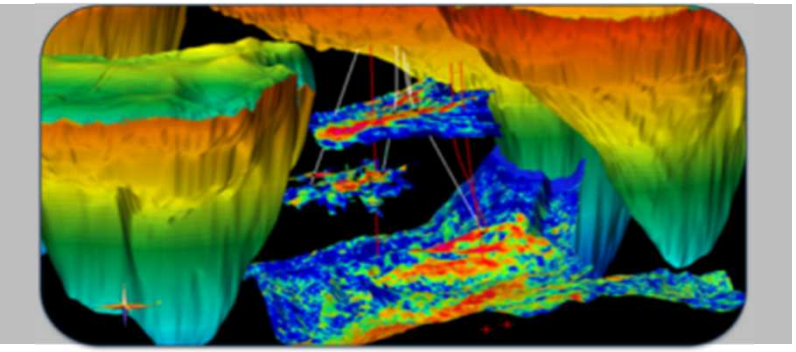
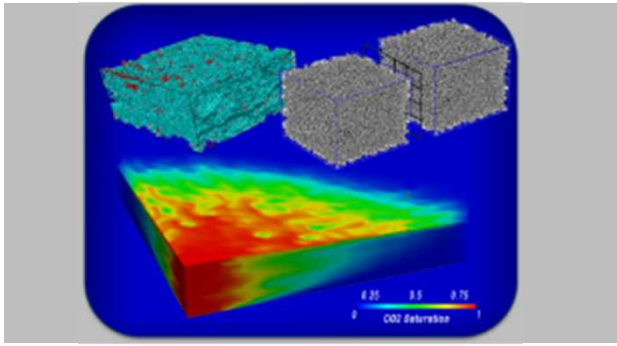
SAND2016-9833PE

Exceptional service in the national interest

Sandia National Laboratories





SubTER: Subsurface Technology & Engineering Research Development, & Demonstration Crosscut

Susan J. Altman
Manager, Geochemistry Department
October 3, 2016

U.S. DEPARTMENT OF ENERGY | NNSA National Nuclear Security Administration

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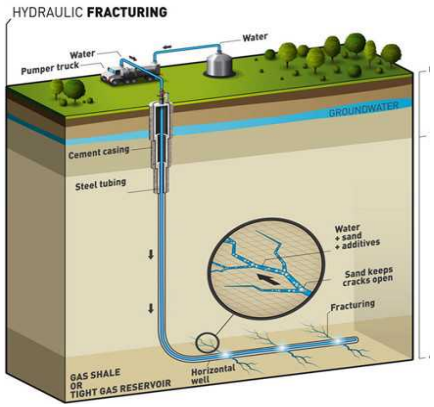
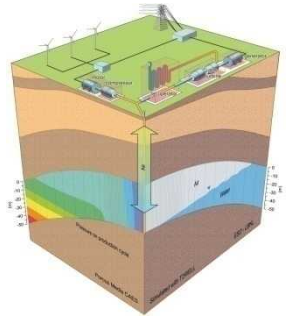
"Adaptive Control" of subsurface fractures and flow

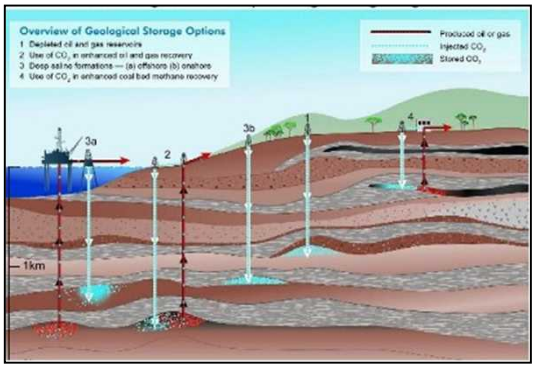
Sandia National Laboratories

Ability to adaptively manipulate – rapidly and with confidence - subsurface fracture length, aperture, branching, connectivity and associated reactions and fluid flow.



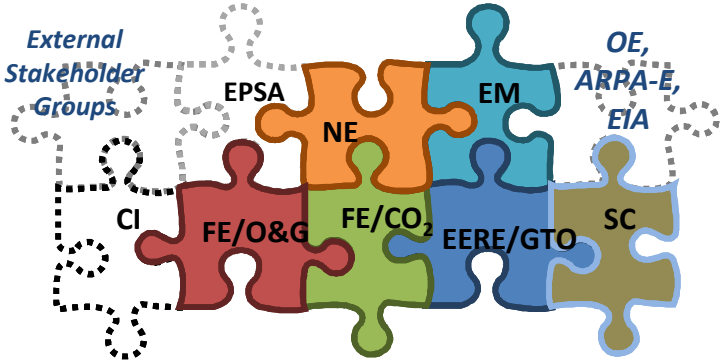


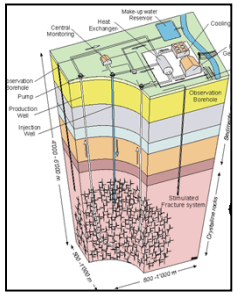
Compressed Air Energy Storage



Carbon Sequestration: Enhance injectivity, optimize storage, plug leakage pathways

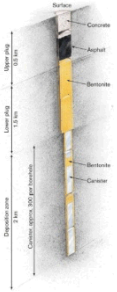
Fractures by Design: Control fracture length & branching patterns in real-time

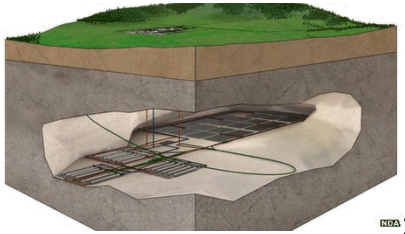




Enhanced geothermal energy

Safe subsurface storage of nuclear waste





Subsurface Control for a Safe and Effective Energy Future

Adaptive Control of Subsurface Fractures and Fluid Flow

Wellbore Integrity & Drilling Technologies

- Improved well construction materials and techniques
- Autonomous completions for well integrity modeling
- New diagnostics for wellbore integrity
- Remediation tools and technologies
- Fit-for-purpose drilling and completion tools (e.g. anticipative drilling, centralizers, monitoring)
- HT/HP well construction / completion technologies

Subsurface Stress & Induced Seismicity

- Measurement of stress and induced seismicity
- Manipulation of stress and induced seismicity
- Relating stress manipulation and induced seismicity to permeability
- Applied risk analysis of subsurface manipulation

Permeability Manipulation

- Physicochemical fluid-rock interactions
- Manipulating flowpaths
- Characterizing fractures, dynamics, and flows
- Novel stimulation methods

New Subsurface Signals

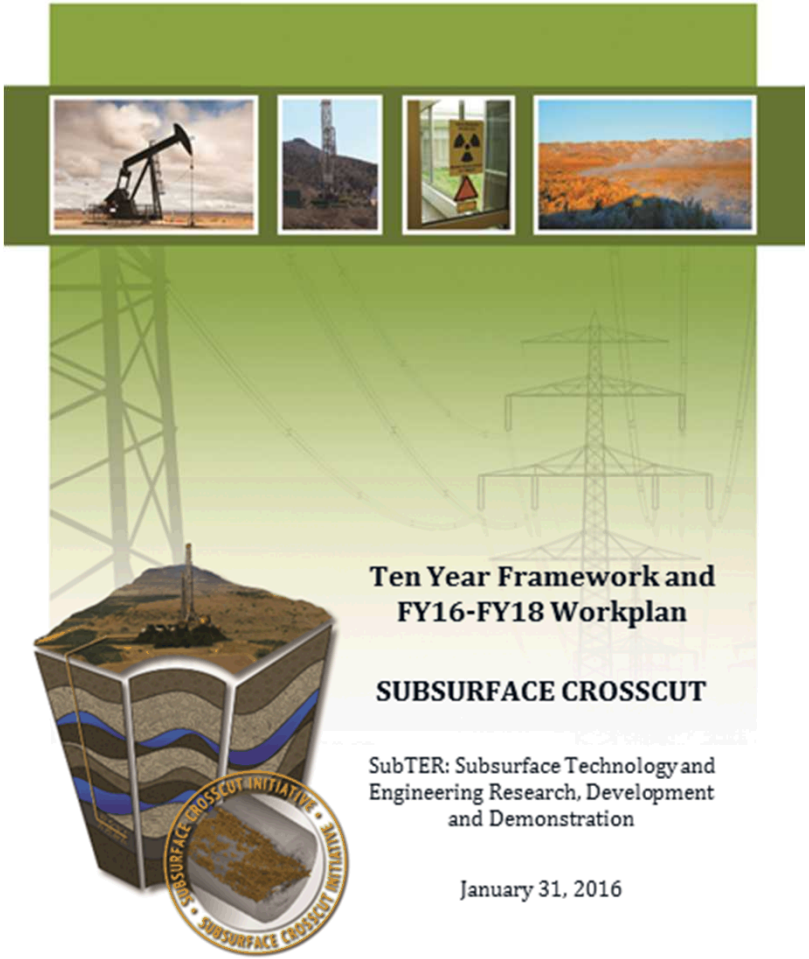
- New sensing approaches
- Integration of multi-scale, multi-type data
- Adaptive control processes
- Diagnostic signatures and critical thresholds

Energy Field Observatories

Fit For Purpose Simulation Capabilities

Multi-year work plan

Susan S. Hubbard, LBNL
Marianne Walck, SNL
Susan Altman, SNL
Jens Birkholzer, LBNL
Doug Blankenship, SNL
Alain Bonneville, PNNL
Grant Bromhal, NETL
Thomas Daley, LBNL
Earl Mattson, INL
Melissa Fox, LANL
Rob Mellors, LLNL
Rajesh Pawar, LANL
Yarom Polsky, ORNL
Curt Oldenburg, LBNL



SubTER Industry Day – Feb 2, 2016

Rice University's Baker Institute for Public Policy

Industry Participants:

President Elect - SEG
ORMAT
California Dept Conservation
Aramco Services
BP
Alberta Geol Survey
Marathon
Exxon Mobile
Shell
Chevron
Archer Daniels Midland
GeothermEx (Schlumberger)
Pinnicle/Haliburton

AAPG / GSA / AGU

Booths & Town Halls

FY17 Appropriations

- Appropriations for DOE Fossil Energy = $15M to $45M
  - Current concept is that funding will be sent to JIP-like organizations
- Appropriations for DOE Office of Science – EFRC = $0 to $11M
- Appropriations for DOE Geothermal Technologies – negligible

Next Steps (from Doug Hollett's GSA Talk)

- Finalize SubTER Multi-Year RD&D Plan
- Lab call for new projects and potential FOA*
- SubTER Energy Frontier Research Centers*
- Collaboration with NSF to use DOE Field Sites (FORGE, Shale Demos etc) as R&D platforms
- Interested in new ideas for collaborations, participation models

**Dependent on availability of FY17 appropriations*

FY16 SubTER Funding Opportunity

Sandia National Laboratories

- Two Areas of Interest
  - Field Demonstration of MVA Technologies ($3.5 - $6M)
  - Development of Novel Subsurface Imaging and Characterization Technologies ($3M)
- Partnered on 9 proposals
- Partners include
  - Texas A&M University
  - New Mexico Tech
  - Nanohmics, Inc. (CARBO)
  - Purdue University
  - University of Alaska Fairbanks
  - University of Montana
  - University of Oklahoma
  - East Carolina University
  - University of Minnesota
  - University of Missouri

FINANCIAL ASSISTANCE
FUNDING OPPORTUNITY ANNOUNCEMENT

U. S. Department of Energy

National Energy Technology Laboratory

Funding Opportunity Number: DE-FOA-0001445

Development of Technologies for Sensing, Analyzing, and Utilizing Novel Subsurface Signals in Support of the Subsurface Technology and Engineering (SubTER) Crosscut Initiative

Announcement Type: Initial

CFDA Number: 81.089 Fossil Energy Research and Development

Issue Date:	**3/7/2016**
Letter of Intent Due Date:	**Not Applicable**
Pre-Application Due Date:	**Not Applicable**
Application Due Date:	**5/5/2016 at 8:00:00 PM Eastern Time**

FY16 SubTER Funding Opportunity

Sandia National Laboratories

- Field Demonstration of MVA Technologies ($8.5M)
  - **Robust In Situ Strain Measurements to Monitor CO_2 Storage:** Clemson University (Clemson, SC) and the Georgia Institute of Technology.
  - **Advancing the Integration of Geophysical and Reservoir Simulation Tools to Monitor CO_2 Movement and Storage Permanence:** The Colorado School of Mines (Golden, CO), the United States Geological Survey, and the University of Utah. DOE: $1,114,398
  - **Automated High Power Permanent Seismic Source System for Long-Term Monitoring of Subsurface CO_2 Containment and Storage:** GPUSA Inc. (Chatsworth, CA), Lawrence Berkley National Laboratory, and the Carbon Management Canada Containment and Monitoring Institute.
  - **Field Demonstration of the Krauklis Seismic Wave in a Novel MVA Method for Geologic CO_2 Storage:** The University of North Dakota, Seismos Inc., CMG Inc., and Denbury Resources Inc.
  - **Validation of MVA Tools for Offshore Carbon Capture and Sequestration: Novel Ultra-High-Resolution 3D Marine Seismic Technology Integrated with Coring and Geochemistry:** The Gulf Coast Carbon Center at the Bureau of Economic Geology, a unit of the Jackson School of Geosciences at University of Texas at Austin (Austin, TX). DOE: $2,498,656

FY16 SubTER Funding Opportunity

Sandia National Laboratories

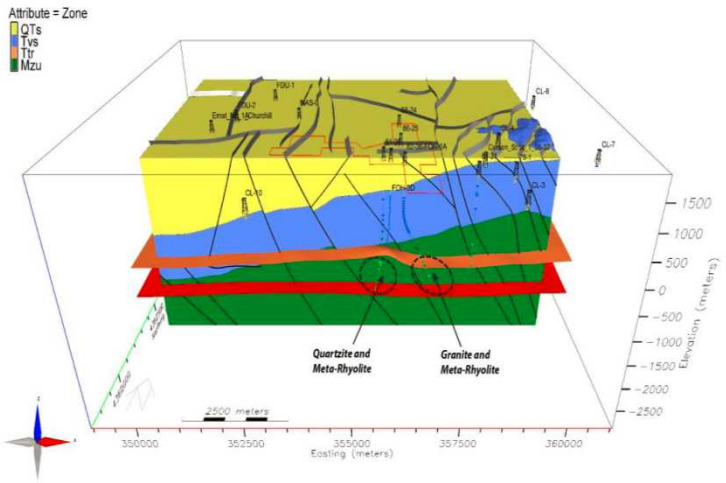
- Development of Novel Subsurface Imaging and Characterization Technologies ($3M)
  - **Development of a Novel, Near Real Time Approach to Geothermal Seismic Exploration and Monitoring via Ambient Seismic Noise Interferometry:** Baylor University (Waco, TX), the University of Nevada–Reno, and Hi-Q Geophysical Inc.
  - **Geothermal Fault Zone Dilatancy and Fluid Imaging through Integrated Geophysical, Geological, Geochemical and Probabilistic Analysis:** The University of Utah (Salt Lake City, UT), Quantec Geoscience Inc., and Geotech Ltd.
  - **A Novel Approach to Map Geothermal Permeability Using Passive Seismic Emission Tomography and Joint Inversion of Active Seismic and EM Data:** U.S. Geothermal Inc. (Boise, ID), Lawrence Berkeley National Laboratory, and Optim Inc.

Frontier Observatory for Research in Geothermal Energy (FORGE)

Sandia National Laboratories

FORGE is a dedicated DOE EGS laboratory to develop, test, & improve technologies to generate and sustain fracture networks in crystalline rock

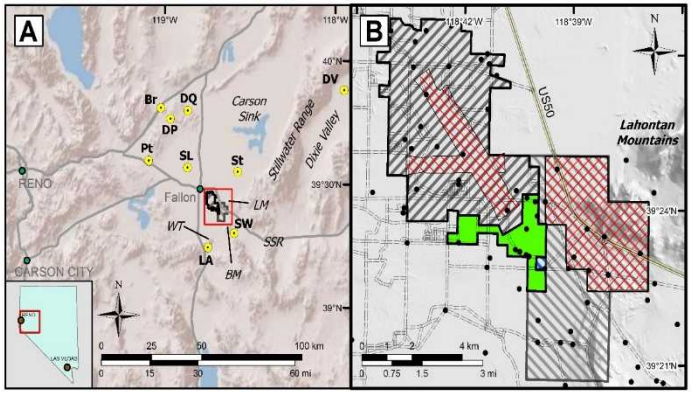
- DOE selected two teams/sites to move forward to next phase
  - SNL led project at NAS Fallon, NV & U of Utah project near Milford, UT - (SNL Coso, PNNL, and INL projects end)
  - Entering phase of environmental permitting and site characterization
- In ~16 months DOE will down select to one site
- NAS Fallon is an outstanding site with an equally qualified team
  - SNL, LBNL, USGS, US Navy, UNR, GeothermEx (Schlumberger), Itasca, Ormat

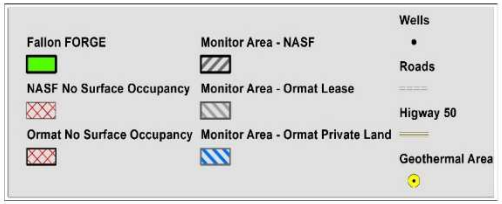


NAS FALLON

FORGE U.S. Department of Energy

Geothermal Research Observatory





FY15 SubTER Funding - Saplings

Sandia National Laboratories

Applicant and Title	Lead	Pillar	Year 1 Funding	Funding Office	Amount to Sandia
Evaluating the State of Stress Beyond the Borehole	LANL	Stress	$1,000,000	CS	$150,000
Novel 3D Acoustic Borehole Integrity Monitoring	LANL	Wellbore	$699,999	CS & GTO	$99,000
Hydraulic Fracture and Stimulation in a Deep Mine Investigation	LBNL	Stress/ Permeability	$1,000,000	GTO	$25,000
Development of microBayesloc Location Method	LLNL	Stress/New Signals	$700,000	CS	$0
Multi Variate Examination of the Cause of Increasing Induced Seismicity	NETL	Stress	$899,523	CS	$100,003
Luminescence Spectroscopy Stress Sensor In Situ Measurement	ORNL	Stress	$675,000	CS & GTO	$30,000
Ultrasonic Phased Arrays and Interactive Reflectivity Tomography	ORNL	Wellbore	$675,000	GTO	$45,000
Borehole Muon Detector for 4D Density Tomography	PNNL	New Signals	$670,000	CS	$50,000
Imaging Fracture Networks Using Joint Seismic and Electrical Change Detection Techniques	SNL	New Signals/ Permeability	$1,000,000	GTO	$460,000
Total:			**$7,319,522**		**$959,003**

Imaging Fracture Networks Using Joint Seismic and Electrical Change Detection Techniques

Sandia National Laboratories

National Lab Team
April 2016 Fracture Test

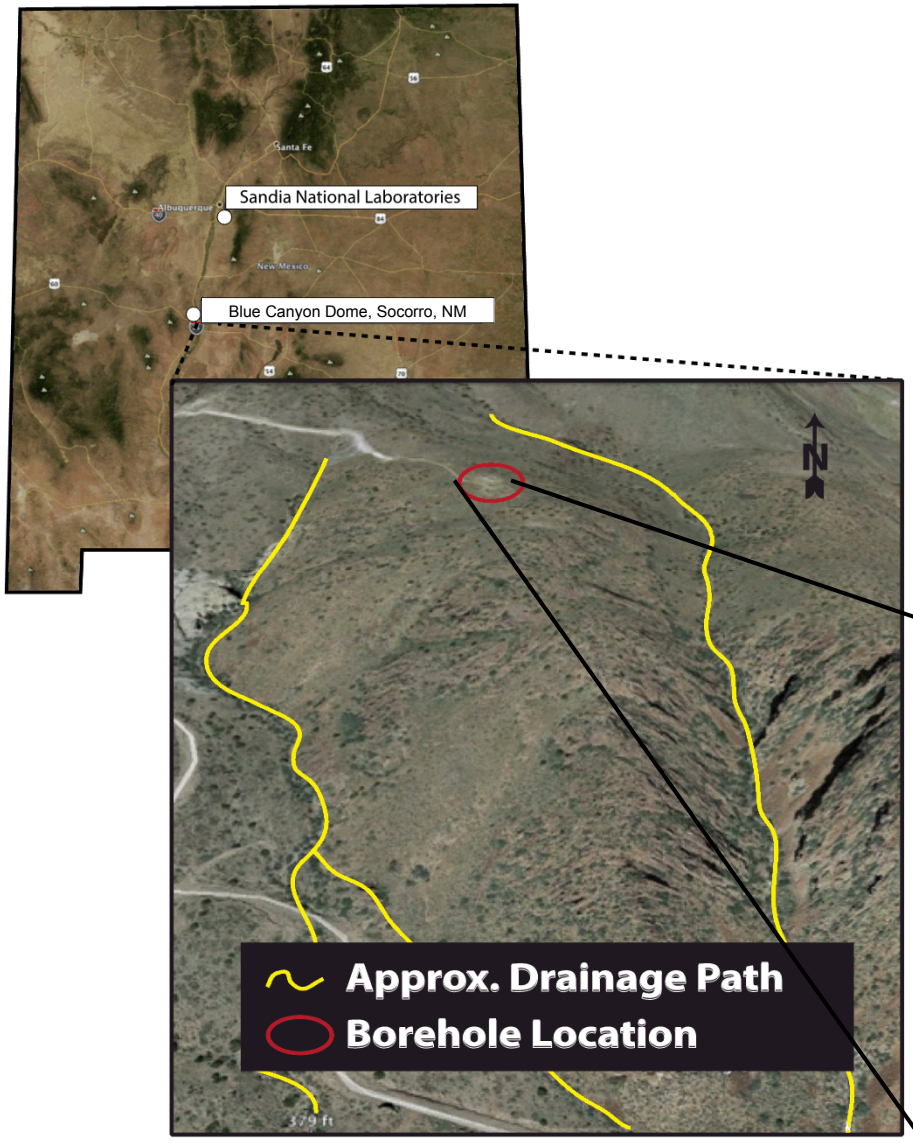
Accomplishments to Date

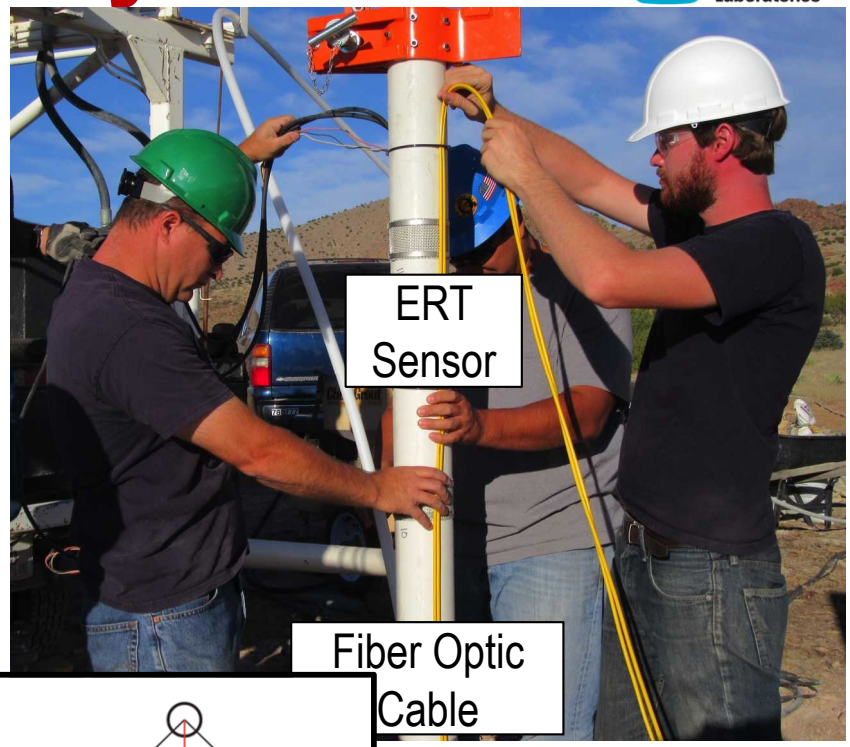
Sandia National Laboratories

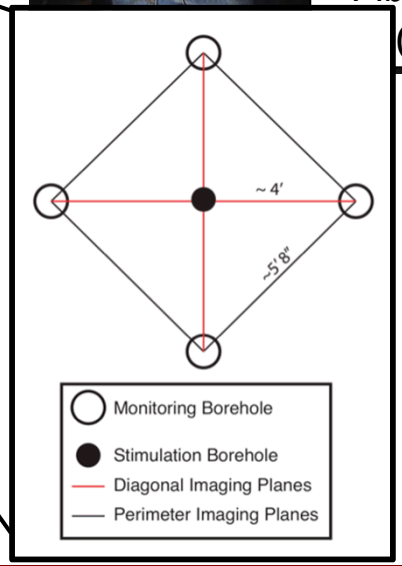
- **Demonstrated:**
  - Successful multi-organizational (FFRDC, private industry, and academia) scientific collaboration and field execution
  - High resolution (spatial and temporal) geophysical imaging
  - Real-time imaging of fracture generation and tracer migration
  - Dense multi-disciplinary data acquisition
- **Developed and/or Improved:**
  - Joint inversion of geophysical data
  - Inversion for fracture conductivity
  - Automatic picking of high frequency seismic data
  - 3D change detection imaging using DAS technology

Field Test at Blue Canyon Dome

Sandia National Laboratories

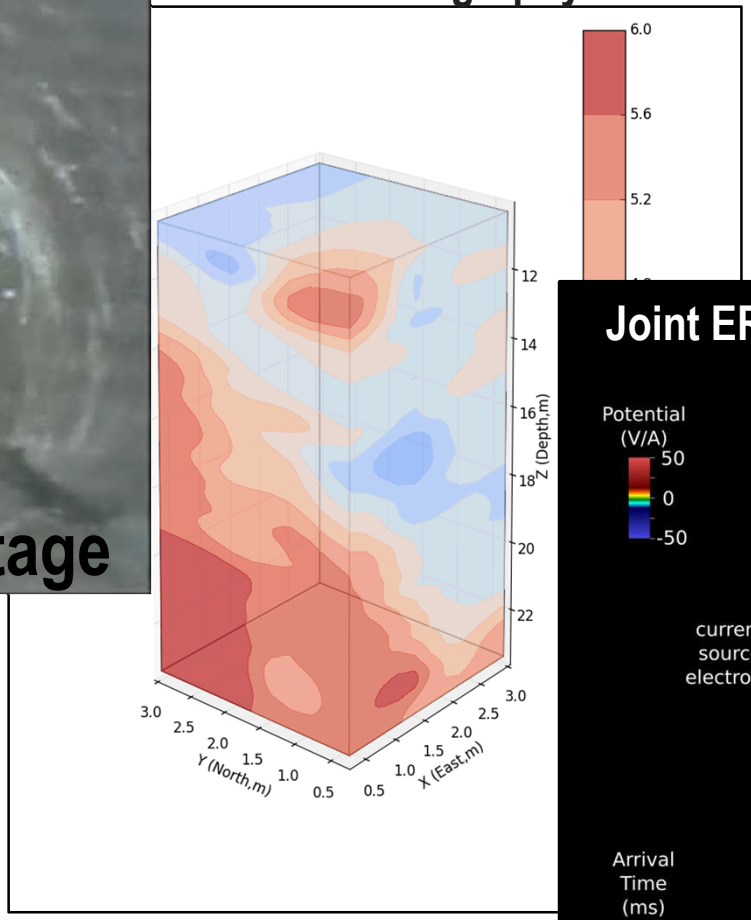






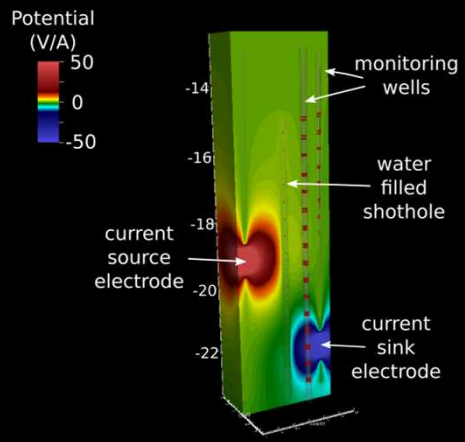
Downhole Camera Footage

Seismic Tomography

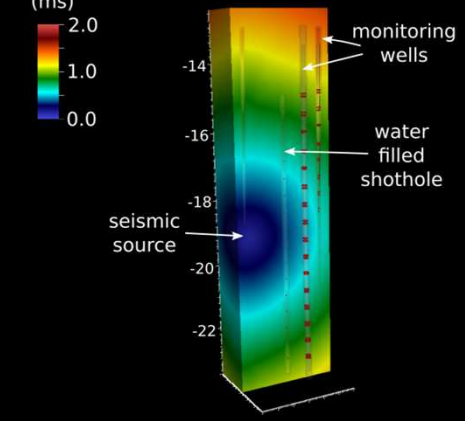


Joint ERT/Seismic Simulation

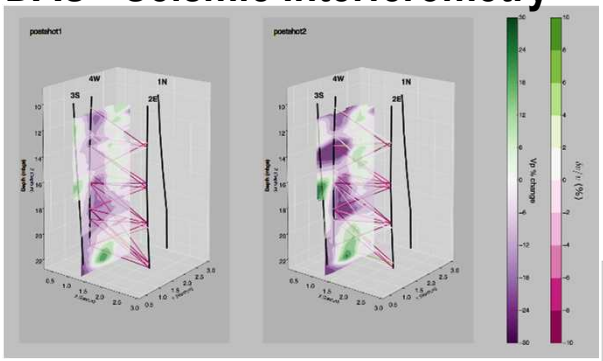
Simulated Potential



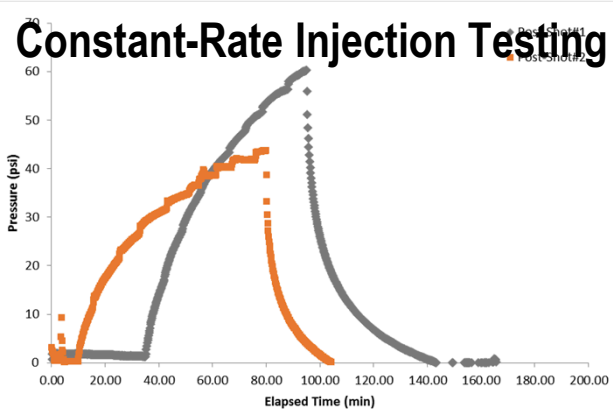
Simulated Travel Time



DAS - Seismic Interferometry



Constant-Rate Injection Testing



	Hydraulic Conductivity (ft/d)	Permeability (md)
Baseline	7E-5 to 3E-9 (book value range)	2E-2 to 1E-6 (book value range)
Post-Shot #1	0.087	32
Post-Shot #2	0.25	92

Energetic Stimulation #2

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Fly-around view of ZVI-filled fracture zone

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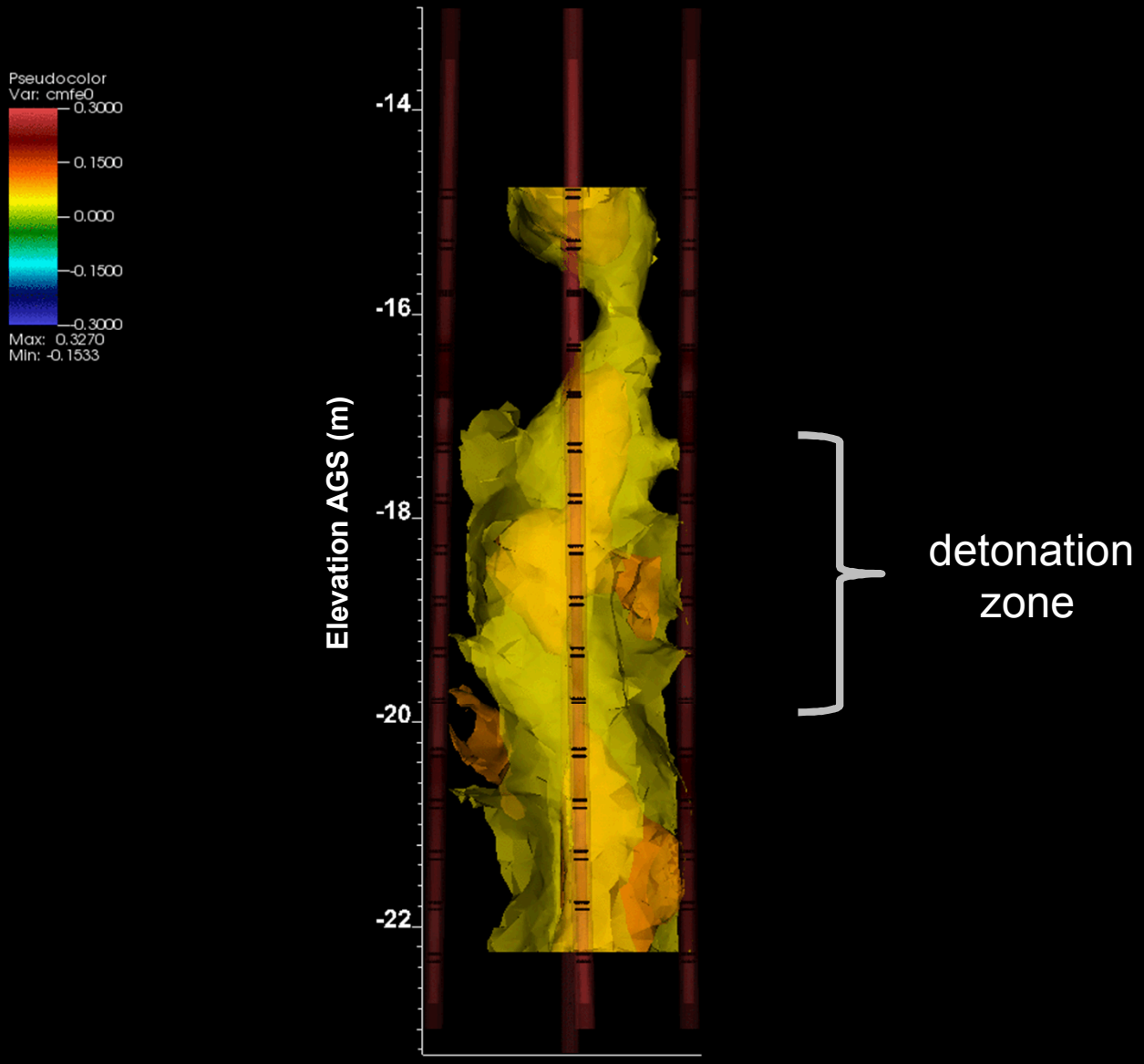


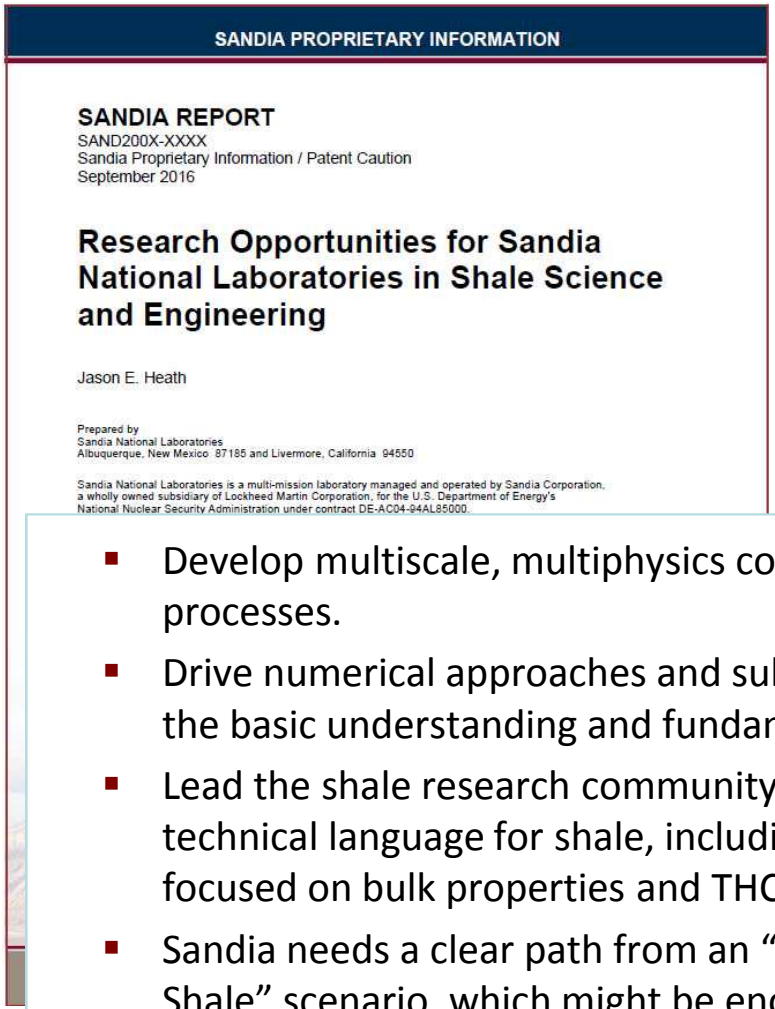
animation

Leadership in Shale Science

- **Shales at All Scales: Exploring Coupled Processes** submitted to Earth Science Reviews on April 23, 2016.
  - **Anastasia G. Ilgen*** (SNL), **Jason E. Heath** (SNL), I. Yucel Akkutlu (Texas A&M University), L. Taras Bryndzia (Shell), David Cole (Ohio State University), Yousif Kharaka (USGS), Tim Kneafsey (LBNL), Kitty Milliken (BEG), Laura Pyrak-Nolte (Purdue), Roberto Suarez-Rivera (W. D. Von Gonten Laboratories LLC), Dean Willberg (Schlumberger)
- ***Subsurface Science and Engineering of Shale***: Sandia-edited book for Wiley & Sons
  - Editors: Tom Dewers, Jason Heath, and Marcelo Sanchez (Texas A&M)
  - Shale and Clay Overview (4 chapters)
  - Repository Science & Engineering (2 chapters)
  - Subsurface Carbon Storage (2 chapters)
  - Unconventional Oil and Gas (4 chapters)
  - The Future of R&D for Shale Science & Engineering
  - Authors: Roger Slatt, Kitty Milliken, Mark Rigali, Yousif Kharaka, Paul Bossart, Yifeng Wang, Pat Brady, Bill Carey, Younane Abousleiman, Tim Kneafsey, Yucel Akkutlu, and Ahmad Ghassemi

Leadership in Shale Science

- **Next Steps**



SANDIA PROPRIETARY INFORMATION

SANDIA REPORT
SAND200X-XXXX
Sandia Proprietary Information / Patent Caution
September 2016

Research Opportunities for Sandia National Laboratories in Shale Science and Engineering

Jason E. Heath

Prepared by
Sandia National Laboratories
Albuquerque, New Mexico 87185 and Livermore, California 94550

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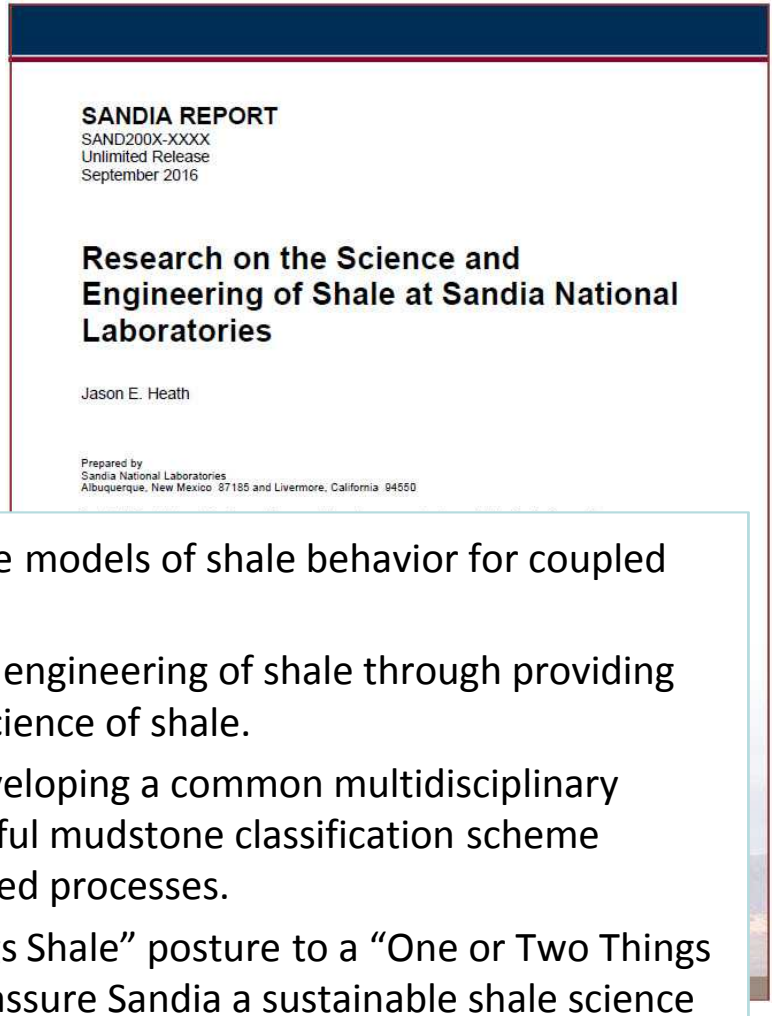

SANDIA REPORT
SAND200X-XXXX
Unlimited Release
September 2016

Research on the Science and Engineering of Shale at Sandia National Laboratories

Jason E. Heath

Prepared by
Sandia National Laboratories
Albuquerque, New Mexico 87185 and Livermore, California 94550

- Develop multiscale, multiphysics constitutive models of shale behavior for coupled processes.
- Drive numerical approaches and subsurface engineering of shale through providing the basic understanding and fundamental science of shale.
- Lead the shale research community into developing a common multidisciplinary technical language for shale, including a useful mudstone classification scheme focused on bulk properties and THCM coupled processes.
- Sandia needs a clear path from an “All Things Shale” posture to a “One or Two Things Shale” scenario, which might be enough to assure Sandia a sustainable shale science future.