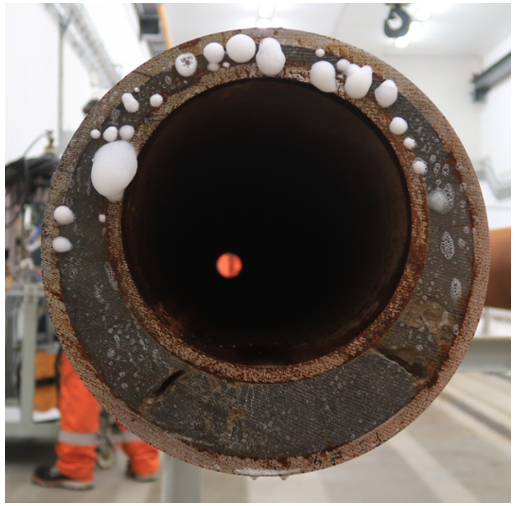
- Preparing for a wave of plug and abandonment as many platforms are heading towards decommissioning
- “Restoring the caprock” (rock-to-rock)
- Bring down costs (rigless plugging)
- Improve plug integrity, examine bridge plugs and plug length
- Section milling
- Shale barriers
- Cut-and-pull operation



Vrålstad et al., Plug & abandonment of offshore wells: Ensuring long-term well integrity and cost-efficiency, J. Pet Sci Eng, 2018

Fluid migration modelling & treatment

KPN project in PETROMAKS2 program 2019



10-m portions of a 30-yr Valhalla well recovered for testing of barrier quality

Cemented sandwich sections, generally good cement bond that agrees with logs and low gas migration by direct physical testing

Liquid permeabilities in microDarcies. Gas permeability in milliDarcies

Unique opportunity to develop new treatment technologies

Improved understanding of migration paths can guide the choice of remedial action to establish well integrity, improve SCP management and support the selection of the right P&A design solution

- Project objectives:
  - **Realistic micro-annuli and crack geometries**
  - Fluid migration analysis and **placement of treatment materials**
  - **Full-scale test assemblies** for qualification of treatment technologies

P&A Innovation Program: *Guillermo et al., SPE-199609-MS (2020); Skadsem et al. SPE-199662-MS (2020)*

The future for P&A and CO_2 storage

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Wells will most likely leak, many wells already do.

Leakage from legacy wells may not be problematic from a climate or environmental perspective

Monitoring requirements will require assurance that all leakage is detected

Need for clear regulations for P&A requirements within context of large-scale CO2 storage deployment

The future for P&A and CO_2 storage

- Discussion points
  - How to ensure Plug and Abandonment is good enough for long-term CO_2 storage?
  - Should all leaks be stopped? Or even can a leak be stopped?
  - Is it good enough to monitor for crediting or offsetting the leaked CO_2 another way?
  - Can we build confidence by demonstrating successful remediation on leaky wells (biogenic gas)?

Thank you for your attention!

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