

LANL: Evaluating the State of Stress Beyond the Borehole

- [D. Coblenz](#), P. Johnson

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The state of stress controls all *in-situ* reservoir activities (e.g., fracture orientation, fluid flow, wellbore breakout, fault failure, etc.), and yet we lack the quantitative means to measure it. Here we propose a method to evaluate the reservoir state of stress using geophysical data coupled with computational analysis. Our approach is based on our major advances in the joint inversion of gravity and seismic data to obtain the elastic properties for the subsurface; and is based on coupling the output from this joint-inversion with theoretical model such that strain (and subsequently) stress can be computed.

Our primary objectives are to develop an approach to extract the stress tensor at reservoir-to-basin scales and to develop a passive-monitoring approach to determine if a fault is near critical stress, as well as locate where the critical stress is taking place. The first objective will be achieved through the development and application of a novel Advance Multi-Physics Tomographic (AMT) method for extracting the elastic parameters from seismic and gravity data, which can then be used to calculate the full stress tensor within the subsurface at the reservoir to basin scale (0.1–10 km). The AMT method provides the means to determine the state-of-stress from integrated density and seismic velocity models. We will demonstrate its feasibility by applying the AMT approach to synthetic data sets to assess accuracy and resolution of the method as a function of the quality and type of geophysical data.

The second objective of evaluating critically stress faults in the reservoir will be achieved through the development of an approach which exploits very low magnitude events (VLME) including slip precursors and triggered precursors by seismic waves and tidal forces. Information about the critical state of stress will be combines with regional- to basinscale estimates of the background state of stress to provide a comprehensive image of the state of stress.

Ultimately we will obtain the differential state of stress over time to identify and monitor critically stressed faults and evolving regions within the reservoir, and relate them to anthropogenic activities such as fluid/gas injection.

LANL: Novel 3D Acoustic Borehole Integrity Monitoring

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The long-term objective of this proposal is to develop a complete 3D imaging system based on a unique acoustic source (highly collimated, high power, broad-band (10-150 kHz)) and advanced image processing techniques for borehole integrity monitoring. The proposed 3D imaging system will both enhance the imaging resolution around the borehole and also extend the investigation range beyond the wellbore casing, to the cement and further into the formation to a distance of about 2 meters from the casing.

In the first year, we plan to lay out a solid foundation for a comprehensive imaging system based on the relevant underlying physics (wave generation, propagation, interaction with defects, and the processing of such data) and laboratory experimental validation of concepts. The target investigation range for the first year will be limited to the wellbore casing and casing-cement interface.

LBNL: Hydraulic Fracture and Stimulation in a Deep Mine Investigation

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In this project, LBNL and its collaborators will develop underground facilities under the name KISMET (permeability (k) and Induced Seismicity Management for Energy Technologies) for stress measurement and modeling, testing permeability enhancement by means of fracture stimulation and shearing, and the use of active and passive seismic and electrical methods to precisely monitor fracturing and associated induced seismicity. At the KISMET site on the 4850L of the Sanford Underground Research Facility (SURF) in South Dakota, the project team will measure and model stress, carry out small to intermediate-scale stimulation (hydraulic fracturing), permeability and tracer testing, and geophysical and electrical monitoring experiments in crystalline rock. This work will be complemented by integrated laboratory studies and hydrogeomechanical modeling of fracture generation carried out at LBNL and other participants' institutions.

The main purpose of the KISMET project is to understand the effects of stress state, rock fabric, existing fractures, and stimulation approach on the character of the fracture(s) created (e.g., permeability enhancement, size, orientation, aperture), the fracturing process, and the associated induced microseismicity. Results of this research will be directly applicable to fracture stimulation and reservoir creation in Enhanced Geothermal Systems (EGS). Hydrologic testing including use of geophysically sensitive tracers and inverse modeling will be carried out to characterize fracturing and permeability enhancement. The induced microseismicity will be analyzed to locate both tensile and shear fractures and fracture propagation, and is applicable to induced seismicity in basement rocks (e.g., as observed below geologic carbon sequestration (GCS) sites and water disposal wells). The second purpose of the project is to establish KISMET as the first DOE SubTER Crosscut community deep mine observatory test site.

LLNL: Development of microBayesloc Location Method

- [Stephen Myers](#)

Lawrence Livermore National Laboratory

LLNL's microBayesloc code locates micro earthquakes with state-of-the-art precision, while providing validated estimates of location uncertainty. Analyses provided by microBayesloc are used for *in situ* assessment of fracture geometry, which is vital for testing computer models of subsurface stress. LLNL currently supports the SubTER effort with analysis of microSeismic activity at the Newberry geothermal field in Oregon, Greene County in Pennsylvania, and the greater Oklahoma region.

Development of methods for Seismic Imaging of Open Fractures (SIOF) is underway. The SIOF effort has a physical basis in enhanced scattering of the seismic wavefield when a crack is open. Numerical simulations show that SIOF signals are low in amplitude and advanced signal processing methods are being developed in order to detect them. Numerical methods of wavefield time reversal are used to back project SIOF signals to their origin. Success of this basic research project would enable us to determine not just whether fracturing is occurring, but also where the opening of fractures enhances permeability.

NETL: Multi Variate Examination of the Cause of Increasing Induced Seismicity

- [Kelly Rose](#)

National Energy Technology Laboratory

The "Induced Seismicity, Geoscience Analytics & Big Data" project is part of DOE's SubTER Crosscut initiative. The goals of this project are to i) develop a probabilistic approach that can be utilized to assess the potential for induced seismicity impacts through big data analyses, ii) develop stochastic approaches to reduce uncertainty and constrain subsurface trends, and iii) improve joint analysis of multiple datasets, with a focus on advancing "Big Data" mining and integration techniques to improve knowledge and reduce uncertainty about subsurface systems. During the first 10 months of this study, the project scope has focused on gathering and integration of key datasets needed to support the goals of the study, and evaluation of enhancements and identifying changes needed for NETL's Energy Data eXchange ([EDX](#)) system to support more robust and efficient data mining, integration and rapid analytical needs in support of the project. To date, the team has assembled over 154 dataset volumes containing millions of data records including: (i) 534,965 Well files, including, production and injection datasets, (ii) over 15,000 seismic events, (iii) over 237,758 well logs, (iv) subsurface and surface faults databases, (v), surficial & subsurface geology interpretations, (vi) aquifers, (vii) roads and cities, (viii) census data, and (ix) climate records. The team has also been conducting a meta-analysis to identify key attributes and indicators associated with natural and induced seismic events to support development of the multi-variate, probabilistic approach in the next phase of this study. Going forward, this project includes two tasks; (i) geoscience big data computing advances to support more efficient data management, fusion, and accessibility (data gathering, mining & integration) not just for this project but for the SubTER Crosscut as a whole, and (ii) developing and testing version 1 of a probabilistic approach to analyze the likelihood of induced seismicity. For the next phase of this project, 10/1/2015-~12/31/2016, the team will expand to include NETL ([project lead](#)), ANL, LANL, LLNL, PNNL, SNL and the Oklahoma Geological Survey.

ORNL: Luminescence Spect Stress Sensor In Situ Measurement

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This project will adapt a previously demonstrated method, based on photo-stimulated luminescence spectroscopy of $\alpha\text{-Al}_2\text{O}_3$, to develop both an in situ stress measurement capability and direct method for measuring behind casing cement stress. The former will directly address one of the primary goals of the State of Stress and Induced Seismicity SubTer pillar while the latter will provide a means for performing long term state of health monitoring of cement, one of the goals of the Wellbore Integrity (Intelligent Wellbores) pillar. Both applications will rely on fiber optic deployments in the wellbore. The first phase of the project will develop material formulations that allow the proposed stress measurement method to be implemented for use as either an in situ stress sensor or permanent behind casing cement stress measurement for state of health monitoring in a field environment. Material development efforts will consider both the performance and wellbore deployment feasibility of the stress responsive material. Characterization of material response over a range of pressure and temperature variations will be conducted in order to confirm that it is suitable for use as sensor in representative application conditions. In general, year 1 tasks will show that the proposed approach for measuring in situ stress and wellbore cement stress can be performed in principle, as demonstrated in a laboratory setting. Follow on activities will progress the technology toward field demonstration within the next three years.

ORNL: Ultrasonic Phased Arrays and Interactive Reflectivity Tomography

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The main goal is to research and develop the use of ultrasound phased arrays and model-based iterative reconstruction (MBIR) techniques to significantly extend both range and resolution of inspection to evaluate the integrity of and characterize the composition of the near-wellbore region for subsurface reservoirs. The MBIR framework improves measurements by modeling of the transmitters pressure waves, sensitivity of the receivers, and propagation of different mechanical waves through the medium, and by exploiting the known intrinsic characteristics of the near-wellbore region. The reconstruction strategy requires that the MBIR algorithm and the phased array system be highly integrated. Preliminary reconstructions of shallow regions are used to maximize the intensity of the ultrasonic signals at deeper regions. The final reconstruction image should correlate to the acoustic properties of the medium, which is critical for precise inspection of the well components and characterization of the near-wellbore. For the first year, we will design and develop a proof-of-concept multi-dimensional ultrasonic phased array system, define a system characterization methodology, define *a priori* parameters for ultrasonic transducers and the near-wellbore media, assess coupling strategies, implement a 3D MBIR algorithm, test the algorithm with existing acoustic simulation engines, and finally, perform laboratory-scale experiments that demonstrate superior performance compared to the current state-of-the-art. For follow on years, we will port the MBIR algorithm to other acoustic systems and prepare for field demonstrations.

PNNL: Borehole Muon Detector for 4D Density Tomography

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The muon borehole detector project objective is to demonstrate the feasibility of using an array of borehole muon detectors, combined with gravity and seismic data, to map out subsurface density variations temporally and spatially. This project will yield important progress on muon sensor development, as well as optimization of sensor deployment strategies and joint inversion techniques. The ultimate product will be an operational muon borehole detector that will be tested in the Tunnel Vault of the LANL campus that is covered by more than 61 m of overburden rocks and compared with large instruments developed by LANL and SNL. Beyond 2016, we envision testing in a deep laboratory, such as the Sanford Underground Research Laboratory (SURF) in Lead, South Dakota and finally a test in an existing deep borehole will be conducted.

The market for the deployment of such a tool is promising. The first challenge is to develop sensors with enough sensitivity to get a full 3D density image of the subsurface, yet small enough to fit in a borehole and withstand the elements over time. The second challenge is to develop a rapid and efficient inversion method that will take into account not only the different muon paths, but also the data generated by other techniques, such as gravity and seismicity, which has the potential to greatly improve spatial resolution and reduce uncertainty. This project will address these two challenges and contribute towards achieving the goals of the New Subsurface Signals pillar of the DOE SubTER program. The team includes PNNL (project lead), LANL, LLNL, SNL, the University of Utah, the University of Hawaii and Paulsson Inc.

SNL: Imaging Fracture Networks Using Joint Seismic and Electrical Change Detection Techniques

- [Hunter A. Knox](#)

Sandia National Laboratories

During the initially phase of this SubTER project, Sandia National Labs (SNL) conducted a series of high resolution seismic imaging campaigns designed to characterize induced fractures. Fractures were emplaced using a novel explosive source, also designed at SNL, that limits damage to the borehole. In the next phase of the project, SNL and its collaborators (LBNL, LLNL, and PNNL) will develop and demonstrate emerging seismic and electrical geophysical imaging technologies that will characterize 1) the 3D extent and distribution of fractures stimulated from the explosive source, 2) 3D fluid transport within the stimulated fracture network through use of a particulate tracer, and 3) fracture attributes through advanced data analysis. Focus will be placed upon advancing these technologies toward near real-time acquisition and processing in order to help provide the feedback mechanism necessary to understand and control fracture stimulation and fluid flow.

The project will consist of two phases. The objective of the first phase is to collect a comprehensive set of 4D crosshole seismic and electrical data to image the fracture network generated from a novel explosive source. In addition, autonomous seismic and electrical resistance tomography (ERT) data will be collected to image the migration of a tracer designed to enhance the electrical conductivity contrast of the fracture network. Near real-time 4D ERT imaging will be tested and demonstrated during this phase. The objective of the second phase is to use data collected during the first phase to 1) develop methods of estimating fracture attributes from seismic data, 2) develop methods of assimilating disparate and transient data sets to improve fracture network imaging resolution, and 3) advance capabilities for near real-time inversion of cross-hole tomographic data. Advancements in these areas are relevant to all situations where fracture stimulation is used for reservoir stimulation (e.g. Enhanced Geothermal Systems (EGS) and tight shale gases).