LEGACY project: mapping, monitoring, leakage modelling and mitigation of legacy wells

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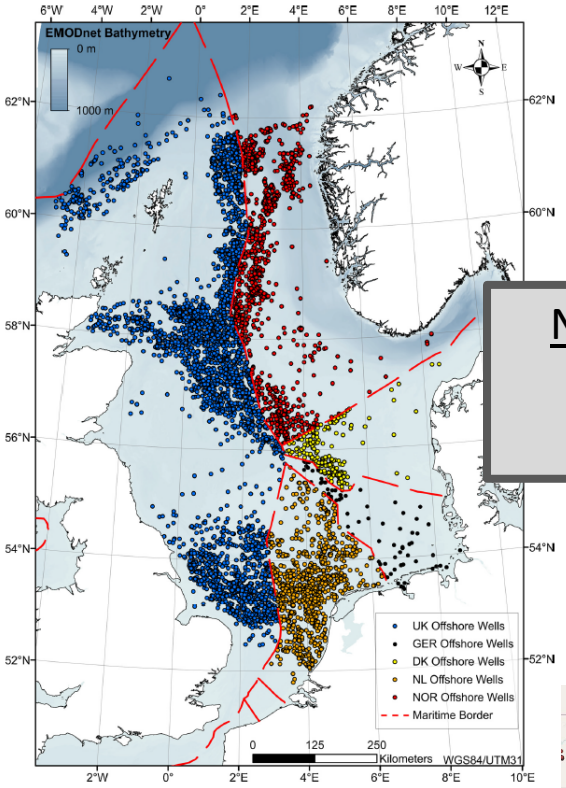
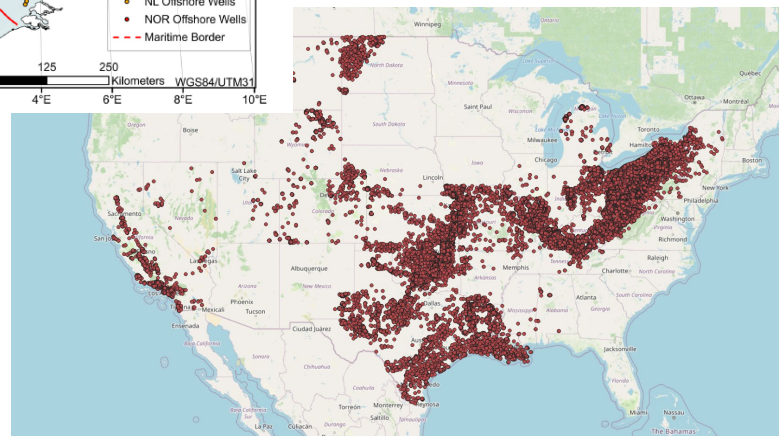
FORCE CCS Legacy Wells seminar, 19 November 2025

Legacy wells

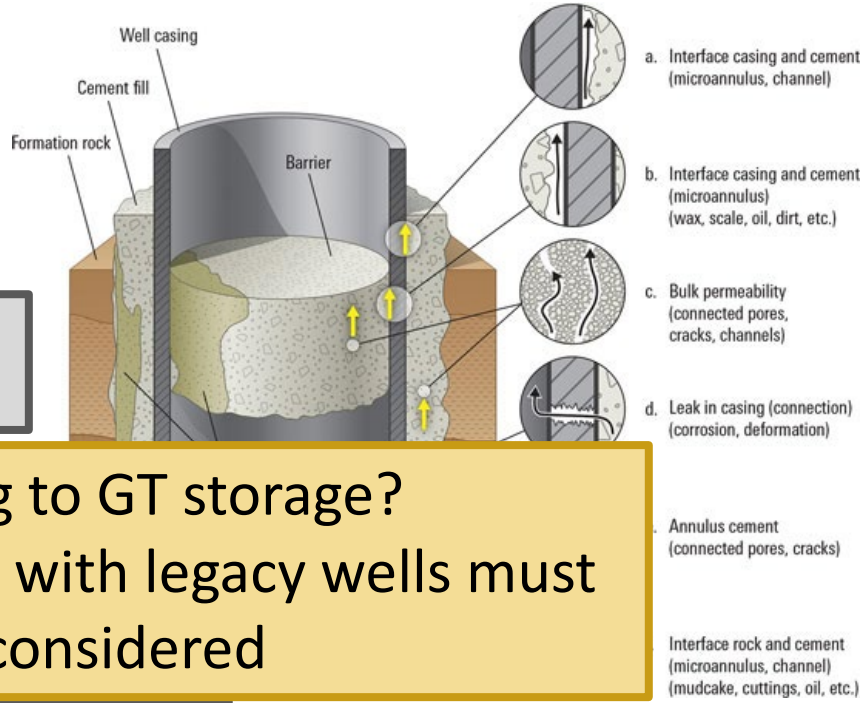




North Sea (Böttner et al., 2020)
Onshore USA (Merrill et al., 2023)

NCS: more than **8000** wells
USA: several **millions** of orphaned wells

Gasda et al., 2004

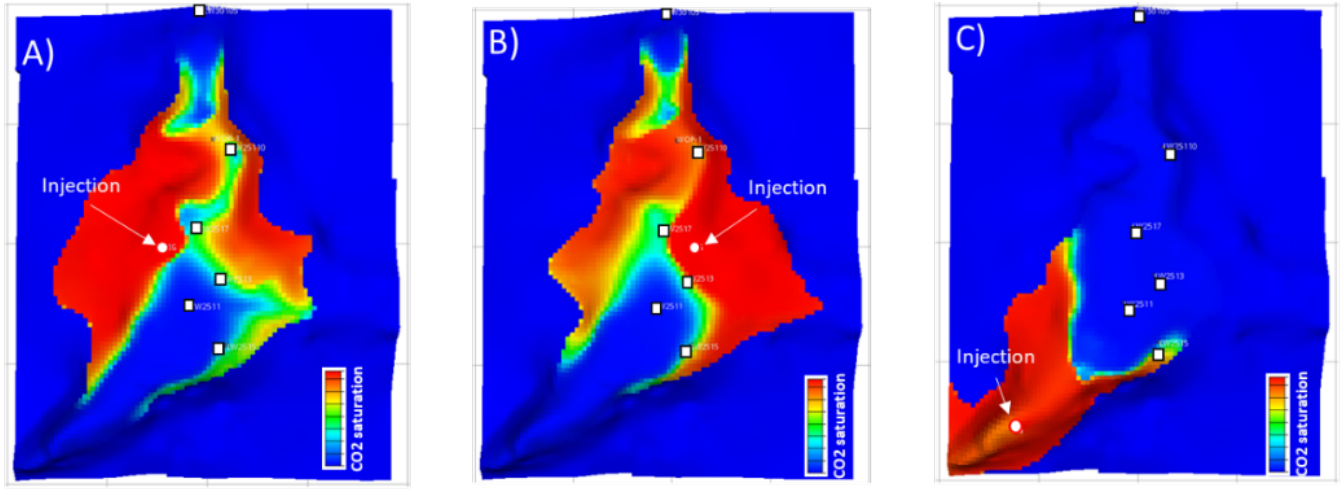


Several potential leakage pathways

Upscaling to GT storage?
➔ storage areas with legacy wells must be considered

Location of legacy wells vs plume migration

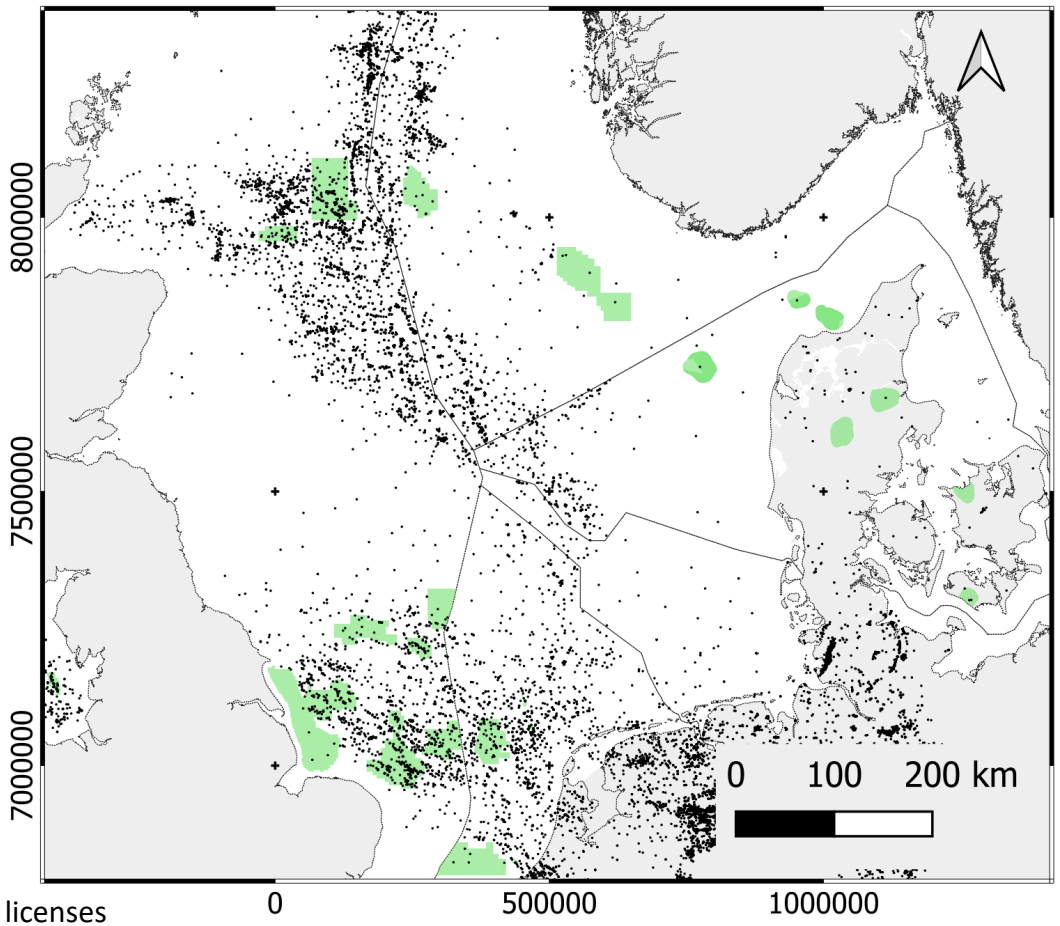
Zonetti et al., 2023



LEGACY project facts

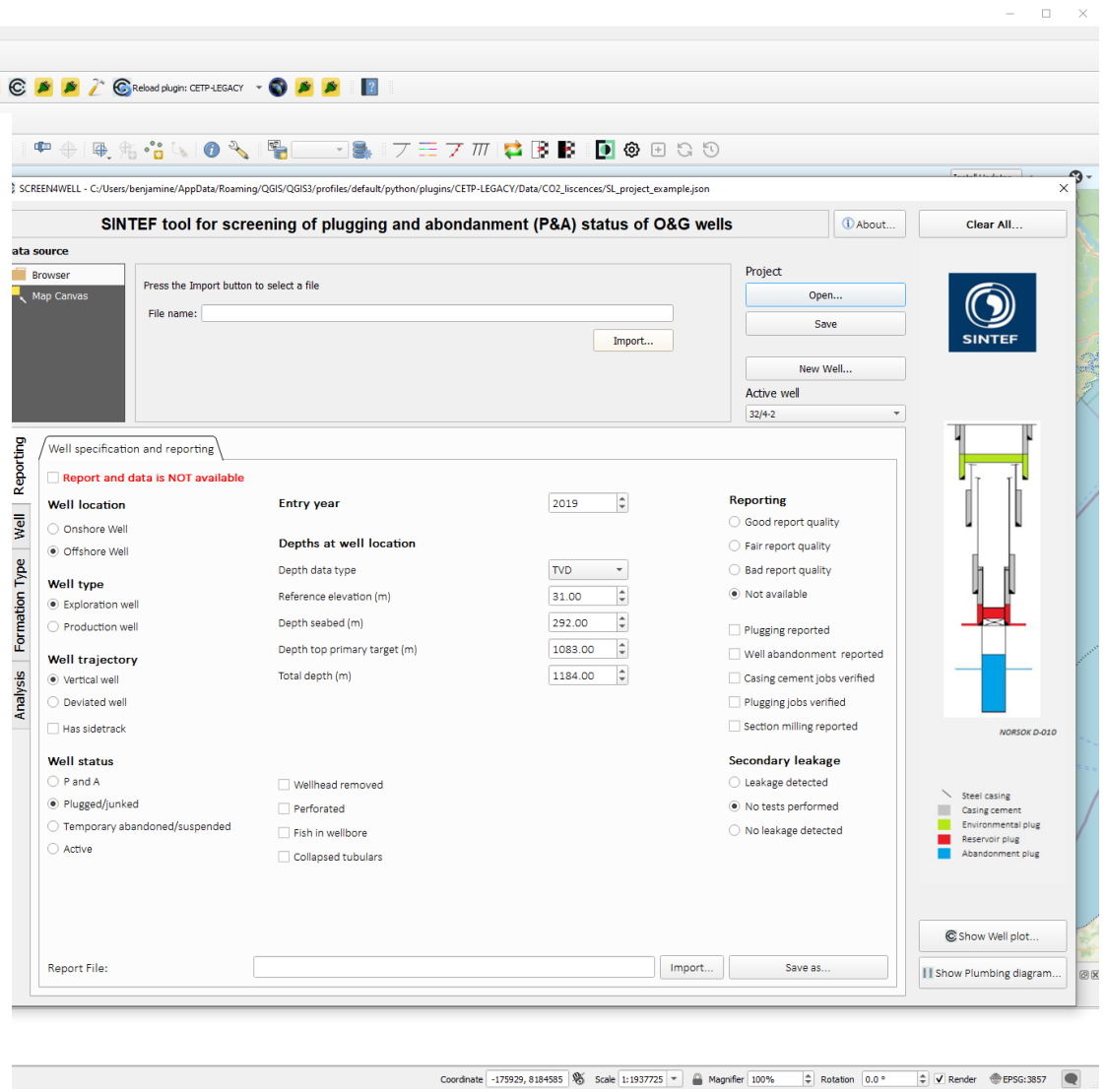
- *LEGACY*: Field studies for de-risking existing wells and CCS
- Main objective: develop tools and technologies for **screening, modelling, monitoring, and mitigation of well integrity issues and leakage**, thereby **enabling** safe and cost-efficient, **large-scale storage** of CO_2 in areas with legacy wells
- Funding: Clean Energy Transition Partnership and industry funding
- Research partners: SINTEF Industry and SINTEF Energy (Norway), LBNL (US), LANL (US), Febus Optics (France)
- Industry partners: Equinor, AkerBP, Vår Energi, Exxon Mobil
- Duration: 2024 - 2026

SCREEN4WELL QGIS plugin



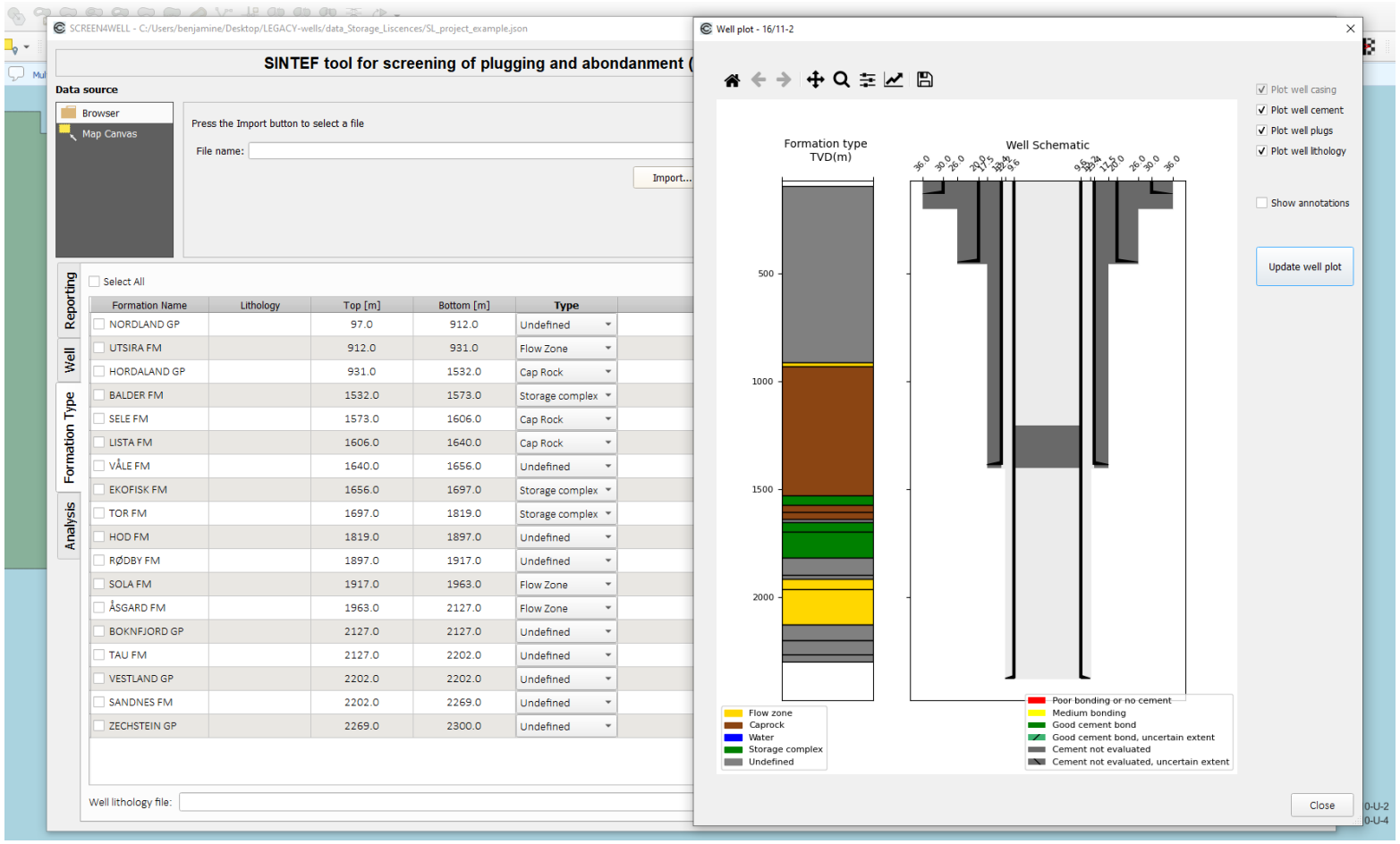
Storage licenses

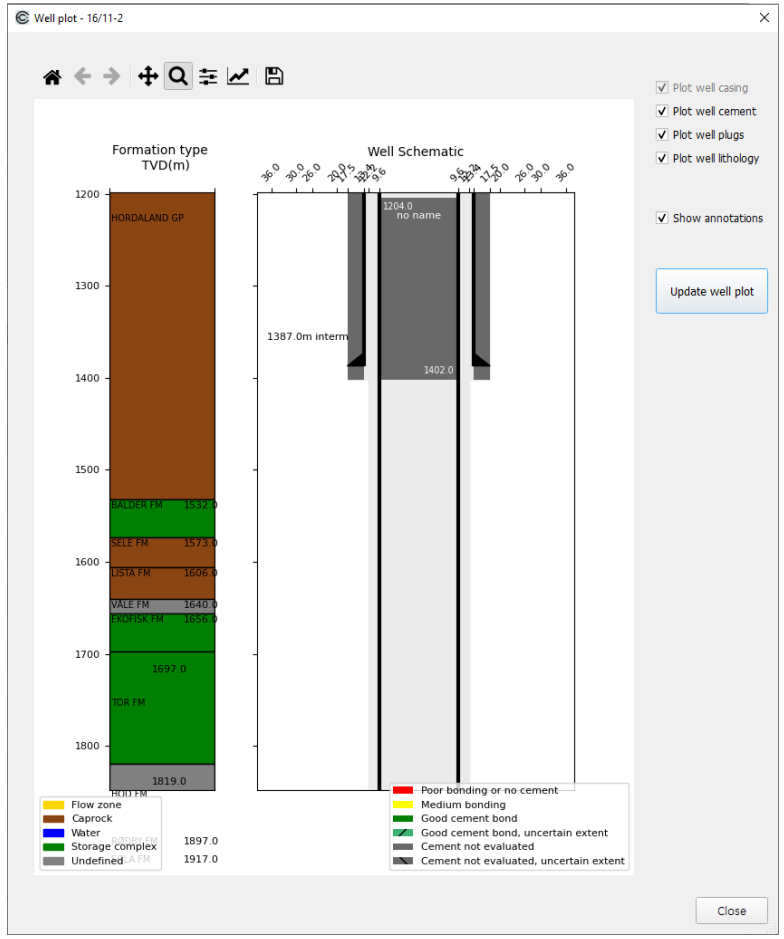
Existing wells



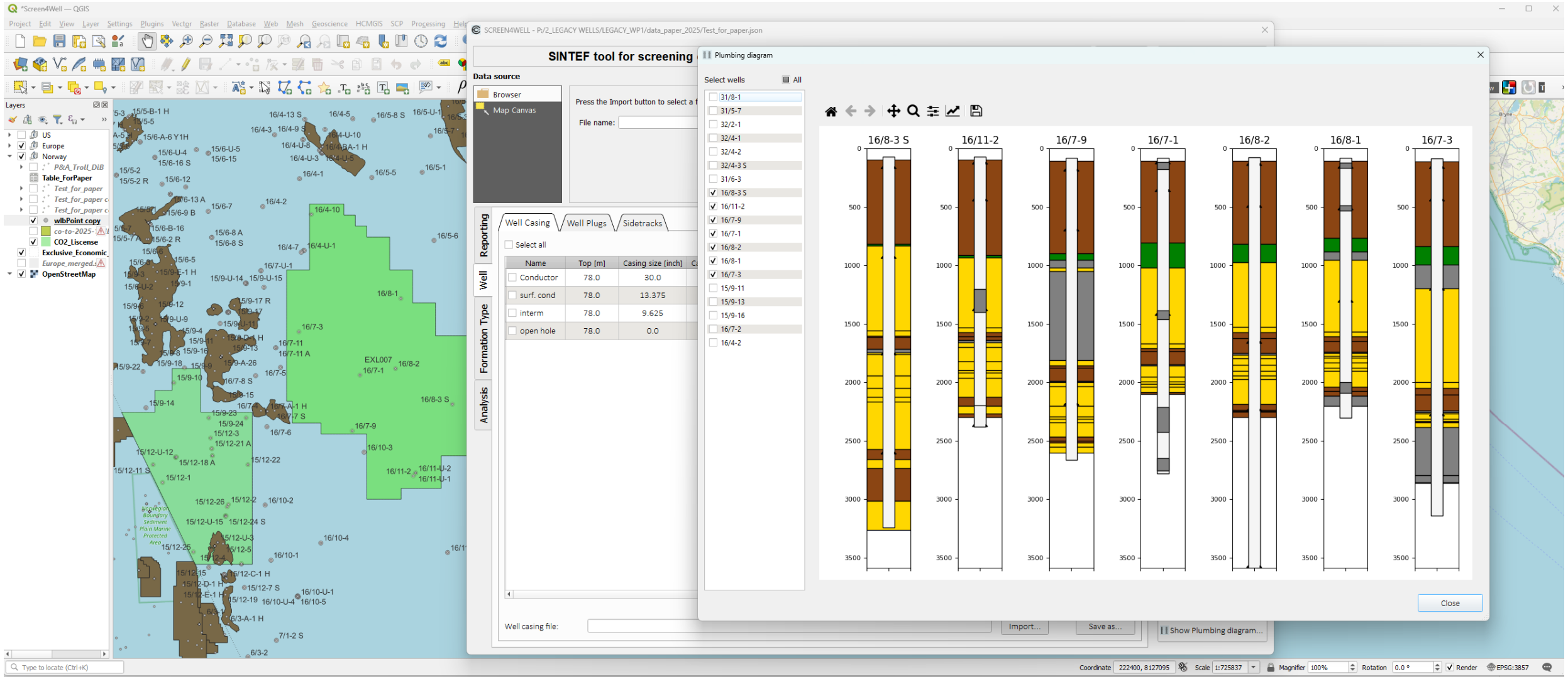
Well architecture and visual inspection

Reset
Move
Zoom in
Configurate subplots
Figure options
Savings





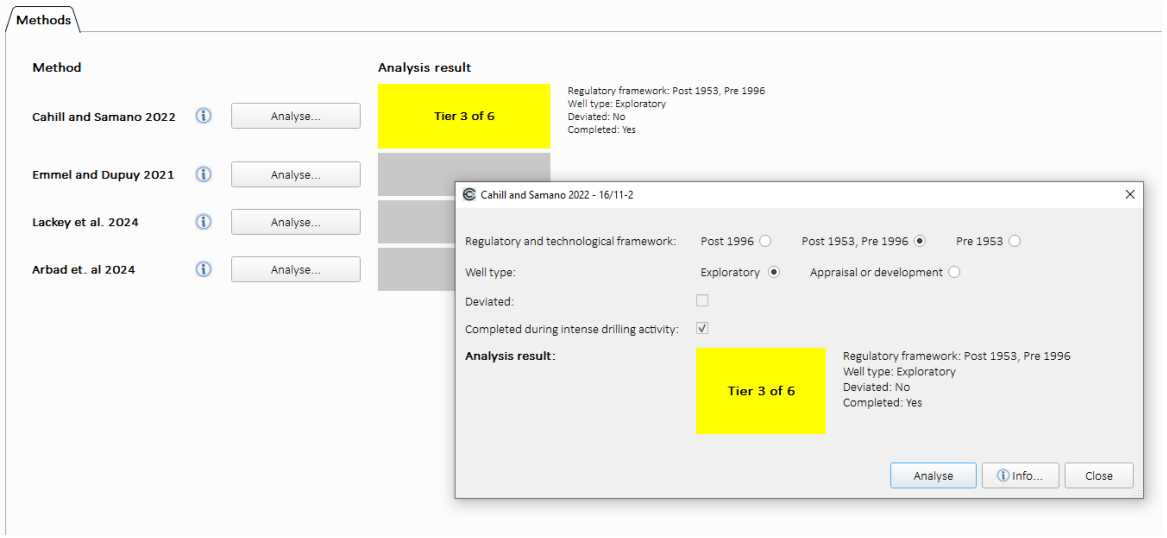
Plumbing diagram

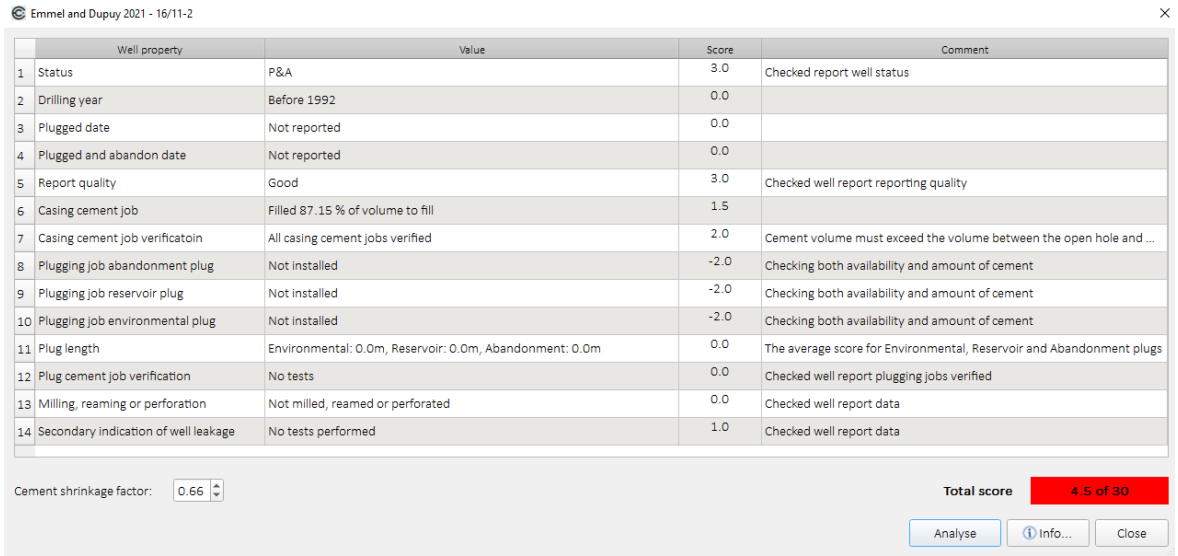


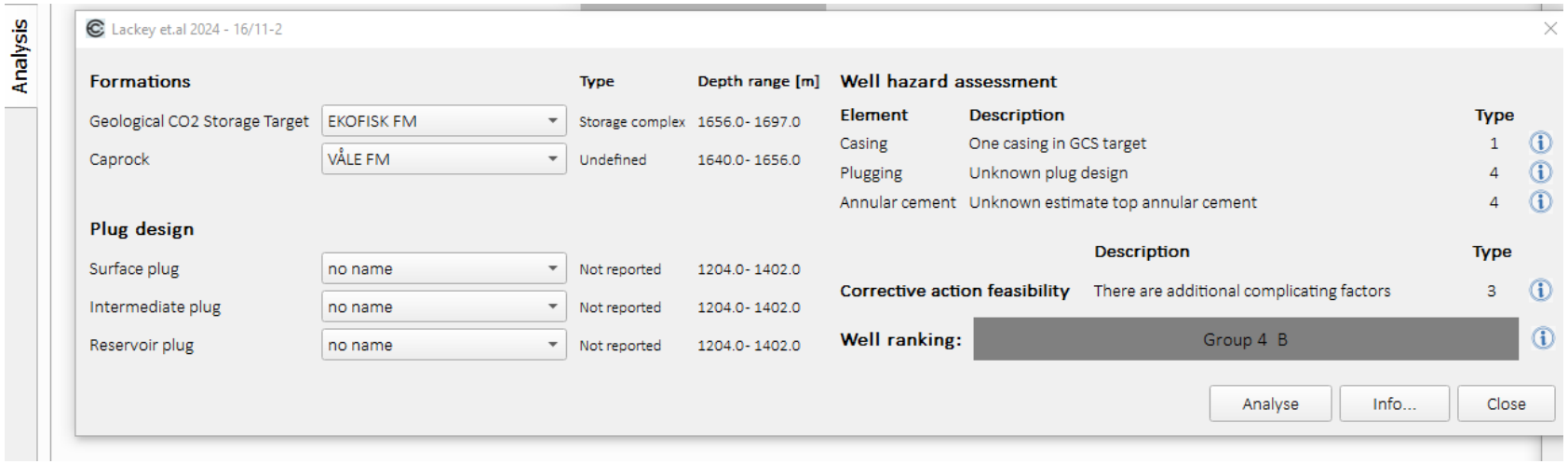
Assessment/analysis methods

Assessments:

- *Emmel & Dupuy, 2021*
- *Cahill & Samani, 2022*
- *Arbad et al., 2022*
- *Lackey et al., 2024*

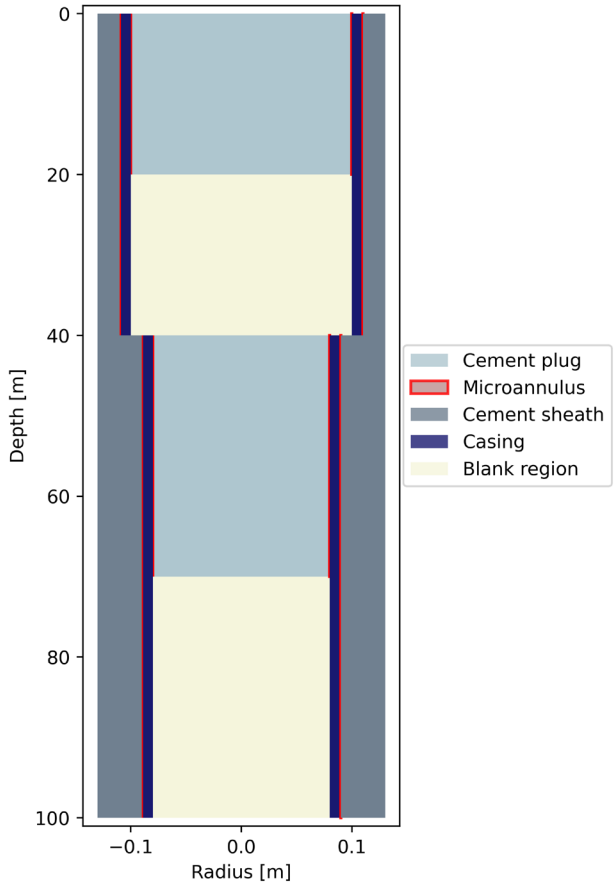




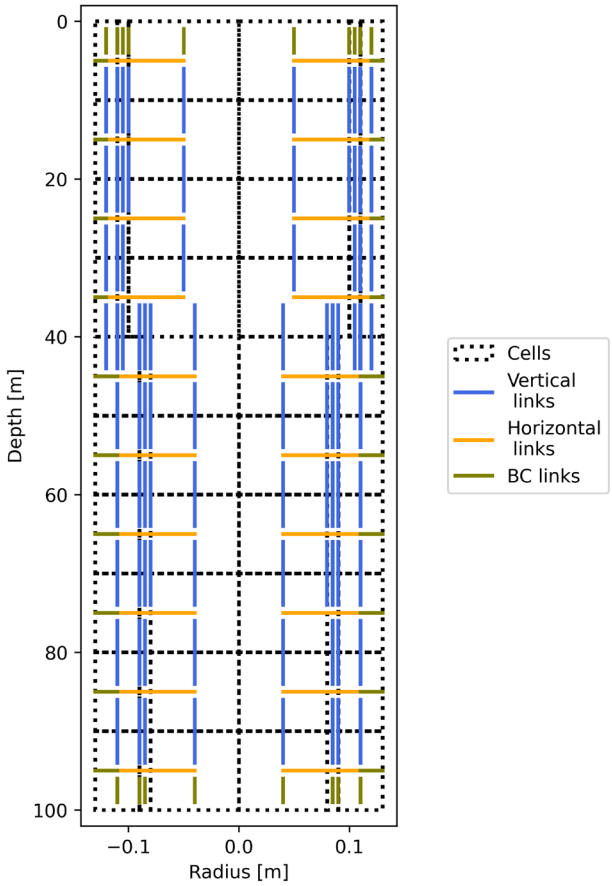


Leakage modelling tool

Well structure:

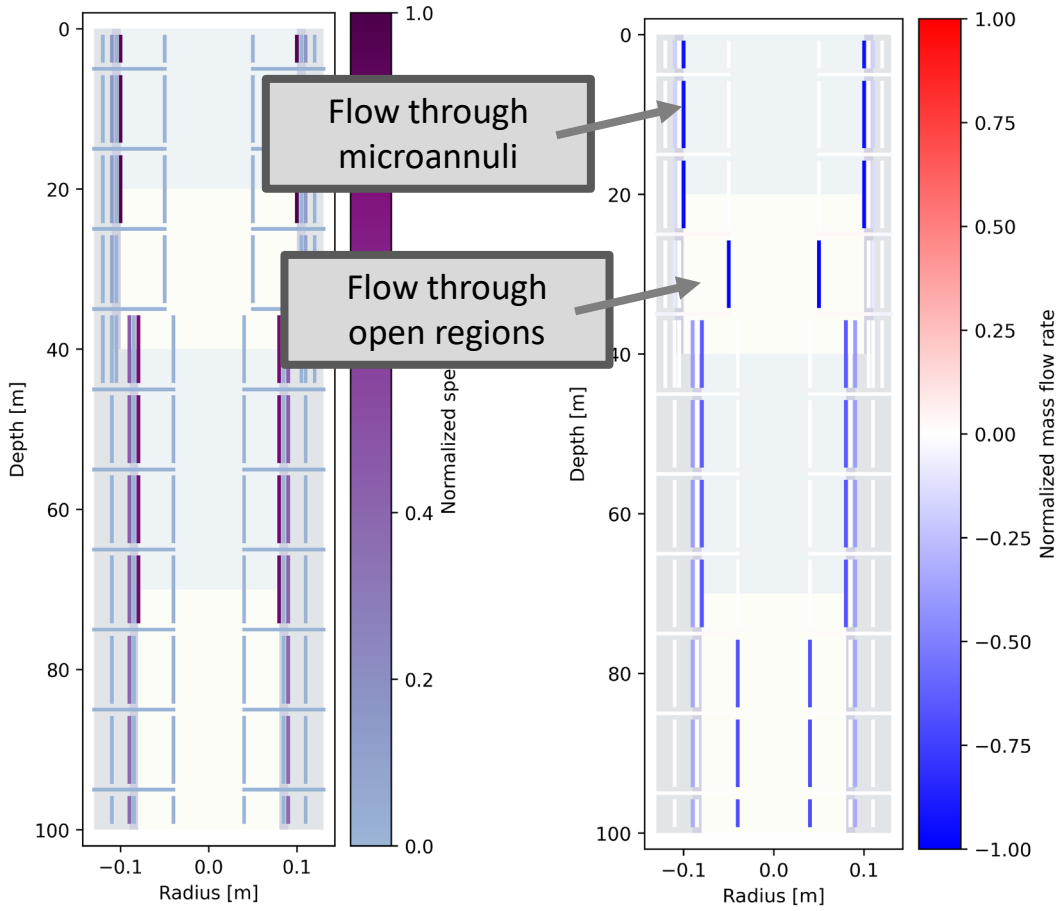


2D network :



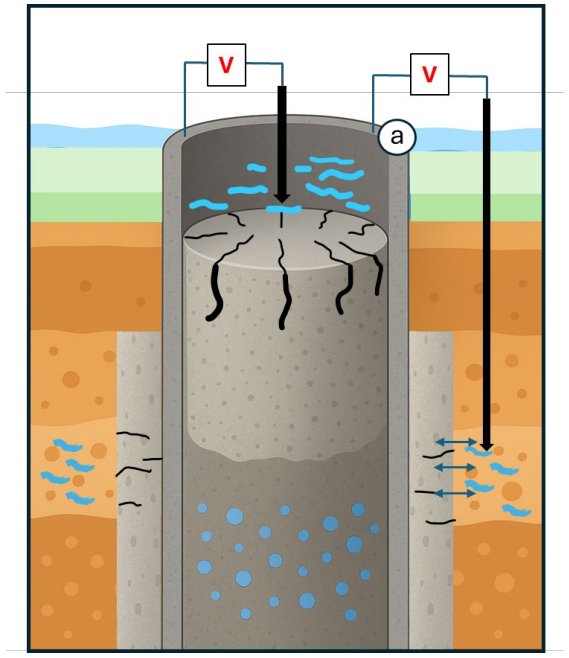
Calculated flow speed:

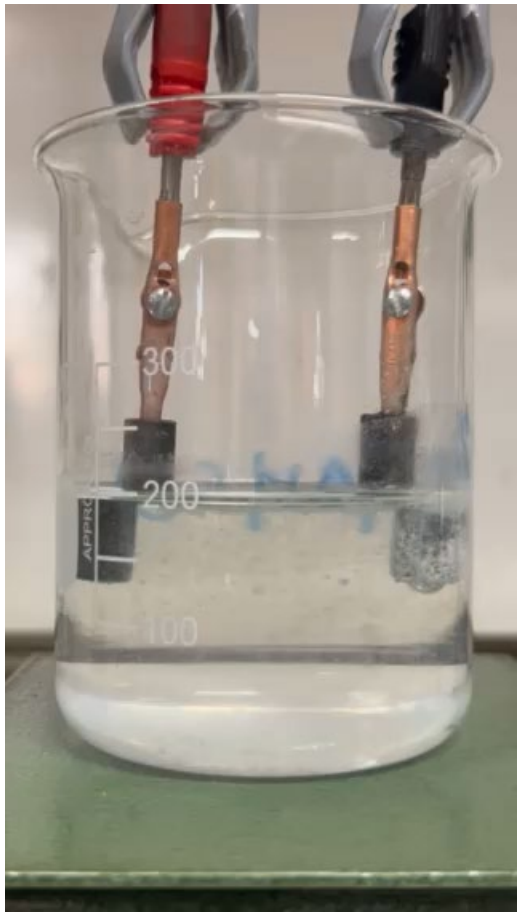
Calculated mass flow:

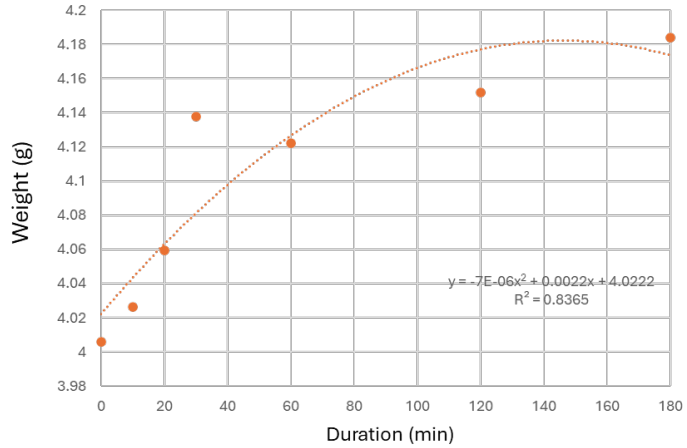


Electrochemical simulation of scale

Scale from synthetic formation water







Electrolysis splitting of water:

Cathode: $2H_2O + 2e^- \rightarrow H_2 + 2OH^-$

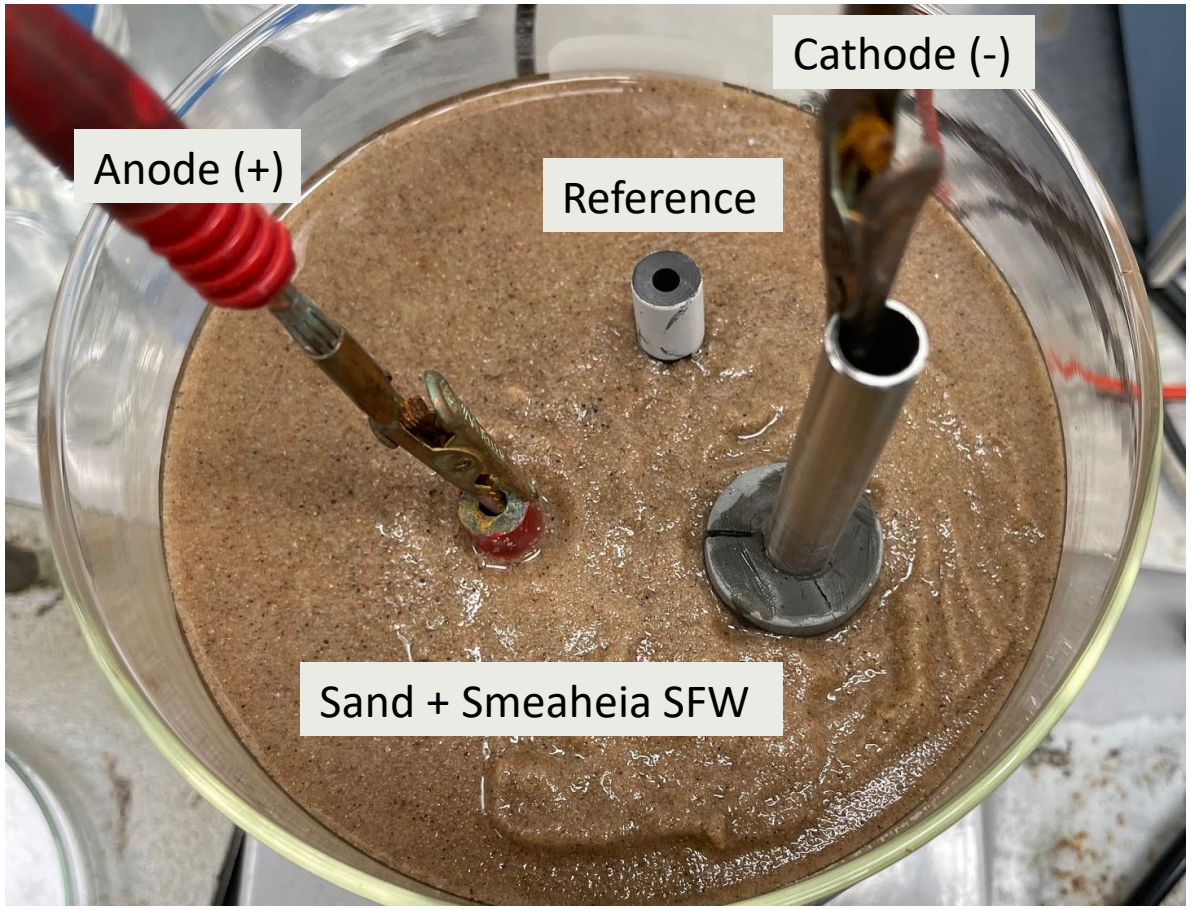
Anode: $2H_2O \rightarrow O_2 + 4H^+ + 4e^-$

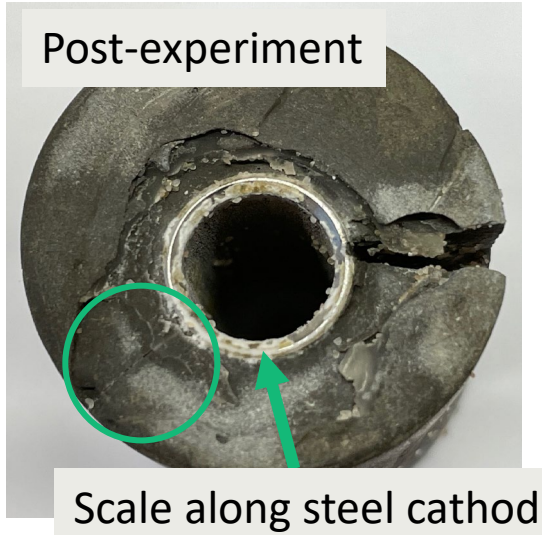
Main mineral reactions at cathode:

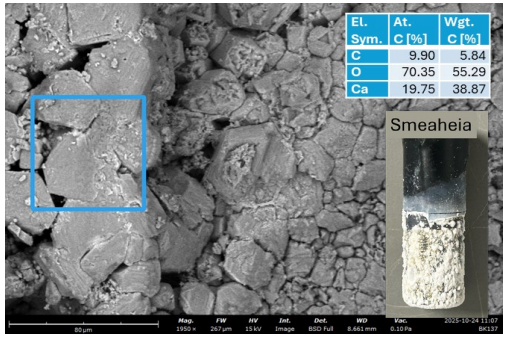
Portlandite: $Ca^{2+} + 2OH^- \rightarrow Ca(OH)_2$

Brucite: $Mg^{2+} + 2OH^- \rightarrow Mg(OH)_2$

Electrochemical simulation of scale



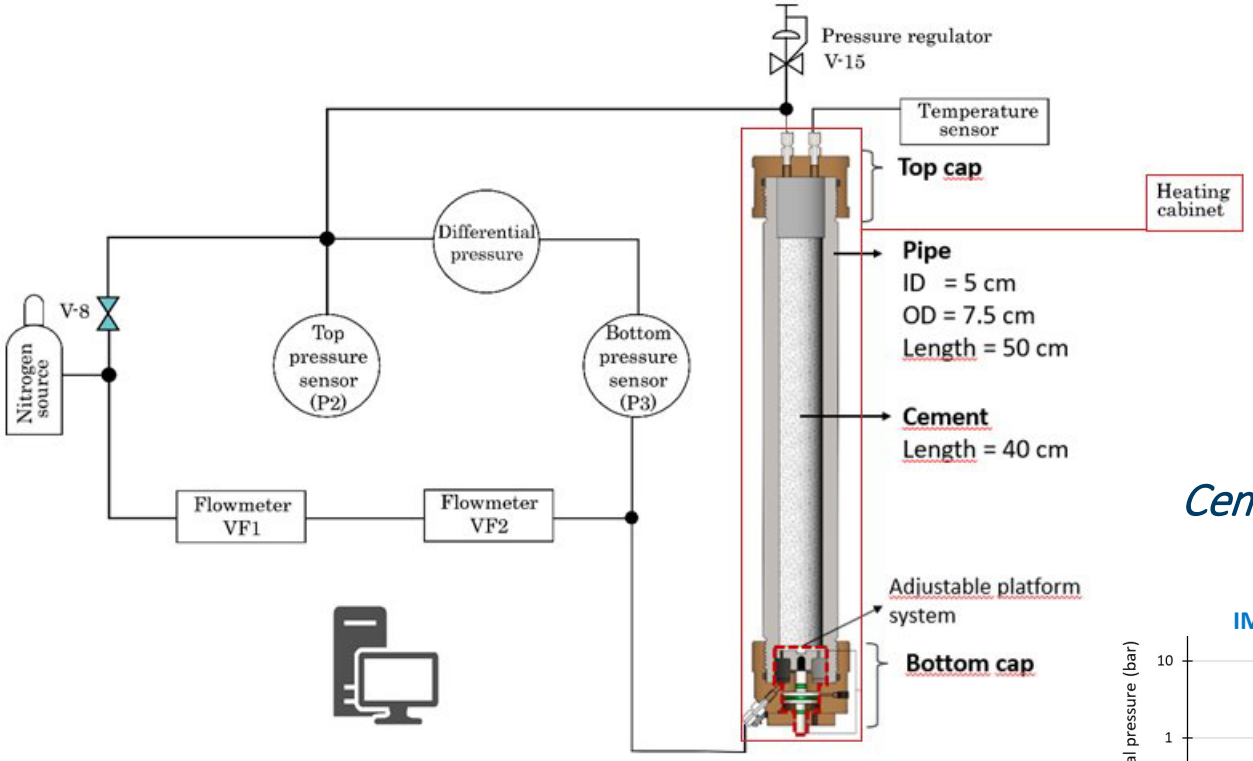




- 24 hrs electrochemical experiment
- Post experimental characterisation of scale via XRD and SEM-EDS

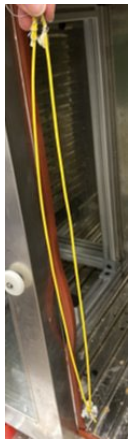
Leakage tests of cement plugs with and without monitoring optical fibers

Can the presence of optical fibers (for monitoring) in cement barriers affects leakage rate ?

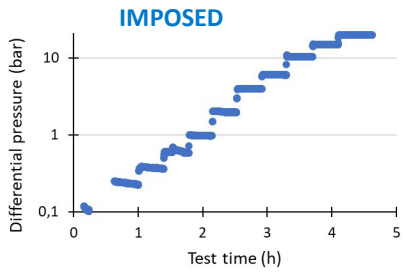


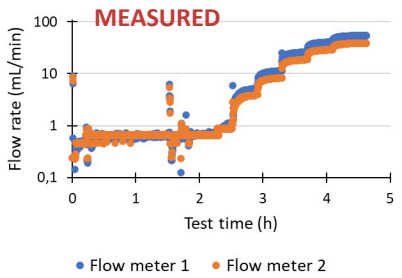
Cement plug setup

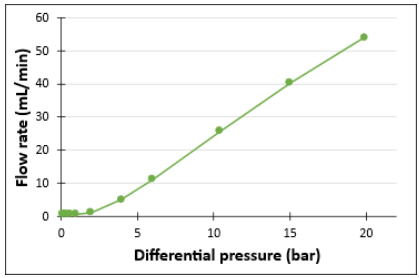
- Cement plug cured 20 bar, 66°C for 4 days
- 2 optic fibers (Ø 1mm) placed in the middle
- Neat cement G
- Cement with expansive agent *(ongoing)*



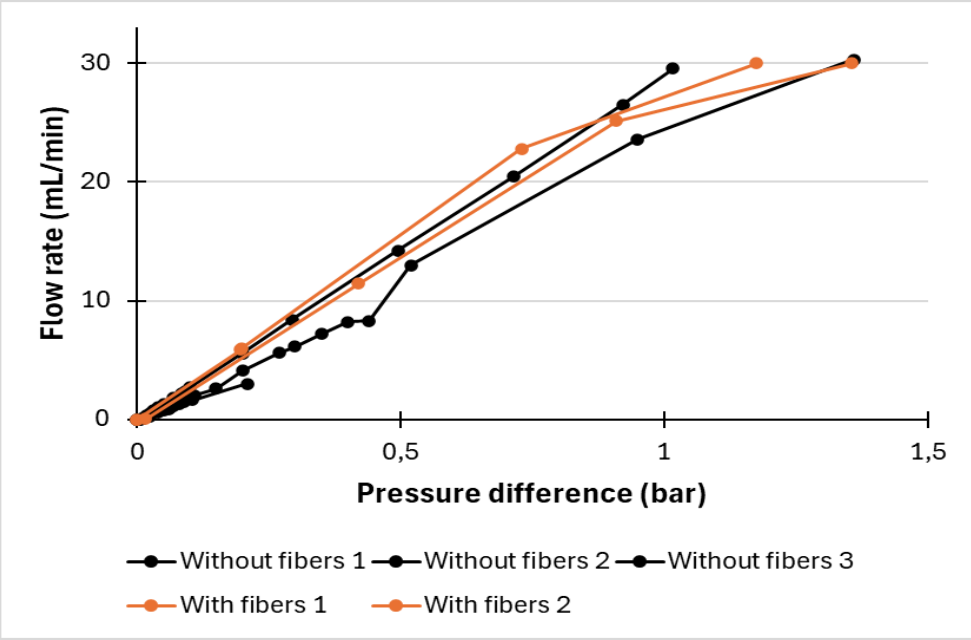
Cement plug sealability: relationship between flow rate and differential pressure over plug







Leakage tests: results

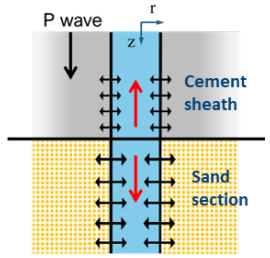


Most of leakage seems to occur at the microannulus (casing-cement interface)

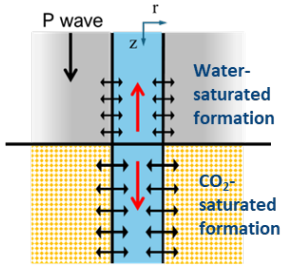
- Presence of optical fibers does not affect the leakage rate **in the case where the initial cement plug has a high leakage rate (regular cement)**
- *Ongoing tests:*
  - *initial cement plug with a relatively low leakage rate (expansive cement)*
  - *Fiber close to the wall (different configuration)*
- **Next:** presence of optical fibers in annulus cement barrier

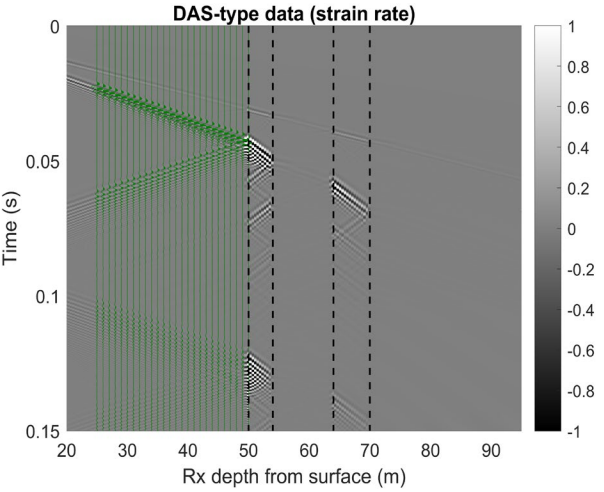
Non-invasive monitoring

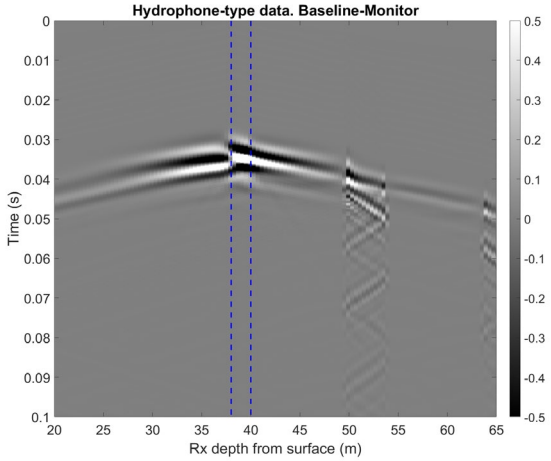
Sensitivity to cement integrity behind casing

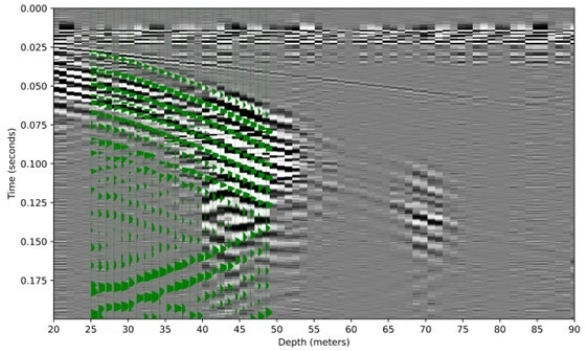


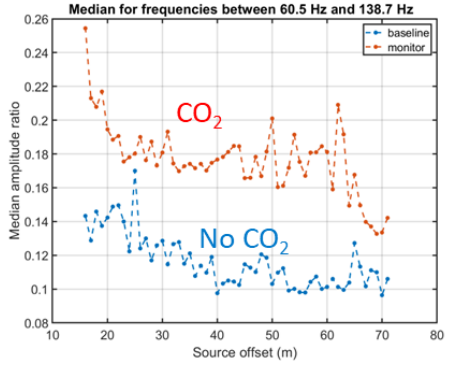
Sensitivity to CO_2 behind casing



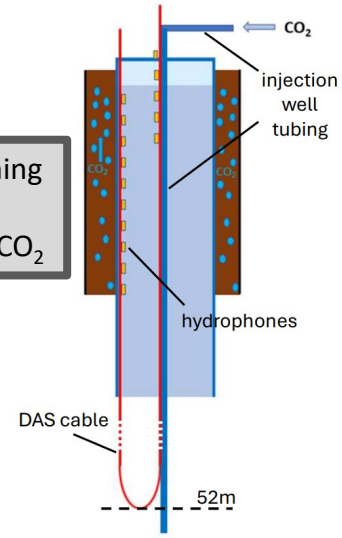




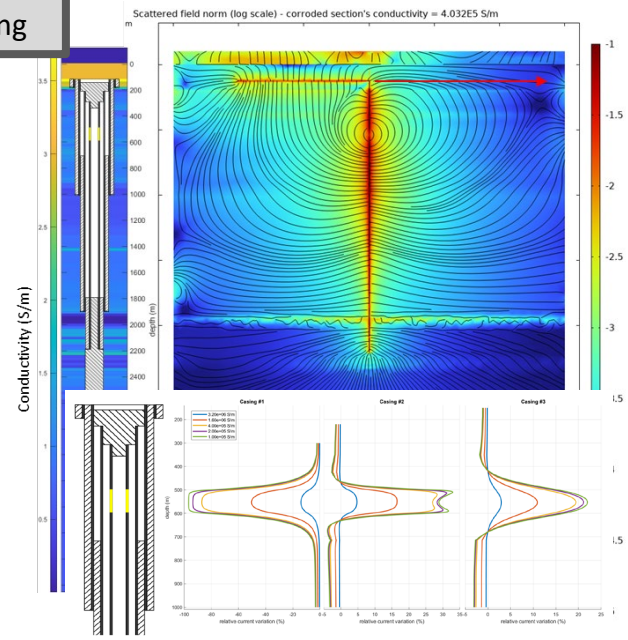




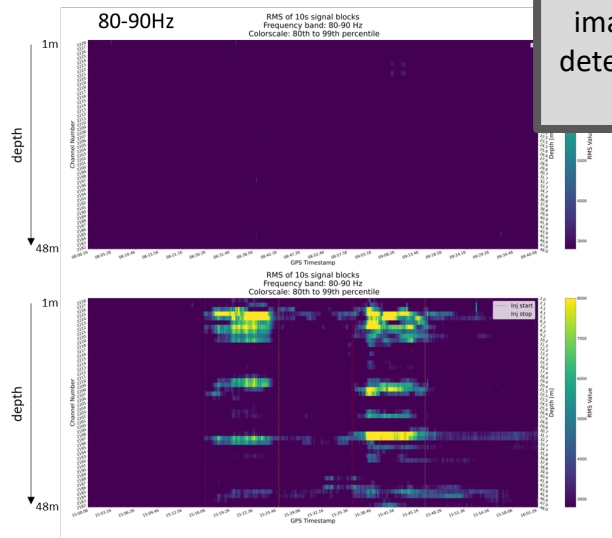
Passive listening of vertical migration of CO_2

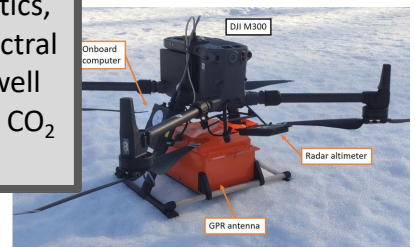


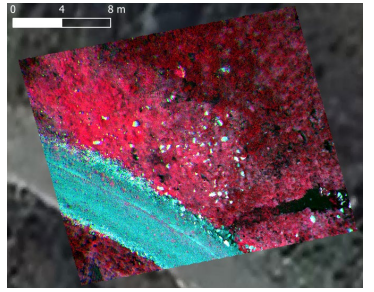
Casing corrosion monitoring



Drone magnetics, GPR, multispectral imaging for well detection and CO_2 seepage



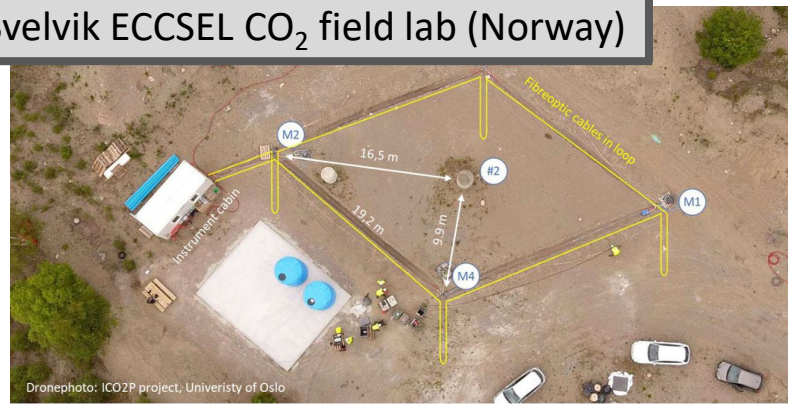


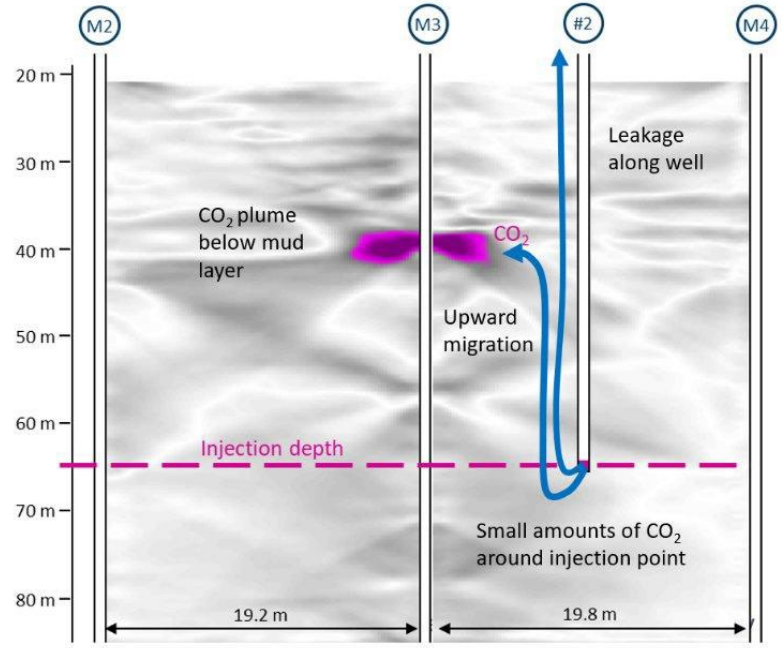


Field campaigns

Svelvik: 24th September – 8th October 2025

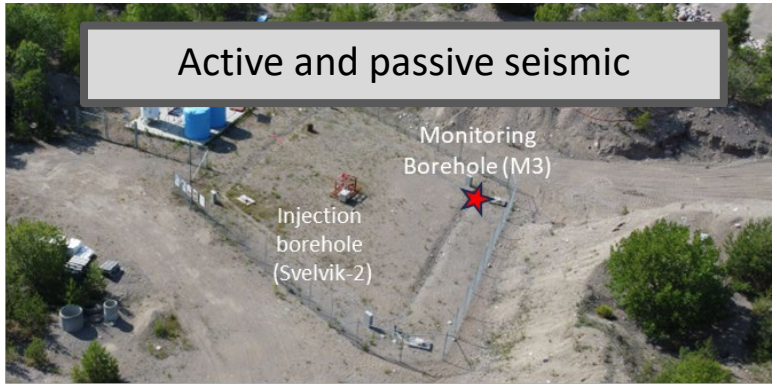
Svelvik ECCSEL CO_2 field lab (Norway)



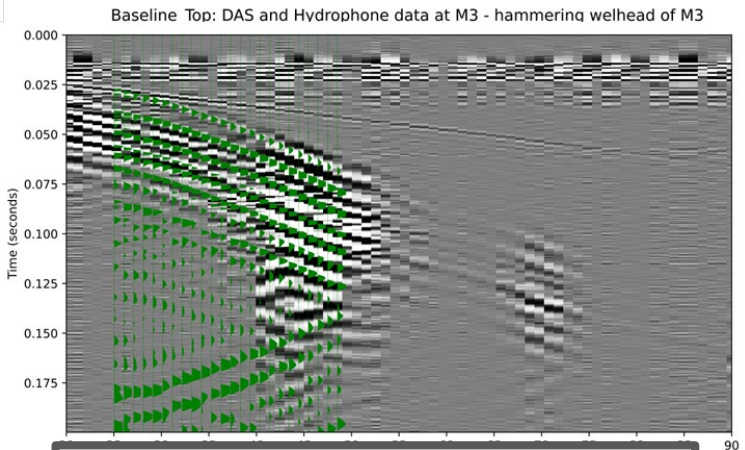


Jordan et al., 2022. EAGE Geotech, London

Active and passive seismic



Zero offset VSP data for tube wave analysis was collected before ("Baseline") and during CO_2 injection ("Monitor").



DAS, DTS, DSS, hydrophones, surface geophones

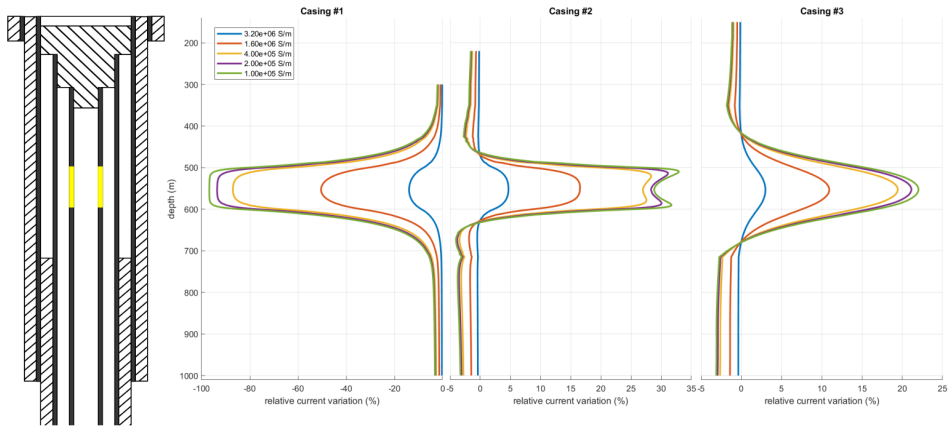
3D printed engineered plug

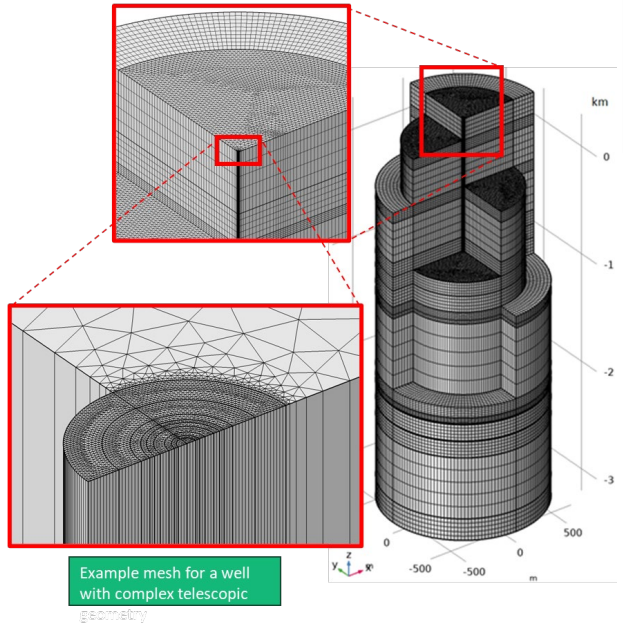
Future field campaigns:

- Rio Vista end 2025 (California): 6000 ft well (tube waves, TDR, energized casing)
- Mt Terri 2026 (Switzerland): near and far field characterization
- Possibly Svelvik 2026: more realistic plug tests

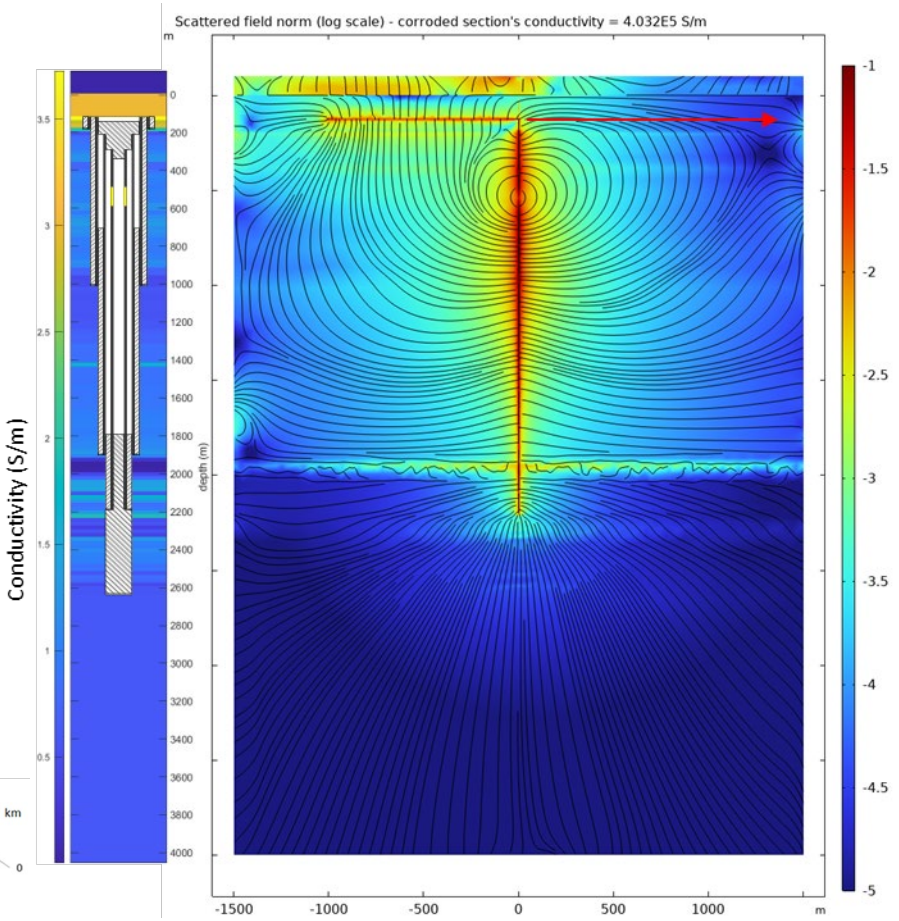
Electromagnetic methods

- Promising modelling showing effect of corrosion of steel casing on EM fields.
- Use of casing as an antenna for enhanced plume migration monitoring
- Time-domain EM reflectometry (Rio Vista, LBNL)





Example mesh for a well with complex telescopic geometry

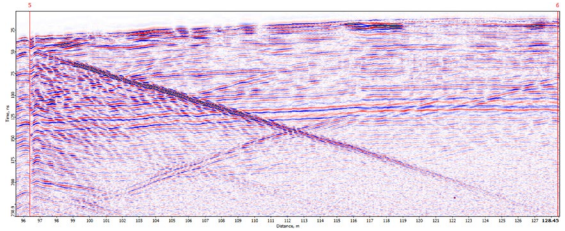


Zonetti et al., The Leading Edge (2023)

Drone remote sensing: wellheads, seepage

Ground Penetrating Radar

1 m AGL flights pre- and post-injection at 4 frequencies.

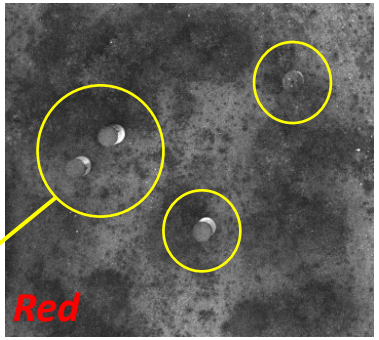


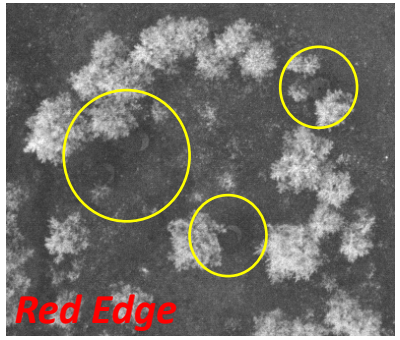
Aeromagnetics

High (60 m) and low (15 m) altitude flights

Multispectral

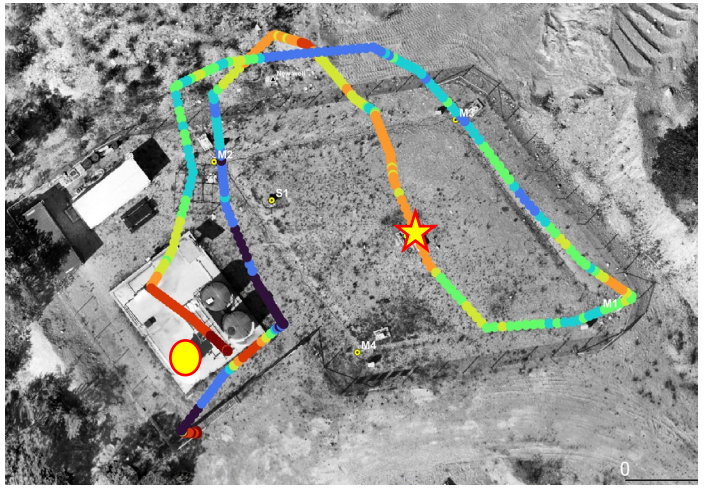
High (60 m) altitude flights (coincident with magnetics)



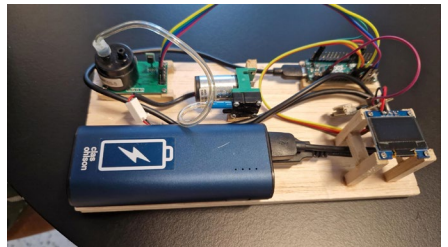


CO_2 measurements

Ground measurements of CO_2



0 - 707
707 - 719
719 - 729
729 - 741
741 - 755
755 - 780
780 - 968
968 - 3499



LOCATE project initiative

- Application to CETP funding
- Aim to start by end of 2026
- Gathering leading researchers on the subject from Europe (4 research institutes and 5 universities) and 9 industry partners
- Involvement of service providers
- Increase TRL by field-scale validations

➔ Quantitative risk management toolbox

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