Intermediate-Scale Hydraulic Fracture and Stimulation Field Laboratory in a Deep Mine for the Investigation of Induced Seismicity and Fracture Flow

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Motivation

The importance of fractures for extracting energy from enhanced geothermal systems, and low-permeability formations with oil and natural gas, CO_2 sequestration, energy storage (natural gas or compressed air), and large-scale disposal of liquid wastes is well documented. Improvements in the recovery efficiency of unconventional hydrocarbons and geothermal energy have, in recent years, involved manipulating subsurface fractures to enhance fluid flow. Conversely, strategies to sequester nuclear waste and CO_2 in subsurface environments, have sought to minimize fracturing and fluid flow.

However, controlling fracturing, and consequently fluid flow, remains a daunting challenge largely due to the difficulty of characterizing the heterogeneous deep subsurface. Induced seismicity resulting from the alteration of subsurface stress and permeability is of great concern to the public and threatens safe and sustained subsurface energy production and waste storage. Due to the complex relation between hydraulic fracturing (which includes inducing shear, tensile, and mixed mode failure) and permeability changes, and the difficulty in accessing the subsurface for measurements, current knowledge has largely been developed using small-scale laboratory experiments, remote monitoring, empirical field production evidence, and numerical modeling. Intermediate scale experiments have been performed in both shallow and deep mines, but not totally focused on the entire suite of processes relating to fracture creation, stress alteration and shadowing, permeability changes, and the spectrum of induced and triggered seismicity phenomena. In addition, the effects of fluids on induced and natural fractures need to be characterized in order to design effective stimulation techniques. These goals can best be achieved if there is physical access to the deep underground, where fracture manipulations take place and advanced instrumentation can be deployed to measure responses - both at the location of fracturing and remotely. Although experiments have been performed at underground sites in the past, advanced instrumentation will allow for wide bandwidth high resolution experiments to mulitiscale processes as well as allow direct access and validation.

Therefore, we propose to develop a sub-region of the Sanford Underground Research Facility (SURF) as an experimental site for advancing next generation subsurface stimulation approaches that allow maximum utilization of the subsurface for energy production and storage while at the same time understanding and minimizing induced seismicity. SURF, which has been developed by DOE as an underground physics laboratory, offers significant opportunities for leveraging investments to advance subsurface engineering. The access to depths up to 1428 m in this facility provides an unprecedented opportunity to develop new approaches to stimulate, monitor, and model stimulation and hydraulic fracturing. The existing infrastructure, availability of mine staff for drilling, and in-mine presence of support staff make feasible a field campaign. The proposal defines the budget needed for an initial suite of activities to plan and layout the experimental underground test site (FY14) and to initiate stimulation experiments, monitoring and modeling activities (FY15). In addition to the activities proposed here, we envision SURF to be a community subsurface observatory that will be widely accessible to enable *in situ* testing of a variety of technologies important for subsurface control.

SURF Background

The former Homestake Mine in Lead, South Dakota, is currently home to SURF. Originally a gold mine, Homestake has excavations extending from the surface to depths of 2400 m. The many levels in the mine are connected by shafts, winzes, and ramps. The geologic setting of the Homestake Mine is metamorphic rock with fracture-controlled permeability. Matrix permeability in the Precambrian phyllites, schists, and amphibolites is very low, but high-permeability fault and fracture zones cut these rocks. Beds are tilted to nearly vertical, which provides the opportunity to access the same geology at a range of depths, and hence at different stress states. While the geology provides ample opportunities for working within test beds directly relevant to geothermal systems and deep waste disposal wells, the extensive infrastructure provides an opportunity to advance our ability to monitor, model and eventually engineer subsurface fractures relevant to many energy strategies.

Proposed Research

We propose to locate and develop an experimental subsurface community observatory (Task 1) at SURF, use the facility to hydraulically create fractures and monitor resulting fracture propagation and induced seismicity(Task 2), and advance models that incorporate new datasets and understanding (Task

3). Subsequent (out-year activities) could focus on using the developed monitoring and modeling approaches to optimize fracture creation and fluid flow while concomitantly minimizing induced seismicity.

Task 1: We will work with SURF management (including the physics community working at SURF) to identify, characterize and develop an experimental test site at the 1428 m (4850 ft) level. Among other data, geologic logs of existing drill holes will be reviewed to develop an initial fracture network model for the test site, which will be used to site the new borehole location. We will install an "exploratory" horizontal borehole (25-50 m in length) into an existing drift wall. Fractures on drift walls near the horizontal well will be mapped and the exploratory well logged for fractures. An important element will be to understand and measure the existing stress field and fracture properties in order to plan future fracture stimulation and hydraulic fracturing experiments. Instrumentation will be selected for measuring critical parameters such as pore pressure, fluid flow, deformation, fracture behavior/flow, and geophysical monitoring (broad band multi-component micro-seismic, continuous active seismic monitoring, fiber optic sensors, EM, etc.).

Task 2: Initial characterization of the existing fractures and stress field will be followed by full instrumentation and characterization of the stress, geologic, hydrologic and fracture system before starting any active hydraulic fracture stimulation. Once fully characterized and monitored, initial stimulation will be carried out. Analysis of near-fracture time lapse monitoring datasets will be performed to map the distribution of fractures, fluid flow, and fracture behavior and stress changes

Task 3: Through this task we will develop full-scale simulation capabilities for fracture propagation with realistic heterogeneity and fluid properties using input from Tasks 1 and 2. Integration of data and knowledge from the advanced monitoring datasets are expected to improve our predictive understanding of subsurface stress manipulation and associated fracture propagation and induced seismicity.

Many out-year (post FY15) activities could be conducted at the SURF community observatory. Select examples include: wellbore technologies to ensure integrity; advanced approaches to quantify and manipulate fluids in fractures; development of advanced approaches to control fracture propagation; identification of new subsurface signals and testing of new imaging approaches; and identification of optimized sensing suite and rapid assimilation into predictive models. Wellbore excavation (drill backs) are also possible to enhance detailed understanding of fracture patterns.

Timeline and Funding

We propose an initial suite of activities (associated with Task 1) to be completed over a period of 6 months with a budget of $250k. We propose that Tasks 2 & 3 be performed in FY15 (budget TBD).

		Months since start of Project																	
Task	**Sub-task**	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1	Identify site	x	x																
	Characterization		x	x	x	x													
	Drill borehole				x	x													
	Develop experimental plan				x	x	x												
	Identify equipment for experiments																		
	Brief community																		
2	Procure equipment for experiments							x	x										
	Fabricate additional equipment							x	x	x	x								
	Install sensors											x	x	x					
	Stimulation Experiments													x	x	x			
	Data Analysis											x	x	x	x	x	x	x	x
3	Numerical Model development									x	x	x	x	x	x	x	x	x	x

Team and SURF Logistics

The LBNL team brings significant expertise to the proposed scope, e.g., in geophysics and fiber optics (Tom Daley, Barry Freifeld), induced seismicity (Ernie Majer), underground field expertise (Pat Dobson), and numerical modeling (Curt Oldenburg, Jens Birkholzer, and Jonny Rutqvist). We have discussed the work with Kevin Lesko (SURF Head of Operations, LBNL) and Jaret Heise (SURF Science Liaison Director) about the proposed effort, and have received overwhelming encouragement from them.