Development of Novel 3D Acoustic Borehole Integrity Monitoring System

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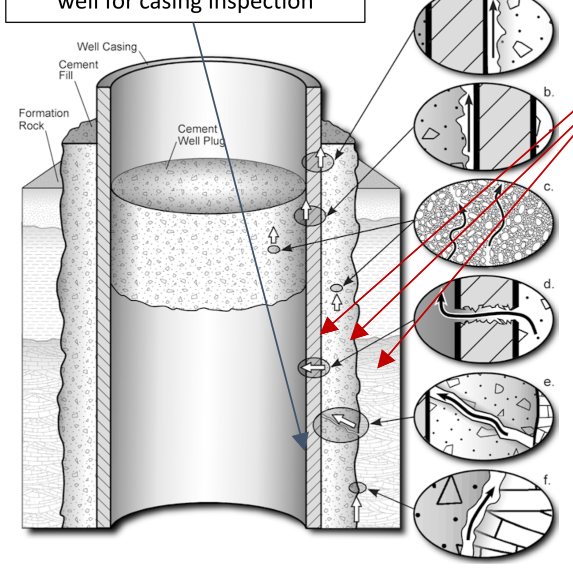
Introduction

- **Primary goal**: fill the existing technology gap between conventional sonic tools and long range sonic imaging tools in providing a robust ability to image the near-borehole environment.

The Problem:
Defects/fracture detection beyond casing with high resolution. No current techniques.

Existing ultrasonic tools work well for casing inspection

We plan to extend applicability to: (1) casing-cement interface, (2) cement-formation interface, and (3) out in the formation (up to ~ 3 meters).



* Picture from S.E. Gasda, Environ Geol (2004) 46: 707-720

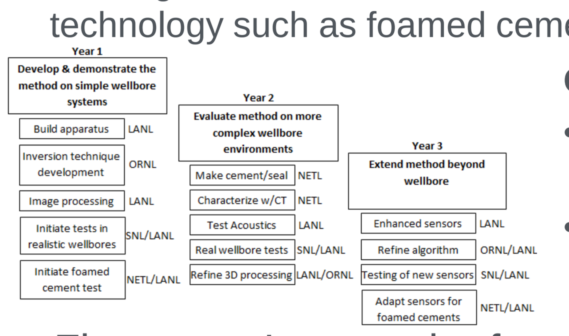
Comparison of existing techniques and the present approach

Method	Frequency (kHz)	Range (m)	Resolution (mm)
Standard borehole sonic probe, e.g. BARS (Borehole Acoustic Reflection Survey)	0.3-8	15	~ 300
Present approach	10-150	~ 3	~ 5
Ultrasonic probe, e.g. UBI (Ultrasonic Borehole Imager)	>250	casing	4-5

Long-term objectives:

Develop a complete 3D imaging system, based on:
- unique acoustic source (low frequency, highly collimated, broad-band: 10-150 kHz, high power)
- advanced image processing.

Investigate effectiveness of next generation wellbore completion technology such as foamed cements.



Outcome:
- improved imaging resolution around the borehole and
- extended investigation range - beyond the wellbore casing

- First year: Lay out the foundation for a comprehensive imaging system based on the relevant underlying physics (wave generation and propagation, interaction with defects, image processing, laboratory experimental validation of concepts)
- The target investigation range for the first year: ***wellbore casing*** and ***casing-cement interface***.

Scientific Approach

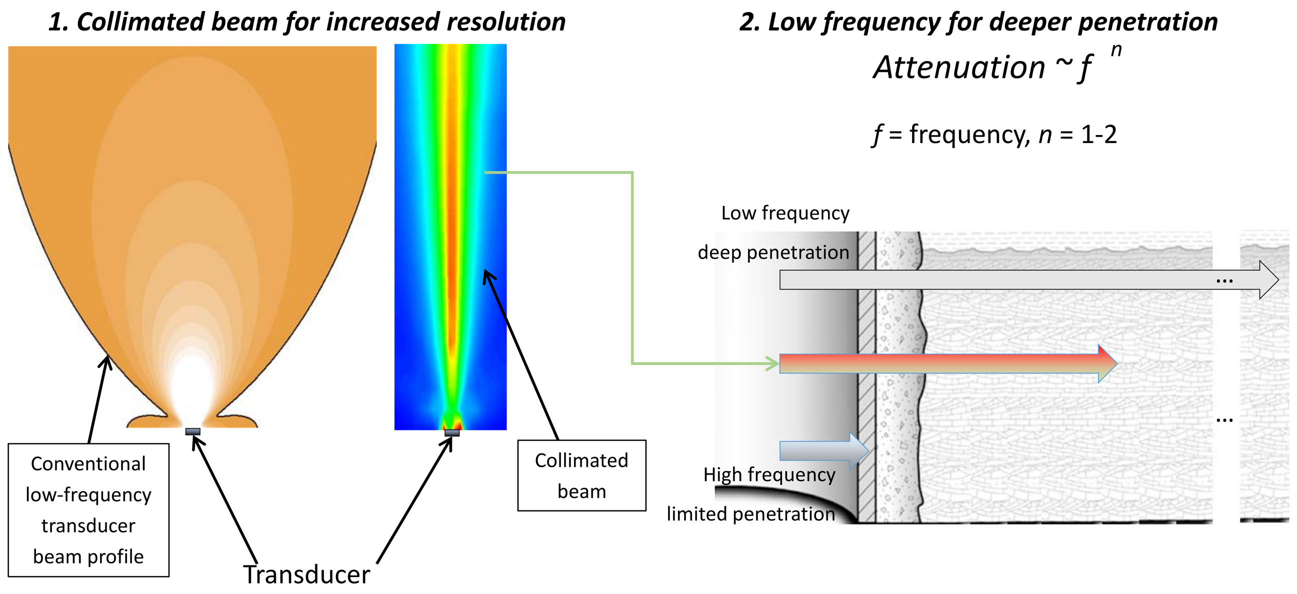
The Proposed Solution:
Novel technique that fills this technology gap.

1. Collimated beam for increased resolution

2. Low frequency for deeper penetration

Attenuation ~ f^n

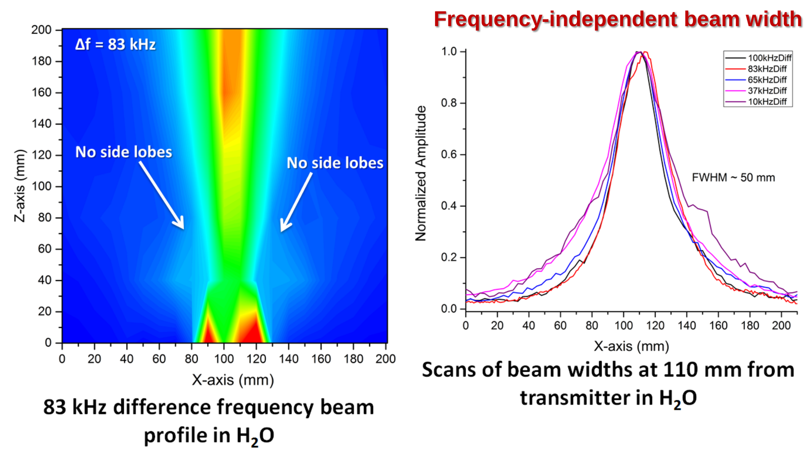
f = frequency, n = 1-2



Investigated three different acoustic sources:

Parametric source	Bessel-like source	Compact parametric source

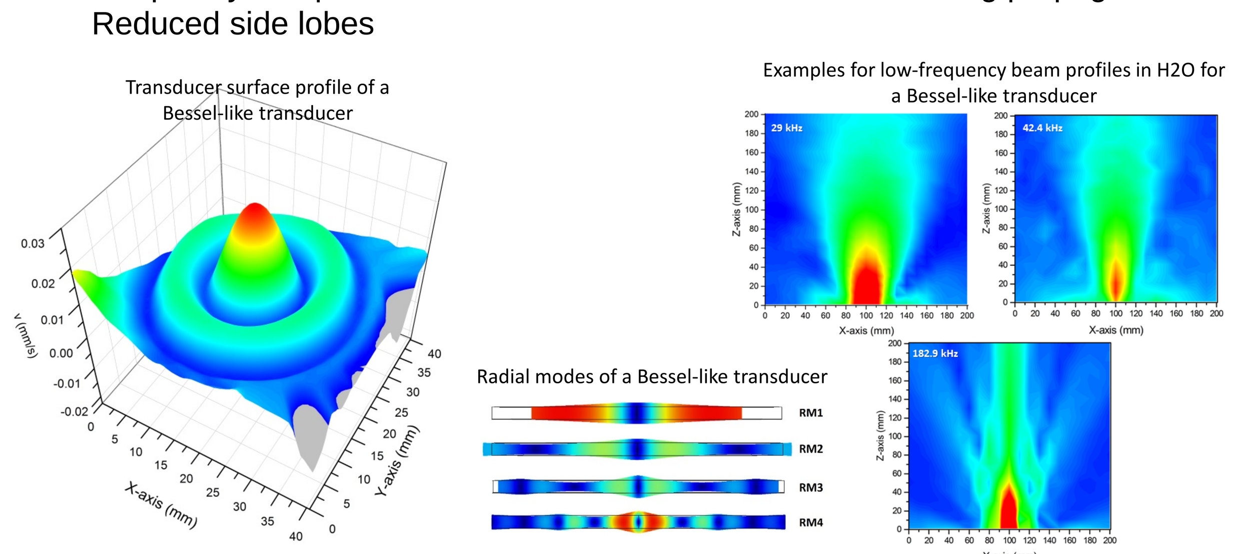
o **Parametric acoustic source**:
Collimated beam
Large bandwidth (140 kHz)
No side lobes
Low frequency (10-150 kHz)
Frequency-independent beam width
Beam divergence < 6 degrees



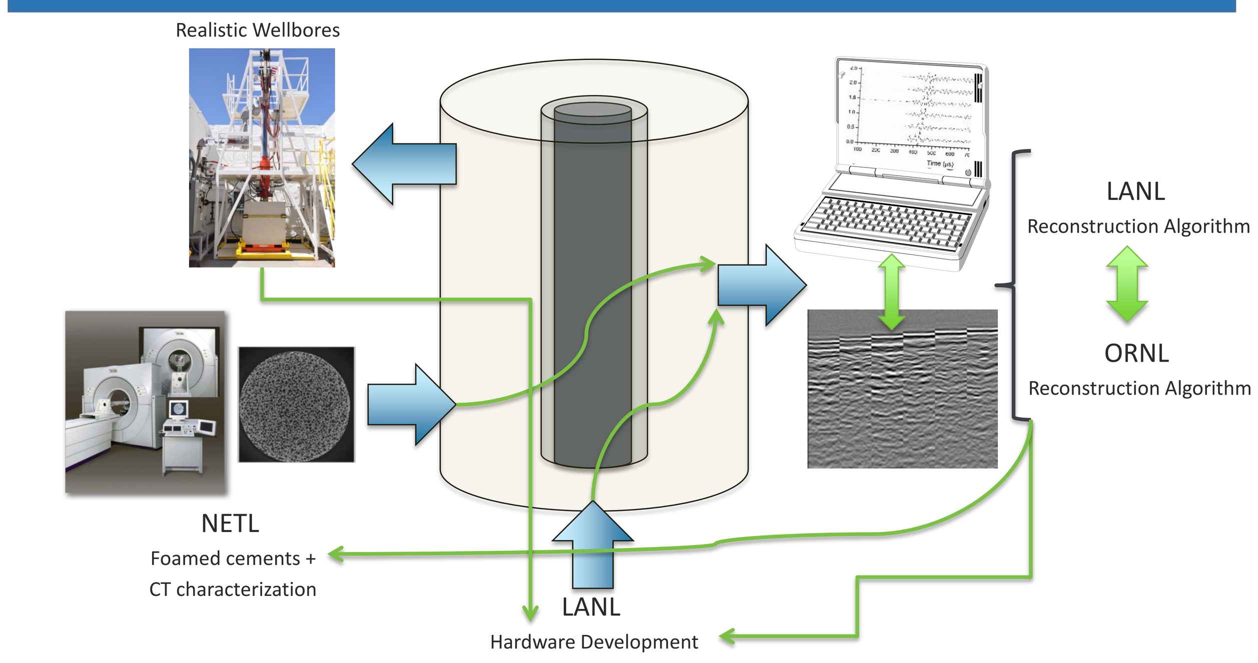
83 kHz difference frequency beam profile in H_2O

Scans of beam widths at 110 mm from transmitter in H_2O

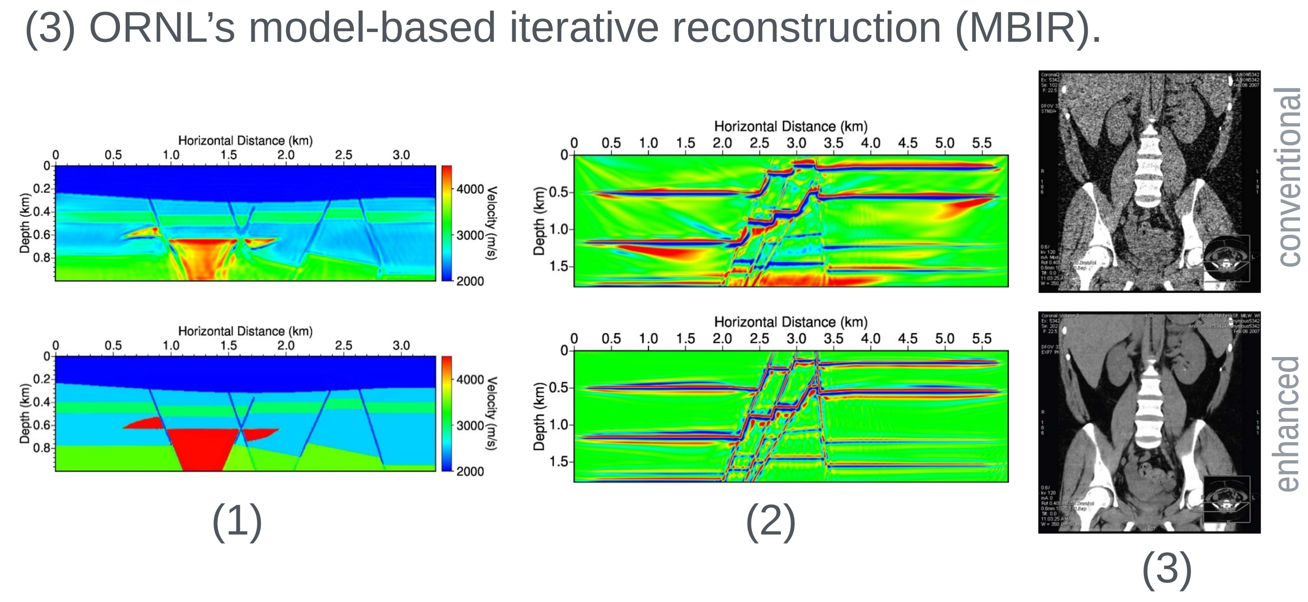
o **Bessel-like source**:
Low frequency (10-150 kHz)
Frequency-independent beam width
Reduced side lobes
Large bandwidth (140 kHz)
Limited diffraction during propagation



Scientific Approach (cont.)



Advanced image processing techniques:
(1) LANL's Elastic-Waveform Inversion,
(2) LANL's Least-Squares Reverse-Time Migration techniques,
(3) ORNL's model-based iterative reconstruction (MBIR).

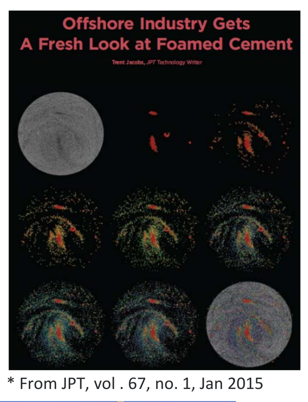


(1) (2) (3)

- **Foamed cements (w/ NETL)**
  - Corroborating characterization information

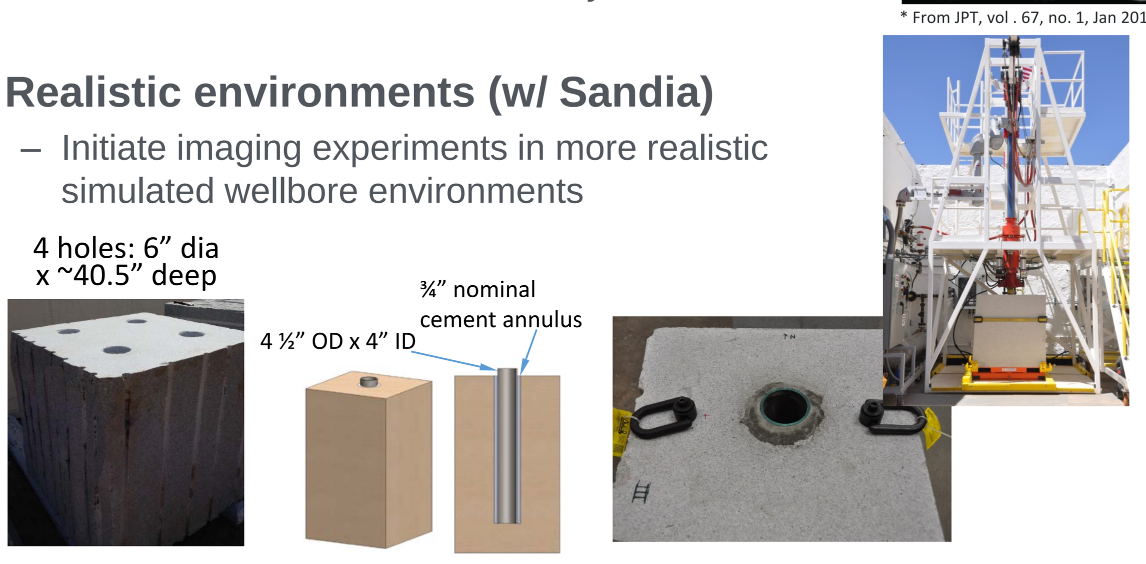
Acoustic (*LANL*) ←→ CT (*NETL*)

Acoustic characterization: sound speed, attenuation, acoustic nonlinearity, elastic moduli



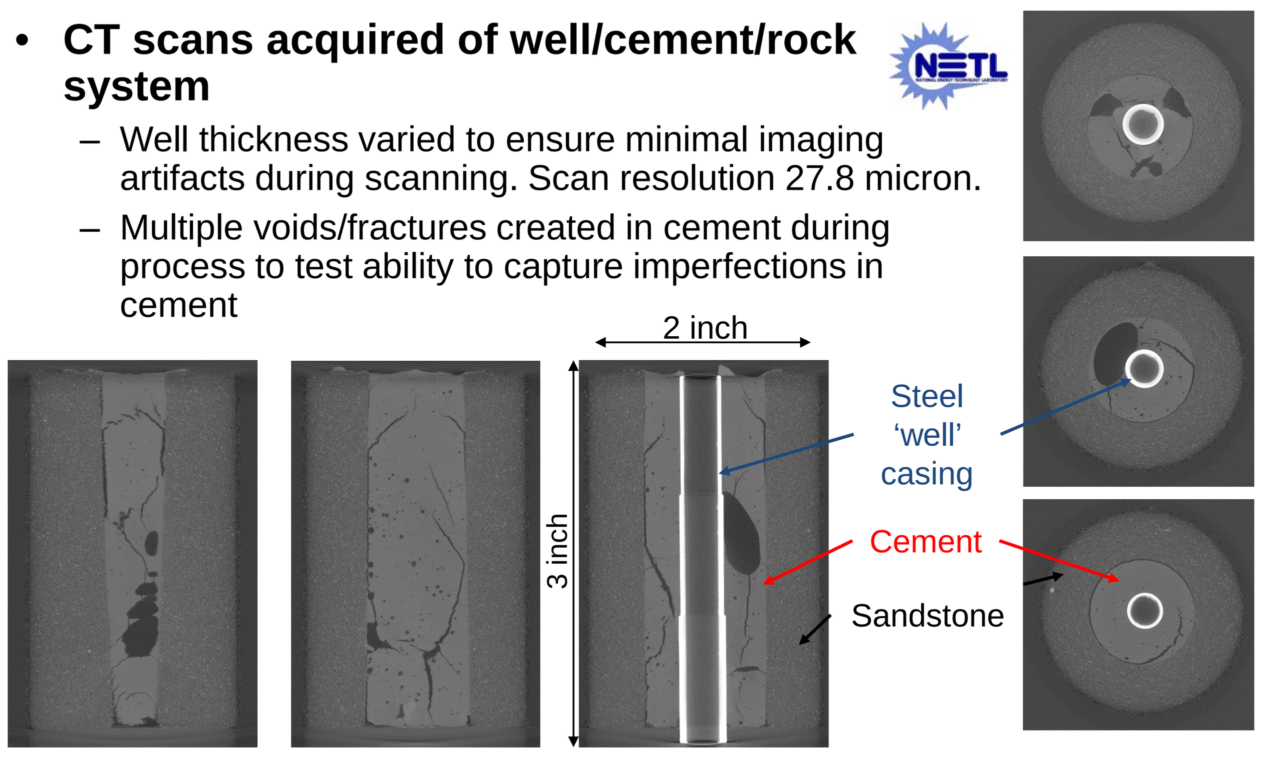
* From JPT, vol . 67, no. 1, Jan 2015

- **Realistic environments (w/ Sandia)**
  - Initiate imaging experiments in more realistic simulated wellbore environments



Experimental results

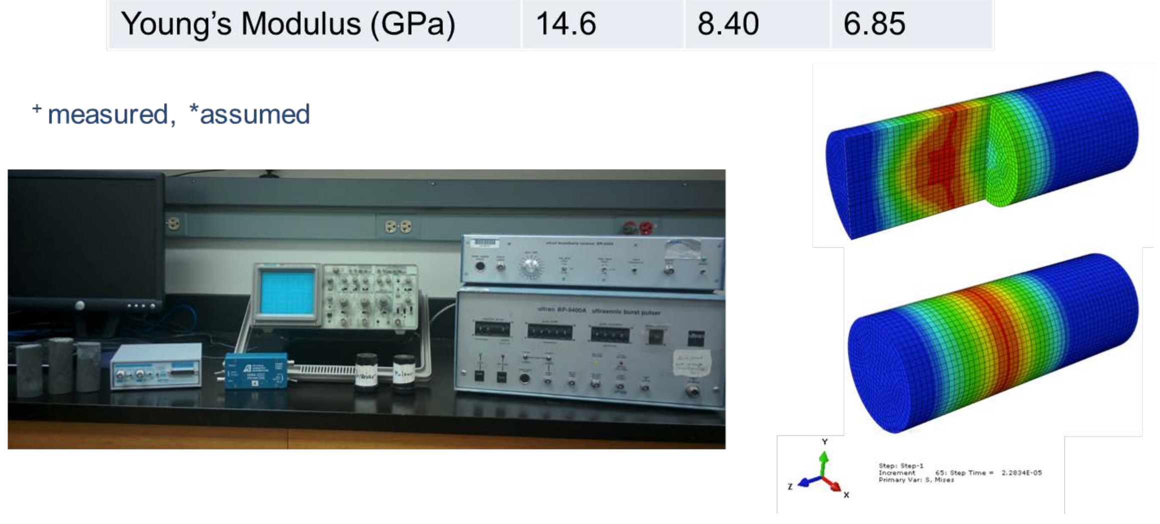
- **CT scans acquired of well/cement/rock system**
  - Well thickness varied to ensure minimal imaging artifacts during scanning. Scan resolution 27.8 micron.
  - Multiple voids/fractures created in cement during process to test ability to capture imperfections in cement



- **Foamed cement properties**

Case (Foam Quality)	10%	20%	30%
P-Wave Velocity⁺ ($^m/_s$)	3055.5	2525.4	2415.4
Mass Density⁺ ($^{kg}/_{m^3}$)	1696.9	1446.7	1304.0
Poisson's Ratio*	0.18	0.19	0.2
Young's Modulus (GPa)	14.6	8.40	6.85

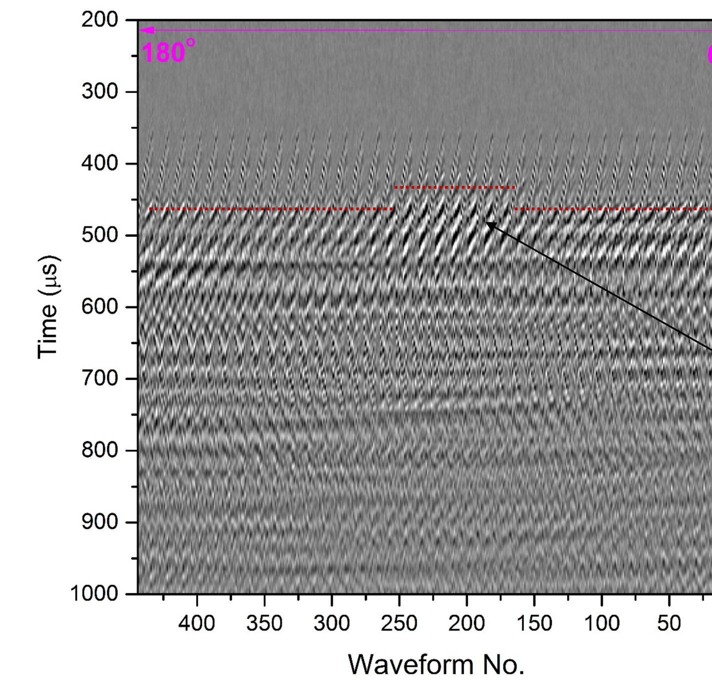
⁺ measured, *assumed



Experimental results (cont.)

- **Imaging with parametric source**

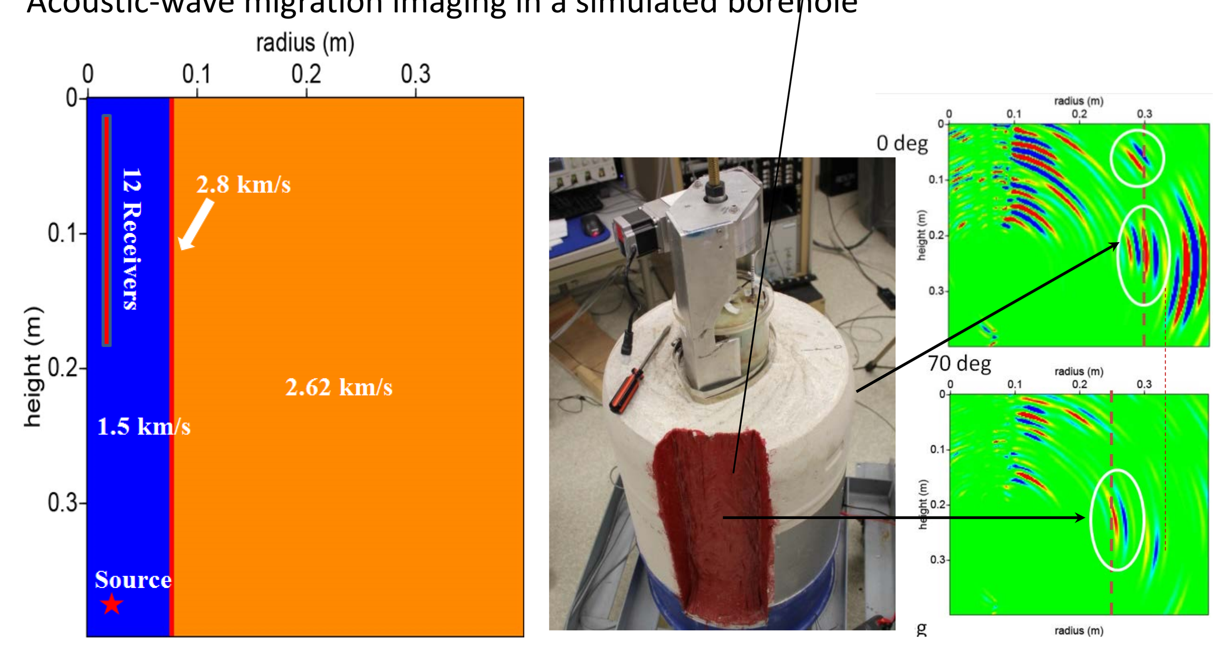
Open borehole configuration (Plexiglas-lined cement barrel)
Reflection seismology – Common azimuth representation



Excitation:
10-150 kHz Gaussian pulse
Azimuthal data collected every 5 deg, for a 180 deg span.

Groove location.

Acoustic-wave migration imaging in a simulated borehole

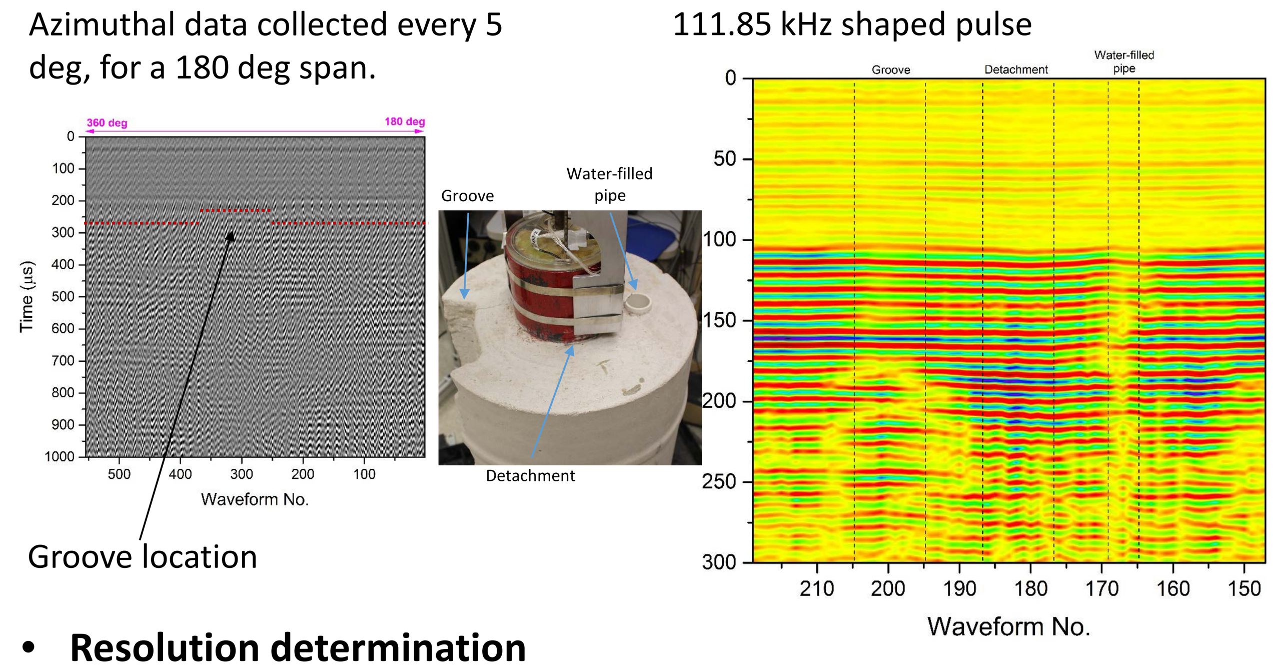


- **Imaging with Bessel-like source**

Cased borehole configuration (Stainless Steel-lined cement barrel)
Reflection seismology – Common azimuth representation

Excitation:
42.2 kHz shaped pulse
Azimuthal data collected every 5 deg, for a 180 deg span.

Excitation:
111.85 kHz shaped pulse



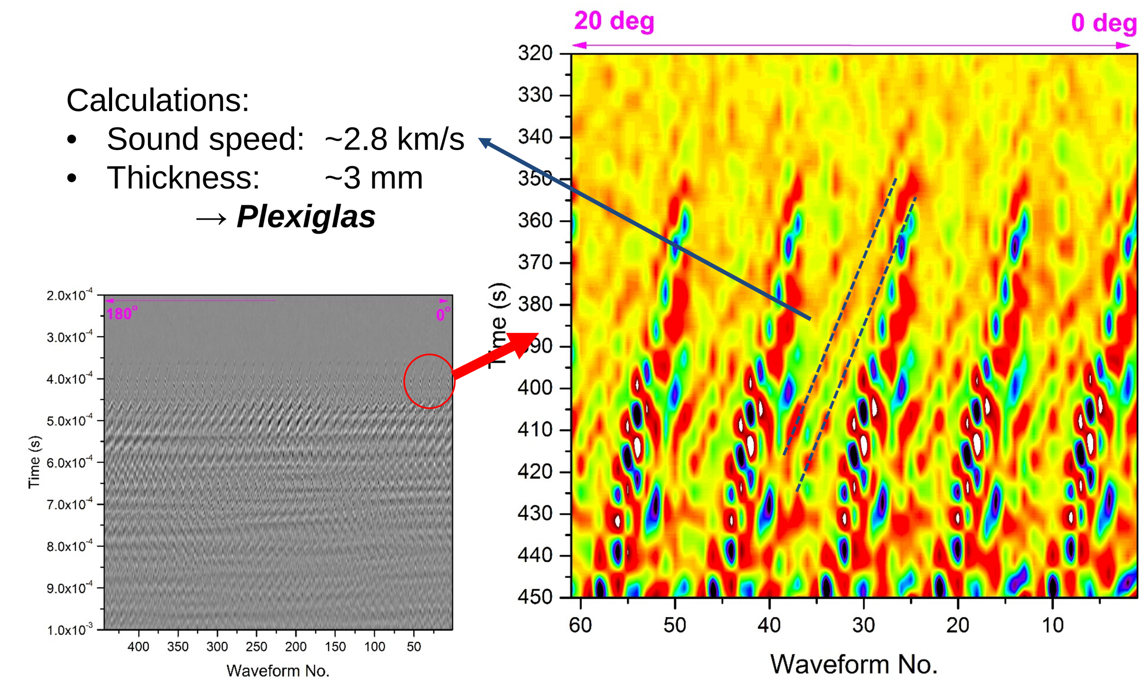
Groove location

- **Resolution determination**

Open borehole configuration (Plexiglas-lined cement barrel)

Calculations:
- Sound speed: ~2.8 km/s
- Thickness: ~3 mm

→ ***Plexiglas***



Summary

- Built and experimentally validated three different acoustic sources that provide a collimated beam of low frequency.
- Beam collimation is maintained after passing trough an inhomogeneous scattering medium (concrete barrel).
- Gained insight in understanding foamed cements, by determining elastic properties and CT scans.
- Demonstrated imaging capabilities of the system, in both open- and cased-borehole, for different induced defects (groove, detachment, fluid-filled void pocket, casing).
- Determined a resolution as low as 3 mm.
- Long-term plan: refine and enhance the capabilities of the 3D imaging system for more realistic environments, and extended investigation range beyond the wellbore casing.