Lab scale ultrasonic logging through casing of shale barrier creation

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- The annular material in uncemented sections will change with time
  - **Shale** may fill the annulus and form a barrier
  - **Baryte** may settle and form a dense packing leaving a less dense mud in the upper part
  - Borehole failure may create **rock material** that settle in the annulus
- Cement bond logs are sensitive to impedance and P-wave velocity of the annular material
- The material filling the annulus may have different sealing properties, but similar impact on cement bond logs.

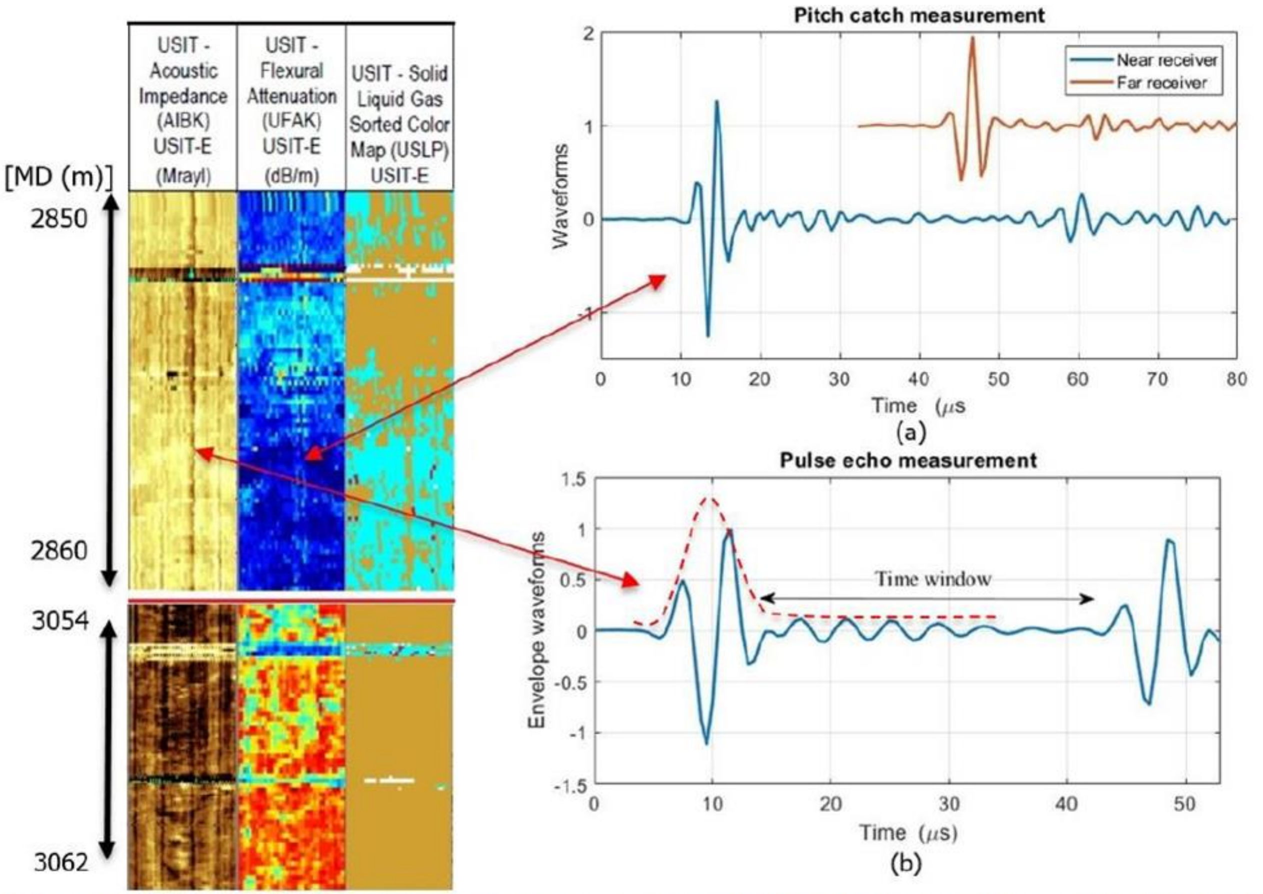

Fig. 6-2: Petrophysical log and the examples of original waveforms from (a) the ultrasonic pitch-catch technique and (b) the pulse-echo method. In the petrophysical log to the left, a light color indicates a low acoustic impedance, while a dark color indicates a high acoustic impedance. In the middle, this is slightly more complex, where a dark blue indicates low attenuation, a light color indicates an intermediate attenuation and a red color indicates a high attenuation. To the right, the blue color indicates a liquid and the brown color indicates a solid behind the casing.

From PhD thesis, Tore Lie Sirevaag, 2019

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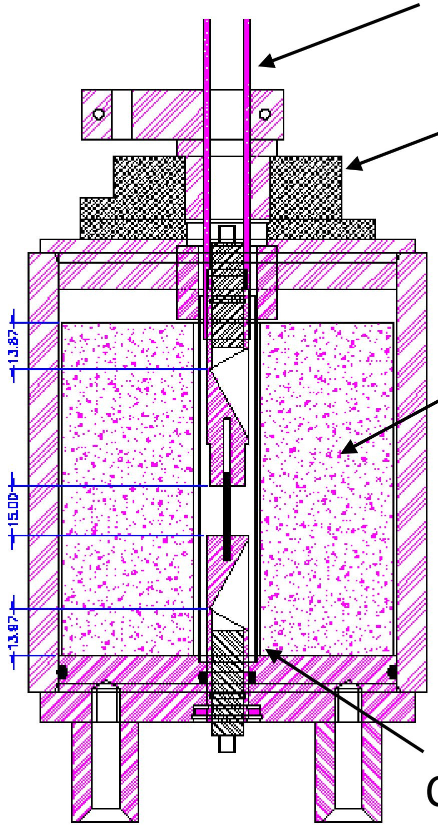
Lab scaled ultrasonic tools

- Two tools,
  - Pitch catch of local flexural wave
  - Pulse echo
- Built around Off-the-shelf components
- Focused transducer and acoustic mirrors used to control angularity
- Measure the Acoustic impedance, $Z = \rho v_p$ and maybe the P-wave velocity, v_p
- Observe Third interface echo and shape and thickness of the pipe



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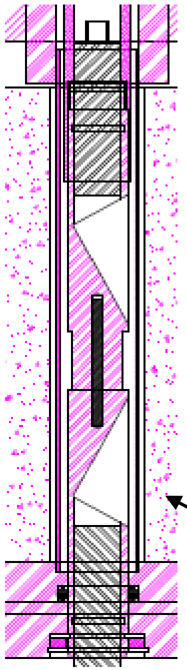
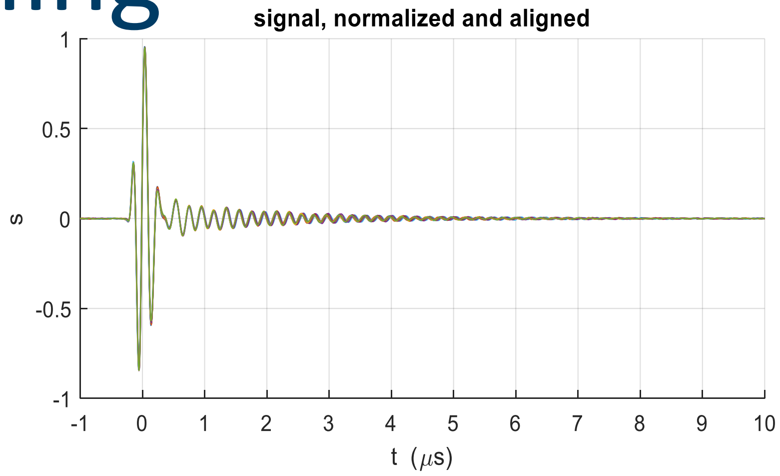
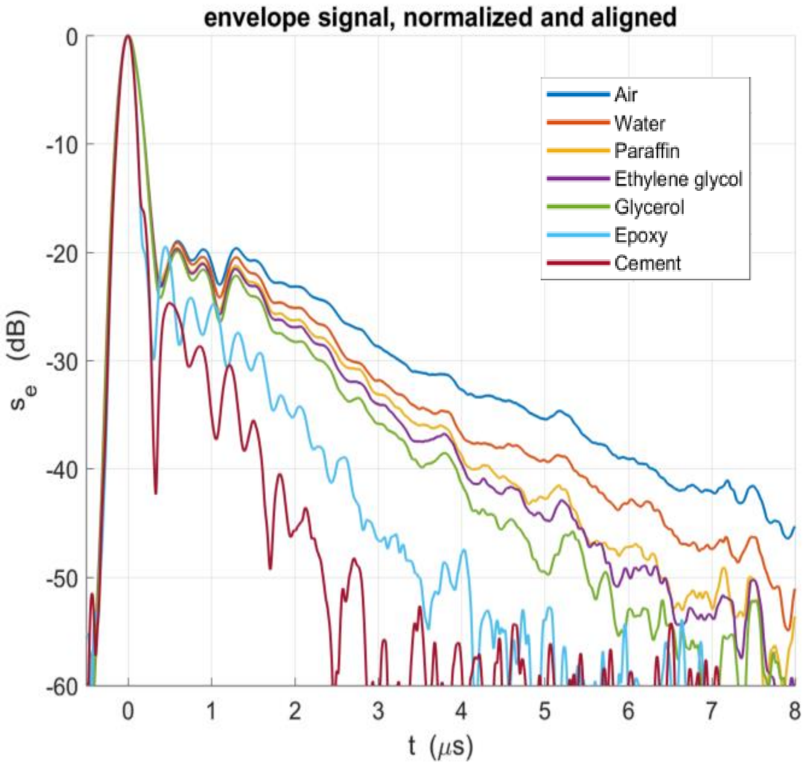


Lab scaled ultrasonic tools, scaling

- Scaling 1:20 compared to common field case
  - Pipe Thickness 0.55mm vs. 10mm
  - Frequency 5MHz vs. 250kHz
- Focused transducers/mirror
  - Long distance between transducer and pipe wall
  - PE: Very long reverberation tail
  - More complicated acoustics/analysis





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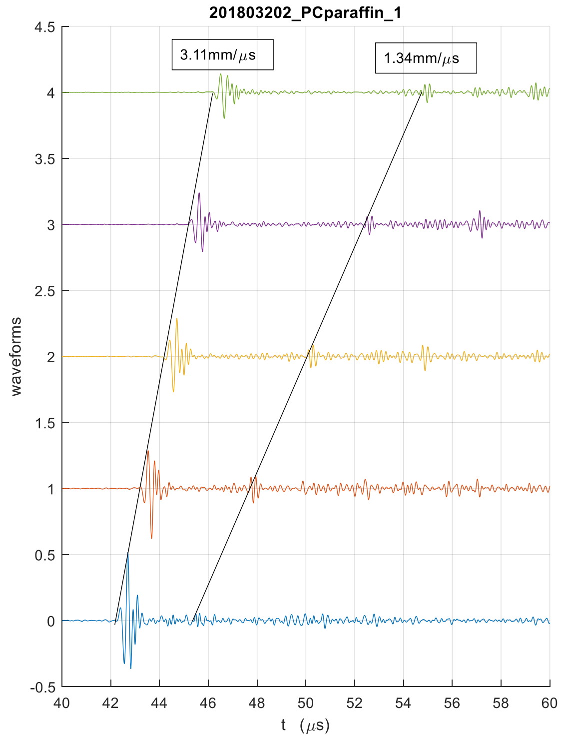
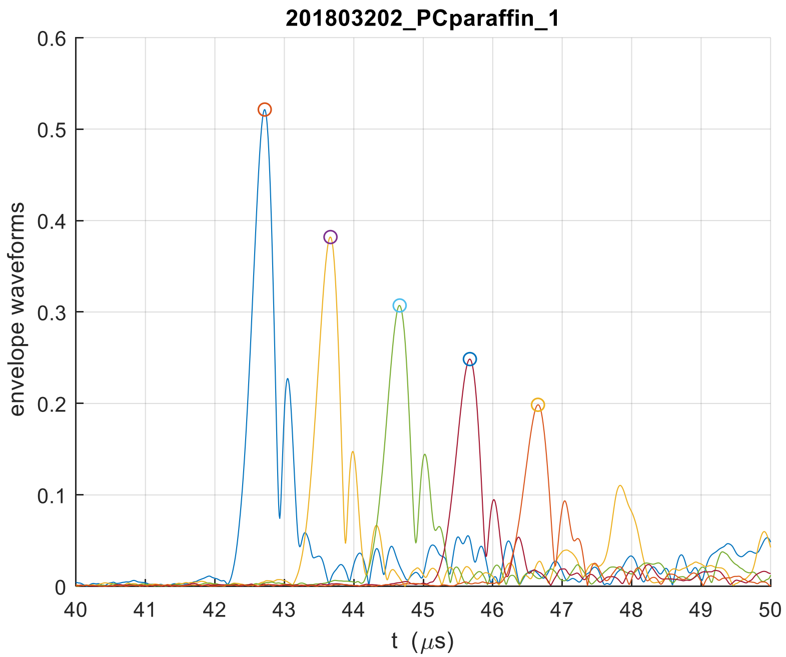
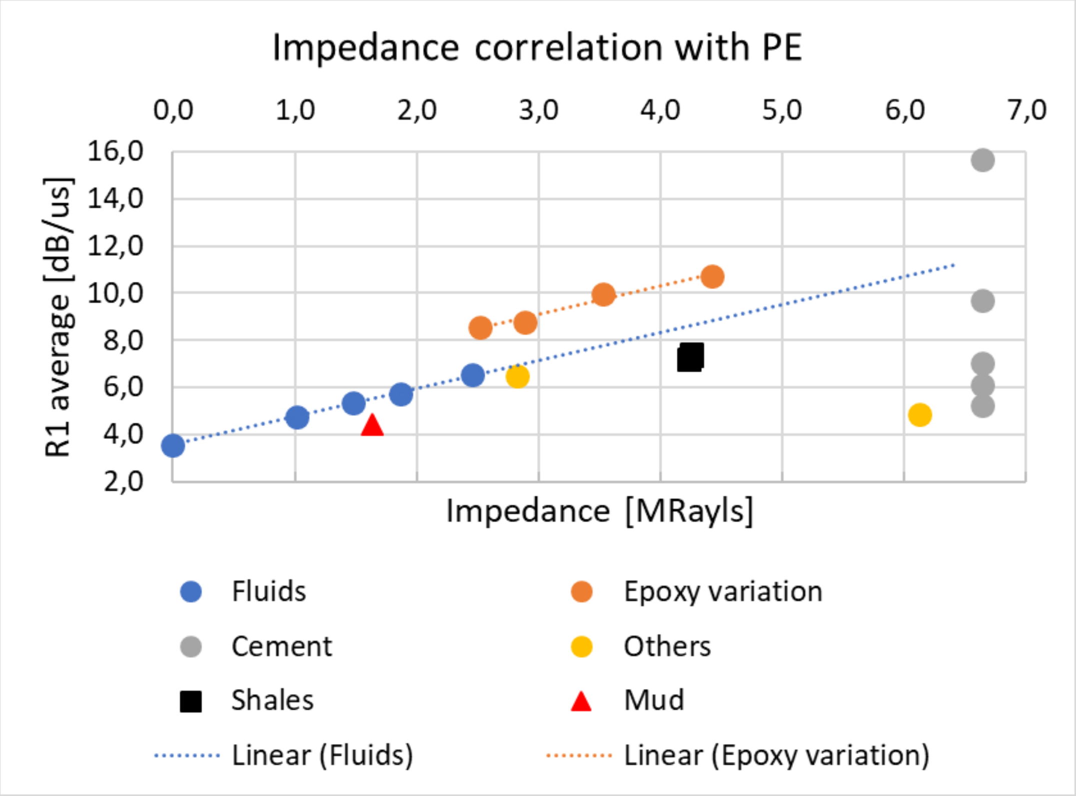
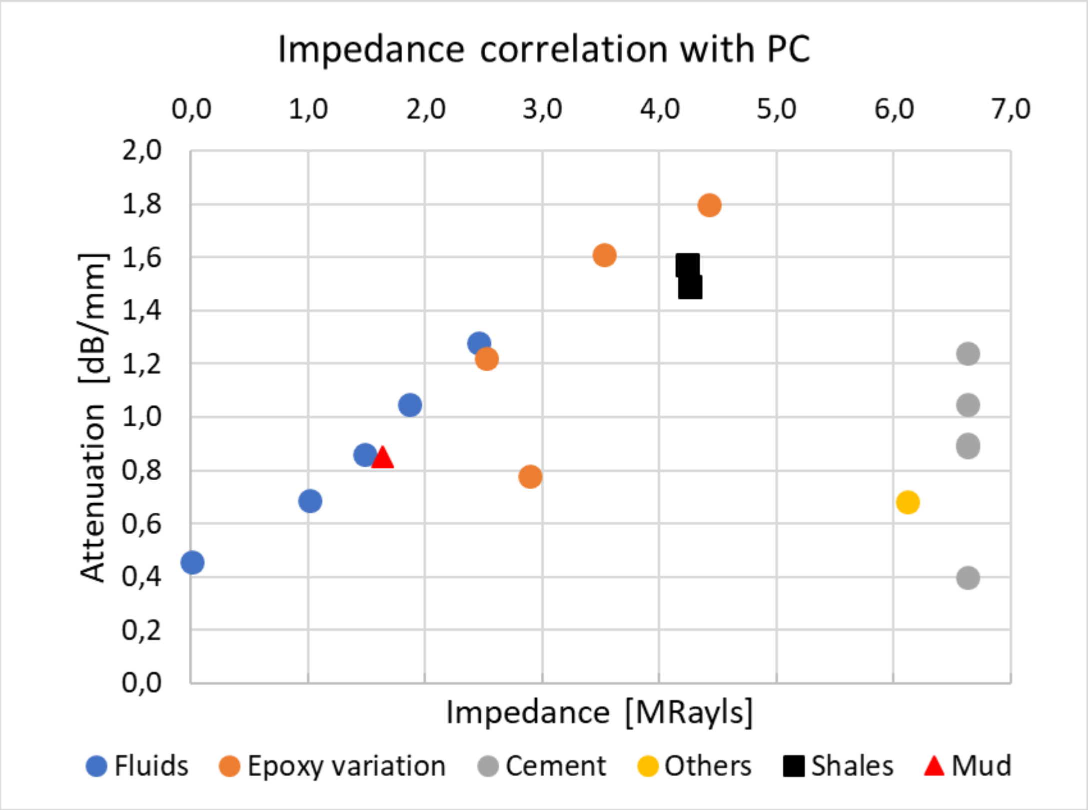
  - PE: Very long reverberation tail
  - More complicated acoustics/analysis
- May use several receiving positions for the pitch catch setup





Lab scaled ultrasonic tools, reference results





- R_1 proportional to Z for fluids and epoxies, with an offset
- The cements are not well bonded, simulated bonded cement relates to "epoxy – trend"
- Mud, clay, and shales simular to the fluids

- Attenuation to Z for fluids
- Epoxies, results dependent Z and v_p
- Mud and shales simular to the fluids

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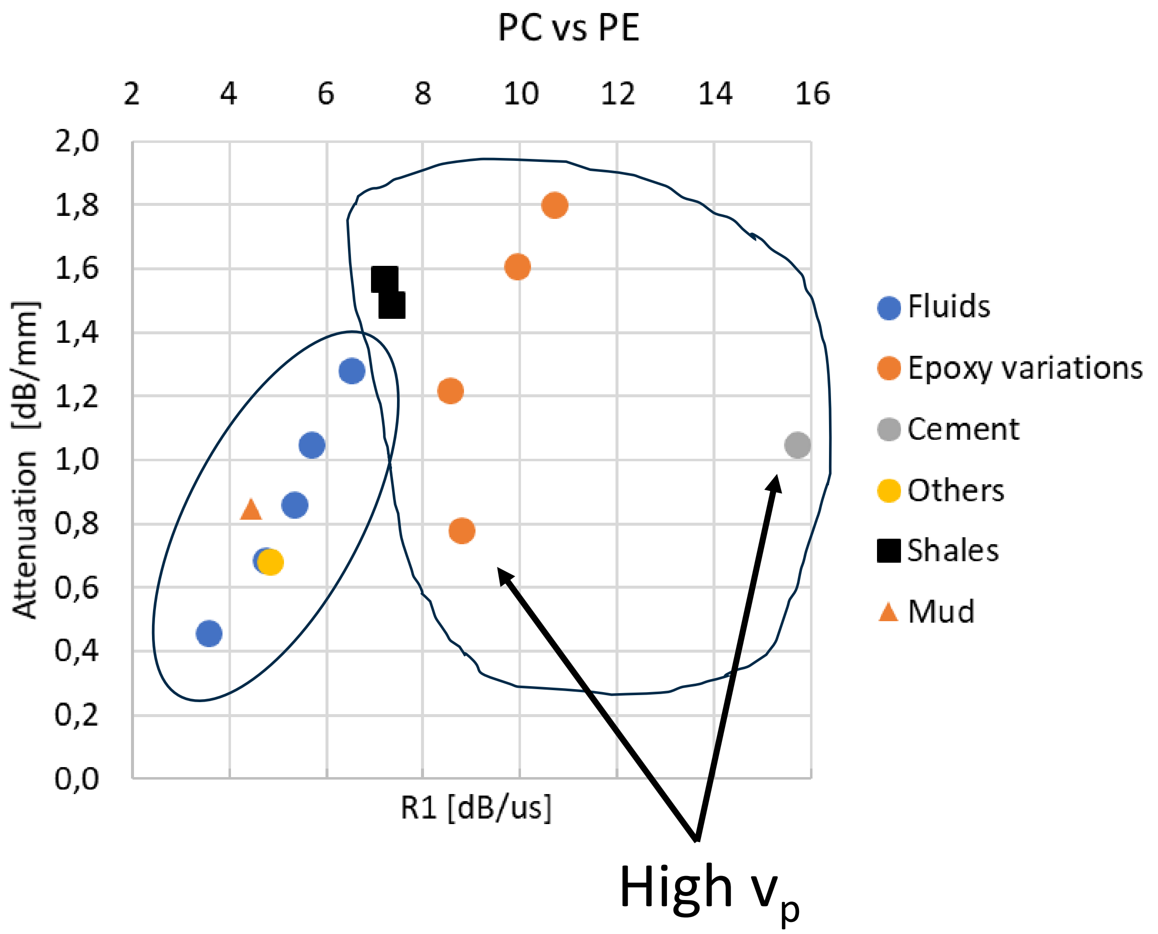
Lab scaled ultrasonic tools, combining PE and PC

- Debonded cement corrupts the trends in diagram
- Fluids and shales follows the same trends
- Solids dependent on low/hi v_p



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Lab scaled ultrasonic tools, low velocity solids

- Flexural wave strongly dispersive, for annulus materials with $2000 < v_p < 2800$ m/s Snell's law shift of attenuation with frequency
- Can be used to distinguish light cement/heavy fluids
- Can not directly distinguish the shales we have tested from fluid

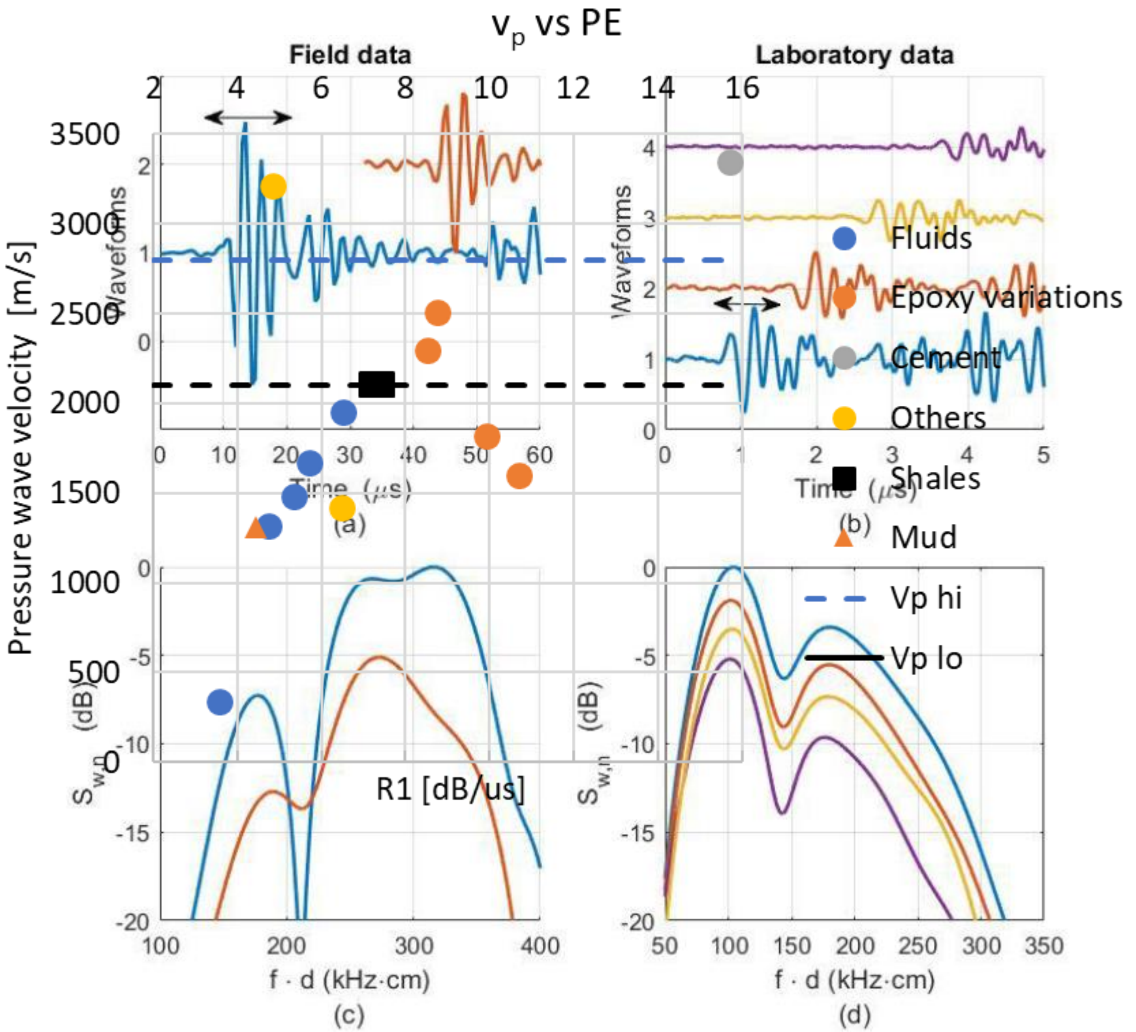
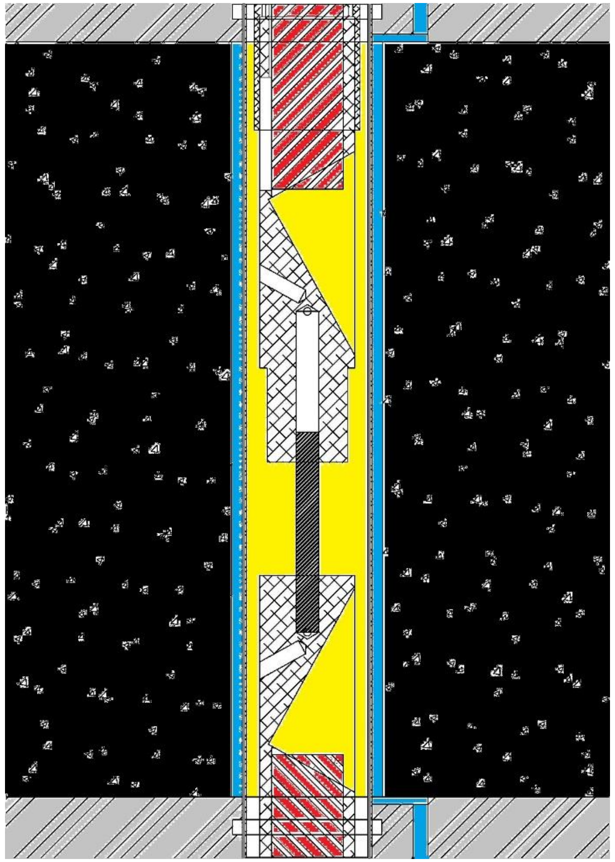
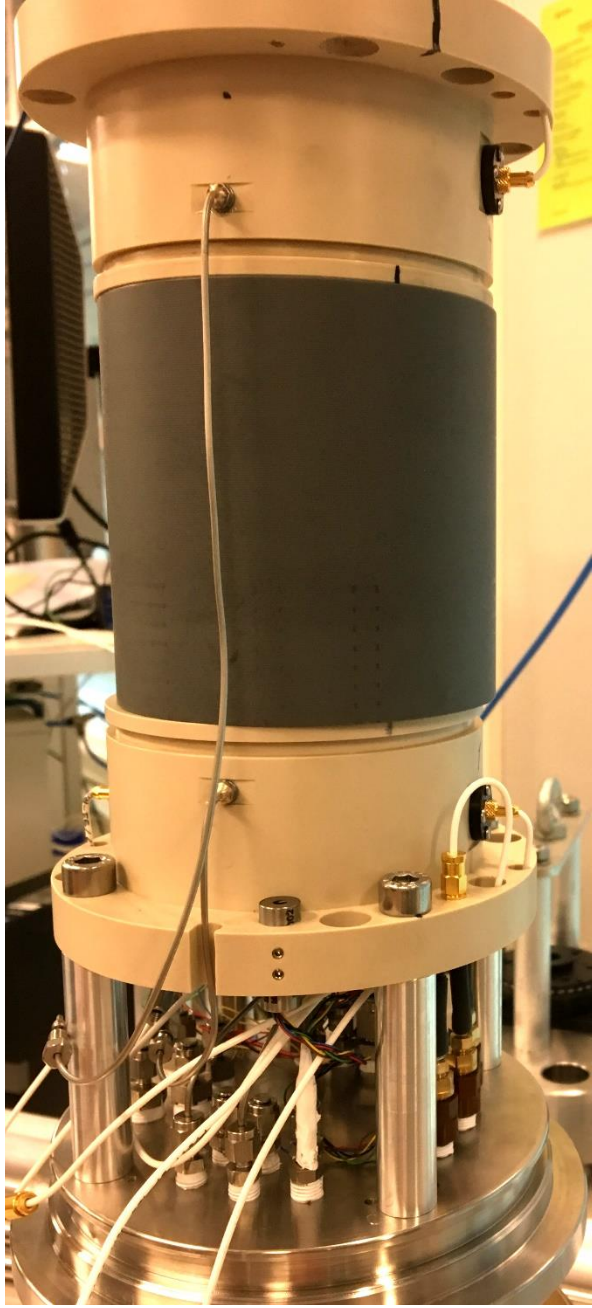


Fig. 6-6: Comparison between field data and laboratory data. The field data is most likely with foam cement behind the casing, and the laboratory measurement is with epoxy behind the casing.

Logging shale barrier tests - Setup

- Hydrostatic cell
- Hollow cylinder sample:
  - 100 mm diameter and length
  - Hole diameter ~20.5 mm
- 17.2 mm OD casing (0.55 mm thick)
  - May be accessed from outside cell
- Fluid ports to annulus top and bottom
  -> permeability measurement





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Logging shale barrier tests - Material

- Pierre II shale (outcrop)
  - 42 % porosity, radial permeability of 39 nD
  - Impedance ~4.2 MRayls
  - Hollow cylinder failure at ~6 MPa net confining pressure

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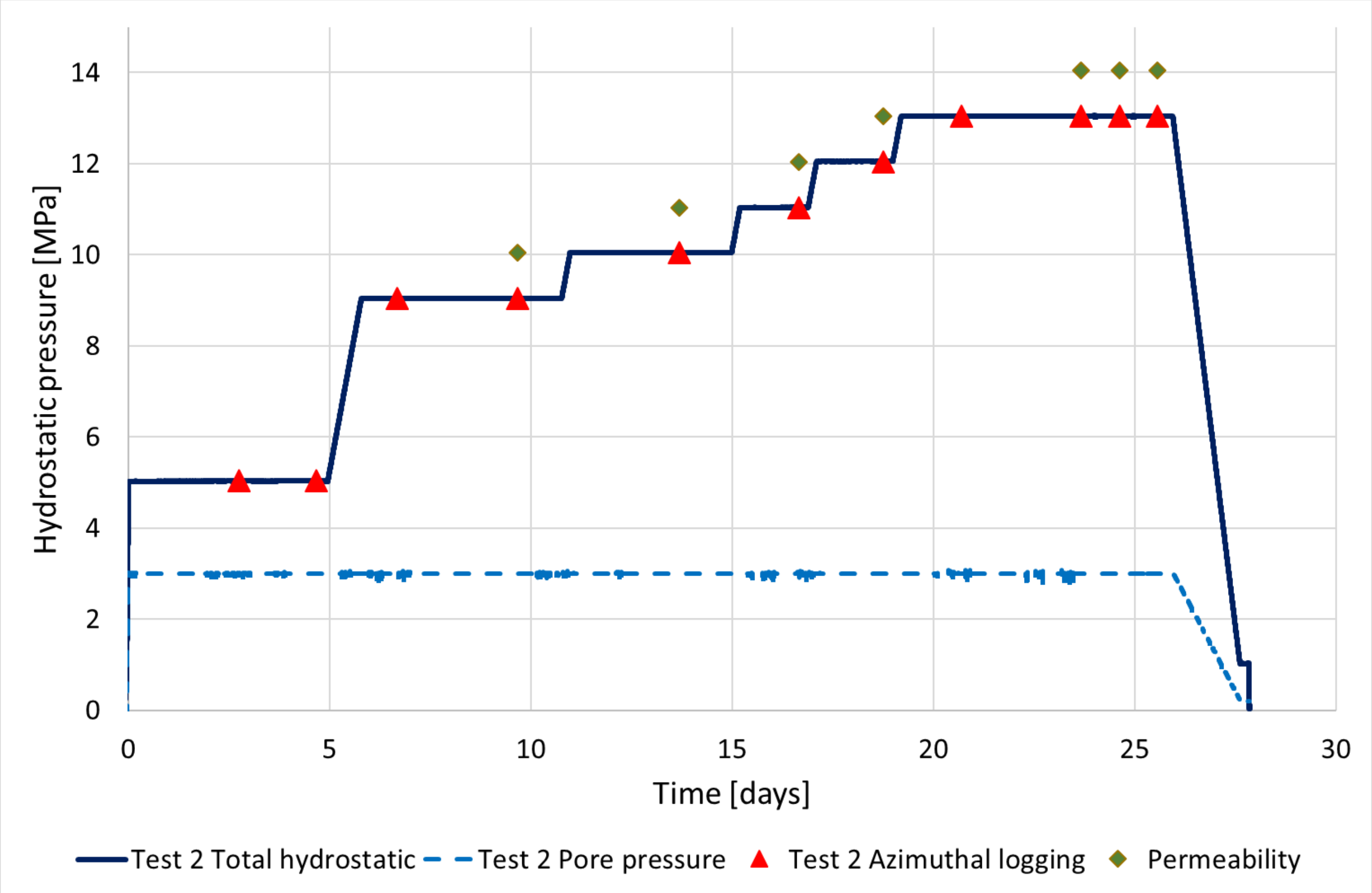
Logging shale barrier tests - Procedure

- Consolidation of sample
- Stepwise ramping up hydrostatic pressure
  - Constant pore pressure and annulus pressure
- Automatic logging at fixed position
- Manual measurement with log tools and permeability



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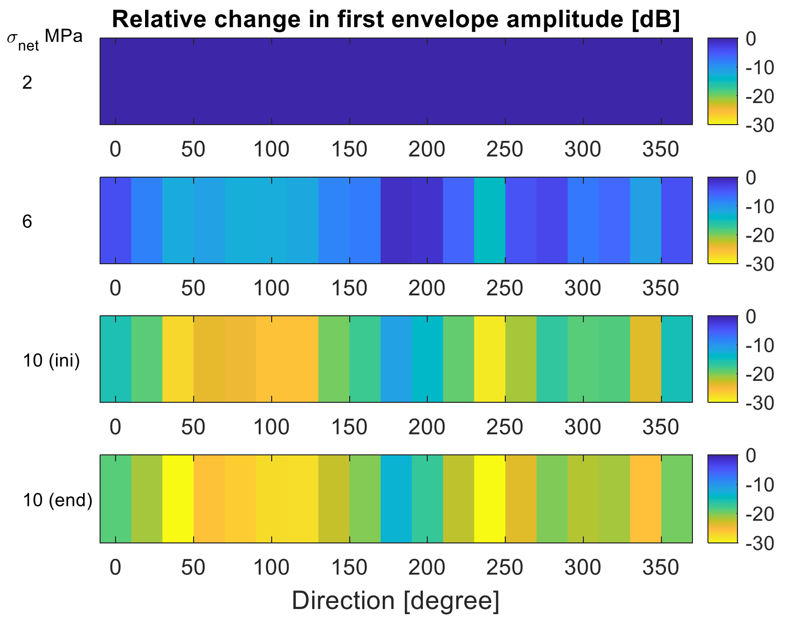
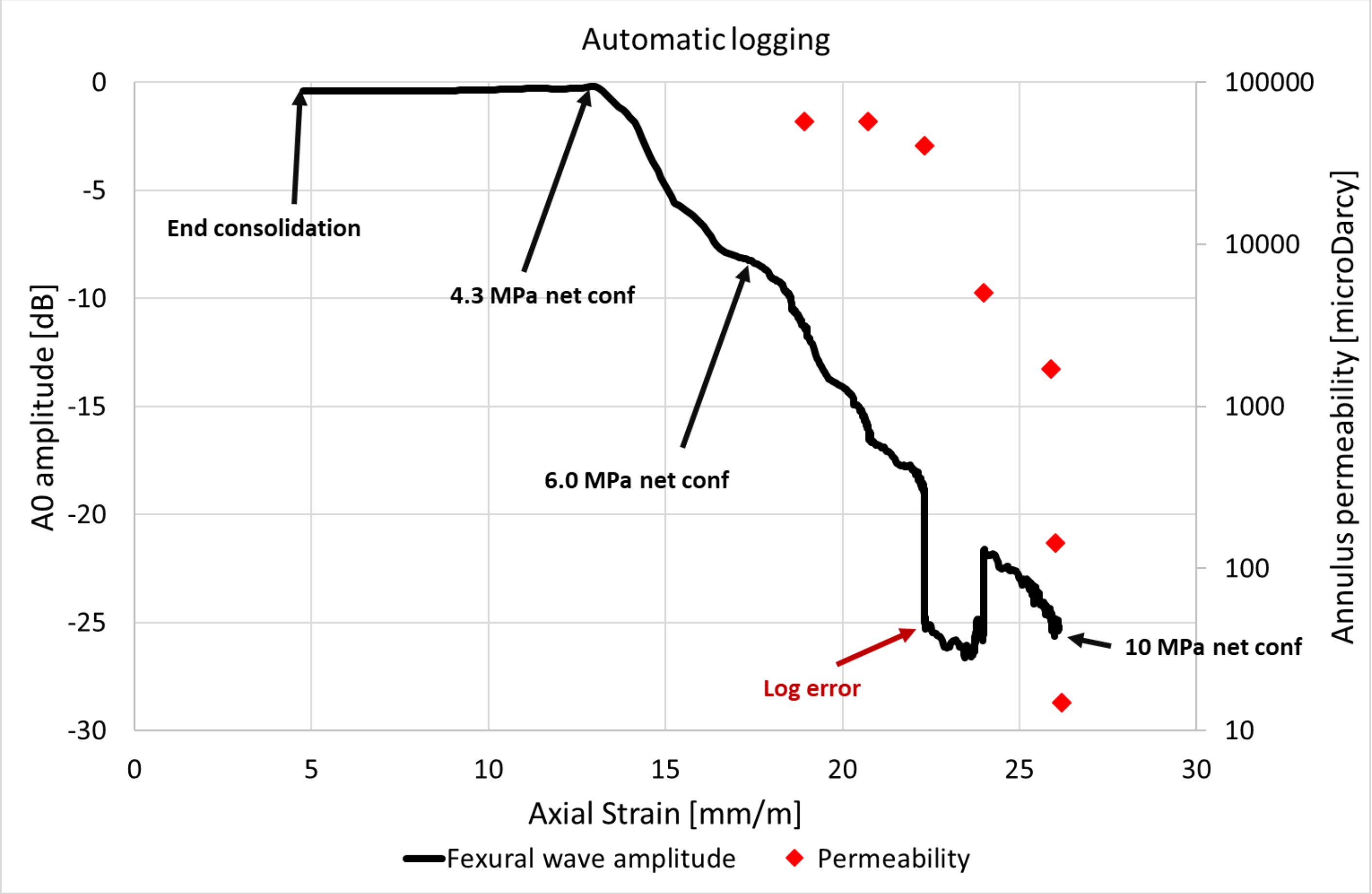
Logging shale barrier tests - Results

- Logging of flexural wave (test 2)
  - Automatic
  - Manual





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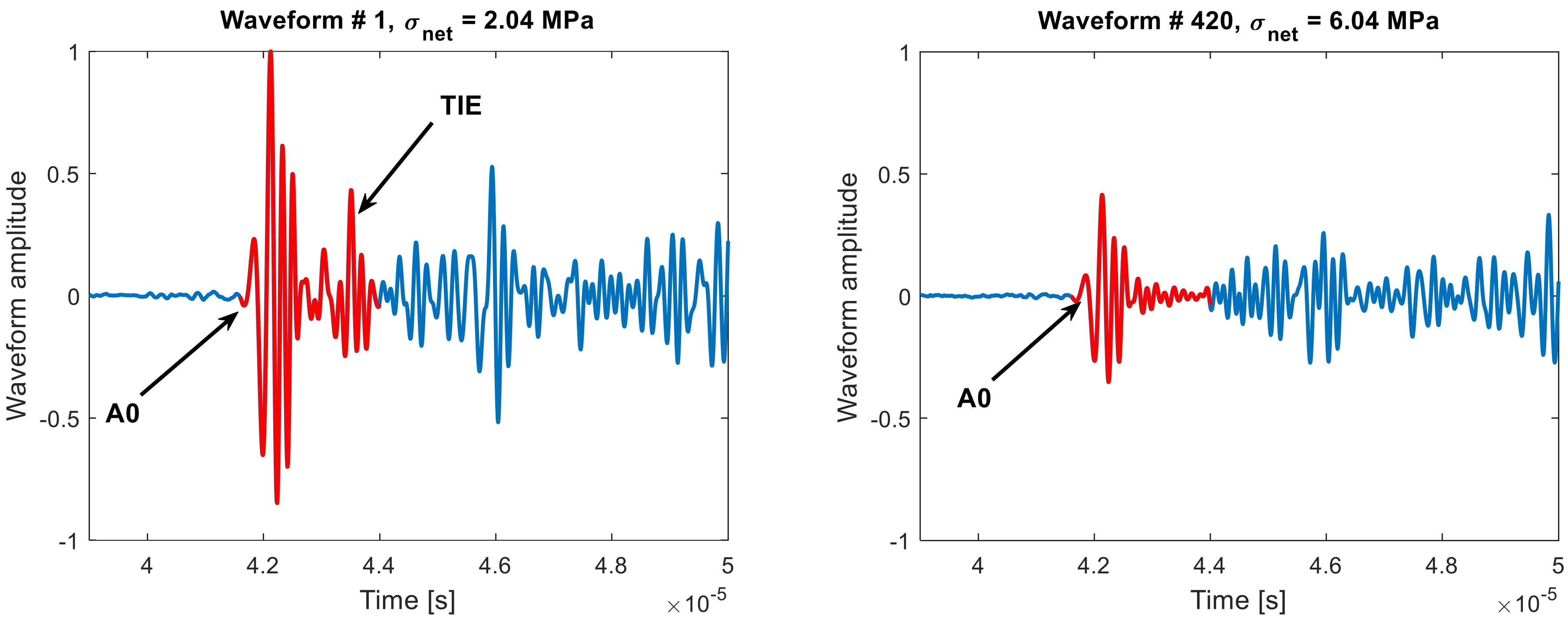
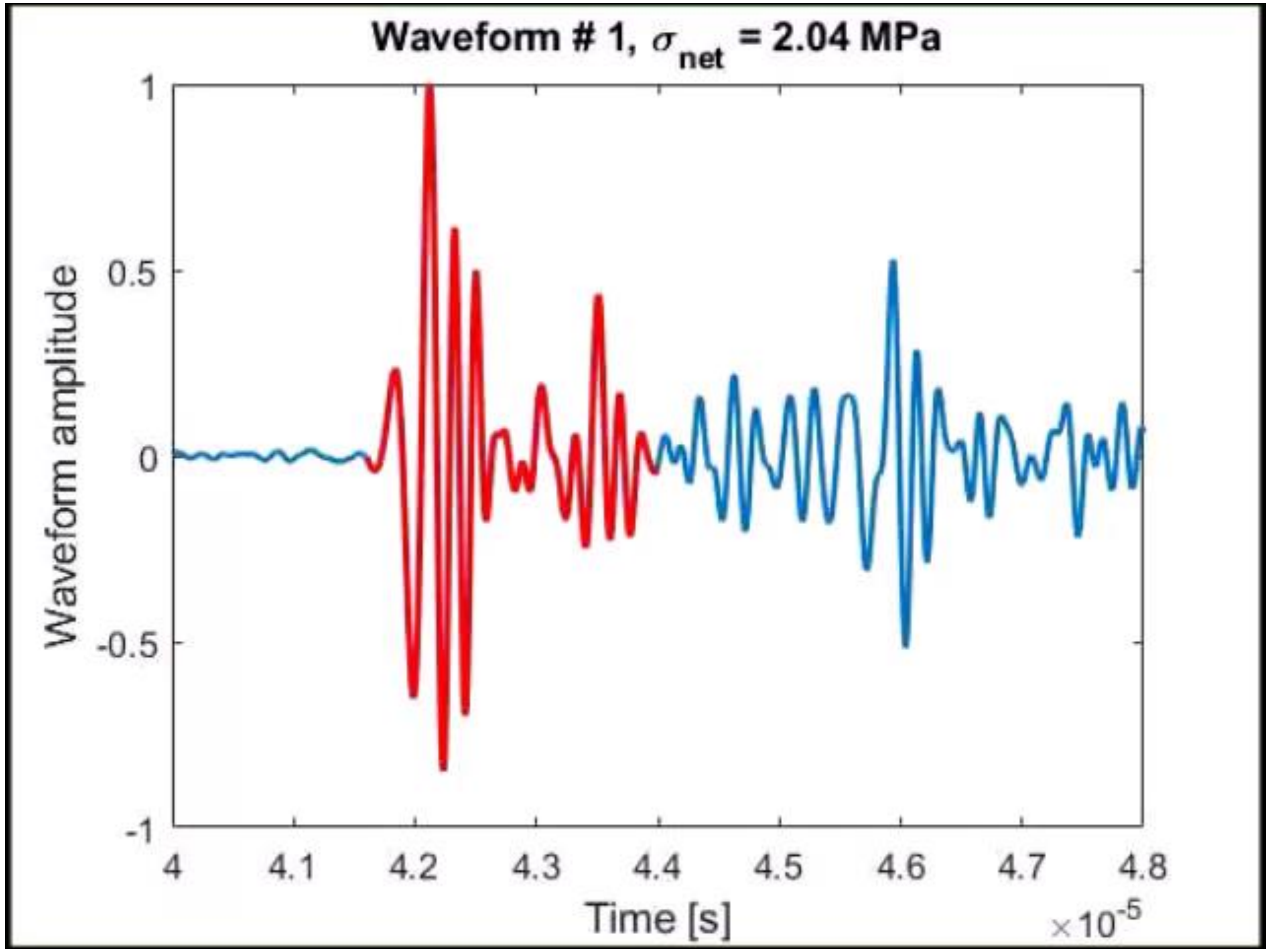
Logging shale barrier tests - Results

- TIE identification



Logging shale barrier tests - Results

- TIE video



Logging shale barrier tests – next step

- Improve setup to increase sensitivity of logging tools
- Run tests with mud in annulus
  - Variation over mud weight and time to settle before increasing confining pressure
  - Measure log response and permeability
- Run test with other shale materials

Summary

- Lab scaled tools for cased hole logging have been developed, tested and verified
- The logging tools has been used at ambient conditions with a range of fluids and solids
- A cell for lab scaled cement bond logging while forming shale barrier give results that show effect on cement bond log as the barrier forms and finally seals the annulus

Logging Shale Barrier before Well Abandonment is a SINTEF project sponsored by
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