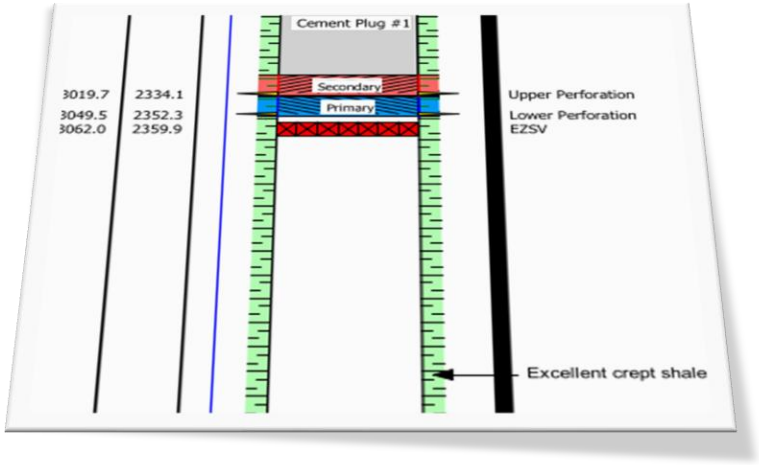
Log-Derived Smectite for Predicting Shale Barriers in Well Abandonment



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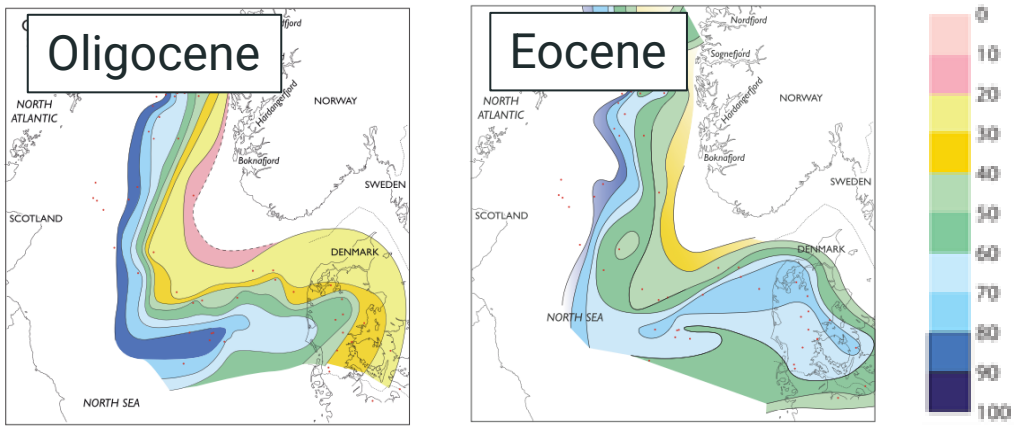
Shales

- The most abundant sedimentary rock on Earth
- Exhibits wide variability in composition and physio-chemical properties
- Smectite — a key clay mineral that strongly influences shale behaviour

wet smectite

Smectite abundant in the North Sea

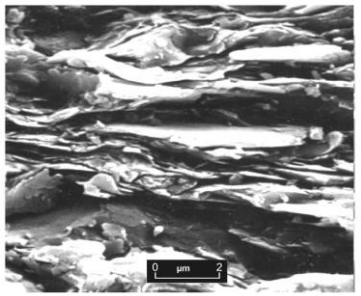


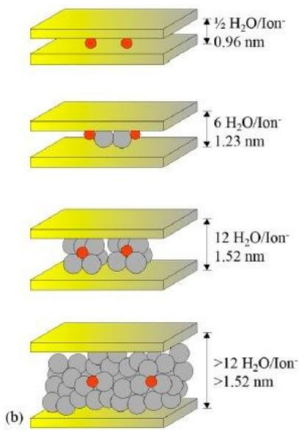
Source: Nielsen et al (2015), J of Sed. Research 85.

dry smectite

Smectites

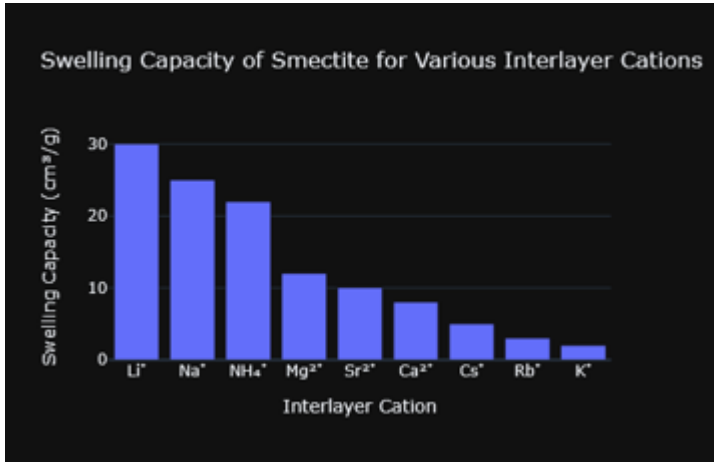
SEM

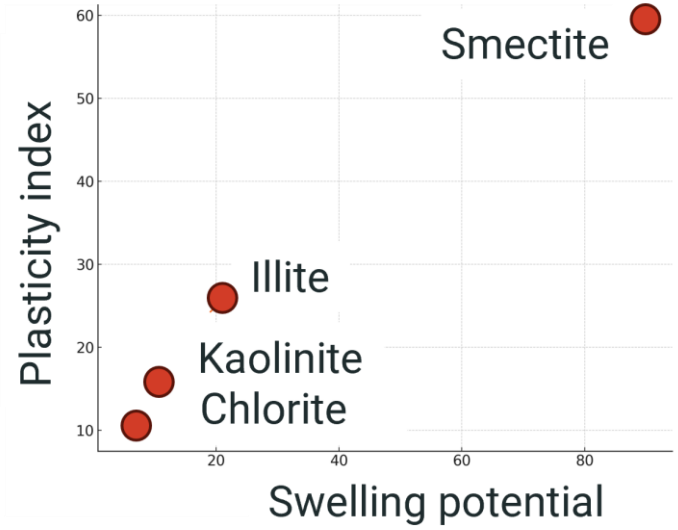




Source: Ipke et al (2020), Env Science

- Composed of layered (sheet-like) structures
- Absorbs water between layers, generating swelling pressure
- Swelling behaviour depends on the type of interlayer cation
- High swelling capacity correlates with high plasticity i.e., viscoplastic creep





Swelling – a double-edged sword

✔️ **Useful in Industry**

Used in products and processes ranging from cosmetics and cat litter to drilling fluids and nuclear waste containment.

⚠️ **But Swelling Can Be a Problem**

Leads to structural issues in buildings and drilling instability in the subsurface.

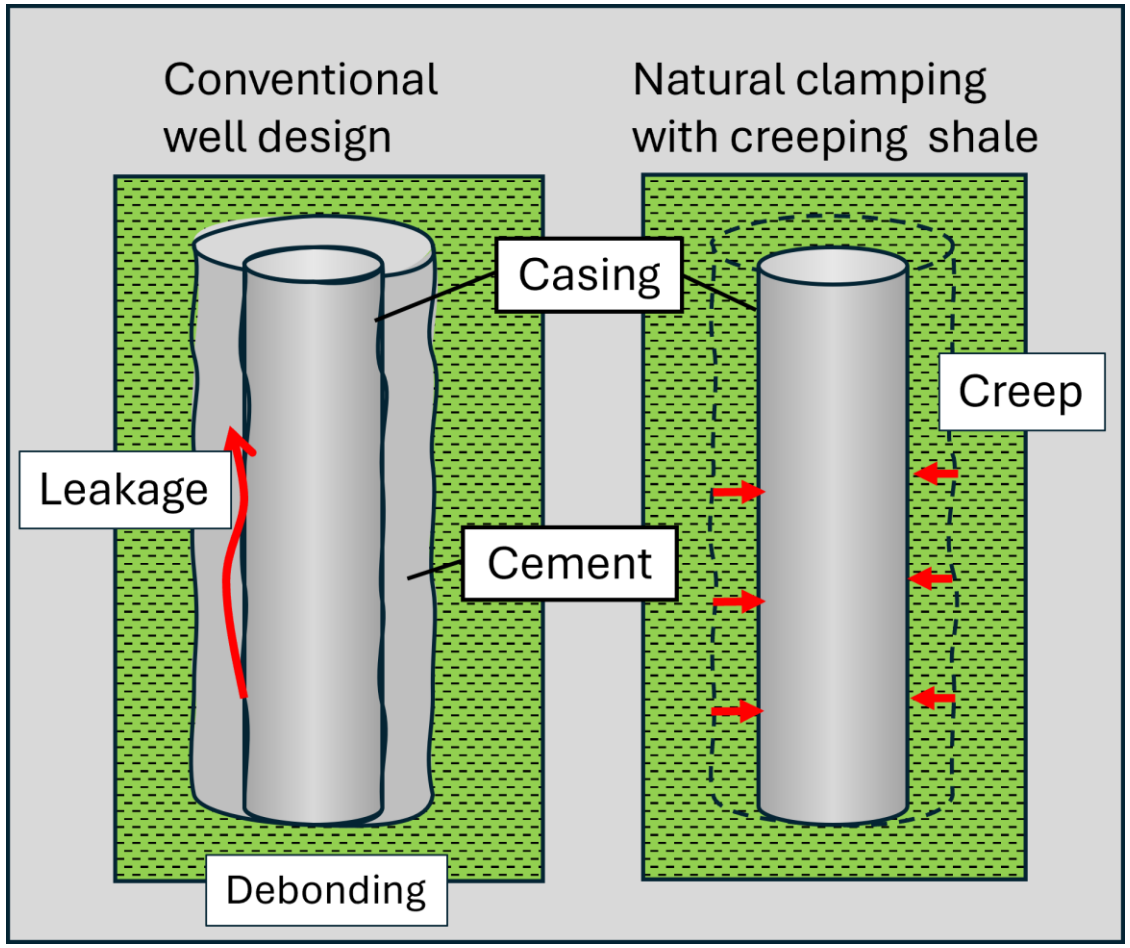
In a typical year in the United States, expansive soils cause a greater financial loss to property owners than earthquakes, floods, hurricanes, and tornadoes combined.

Source: www.geology.com

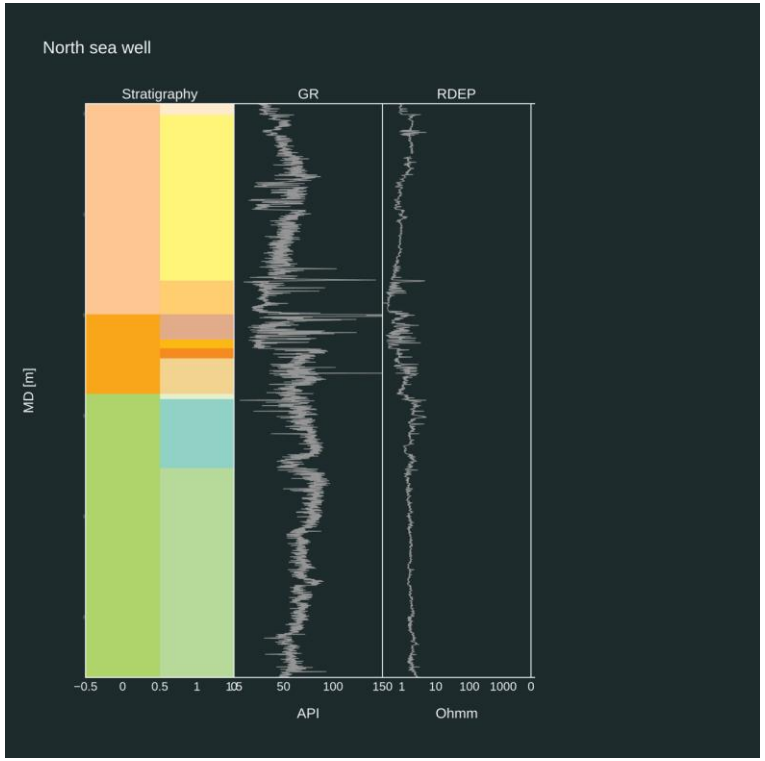
Creeping formations: the key to reliable barriers

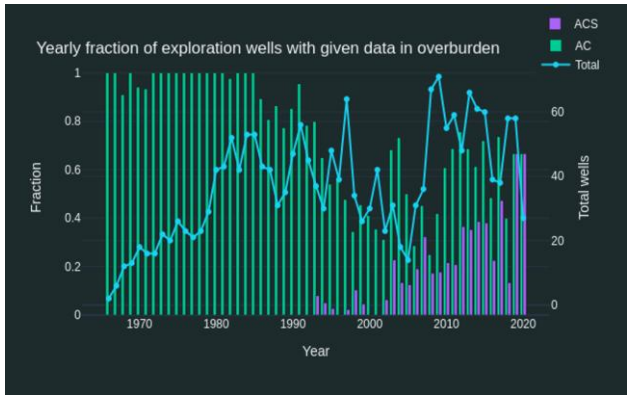
- Cement sheds all mechanical stress — offering no long-term clamping
- Lack of clamping can lead to a debonding fracture and small gas leaks
- EU Methane Regulation now demand ultra-low leak rates (~1 cow's annual emissions)
- Effective sealing requires natural clamping — only achieved by creeping rocks like halite or smectite-rich shales and marls

Design smarter: Use creeping formations to avoid costly cement redesigns and remediation



The challenge – where is the smectite?





- Sparse well data in the overburden
  - particularly sonics missing
- Smectite-rich shales are difficult to identify using conventional logs or seismic
- Lab-based methods are costly, slow and often only semi-quantitative:
  - XRD – limited resolution and accuracy
  - Core – expensive and difficult to preserve
  - Cuttings – affected by depth uncertainty, smearing, contamination and dissolution

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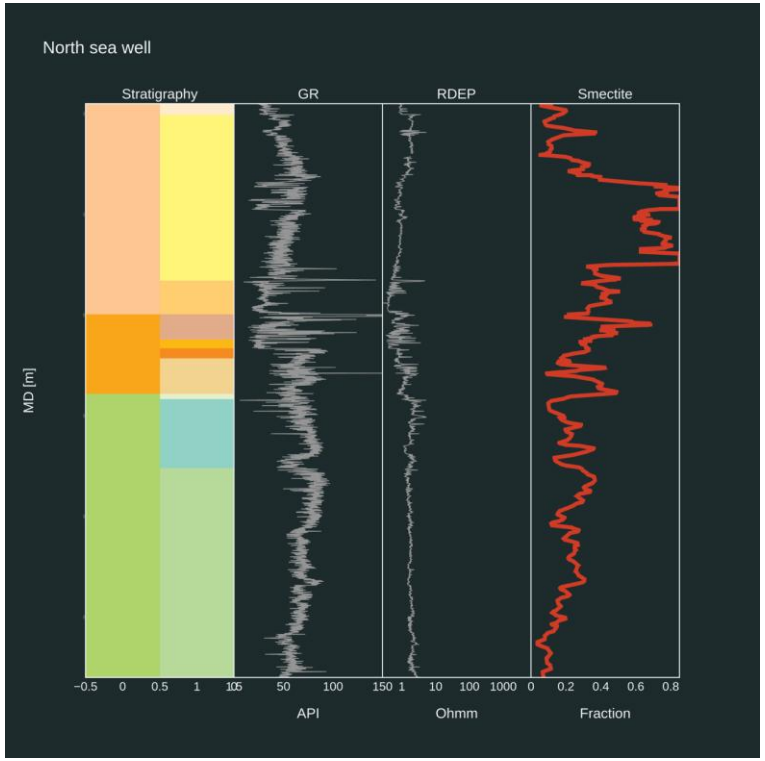

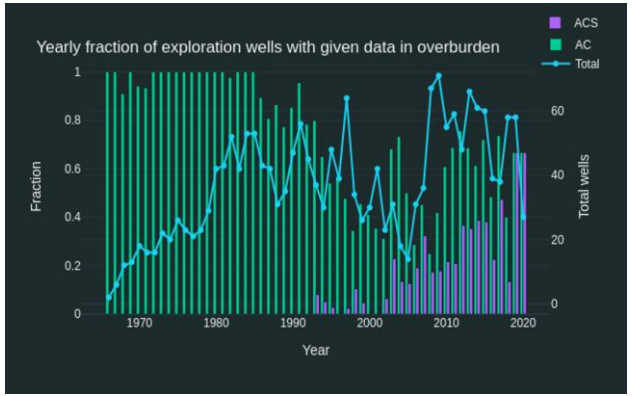

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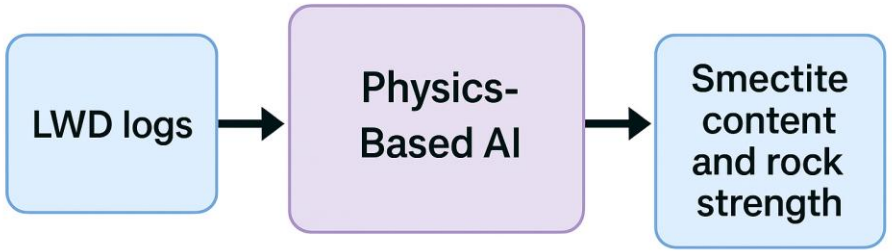
Our solution



Log-Based Prediction

- ✓ High-resolution, in-situ
- ✓ No additional data acquisition required

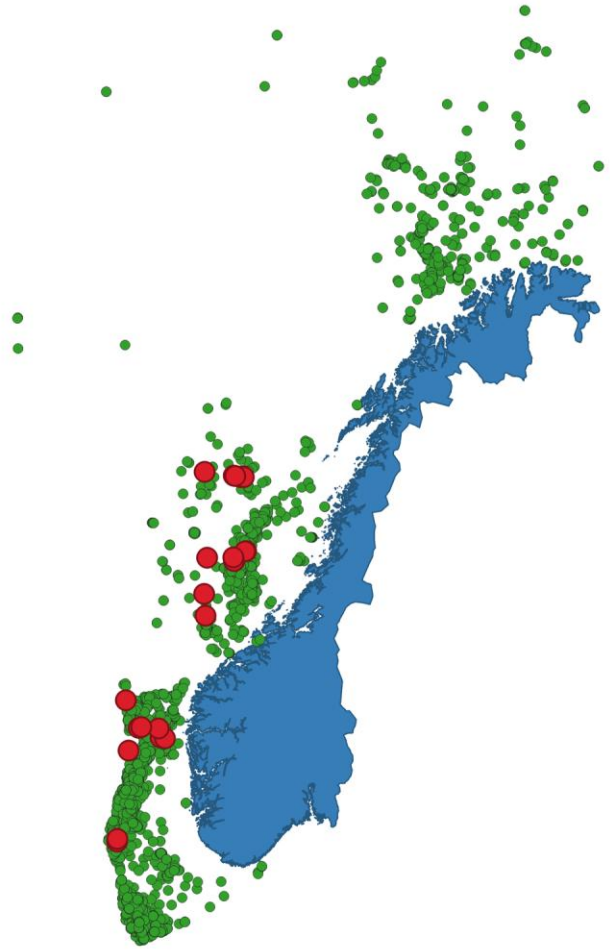
Minimal Input, Maximum Reach

- ✓ Uses standard LWD logs typically available from seafloor to TD
- ✓ Applicable across most wells and regions

Flexible Integration

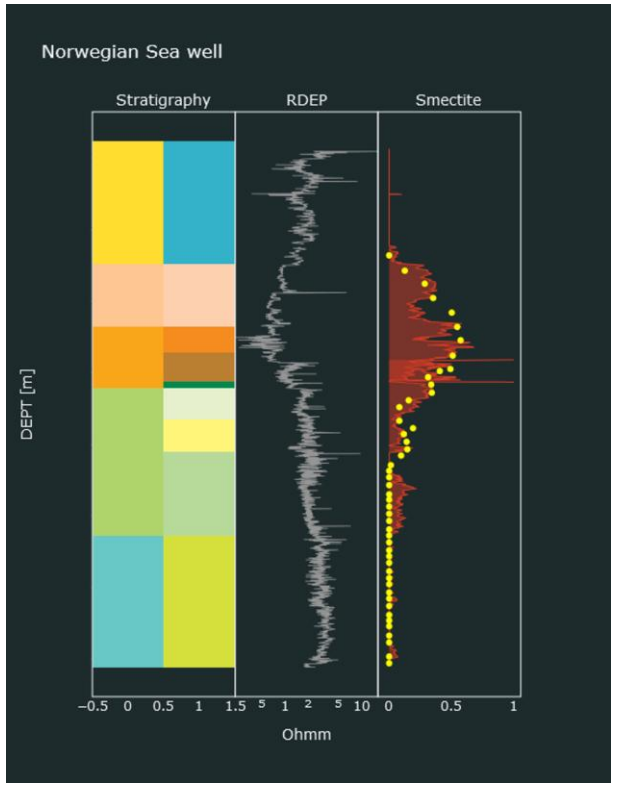
- ✓ Precision can be be increased by including data from XRD/cuttings or any other method

Applicability



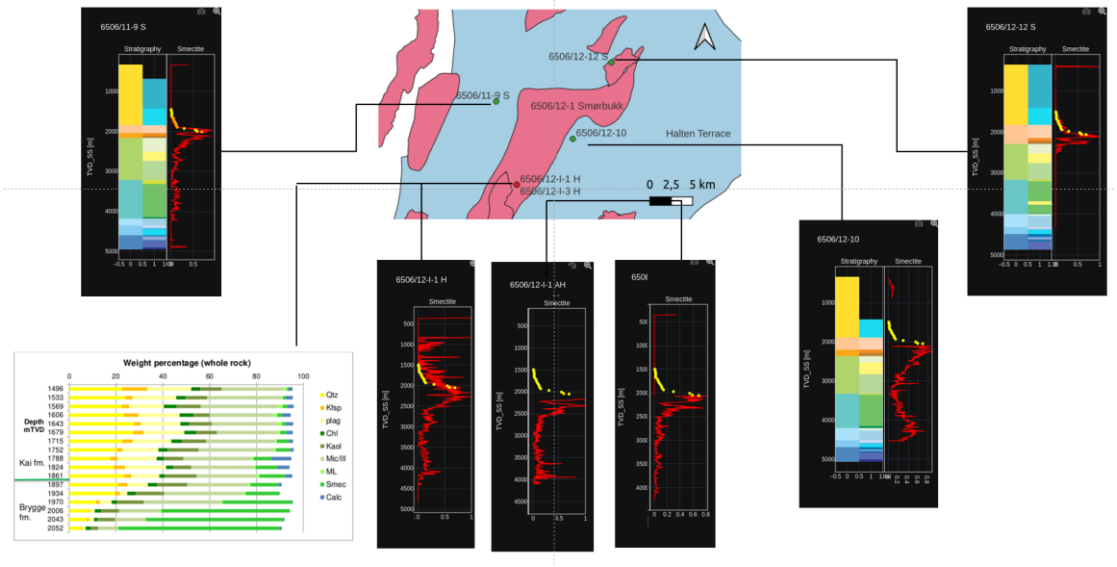
- 97 % of NCS exploration wells with sufficient data (green dots)
- Method validated in more than 20 wells on the NCS (red dots)
- Access smectite data in nearly every well
  - Integrate seamlessly with existing legacy data (e.g. CBL, XLOT)
  - Reassess past incidents with fresh insight
- Build basin shale models

Qualitative validation



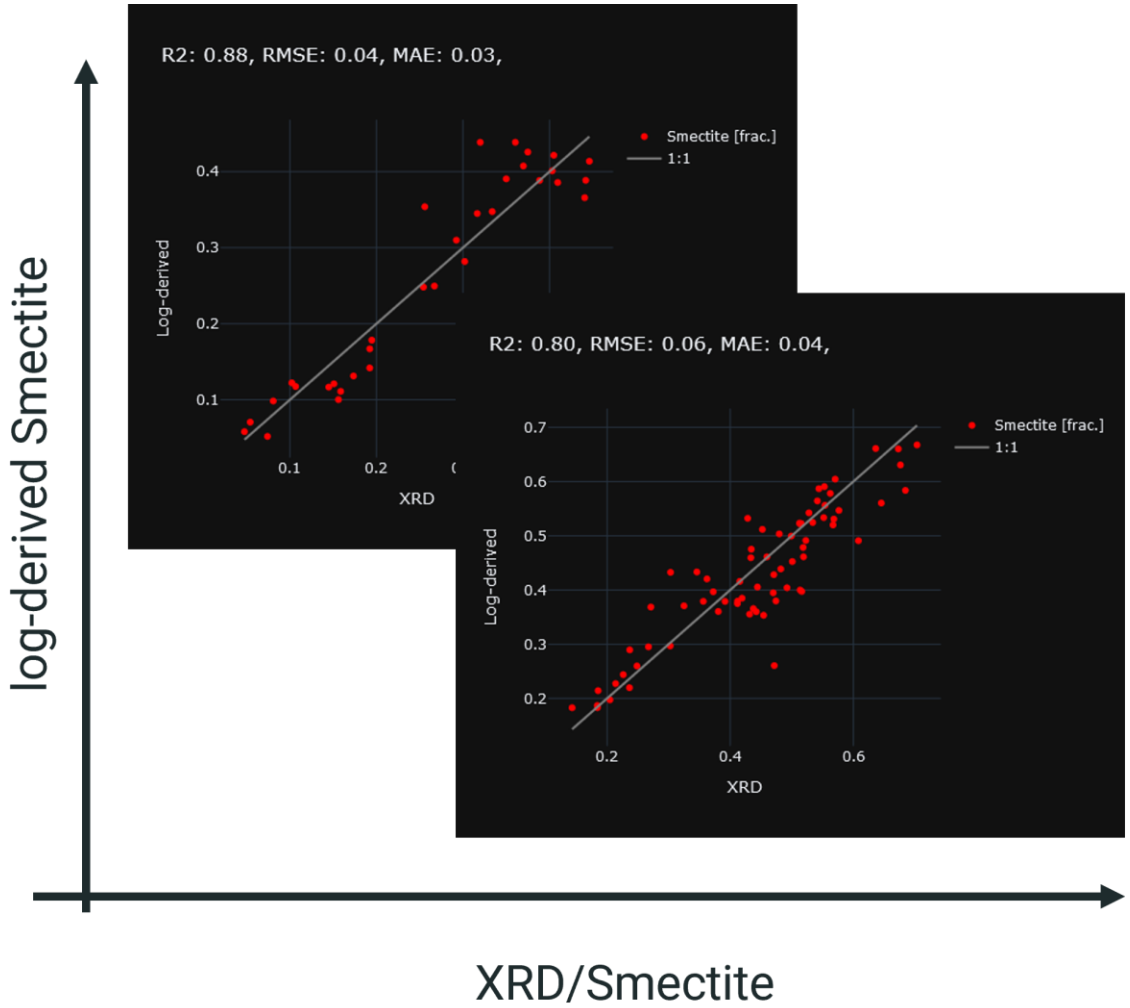
Qualitative agreement

- Comparison to XRD/cuttings (yellow dots)



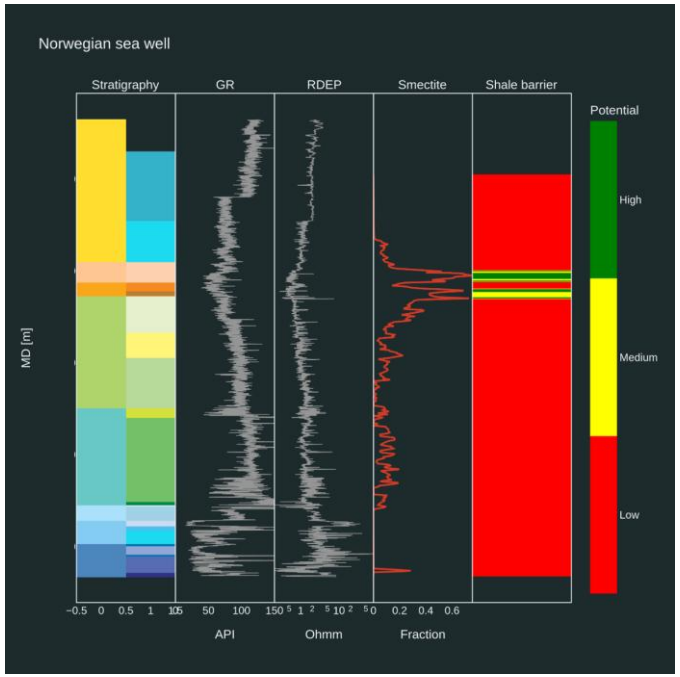
Regional consistency

Quantitative validation

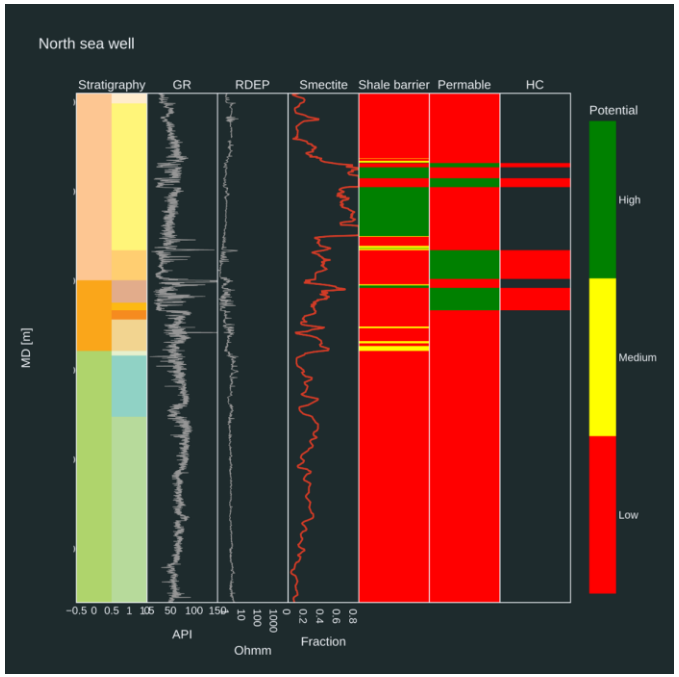


- Log derived smectite compared to smectite from XRD/cuttings
- Root mean squared error ~5%
  - XRD/cuttings are not necessarily error-free

Shale barrier predictions

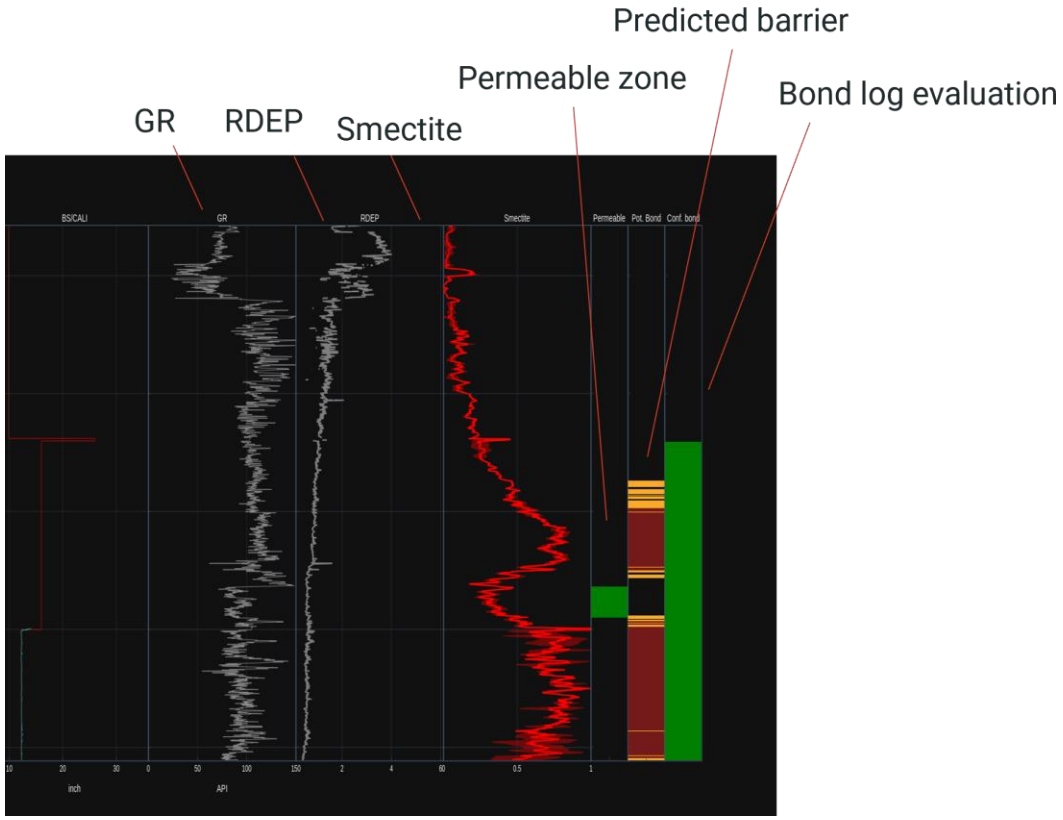


Barrier prediction



Barrier and permeable zone prediction

Barrier predictions compared to bond evaluation



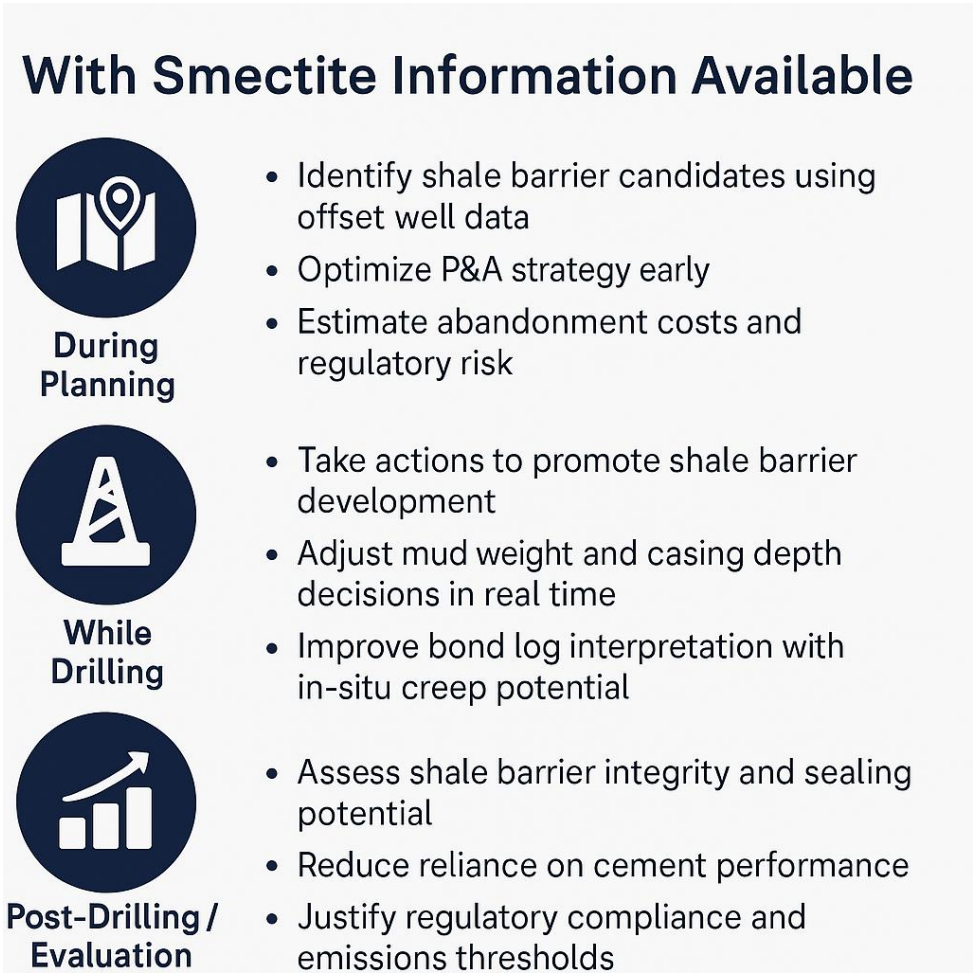
Source: Aadnøy et al (2023), IADC/SPE-212556-MS

Porosity (%)	UCS (MPa)	Vp (km/s)	E (GPa)	G (GPa)	Internal friction angle (deg)	DTC (μs/ft)	Kaolinite+ Smectite (%)
>30	<10	<2-2.25	<1	<0.5	<20	>140-150	>50

- Criteria for barrier identification:
  - high, smectite > 55 %
  - moderate, smectite 45-55 %
- Classified as excellent by expert CBL
- Reasonable agreement

Value proposition

- **No viable alternative** to mitigate slow gas leaks
  - Shale barriers are essential, especially if you don’t have salt at hand
- **Reduce costs** from reduced remediation and cement optimization
- **Extend production life** by deferring premature abandonment
- **Minimize decommissioning costs and risks** by eliminating gas migration and accumulation in shallower permeable zones
- **Lower emissions**, meeting stringent methane regulations



Summary

- New tool predicts **smectite content directly from well logs**
- Smectite is a **critical property for shale barrier performance**
- Our solution is well suited for **identifying and evaluating shale barrier potential**

This enables:

- Proactive planning to meet **leakage risk regulations**
- **Promotion of shale barriers** during drilling operations
- **Post-drilling risk assessment** and barrier quality evaluation

What’s Next

- Smectite remains a key indicator for understanding shale behaviour
- Creep analysis requires better constraints on in-situ stress state
- Collaborating with Stag Geological Services to enhance model evaluation
- Generalizing the method for broader shale characterization — with potential applications in drilling optimization and CO_2 storage