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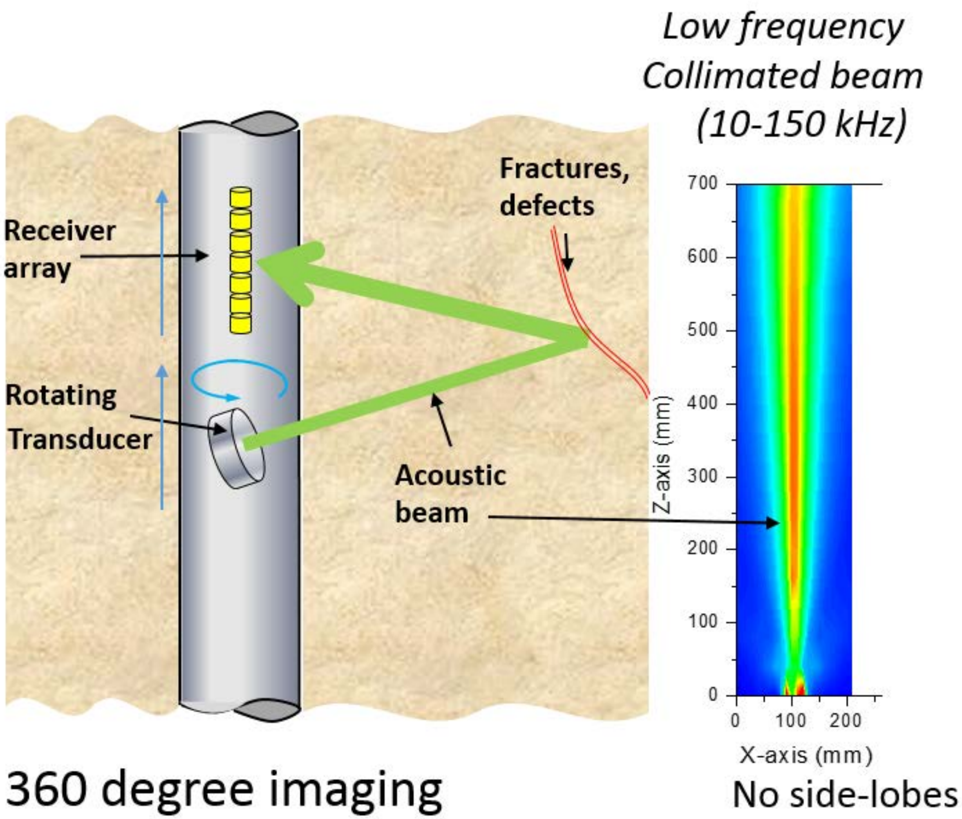

High-Resolution 3D Acoustic Borehole Integrity Monitoring System

Project Officer: xx

Total Project Funding: $2,905K

November 14, 2017

PI: Cristian Pantea

Los Alamos National Laboratory

Track 2, SubTER

Partners/Collaborators

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Relevance to Industry Needs and GTO Objectives

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Main objective: develop a high-resolution 3D imaging system for improved wellbore diagnostics and integrity assessment

- Challenges addressed: imaging, with high-resolution, of defects/fractures beyond casing
- Costs – similar to existing technology
- Performance – improved performance, better resolution
- Applications – wellbore integrity assessment
- Markets – any underground borehole
- Innovative aspects: low frequency, collimated beam.
  - Combination of a unique source with advanced image processing
  - An approach that can be deployed to characterize foamed cements in-situ

    → identify acoustic-based metrics from comparison with CT scans

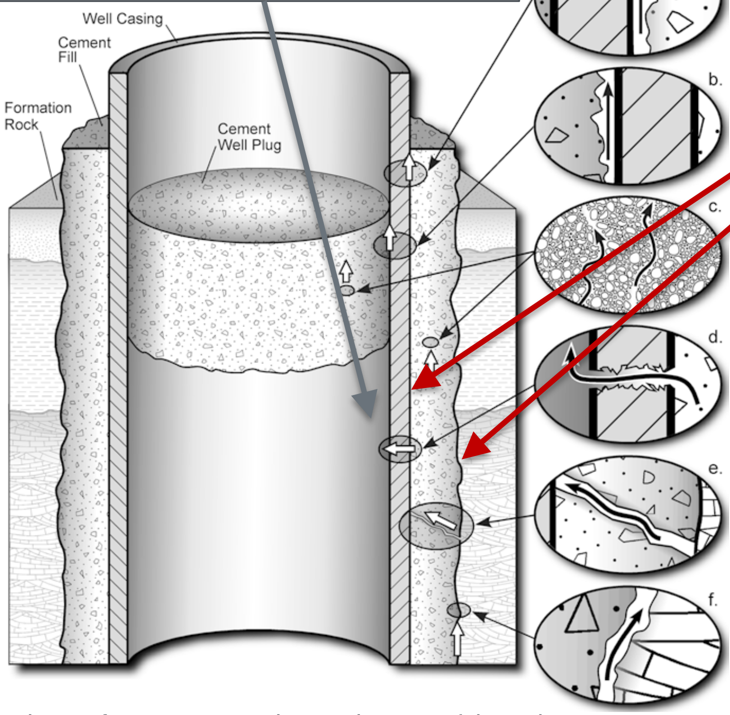
Main objective: develop a high-resolution 3D imaging system for improved wellbore diagnostics and integrity assessment

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

Relevance to Industry Needs and GTO Objectives

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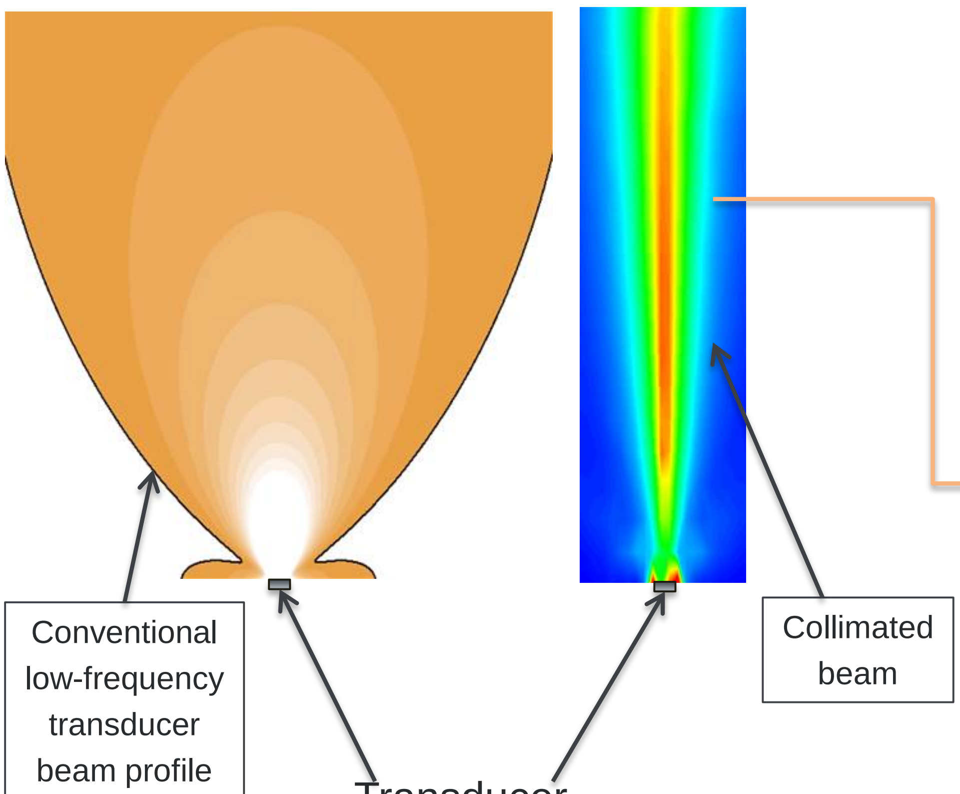
The Proposed Solution:

Novel technique that fills this technology gap.

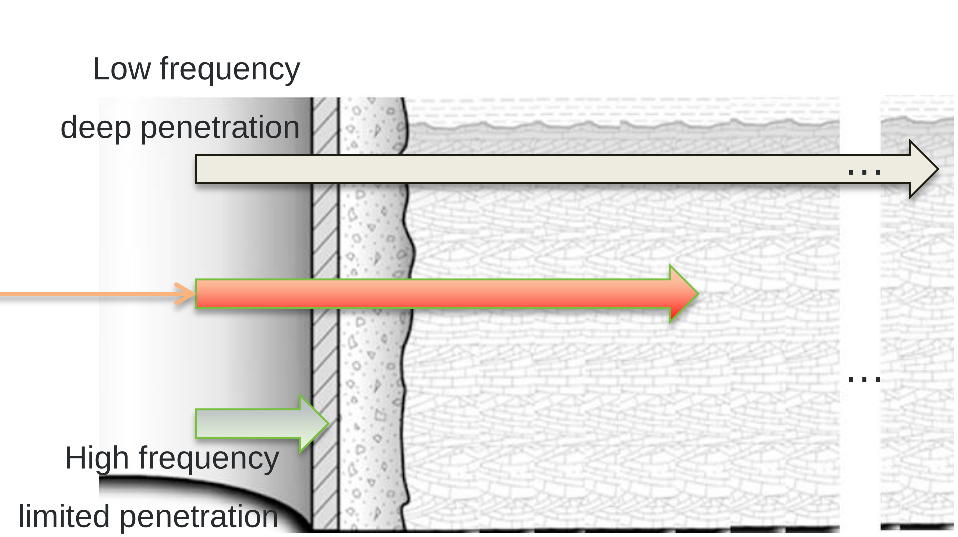
1. Collimated beam for increased resolution



2. Low frequency for deeper penetration

$$Attenuation \sim f^{n}$$

f = frequency, n = 1-2



Relevance to Industry Needs and GTO Objectives

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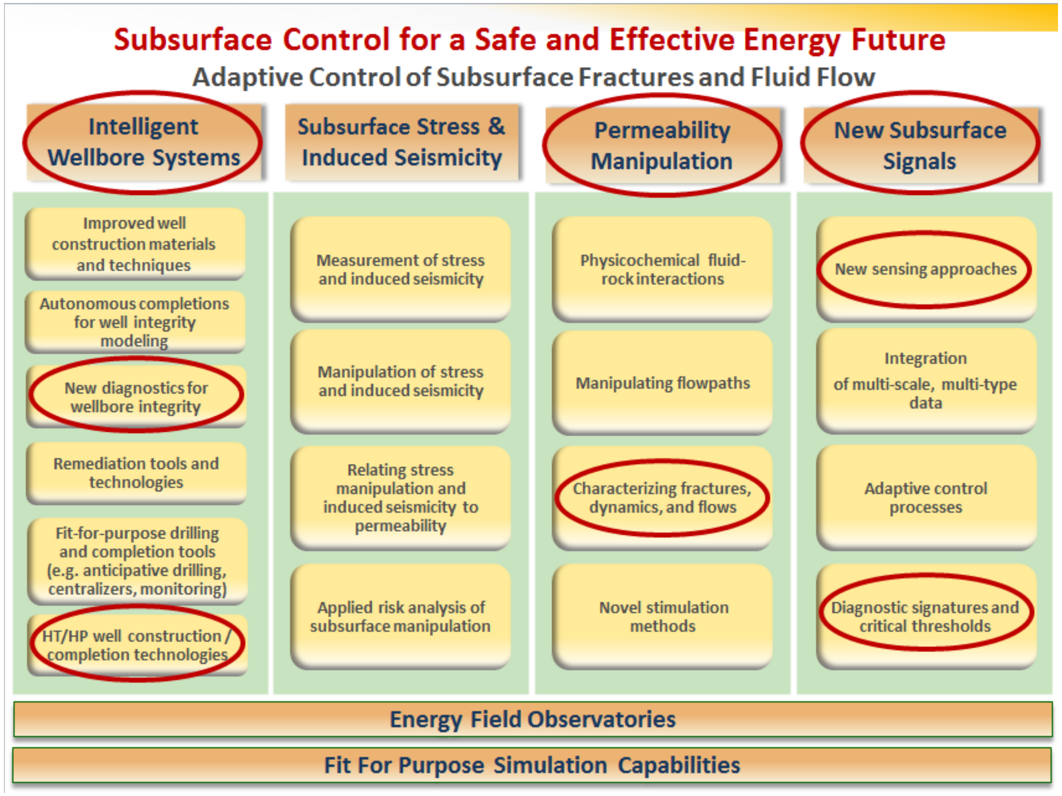
Relevance to the SubTER pillars:

Comprehensive solutions to wellbore integrity monitoring and improved near wellbore fracture detection are needed in multiple energy sectors (CO_2 Storage, Geothermal, Oil & Gas, Nuclear).

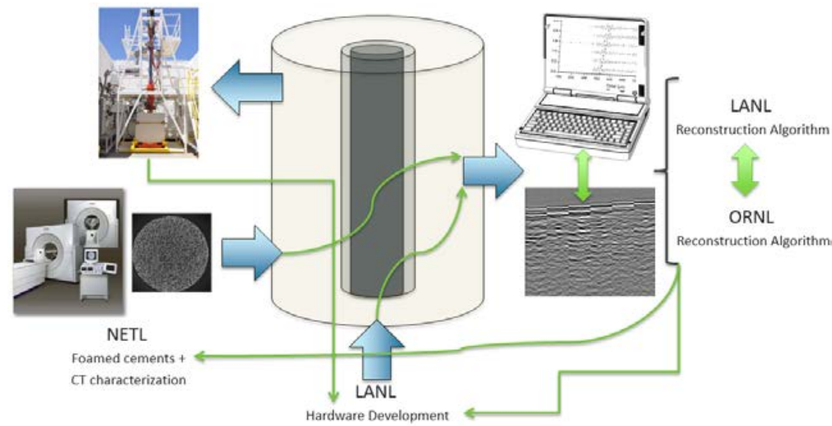


Geothermal Technologies Office's goals targeted by this project

- Overcoming technical obstacles and mitigating risk
- Overcoming deployment barriers
- Collaborating on solutions to subsurface energy challenges

Multi-lab project

Inter-lab collaboration and teaming arrangements/partnerships



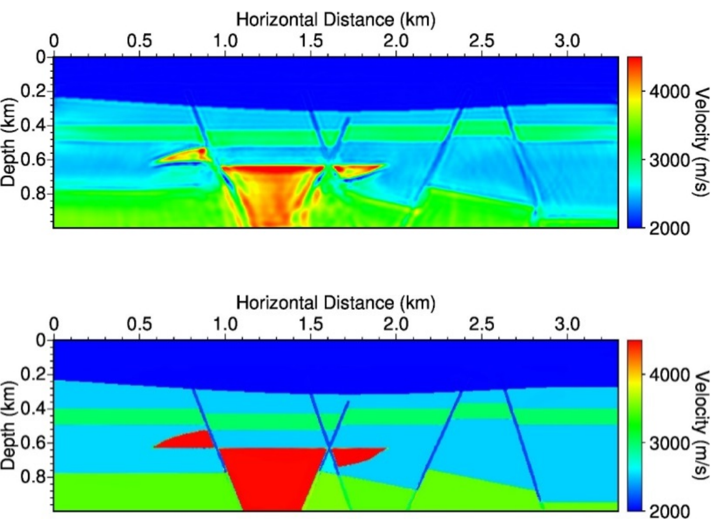
- LANL: Develop acoustic source, imaging system, and image processing.
- NETL: Investigate acoustic metrics for foamed cements. Incorporate new metrics for wellbores in the field.
- ORNL: Explore different image processing approaches.
- SNL: Perform experiments in more realistic boreholes. Incorporate data from realistic borehole and compare resolution with lab experiments.

Advanced image processing techniques:

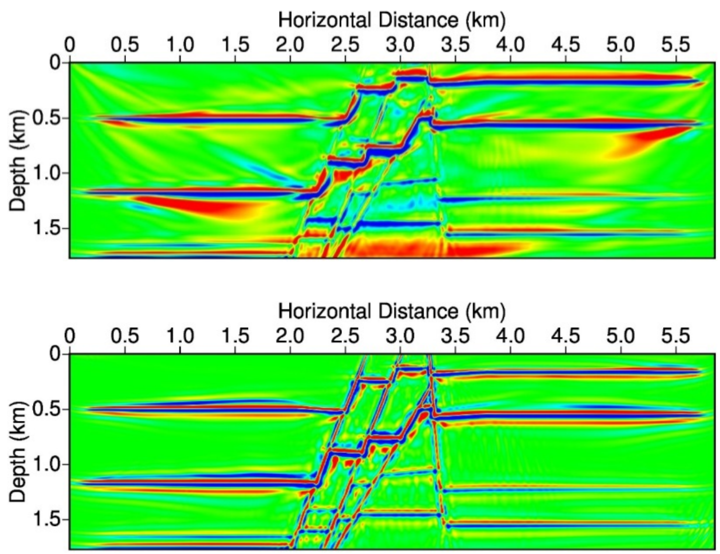
(1) LANL's Elastic-Waveform Inversion,

(2) LANL's Least-Squares Reverse-Time Migration techniques,

(3) ORNL's model-based iterative reconstruction (MBIR).



(1)



(2)

conventional

enhanced

(3)

Methods/Approach

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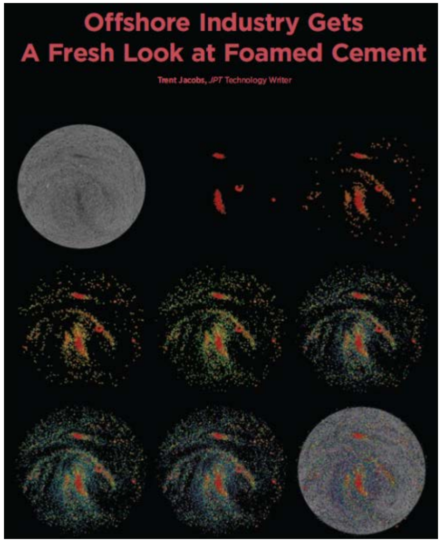
- **Foamed cements (w/ NETL)**
  - limited information on foamed cement behavior at conditions specific to wellbores exists at present and
  - conventional methods have difficulty detecting foamed cement due to low impedance contrast.



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

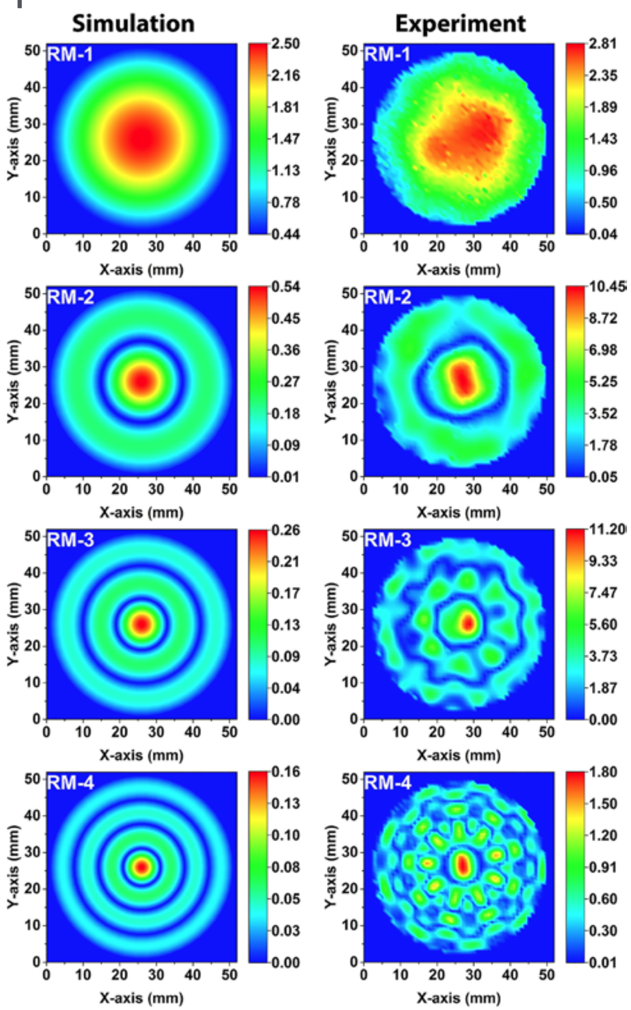
Acoustic (*LANL*) ←→ CT (*NETL*)

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

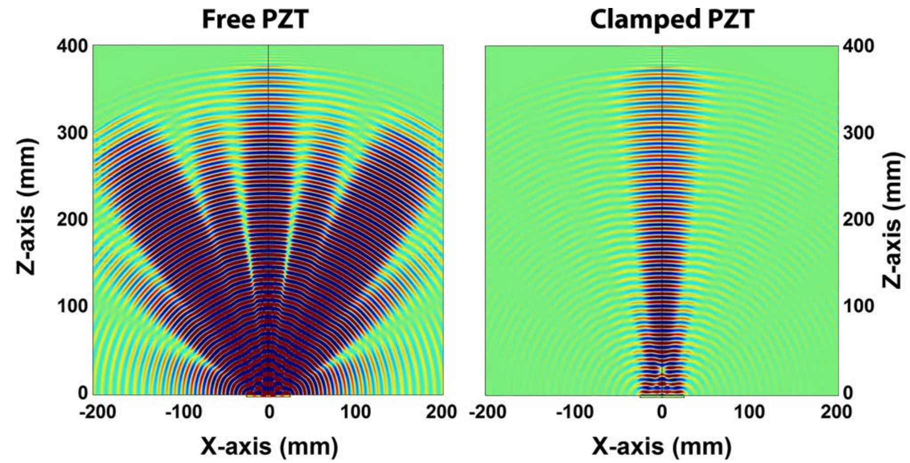
- **Realistic environments (w/ Sandia)**
  - Perform imaging experiments in more realistic simulated wellbore environments

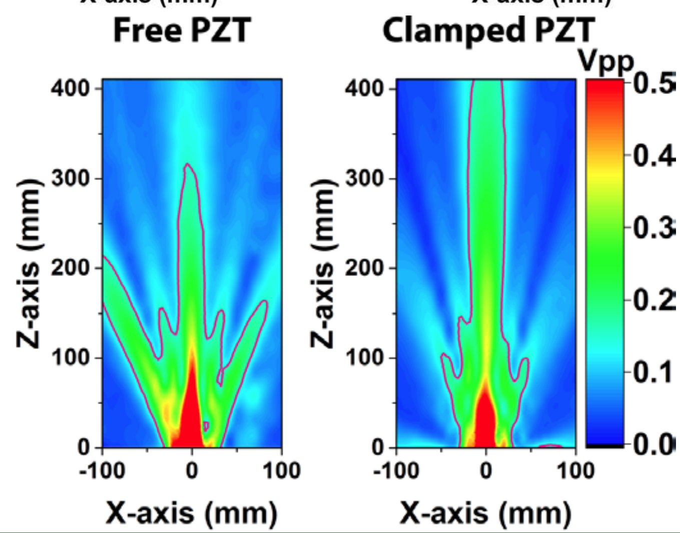
Bessel-like Acoustic Source

First four radial modes of a piezoelectric disc transducer



Beam profile in water for the 3rd radial mode RM-3; free transducer (left) and clamped transducer (right)





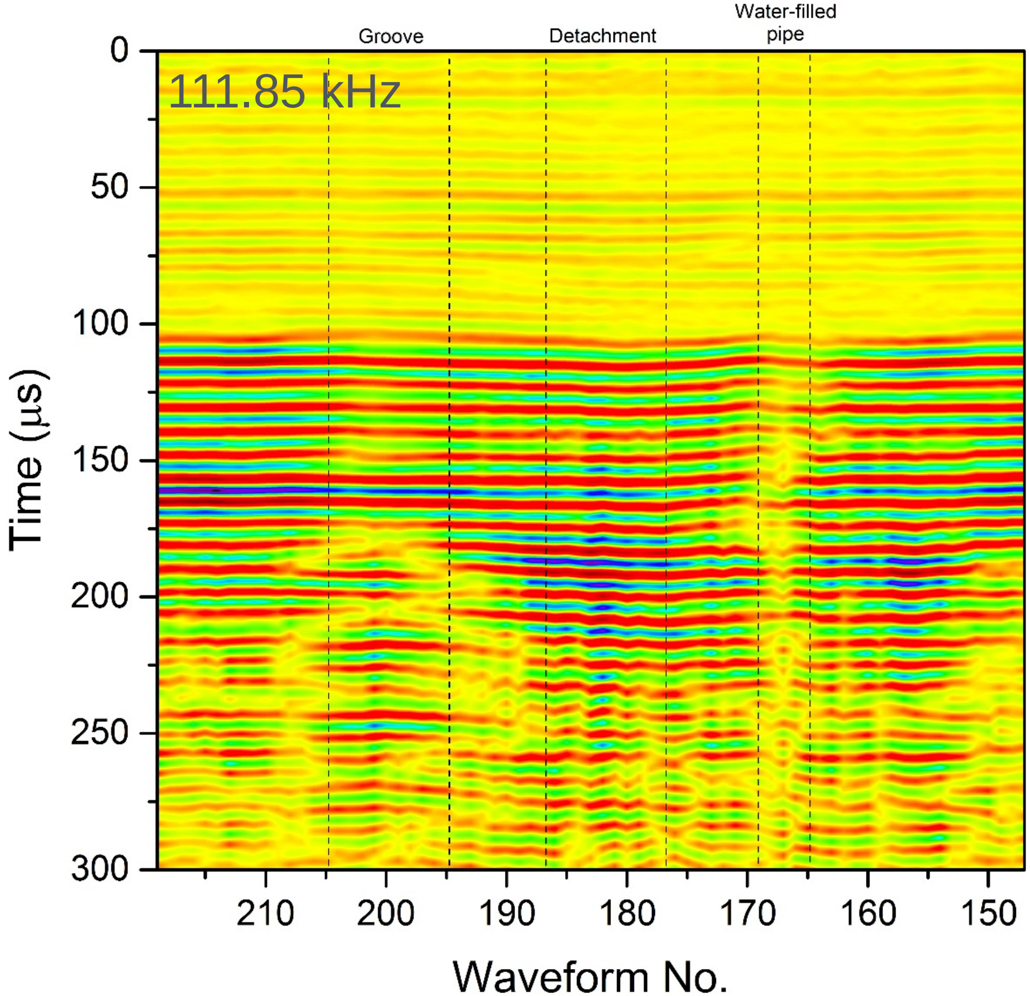
 Appl. Phys. Lett., vol. 110, issue 6, (2017), 064101

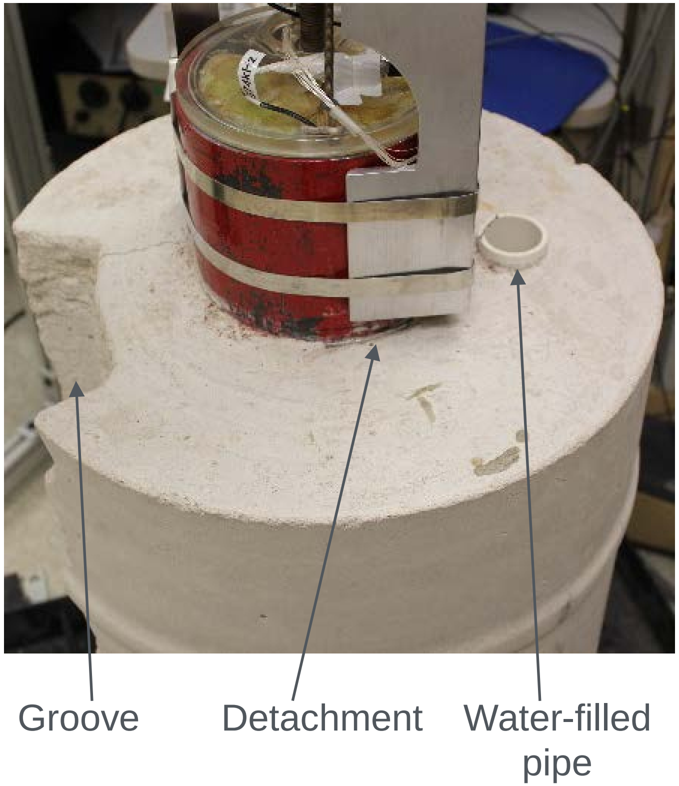
Defects detection – Bessel-like Source

Cased borehole configuration (Steel-lined cement barrel)

Reflection seismology – Common receiver representation

Cement OD: 460 mm
Cement ID:170 mm
Steel pipe ID: 148 mm
Steel pipe thickness: 10 mm
Groove depth: 50 mm
Plastic pipe location: 25 mm

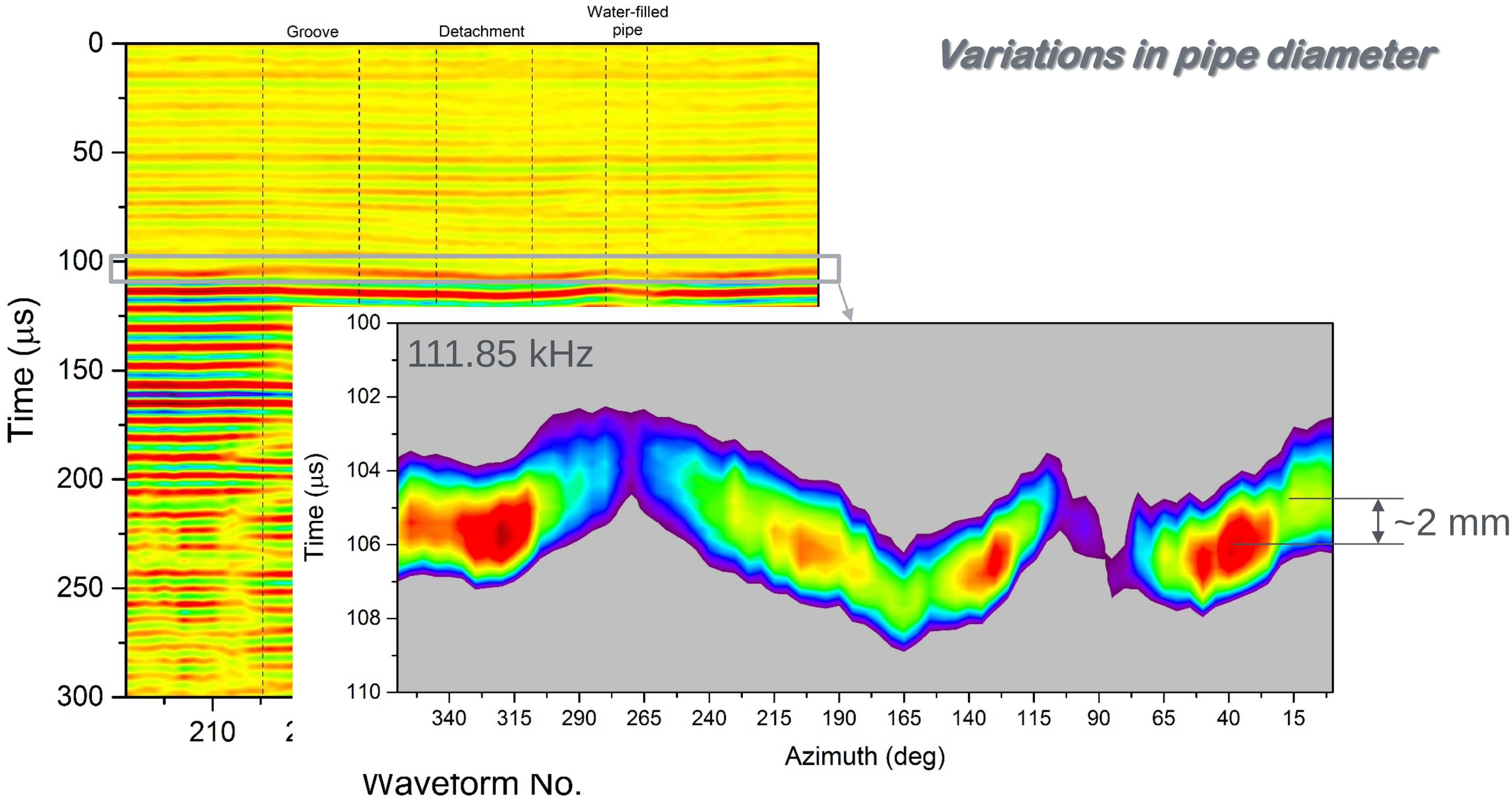




Defects detection – Bessel-like Source

Steel casing barrel – Bessel-like Source

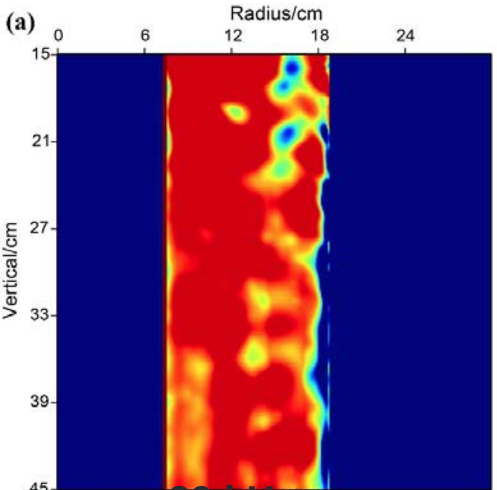
Variations in pipe diameter



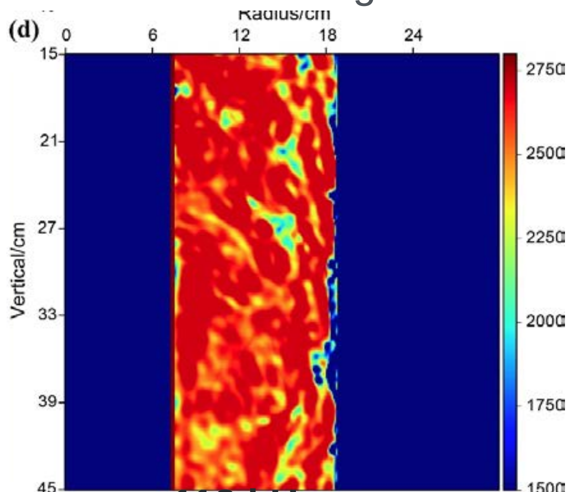
LANL image processing

Open borehole configuration (Plexiglas-lined cement barrel)

Multi-scale acoustic full-waveform inversion algorithm for velocity model



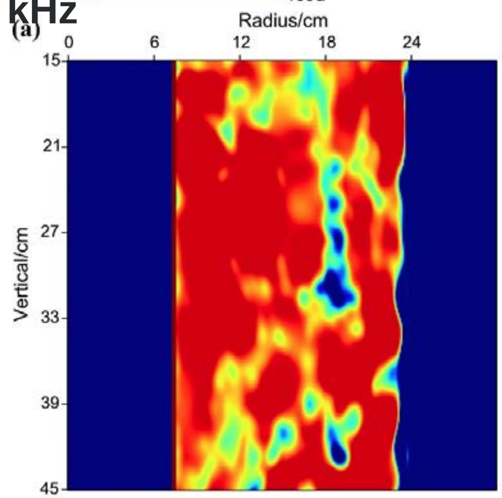
29 kHz



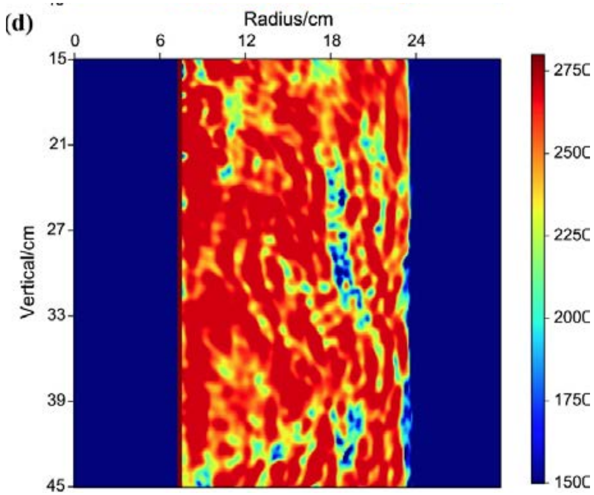
112 kHz

Excitation: 29-112 kHz Bessel-like Acoustic Source

Data collected using fixed azimuth, and vertical translation of source and receivers.



29 kHz



112 kHz

Elastic Properties of Foamed Cement

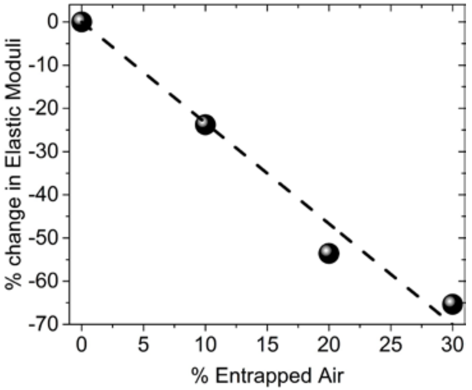
- Ultrasonic testing of Foamed Cement cylinder specimens with size approximately 25 mm (diameter) x 110 mm.

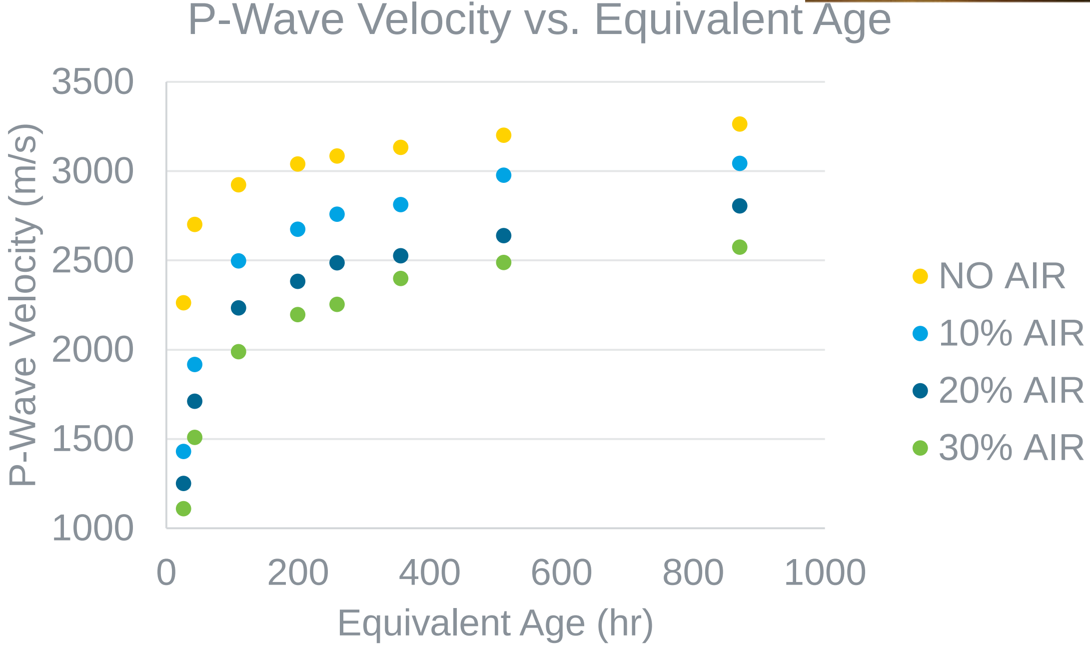
- Equivalent Age was calculated using the Arrhenius equation with an Activation Energy of 35,418 J/mol.

Case (Foam Quality)	0%	10%	20%	30%
P-Wave Velocity+ ($^{m}/_{s}$)	3371.5	3060.4	2877.6	2661.8
Mass Density+ ($^{kg}/_{m3}$)	2120.9	1853.2	1650.3	1468.4
Poisson's Ratio*	0.18	0.18	0.19	0.2
Young's Modulus (GPa)	22.2	15.48	11.9	8.8

+ measured, *assumed

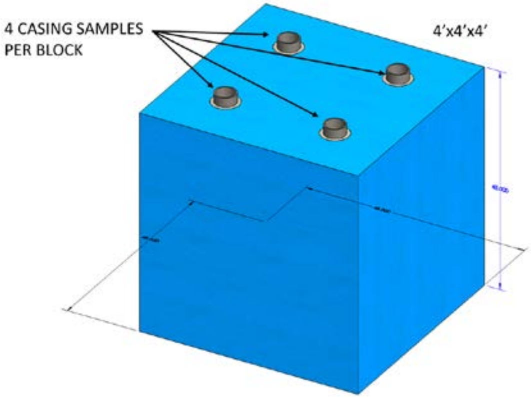
LANL got similar values.
Poisson ratio was determined to be ~0.25, for both longitudinal and shear propagation modes.
Large change in elastic moduli with air content → significant softening



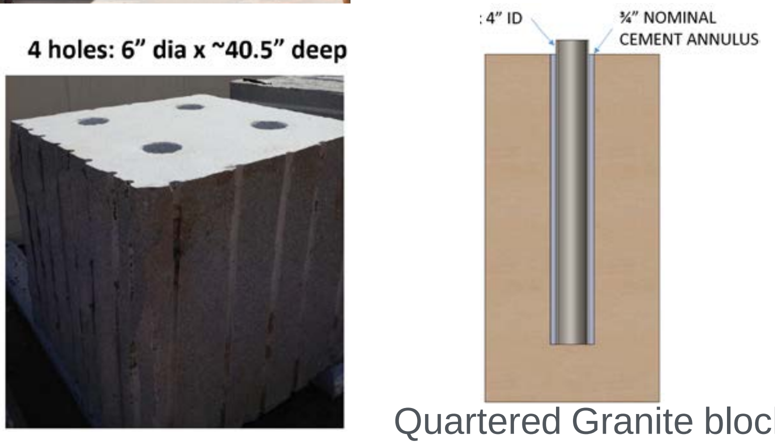


Granite Block Samples – Sandia National Laboratory

Rock sample in drilling facility



4 holes: 6" dia x ~40.5" deep



Quartered Granite block

Targeted Casing Defects:

- **Wall thinning**
  - **Pre-machine thin section in casing prior to cementing**
- **Casing eccentricity**
  - **Offset casing with jig during cementing**
- **Channeling**
  - **Removable insert**
- **Delamination**
  - **Thin-layer Silicone insert**

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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 into understanding foamed cements, by determining elastic properties and performing 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 spatial resolution as low as 3 mm.
- Long-term plan: refine and enhance the capabilities of the 3D imaging system for more realistic environments, and extend investigation range beyond the wellbore casing.

Research Collaboration and Technology Transfer

- Industry/academic engagement that is taking place under this project.

  - multi-lab project: LANL, SNL, NETLS, ORNL
  - West Virginia Univ, through NETL
  - industry: contacted an oil & gas company. They’re interested in a future collaboration for “real-world use”

Future Directions

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Task	Year 1				Year 2				Year 3			
	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
Phase 1 - Feasibility study												
Task 1 – Investigation of existing technology		M2										
Task 2 – Define metrics	M1											
Task 3 – Industry partners/technology maturation plan												
	GoNoGo1											
Phase 2 - Evaluate method on more complex wellbore environments												
Task 1 - Channeling outside casing			M3									
Task 2 - Hardware/software refinement												
Task 3 - Speed-up measurement & analysis												
Task 4 - Method testing on more complex wellbore environments				M4								
Task 5 - Foamed cements manufacturing												
Task 6 - CT of foamed cements												
Task 7 - Acoustics metrics of foamed cements												
Task 8 - Tests on simulated wellbores with foamed cements				M4								
			GoNoGo2									
Phase 3 - Extend method beyond wellbore												
Task 1 - Acoustic source improvement					M5							
Task 2 - Receivers enhancement												
Task 3 - Ruggedized tool							M7					
Task 4 - Image processing refinement						M6						
Task 5 - Technique refinement								M8				
Task 6 - Enhance capabilities for foamed cements												
							GoNoGo3					
							GoNoGo4					
Phase 4 - Technology Development and Verification												
Task 1 - Prototype development									M9			
Task 2 - Prototype verification at lab scale and in field											M11	
Task 3 - Hardware/software enhancement and refinement										M10		

Go/No-Go1 (end Q2Y1)

Tabulate commercial 3D imaging techniques for borehole integrity

- no commercial technologies for high-res 3D imaging technology with similar depth of penetration (~3 m) and resolution (< 5 mm)

Go/NoGo2 (end Y1)

Detect defects at the cement-formation interface, with high resolution- defects detection at the cement-formation interface with a resolution of at least 5 mm

Go/No-Go3 (end Y2)

Tool survival in adverse conditions of corrosiveness, high temperature and high pressure (brines, 250°C, 45 kpsi)

- imaging system can survive in adverse conditions of temperature, pressure and corrosiveness

Go/No-Go4 (end Y2)

Imaging capabilities out in the formation, up to 3 meters

- defects/features (up to ~ 3m) can be resolved in the received signal