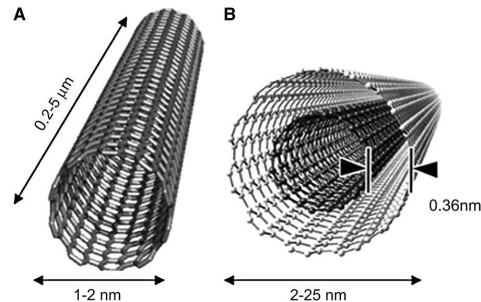## Multi-walled Carbon Nanotubes

Forward Acoustic Modeling
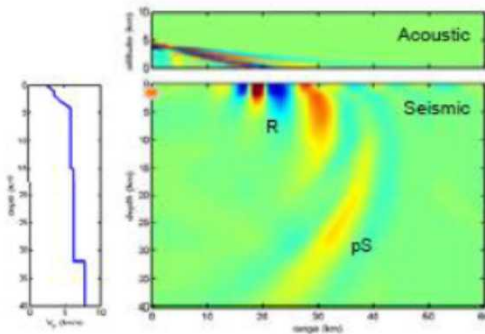
UT Devine Site
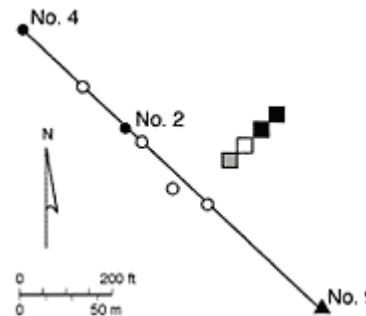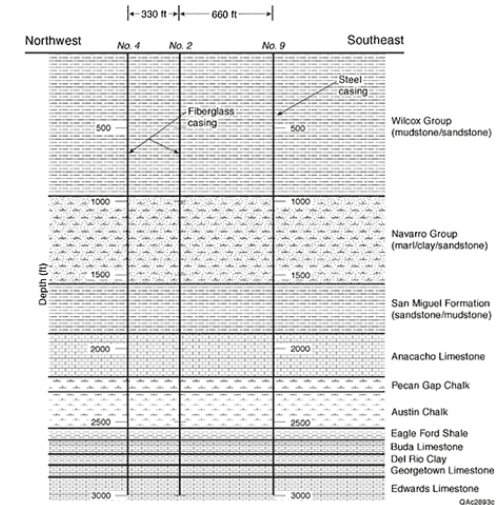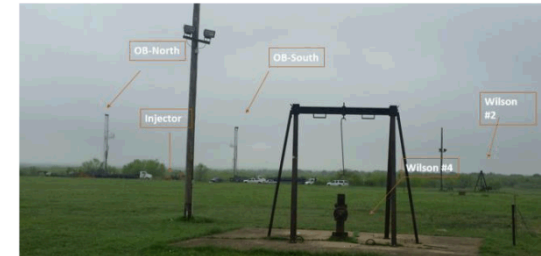
Advanced Downhole Acoustic Sensing for Wellbore Integrity

Project Officer: Alexandra Prisjatschew

Total Project Funding: $3.8M

November 14, 2017

This presentation does not contain any proprietary confidential, or otherwise restricted information.

Principal Investigator

Thomas Dewers

Sandia National Laboratories

Advanced Downhole Acoustic Sensing for Wellbore Integrity

Project Objectives

Develop step-change in *non-destructive, non-intrusive, continuous monitoring* of wellbore integrity including:

- Downhole networks for continuous acoustic sensing at relevant frequencies

- Cable-free sensors and/or acoustic contrasting agents emplaced in cement for behind-casing monitoring to improve signal-noise ratios and flaw detection

- A means to excite sensors or contrast agents continuously, or at will

- Enhanced methods for data acquisition, filtering signals, and machine-learning for detection in complex, noisy, high-temperature-high-pressure (HPHT) downhole systems.

"Wellbore integrity refers to… zonal isolation of liquids and gases from …the target formation or from intermediary layers through which [a wellbore] passes"

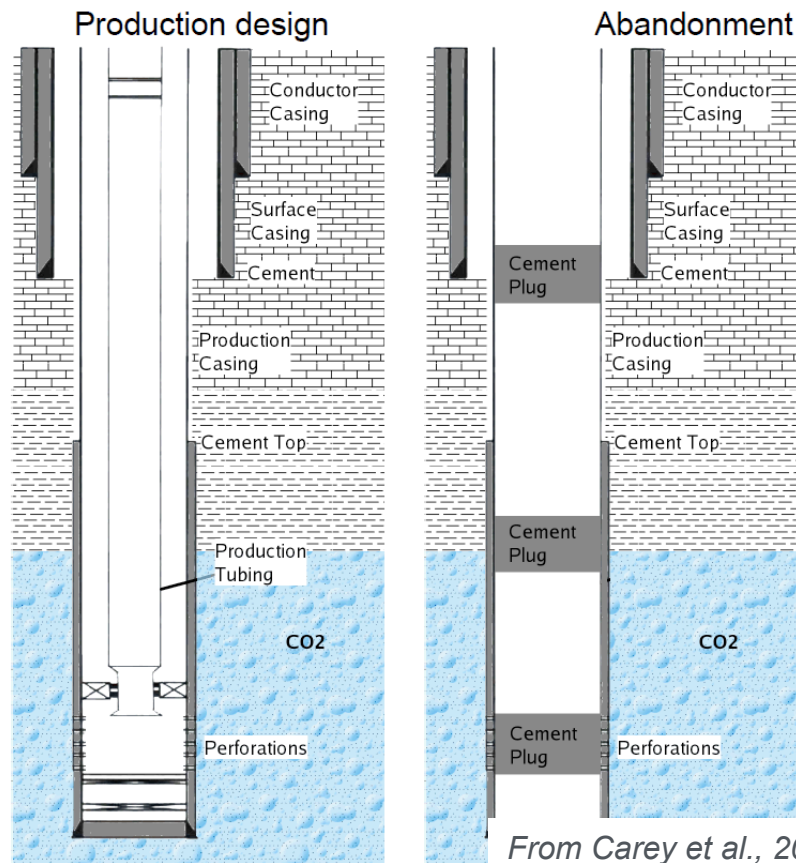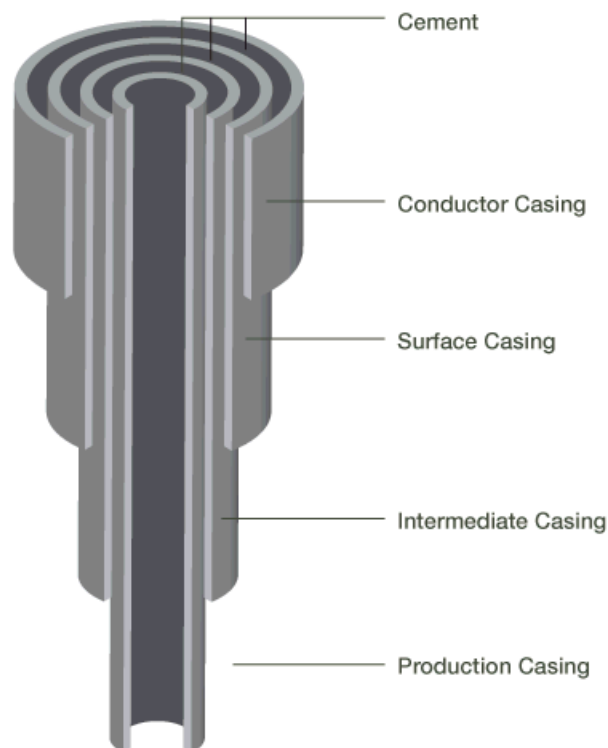*Jackson, PNAS, 2014*

"Application of technical, operational, and organizational solutions to reduce risk of uncontrolled release…throughout life cycle of a well"   *NORSOK, 2014*

Typical Well Casing Diagram (Not to Scale): Cement, Conductor Casing, Surface Casing, Intermediate Casing, Production Casing

Production design / Abandonment

From Carey et al., 2010

Sandia National Laboratories logo

Los Alamos National Laboratory logo

Purdue University logo

Bureau of Economic Geology logo

The University of New Mexico logo

<u>Sandia National Laboratories (SNL)</u>: Thomas Dewers (testing at conditions, acoustics), Ed Matteo (cement science), Leiph Preston (forward finite difference modeling); Zack Cashion (sensor development and deployment); Budi Gunawan (fiber sensing and deployment).

<u>Los Alamos National Laboratory</u>: Bill Carey (cement-CO_2 interaction, testing at conditions), Paul Johnson, advanced wave physics)

<u>Purdue:</u> Laura Pyrak-Nolte (physics and interpretation of guided and body waves in layered media, machine learning, failure mode detection)

<u>UT-BEG</u>: David Chapman (sensor development), Praveen Pasupathy and Mohsen Ahmadian (sensor miniaturization, ruggedizing, and deployment)

<u>UNM</u>: Shreya Vemuganti (PhD student), Mahmoud Taha and John Stormont (cement fabrication and design, functionalized carbon nanotubes)

Methods/Approach

> **_Goal 1_**_: For the proposed research, we will focus on guided wave excitation and detection, using higher frequency excitation and detection with techniques recently developed by Pyrak-Nolte at Purdue and Paul Johnson at LANL. Excitation will be accomplished by either or both of the contrasting agents or passive acoustic tags described below. Advanced forward acoustic modeling will be performed at SNL, which will guide the choice of, and subsequent development, of the sensing agents._

- Guided ultrasonic waves (Pyrak-Nolte et al., 1996; Shao et al., 2015) are a relatively new area in non-destructive testing

- capable of propagating along interfaces or between surfaces for distances on the order of 25 – 50 wavelengths

- sensitive to the bonding condition of the interfaces/surfaces

Methods/Approach
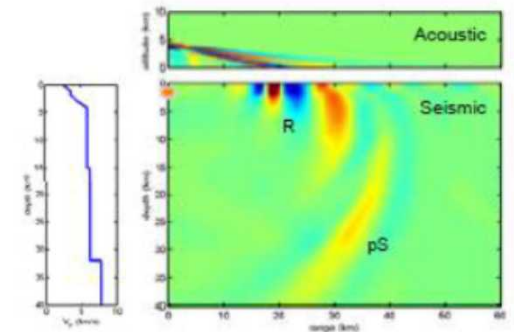
Goal 2: For the proposed research, using HPHT rock mechanics and acoustic facilities at SNL and LANL, we will test behavior of single-walled carbon nanotubes as cement contrast agents under downhole conditions. We will also test new proposed contrast agents under development by the UT-BEG.

- used to improve acoustic imaging to increase detection depth and to improve signal-to-noise ratio

- Functionalized multi-walled carbon nanotubes
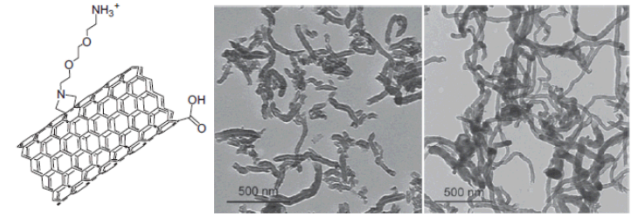
MWCNTs, from Delgou et al., PNAS 109(41), 2012

Goal 3: For the proposed research, the AEC will apply expertise in modifying off-the-shelf piezoelectric materials, including lithium niobate crystals, as PATs for cement embedment. SNL will collaborate in miniaturization and ruggedizing of PATs for downhole use.

- wireless sensors for embedding in cement that are excited acoustically to send or receive information acoustically

- passive i.e. operate with no onboard battery or electronics

Goal 4: *For the proposed research, SNL and LANL will collaborate with the BEG to investigate limitations of using passive frequency sources and downhole casing ultrasonic excitation as viable and continuous sources of embedded sensor excitation. We will also examine the potential for use of RF sensor excitation. These will be accomplished first in bench-top laboratory testing, but will advance to downhole proof-of-concept testing at the Devine site.*

- cement bond log and/or variable density logging (CBL/VDL) wireline tools as is current practice, but this would restrict sensor excitation and detection to usual cement bond logging or to potentially dangerous work-over periods.

- passive acoustic sources, such as injected or produced fluid in the borehole tubing itself (e.g. during active injection of $scCO_2$, brine withdrawal, or circulation of geothermal heat-exchanging fluid)

- use of the casing itself (which could be excited ultrasonically at the surface or downhole via specially designed couplers)
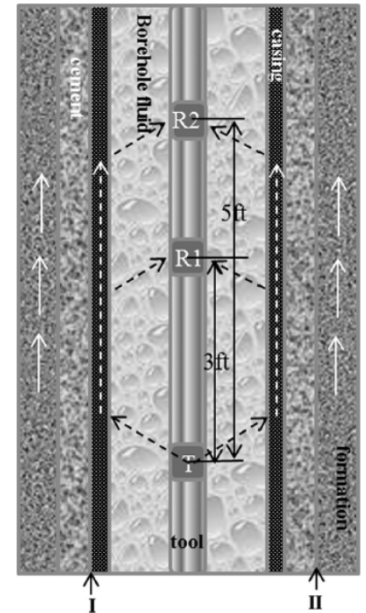

CBL/VBL, Wang et al., 2017, JASA

> **Goal 5**: *For the proposed research, AEC together with SNL will examine use of downhole fiber DAS in detecting signals of activated CA and PAT in micro-annuli detection. This will be done first at SNL under laboratory HPHT conditions, with a Micron Optics optical sensing interrogator, then tested under downhole conditions at Devine.*

- fiber optic DAS are being deployed in a variety of structural health and sensing configurations for wind turbine and ocean energy harvesting applications
- cross well acoustic detection of fracture networks

> **Goal 6**: *For the proposed research, Purdue and LANL will collaborate in advancing methods for detection using full waveform techniques. SNL and LANL will perform laboratory acoustic imaging of interfacial flaws in cement-casing mock-ups with acoustic imaging under HPHT conditions, including tests performed with in situ x-ray computed tomography, as "ground truthing" for the signal detection algorithms.*

- Detection of material-based PAT through reconstruction,
- inversion techniques deployed in acoustic (NDE/T) based on impedance (Z) changes
- acoustic backscatter and acoustic 'tomographic' reconstruction also to be explored
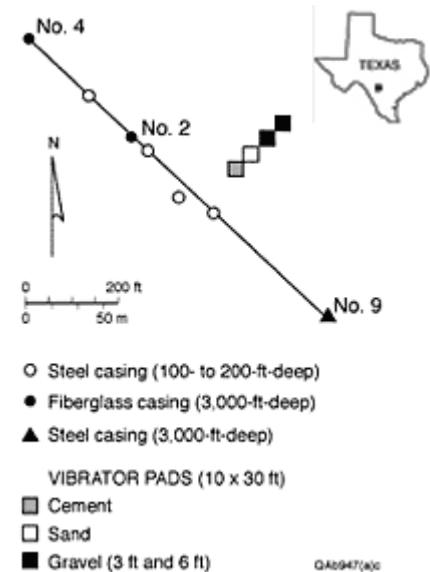
Task Structure

- Task 1: Project Management, shared by Dewers (SNL), Chapman (BEG), Pyrak-Nolte (Purdue) and Carey (LANL)

- Task 2: Go/No-Go evaluation, bi-annually through the project (given below)

- Task 3: Sensor and Contract Agent Development; BEG (PAT and CA) and UNM (CNT Cas) teams collaborate with SNL (testing and ruggedization)

- Task 4: Benchtop testing and Analysis (SNL, LANL, and Purdue)

- Task 5: Elastic Wave Modeling and Signal Interpretation (SNL, LANL and Purdue)

- Task 6: Field Implementation and Tech Transfer
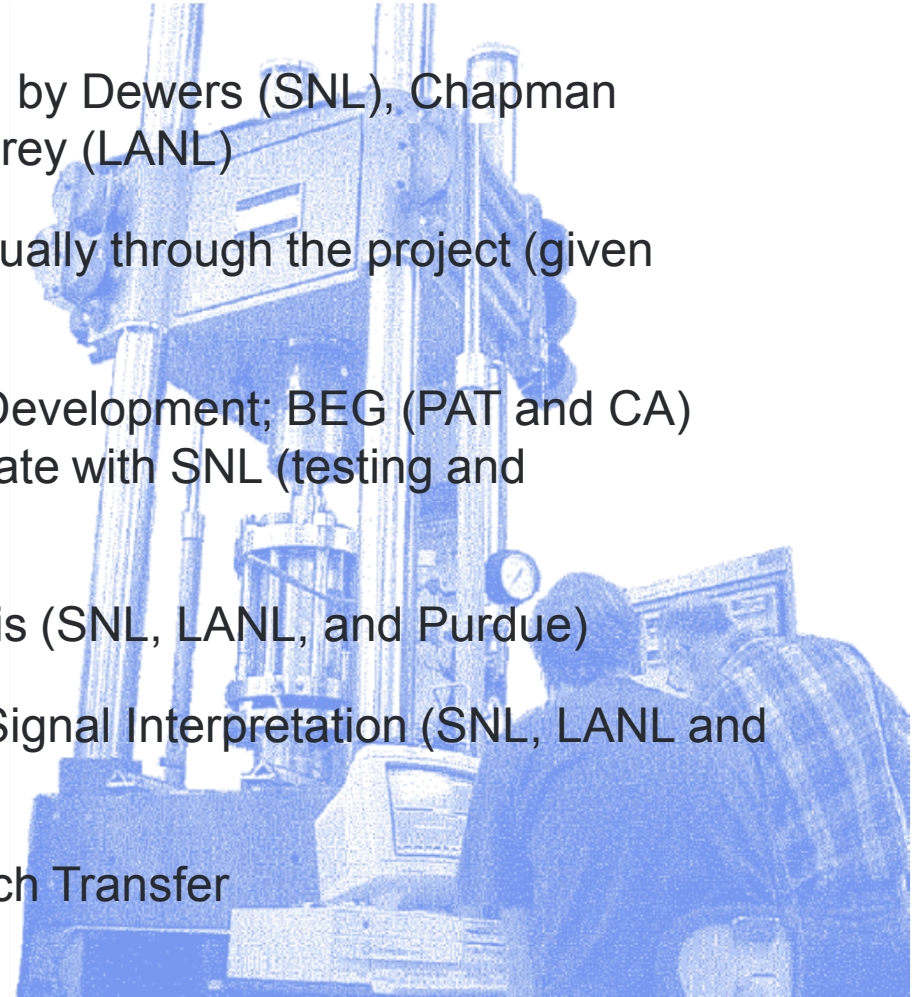
Milestones and Schedule

	Title	Task	Go/No-Go #	Milestone Description	Planned Completion Date	Verification Method
FY 18	PMP 1	1	NA	Updated Project Management Plan	Begin Q4/FY17	PMP pdf file
	Phase 1 Intro Mtng 1	1	NA	Kickoff Meeting Webinar	Begin Q4/FY17	Presentation (ppt)
	Sensor 1	3	1	Phase 1 Sensor Selection Completion	End Q1/FY18	Pdf File
	Test 1	4	1	Phase 1 Benchtop Testing Completion	End Q1/FY18	Pdf File
	Model 1	5	1	Phase 1 Wave Modeling Completion	End Q1/FY18	Pdf File
	GNG 1	2	1	Go/No Go Decision Meeting	End of Q1/FY18	Presentation (ppt)
	Phase 2 Intro Mtng 2	1	NA	Phase 2 Intro Mtng	Begin Q2/FY18	Presentation (ppt)
	Sensor 2	3	NA	Sensor Update Report	End Q4/FY 18	Pdf File
	Test 2	4	NA	Testing update Report	End Q4/FY 18	Pdf File
	Model 2	5	2	Modeling Comparison of DAS with Fiber	End Q4/FY18	Pdf File
	GNG 2	2	2	Go/No-Go Decision Meeting	End Q4/FY 18	Presentation (ppt)
FY19			3	Sensor Status Update and Report	End Q2/FY 19	Pdf File
	GNG 3	2	3	Go/No-Go Decision Meeting	End Q2/FY 19	Presentation (ppt)
	Test 3	4	4	Lab Testing Update on Sensor Performance and Impact on Cement Structure	End Q4/FY 19	Pdf File
	Model 3	5	4	Wellbore Model Report	End of Q4/FY 19	Pdf File
	Well Update	6	4	Well Testing Status Update and Report	End Q4/FY 19	Pdf File
	GNG 4	2	4	Go/No-Go Decision Meeting	End Q4/FY 19	Presentation (ppt)
FY20	Phase 3 Intro Mtng	1	NA	Phase 3 Intro Mtng	Begin Q1/FY 20	Presentation (ppt)
	Fiber Report		5	Report on use of Fiber in CA/PAT Detection		Pdf file
	Sensor 3	3	5	Update on CA/PAT Activation		Pdf file
	GNG 5	2	5	Go/No-Go Decision Meeting		Presentation (ppt)
	Well Mtng	6	NA	Status of Well Construction	End of Q1 FY 20	Presentation (ppt) and Site Visit at Devine
	Final Report		NA	Final Report on Well Testing and Noninstrusive Structural Health Monitoring	End of Q4 FY 20	Pdf File
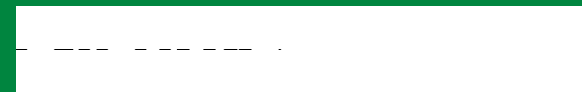
Go/No-Go Decision Points

1. **At the end of Q1 FY18**: Lab Testing and Modeling check viability of using CA and PAT technologies for use in high frequency micro-annuli and small crack detection.

2. **End of FY 18**: If modeling and benchtop testing suggest downhole Fiber DAS sensing with CBL tool activation of PAT is feasible, then project is to continue.

3. **End of Q2 FY19**: Decision as to whether off-the shelf piezoelectric materials perform satisfactorily, or further development is needed.

4. **End of FY19**: Validation of approach in Devine Field Studies and Sensor/CA in Lab Studies. Is continued well testing at Devine yielding satisfactory results? Are lab results translating to field setting satisfactorily? If so, then continue.

5. **End of Q2 FY20**: Can sensors be activated sufficiently using passive noise or by sonication of casing? Can CA contrasts be detected with fiber arrays? Decision point as to viability of full approach for noninvasive well integrity monitoring.

# Research Collaboration and Technology Transfer

- Organized AGU Wellbore Panel Session on Wellbore Integrity with panel members from industry and academia (Dec 10, 2017)

- Discussions with Steve Nowaczewski from TransCanada

- Discussions with Yang Liu and David Linton Johnson from Schlumberger-Doll

- Discussions with Pioneer on sensor deployment

- UT-BEG co-Ps are part of the UT-Advanced Energy Consortium supported by industry
  http://www.beg.utexas.edu/aec/members.php

Summary

Together, these goals for the proposed research include:

- feasibility assessment and development of noninvasive, continuous borehole cement evaluation methods

- investigating acoustic contrast agents, embedded sensors (passive acoustic tags), methods for sensor excitation, and new methods of detection of damage from the associated signals

Wellbore integrity plays a crucial role in maintaining US energy and environmental security by enabling sustainable injectivity, resource recovery, and prevention of emergent failures
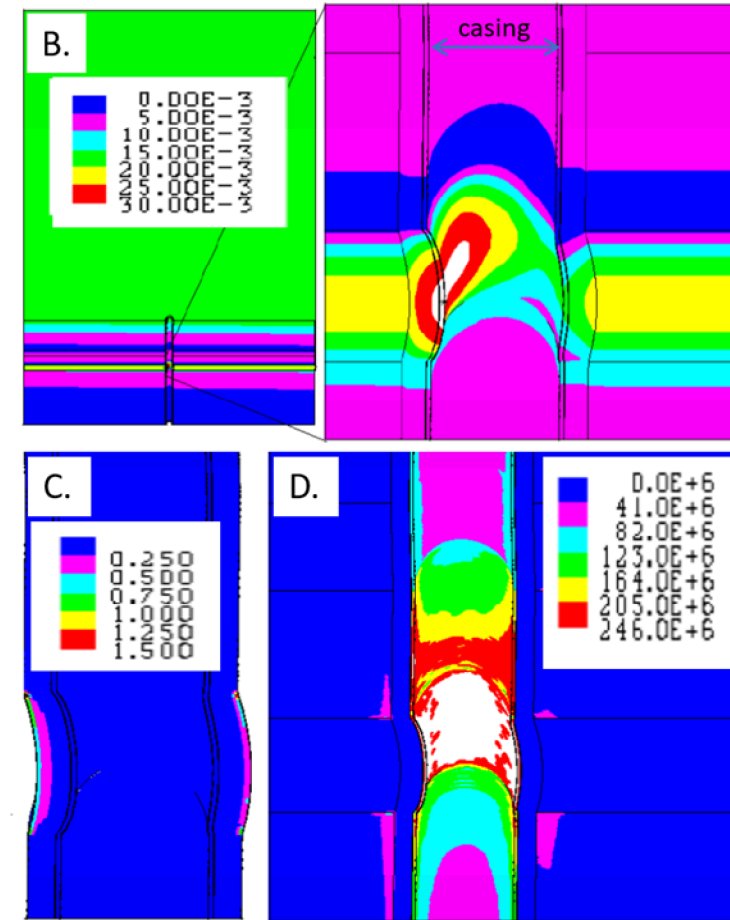
Numerical Models of Wellbore Failure, Dewers et al., in press)