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Editor's Note

This issue of the ARMA e-Newsletter is a particularly important one to our readers. In it you will find articles describing two new major initiatives undertaken by the U.S. Department of Energy (DOE), both of which have a strong rock mechanics/geomechanics component.

The SubTER (Subsurface Technology and Engineering Research, Development and Demonstration) initiative is intended to achieve adaptive control of subsurface fractures and fluid flow in order to radically improve subsurface energy production and waste storage strategies. One of the first projects supported by SubTER is kISMET, under which a hydraulic fracture and stimulation field laboratory is being established at the Sanford Underground Research Facility (SURF) in Lead, South Dakota, for research on permeability enhancement and induced seismicity in crystalline rock. kISMET is the subject of the article by Curtis Oldenburg (LBNL) and others.

The second initiative, DBD (Deep Borehole Disposal) is being considered by the US Department of Energy Office of Nuclear Energy (DOE-NE) as an alternative to a mined geological repository for small radioactive waste forms. Kristopher Kuhlman (SNL) describes in some detail the concept of disposing of such waste in a deep hole, the safety of deep hole storage, and the field test that is now in preparation, involving two 5 km deep holes.

These two major national projects are not only a shot in the arm for the American rock mechanics community, but they also highlight the importance of this field to our energy supply, national security and general wellbeing.

Bezalel Haimson

Chair, ARMA Publications Committee

kISMET at SURF:

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

Submitted by Curtis M. Oldenburg (Senior Scientist), Patrick F. Dobson (Staff Scientist), Thomas M. Daley (Staff Scientist), Jonny Rutqvist (Staff Scientist), and Jens T. Birkholzer (Senior Scientist); Earth and Environmental Sciences, Lawrence Berkeley National Laboratory.

Introduction and Motivation

The purposeful control of subsurface fluid flow requires engineering of subsurface permeability, which in turn relies on the ability to create and design fractures of desired size, aperture, orientation, and connectivity. For applications such as geothermal energy and oil and gas production, the reservoirs are deep and accessible only by long boreholes (wells). The efficiency of recovery of heat or hydrocarbons from these reservoirs is often assisted by well stimulation to increase fluid flow; however, design and execution of effective stimulation depends on knowledge of key properties such as stress state, rock structure and fabric, fractures, and permeability. Given the remote nature of the subsurface environment, it is very challenging to characterize these properties before and after stimulation (e.g., Dusseault, 2011). This situation results in incomplete knowledge of the effects of active stimulation as obtained from hydraulic testing and geophysical monitoring, thereby preventing development of advanced adaptive control of fractures for permeability management. Similarly, distant monitoring of microseismicity associated with stimulation can result in uncertain event locations and low-resolution mapping of dynamic fracture-tip propagation and hydroshearing processes. In contrast, deep mine environments offer the possibility of detailed characterization and proximal monitoring of intermediate-scale fracture stimulation, which in turn provides high-resolution data sets for improved understanding of stimulation and related model development and testing.

Overview of kISMET

Earth scientists from several national laboratories and three universities have initiated work on a $1.25M project to develop a new underground facility at the Sanford Underground Research Facility (SURF) in Lead, South Dakota (Heise, 2015), for research on permeability enhancement and induced seismicity in crystalline rock. The project is funded by SubTER (See Note 1).

Under the name kISMET (permeability (k) and Induced Seismicity Management for Energy Technologies), the facility will be located on the 4850L of SURF (4,850 feet below ground surface) where numerous existing physics research facilities are currently operating (See Note 2). At the kISMET site, we 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 along with integrated laboratory studies and hydrogeomechanical modeling of the stress field and fracture generation.

The SURF site has been the subject of detailed geologic, hydrologic, and geomechanical studies (e.g., Carter et al., 2011; Ebenhack, 2013; Gage et al., 2014; Girard et al., 1997; Harms et al., 2010; Hart et al., 2014; Murdoch et al., 2012; Roggenthen and Koch, 2013; Wang et al., 2007) that provide valuable background information for the kISMET field experiments. The geology of the SURF site consists of a sequence of intensely folded Precambrian metamorphic schists,

Note 1: SubTER

SubTER is the U.S. DOE's Subsurface Technology and Engineering Research, Development and Demonstration "Crosscut" initiative, which started in 2014. With U.S. economic development, environmental sustainability, and national security strongly dependent on clean and affordable energy, motivation for SubTER arose from the challenges faced by the nation in producing and managing subsurface energy and energy-related waste streams. The term crosscut refers to the recognition that common scientific and technical challenges currently limit optimal and responsible utilization of the subsurface for a variety of energy strategies, including oil and gas, geothermal energy, geologic carbon sequestration, and nuclear waste disposal. The overarching, ten-year SubTER goal is *adaptive control of subsurface fractures, reactions, and fluids*. Coordinated research on subsurface wellbore integrity, stress and induced seismicity, permeability control, and new subsurface signals is proposed, and DOE has initiated support to several national labs and associated university and industry partners on early projects. On-going funding opportunities are expected. For more information see: http://esd1.lbl.gov/research/projects/subter/index.html

Note 2: SURF

The Sanford Underground Research Facility (SURF) is located in the former Homestake Gold Mine in Lead, SD. This facility is under ownership and operation authority of the South Dakota Science and Technology Authority, with scientific management provided by the U.S. DOE through Lawrence Berkeley National Laboratory. SURF is currently home to 18 active research programs, among which are three major physics experiments (Heise, 2015). A fourth experiment, the Long Baseline Neutrino Facility and associated Deep Underground Neutrino Experiment (LBNF/DUNE) is moving forward and is designed to detect neutrinos originating at Fermilab in Batavia, IL. The physics experiments and kISMET are all located on the 4850L (4,850 feet below ground surface). The rock at SURF is tightly folded, low- to moderately-fractured Precambrian schist, phyllite, and amphibolite. Two shafts (Ross and Yates) provide surface access to the 4850L. Extensive collections of rock core and geologic and geotechnical data from over 100 years of operation are available and accessible to researchers. SURF is committed to growing its scientific and engineering research portfolio. For more information, refer to: http://sanfordlab.org phyllites, and amphibolites, which have been cut by a number of Tertiary rhyolite dikes. It is also host to the Homestake gold deposit, which was the impetus for the underground workings that served the largest gold mine in North America (Caddey et al., 1991).

The kISMET project is primarily aimed at understanding 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). Extensive 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 this project is to establish kISMET as the first deep-mine SubTER observatory test site to facilitate achievement of SubTER goals, as recommended in the 2014 Jason's report (JASON, 2014). In the long term, we envision the kISMET site(s) to be community underground laboratories for SubTER teams working on various objectives (such as novel stimulation or monitoring methods) and generating observational data for analysis and modeling by the community.

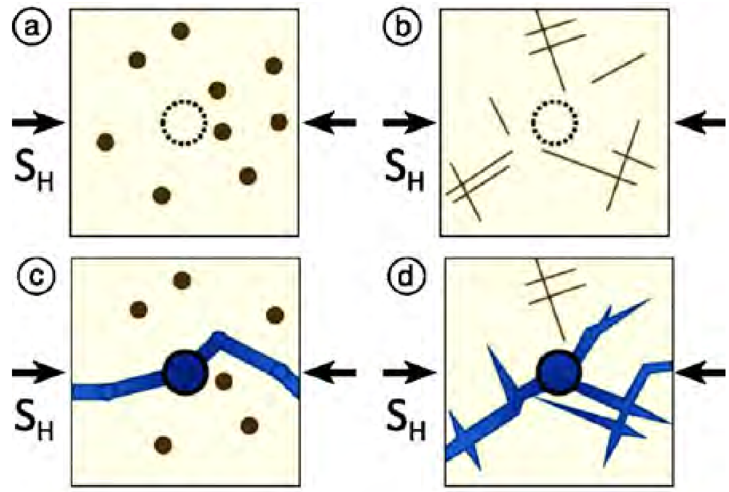

Figure 1. Schematic representation of potential response to hydraulic stimulation in geothermal reservoirs (Zang et al., 2014). Weaker sedimentary rocks (left column) and stronger crystalline rocks (right column) are displayed prior to (upper row) and after (lower row) hydraulic stimulation. Arrows indicate orientation of S_{HMax}, and large circles depict location of stimulated borehole. Filled circles indicate open pores in sediments and lines indicate preexisting fractures. Fluid flow pathways following stimulation are highlighted in blue.

Research Needs

The response of a reservoir to hydraulic stimulation is dependent on rock properties, stress orientation, and the presence and orientation of preexisting fractures (Figure 1). Fracturing is the key to enhancing permeability for subsurface energy applications in tight formations. For example, in EGS, hydraulic fracturing or shearing of existing fractures is used to generate flow paths through which water can be injected and produced for energy extraction. Challenges in EGS include difficulty in estimating stress state, the frequency, magnitude, and temporal and spatial distribution of induced microseismic events, effects of heterogeneous rock properties (e.g., rock fabric and existing fractures), and the resulting low heat recovery due to non-optimal fracture networks (Grant and Garg, 2012). Zang et al. (2014) suggest that for crystalline rocks, tensile crack formation may dominate in the near-field area, while hydroshearing of existing fractures may be the dominant process farther away from the well bore. In oil and gas production, fracturing to enhance permeability in multiple stages along long horizontal wells in organic-rich source rocks can be influenced by rock fabric (e.g., Suarez-Rivera et al., 2013). Production from hydrocarbon wells is often dominated by a few fractures, resulting in poor zonal coverage (Warpinski et al., 2009). Finally, there is a need in many injection- and storage-related applications (e.g., GCS, deep disposal of produced water, compressed air energy storage) for enhancing and controlling permeability to improve injectivity around the well, and to reduce permeability of seals or cap rocks. All of these challenges can be addressed through greater knowledge of how stress state, rock fabric, existing fractures, and fracturing approach interact to affect permeability creation and associated microseismicity.

kISMET Project Plan

We are planning to drill and core five 50-m-deep vertical boreholes which will provide the test bed for Phase 1 (Figure 2). Vertical boreholes are planned because the maximum principal stress at SURF is sub-vertical (Wang et al., 2012). From the orientations of the generated fractures, the direction of the minimum horizontal stress can be approximately determined. Subsequent fracture experiments can be carried out in horizontal boreholes drilled in the direction of minimum horizontal stress.

The 50-m-long boreholes at the kISMET site on the 4850L offer the opportunity of dual-stage fracturing. We hypothesize that schistosity and existing fractures will play a significant role in controlling hydraulic fracture orientation (e.g., Nasseri et al., 1997; Zang et al., 2014). Hydraulic fracturing of similar rock types in the Black Hills has proved successful in improving well permeability (Rahn, 1994). EPS sites are

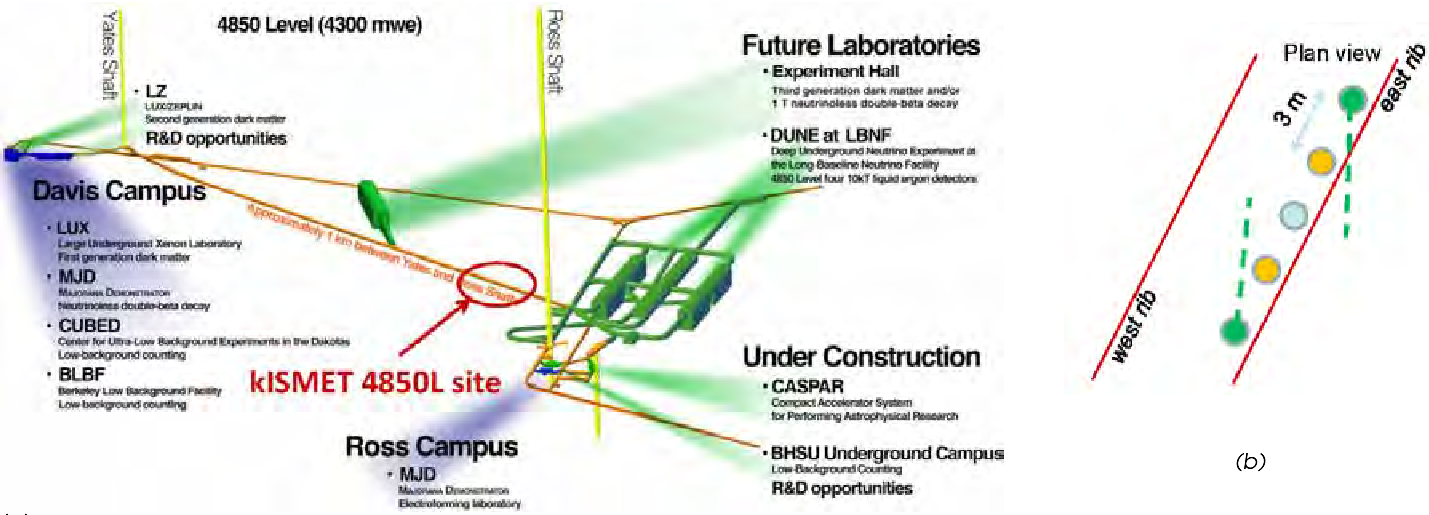

Figure 2. (a) kISMET location on the 4850L and (b) planned well layout. The two outer wells (green) are deviated to form a five-spot pattern at depth with the middle well (light blue) in the center.

known to be located in similar schistose rocks in which fracture stimulation will be essential to unlock energy recovery potential.

A variety of tasks will be carried out by LBNL, our national lab collaborators, and a team comprising Univ. of Wisconsin-Madison, Golder Associates, Stanford, and Sandia National Laboratories (SNL), hereafter referred to as WGSS. Prior to and following drilling of boreholes for stimulation and monitoring, we will analyze extensive existing SURF datasets, map fractures, and analyze and model stress (LBNL, WGSS, LLNL, South Dakota School of Mines & Technology (SDSMT)). Following coring, laboratory studies of selected core will be undertaken (LBNL, WGSS) to determine geomechanical and geophysical properties, which will feed into modeling for design of hydraulic fracturing experiments and the monitoring campaign (LBNL, INL, LLNL, LANL). Borehole and remote monitoring instrumentation including real-time active and passive seismic will be developed and installed by LBNL (e.g., Ajo-Franklin et al., 2011), along with Electrical Resistance Tomography (ERT) (LBNL) including near-realtime ERT (PNNL). Pre-stimulation hydraulic testing will be carried out by WGSS and LBNL, with the hydraulic fracturing itself carried out by WGSS and SNL. Post-stimulation hydrologic testing and tracer studies will be carried out by LBNL, INL, and WGSS, while the monitoring and modeling groups (LBNL, LLNL, INL, PNNL, LANL) analyze and model resulting data. Significant effort will go into microseismic monitoring for locating discrete events during the fracturing process. This work supports SubTER goals of better understanding of induced seismicity and development of active fracture control technologies.

Expected Benefits

Results of this project will benefit a wide variety of subsurface energy technologies. The crystalline rock at SURF means that the most direct beneficiary of the project will be geothermal applications (EGS) which often suffer from short-circuiting or low effective hydraulic conductivity, but effects of rock fabric that we will study are also relevant to fracturing in marl and shale, of importance to unconventional hydrocarbon reservoirs. Similarly, the fracture propagation monitoring that is enabled by proximal access at the kISMET site will yield general knowledge about effects of stress, rock fabric, existing fracture network, and stimulation approaches on resulting fracture character. On the induced seismicity side, the work proposed will lead to better understanding of event triggers and wave propagation in fractured anisotropic rock. Finally, microseismic monitoring of fracturing has broad applicability, and knowledge gained in the project about wave propagation in fractured rock and shearing of existing fractures will apply to EGS, GCS, and waste-water injection-related induced seismicity. In addition, the kISMET site will provide long-term benefits as an experimental facility for collection of community data sets related to SubTER pillar goals.

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Deep Borehole Disposal Concept and Field Test

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Deep Borehole Disposal Concept

Deep borehole disposal (DBD) is being considered by the US Department of Energy Office of Nuclear Energy (DOE-NE) as an alternative to a mined geological repository for small radioactive waste forms (DOE-managed High Level Waste and Spent Nuclear Fuel). Deep borehole disposal below 3 km depth in crystalline basement has been recognized as a potentially viable option for the disposal of such wastes for several decades. Advances in drilling and characterization technologies have decreased the costs and increased the reliability of constructing boreholes of sufficient diameter (8.5 to 17 inches in diameter) to 5 km total depth in crystalline basement rock (Cornwall, 2015; *Science*, 349 (6244):132-135).

The DBD concept comprises drilling a borehole or array of boreholes with a bottom-hole diameter of 8.5 to 17 inches into crystalline basement rock in a geologically stable continental location, emplacing DOE-managed high-level waste in the lower 2 km of the borehole, and sealing the upper portion of the borehole. The lower portion of the borehole seal will be emplaced directly against the top 1 km of crystalline basement, whereas the portion of the borehole through the sedimentary overburden will be sealed inside the casing emplaced for stability. The disposal concept is shown schematically in Figure 1. The borehole sealing system that would be deployed in a future disposal borehole is an area of active research, but would likely consist primarily of compacted bentonite seals and cement plugs.

Several geological or hydrogeological conditions that could compromise the safety of deep borehole disposal should be avoided. The presence of economically attractive resources, such as potential ore deposits, petroleum reservoirs, or geothermal resources in the disposal zone could attract future human intrusion. Young meteoric pore fluids at depth are likely indicative of high-permeability pathways (i.e., advection rather than diffusion-dominated) to the surface or shallow formations. Over-pressurized fluids at depth (i.e., significantly greater than hydrostatic pressure) related to tectonic activity, active sedimentary basins, or geothermal heating, might drive upward convection and enhance radionuclide migration away from the disposal zone. Active volcanism, excessive seismicity, and strong differential horizontal stress could decrease the integrity of the borehole sealing system and waste isolation. Even when areas with these unfavorable factors are excluded, many potential suitable locations remain across the continental United States.

Several factors suggest deep borehole disposal would be safe. The great depth of the disposal concept provides confidence in isolation of these wastes from surface and near-surface environments, relative to shallower mined geological repositories (The examples of Onkalo, Finland and the Waste Isolation Pilot Plant, USA are shown in red in Figure 1). Borehole seals and potential flow pathways are up to 10 times longer in the Deep Borehole Disposal concept than in mined repositories. Increasing groundwater salinity with depth, as well as decreasing fracture aperture and bulk permeability with depth, will ensure long pore fluid residence times, rock-dominated fluid geochemistry, low fluid flow velocity, and effective isolation from shallow groundwater resources (A typical lower limit is indicated by the dashed blue line in Figure 1).

A stable fluid density profile (dense saline water below fresh water) counteracts upward groundwater flow due to geothermal gradients. Geochemically reducing, high salinity, rock-dominated conditions in deep crystalline basement will stabilize redox-sensitive, low-solubility phases, prevent colloidal transport of radionuclides, and enhance sorption and retardation of key radionuclides.

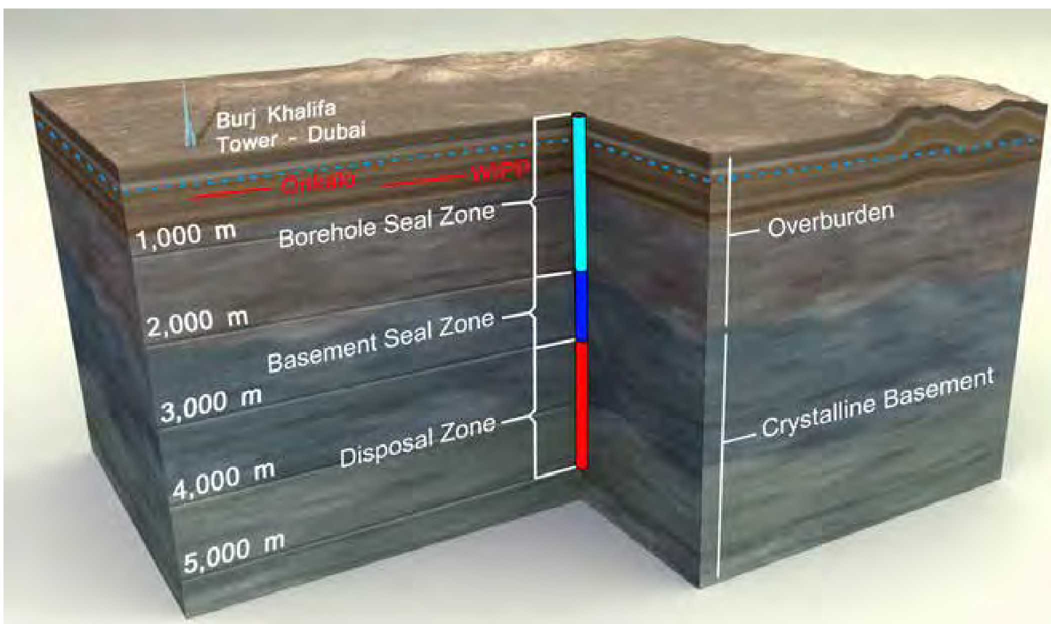

Figure 1.Concept for Deep Borehole Disposal of High-Level Radioactive Waste.

Deep Borehole Field Test

The DOE-NE has begun the request for proposal process for a field test site, drilling operations, and site management to drill the first of a pair of 5-km deep boreholes as part of the 5-year Deep Borehole Field Test (DBFT; see table for major components of DBFT). This project seeks to drill an 8.5-inch diameter Characterization Borehole (CB), potentially followed by a 17-inch diameter Field Test Borehole (FTB), to a total depth of 5 km into crystalline basement rock (nominally 200 m apart). The majority of the geologic, hydrologic, geochemical, geomechanical and thermal testing will take place in the CB, which will be mostly open-hole across the crystalline basement (as downhole conditions allow). Surface handling and borehole emplacement operations demonstrations illustrating engineering feasibility and disposal safety are planned to be tested at the surface and in the FTB. The DBFT will not involve any radioactive wastes or emplacement of permanent seals.

Two boreholes provide a robust approach to achieve the overall goals of the DBFT. First, downhole characterization can be achieved with standard oilfield and geothermal logging technology and methodology in the CB, whereas characterization in the larger-diameter FTB may present technical challenges. Second, if needed, the diameter of the CB will be large enough to accommodate testing the emplacement methods/systems for waste forms such as cesium (CsCl) and strontium (SrF_2) capsules. Third, by conducting characterization activities in the smaller CB, the costs associated with those activities could be reduced significantly compared to the costs for the same activities in the FTB. Finally, two holes will afford cross-hole testing at depths up to 5 km, if such testing is needed. Both geophysical and hydrological cross-hole testing could be used to assess the level of minimally sufficient characterization needed at a future deep borehole disposal site, perhaps from a single borehole.

The six primary science objectives for the characterization borehole in the deep borehole field test are (Kuhlman et al., 2015; "Deep Borehole Field Test: Characterization Borehole Science Objectives," SAND2015-4424R):

- Confirm that deep groundwater in the crystalline basement is very old (i.e., as much as millions of years old) and that it has been isolated from the surface environment for a long time;
- Confirm that no ambient fluid potential gradient exists to drive flow from the disposal zone to the shallow subsurface (i.e., over-pressured conditions are not present at depth, while under-pressured conditions in the crystalline basement would be favorable);
- Confirm that deep groundwater has high salinity (i.e., fluid density gradient is stable and opposes regional vertical circulation), has a well known chemical composition, and is chemically reducing (which generally decreases the solubility and mobility of radionuclides);
- Confirm that bulk permeabilities of the host rock and the borehole disturbed rock zone are acceptably low (i.e., permeability at the borehole scale, rather than the core scale);
- Reduce uncertainty to acceptable levels regarding host rock and disturbed rock zone parameter values used in site-specific numerical models (i.e., chemical, thermal, geomechanical, hydrological properties and constitutive laws); and
- Confirm that the borehole can be drilled, constructed, completed, and characterized safely (i.e., involving monitoring and control of deviation, detection of borehole breakouts, selection of drilling fluid composition, and achievement of an acceptable penetration rate).

These characterization objectives will be addressed through observations made while drilling, borehole geophysics, packer-based in situ borehole testing, and laboratory testing on core and water samples. Most of the characterization activities in the borehole will be focused on the crystalline basement portion of the borehole, as the technology readiness level of characterization in sedimentary overburden rocks is sufficiently high and does not need to be demonstrated as part of the DBFT.

Deep Borehole Field Test (DBFT) Activity	2015	2016	2017	2018	2019
Acquire site and drilling/management contractors	◆				
Drill 8.5″ diameter Characterization Borehole (CB)		◆	◆		
Perform characterization activities in CB			◆	◆	
Acquire drilling contractor for Field Test Borehole (FTB)			◆		
Drill 17″ FTB			◆	◆	
Perform emplacement system demonstration in FTB				◆	◆

During the drilling process, the solid, liquid, and dissolved gas components of the drilling fluid will be monitored continuously to estimate changes in lithology and pore-fluid composition. Drilling fluid will be marked using conservative tracers. Core will be collected across a minimum of approximately 5% of the crystalline basement (150 m total), and will be used to conduct extensive hydrological, geomechanical, geological, and geochemical laboratory characterization testing. Borehole geophysics is planned to be conducted in all sections of the characterization borehole before setting casing (see Figure 2). Fluid production logs of the open portion of the crystalline basement will locate any permeable fracture zones that exist. These more permeable zones would be the focus of packer-based hydraulic testing and sampling.

To estimate the provenance and stratification of pore waters in the crystalline basement, profiles of environmental tracers (e.g., ^{4}He, other noble gases, atmospherically derived radioisotopes, and stable water isotopes), fluid density, major anions and cations, temperature, and fluid pressure will be collected. If higher-permeability basement intervals are found, they will be sampled downhole during pumping. Low-permeability intervals will be hydraulically tested via pulse or slug methods to estimate static formation pressure, permeability, and compressibility. Uncontaminated fluid samples from low-permeability intervals may only be available from cores, which will not provide large enough fluid volume for some analytes.

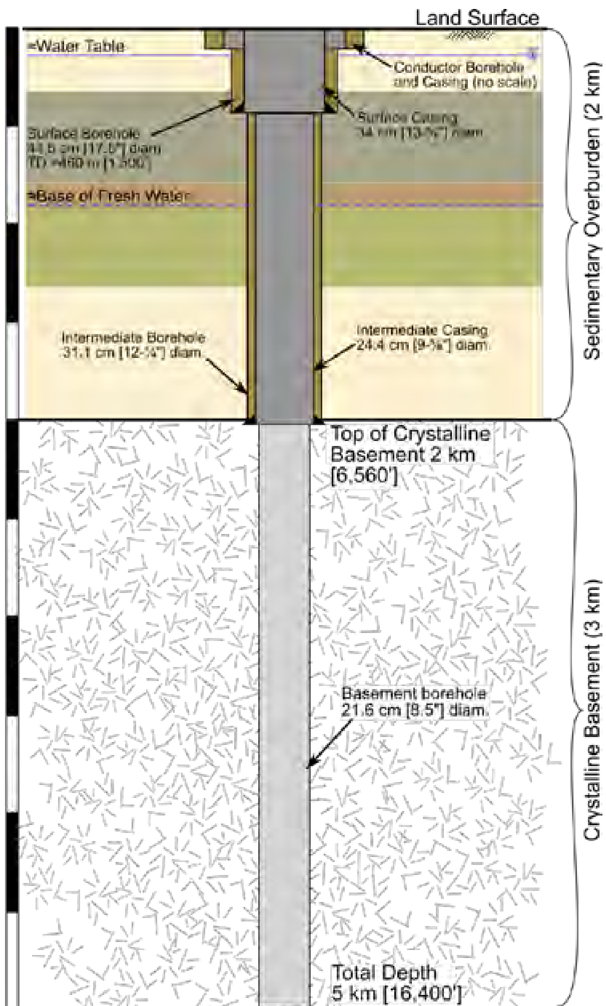

Figure 2. Deep Borehole Field Test Characterization Borehole Diagram

Both single-interval injection-withdrawal and dipole packer-based tracer tests will be conducted to estimate flow and solute transport properties in the disposal and bedrock seal intervals. A heated mock-up waste package test is planned for the disposal interval of the borehole, to better understand the in situ thermal-hydraulic-mechanical response of the borehole system. Hydraulic fracturing tests will be conducted at several depths to estimate the vertical variability in the least principal stress. Downhole geophysical borehole imaging methods will be used to observe the orientation and magnitude of borehole breakouts. Detailed temperature logs will be conducted under both static and flowing conditions to estimate the location of flowing fractures. These high-resolution temperature logs, used in conjunction with borehole imaging, can be used to observe the hydro-mechanical coupling in the system; flowing fractures tend to be oriented perpendicular to the least principal stress.

Current geothermal industry drilling and completion technology readiness levels mean the smaller-diameter CB (8.5-inch diameter at 5 km total depth) will be within current drilling practice. The in situ characterization of the low-permeability crystalline basement rock under high-stress and possibly elevated temperatures will be an important research portion of the DBFT. The larger-diameter field test borehole (17-inch diameter at 5 km total depth) will be at the limits of current drilling technology. The demonstration of the ability to drill and complete the borehole will be an important aspect of the DBFT demonstration. The FTB will also provide a key demonstration of the safe emplacement and retrieval of canisters under expected field conditions for a future DBD site.

The DBFT seeks to advance the understanding of coupled processes occurring in deep crystalline basement systems over the next five years, particularly relevant to their ability to isolate high-level radioactive waste from the accessible environment. Characterization of these deep crystalline basement systems has typically been limited to geothermal energy development, mineral exploration, or a few deep scientific drilling programs. Compared to mined repositories for disposal of radioactive waste, the deep borehole disposal concept is in some ways simpler (e.g., single phase fluid flow), and the long-term safety assessment rests on the possibility of robust geologic isolation, rather than on the construction of significant engineered barriers.

Acknowledgement

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ARMA 2015 Symposium, Workshop Report: "Geomechanics for Unconventionals"

Submitted by Neal Nagel, Oilfield Geomechanics

In association with the annual ARMA symposium held in San Francisco in June, 2015, an industry-focused workshop was held on key geomechanics aspects of the development of Unconventional oil and gas resources. During the workshop, industry experts made seven keynote presentations followed by extended discussions with workshop participants.

Dr. Mark Zoback (Stanford University) began the workshop with a presentation on "The Rocks Matter: Optimizing Production from Unconventional Reservoirs" in which he focused on seismic versus aseismic reservoir response during hydraulic fracturing and the concept of slow slip, the viscoplastic behavior of some Unconventional reservoirs and its impact on in-situ stress magnitudes, and the importance of understanding and correctly measuring matrix permeability in Unconventional reservoirs.

Dr. Paul La Pointe (Golder Associates) followed with a presentation on the importance, generation, and modeling of natural fractures as well as their impact on hydraulic fracturing operations. Dr. La Pointe focused on the common means of developing a natural fracture model utilizing seismic coherency, curvature, anisotropy in velocity and amplitude, and edge detection as well as constraining the model using mechanical layering, statistical techniques like multivariate analyses, and calibration with field and pressure data.

The third presentation was given by Dr. John McLennan (University of Utah) on the current state of hydraulic fracture simulators for Unconventional plays. Dr. McLennan reviewed the historical development of hydraulic fracture simulators from the original PKN and KGD 2-D models up through the present development of boundary element, displacement discontinuity, and discrete element models for treating the generation and propagation of a hydraulic fracture within a naturally fractured rock mass.

Ron Dusterhoft (Technology Fellow, Halliburton) presented "Field Fracture Design Considerations and Methods for Unconventionals" in which he focused on the importance of proper reservoir characterization, including stresses, mechanical properties, and heterogeneities such as natural fractures, proper well and completion design, calibration, validation, and the need to incorporate these in an overall process for improvement.

The fifth presentation of the workshop was given by Dr. Neal Nagel (OilField Geomechanics). He focused on key geomechanical reservoir responses to hydraulic fracturing including stress shadows and the mechanical interactions between a propagating hydraulic fracture and natural fractures and weakness planes. Dr. Nagel also reviewed the concept of `complexity' used in Unconventionals and the need to move away from a paradigm in which `complexity' can be created to one in which `complexity' is a fundamental characteristic of the formation.

Dr. Norm Warpinski (Technology Fellow, Pinnacle) presented "Hydraulic Fracture Diagnostics for Unconventional Reservoirs" in which he reviewed the important diagnostic tools available to the industry including microseismic monitoring (both downhole and surface), fiber-optic DTS and DAS techniques, tiltmeters (both downhole and surface), tracers (both chemical and radioactive), and pressure techniques. He concluded by focusing on utilizing these techniques to calibrate predictive models.

The final presentation was given by Dr. Ibrahim Abou-Sayed (i-Stimulation Solutions, Inc.) on geomechanical aspects of refracturing. In his presentation, Dr. Abou-Sayed focused on understanding the formation and its response to production, proper candidate selection for refracturing, and key implementation issues for refracturing as well as the development of screening tools to help identify the best refracturing candidates.

ARMA 2015 Symposium, Workshop Report: "Digital Rock Physics Derived Rock Mechanics Properties"

Submitted by John Shafer, Petrophysicist (Anacortes, Washington)

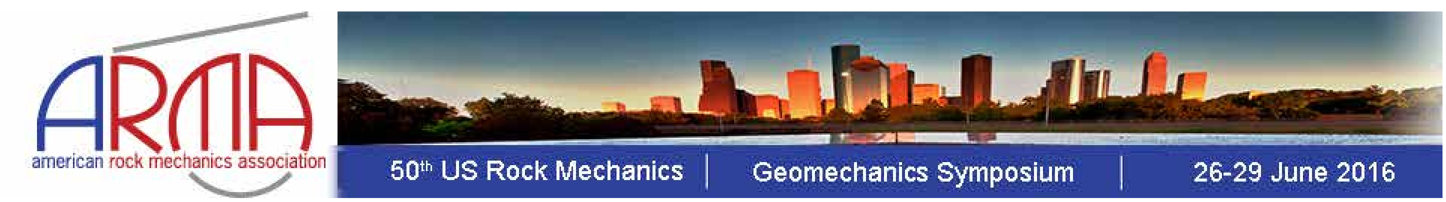
Forty-seven people attended a one day workshop on "Digital Rock Physics Derived Rock Mechanics Properties" at the ARMA Symposium, June 2015, with representation from industry, service companies, and academia. There were no keynote presentations, except for an opening address "Introduction to Digital Rock Physics and Predictive Rock Properties", given by Mike Marsh. There were twelve presentations with ample time set aside for discussion. The primary objective for this workshop was to open a dialog between experts in conventional rock mechanics and experts in digital rock physics (DRP). The workshop exposed DRP attendees whose previous focus had been on measuring porosity and predicting flow properties to the challenges of predicting rock mechanical properties, and thus, offer them a chance to network with the rock mechanics community.

The workshop started with an overview of DRP based on micro CT (computed tomography) images for conventional rocks and FIBSEM (Focus Ion Beam Scanning Electron Microscope) for shale samples -- providing an overview of how high-resolution, 3D images can help in predicting physical properties in general. This was followed by computing and scale-up issues, compaction experimental data, and finally mapping mechanical properties from mm to cm to log scale. The workshop concluded with an open discussion on what advances are required to derive rock mechanical properties from DRP. The expected work flow includes micro or nano X-ray tomography (CT) imaging of rock samples, image processing to resolve pores and grains, and modeling mechanical and acoustic properties on the segmented image. And in all cases, scale-up concerns need to be addressed.

The science and art of DRP measurements of porosity and prediction of single phase permeability are much further advanced than the prediction of mechanical properties, such as elastic moduli and acoustic velocities. To date these DRP derived properties have been largely based on micro-CT images obtained at ambient conditions. Several presentations at the workshop indicated that because such properties will be stress dependent, the ambient images should be digitally compacted before deriving flow and mechanical properties. Several presentations focused on the design of such rock mechanics load cells that can accommodate micro-CT imaging.

Areas that are being pushed actively in order to expand the DRP envelope in support of rock mechanical properties are in situ imaging, nano-tomography, multiscale characterization and dynamic process simulation. As far as mechanical properties are concerned, the challenge is great. The macroscopic behaviors that need to be accounted for are non-linear and are associated with micro-mechanisms at both grain and aggregate scales. One might ultimately expect that a digital rock mechanics laboratory experiment might include strain hysteresis, strain localization, effective stress coefficients, and strain rate dependency. While the DRP derivation of poroelastic properties is feasible, the prediction of the onset of compaction and plastic deformation will be much more difficult.

For detailed contents of the workshop presentations, please see the ARMA website: www.armarocks.org/meetings/past-meetings/



Invitation to Houston

ARMA invites you to its 50th US Rock Mechanics/Geomechanics Symposium to be held in Houston, Texas, USA on 26-29 June 2016. The organizing committee, chaired by David Yale, will present a program that encompasses all aspects of rock mechanics, rock engineering, and geomechanics. To learn more about the symposium, visit: www.armasymposium.org.

Call for Papers

We invite abstracts of scientific and engineering papers in the following subject areas:

- Petroleum engineering
- Civil Engineering
- Geology and geoengineering
- Mining engineering, and
- Underground construction
- Interdisciplinary aspects of rock mechanics and geomechanics.

The deadline for submission of abstracts of papers to be considered for the symposium is 1 November, 2015. To submit an abstract, visit: www.armasymposium.org/abstract-submission

Authors will be notified by 11 January, 2016 and papers are due 29 February, 2016.

News Briefs

ARMA Awards Banquet, San Francisco, June 2015
Photo: H. Montague

ARMA successfully held its 49th US Rock Mechanics/Geomechanics Symposium in San Francisco in June 2015. Joe Morris chaired the event; Alvin Chan, Greg Hasenfus, Russ Detwiler and Haiying Huang comprised the technical committee that organized a program that featured a record number of papers. Jim Rice delivered the MTS lecture, and Kate Baker, Chris Marks, and Steve Glaser were featured keynotes. Close to 50% of the 572 attendees were from outside the US.

The ARMA Board of Directors met during the symposium. Four new board members were seated: Joseph Labuz (MSES/Kersten Professor, University of Minnesota); Loren Lorig (CEO, Itasca Consulting Group, Inc.); Joseph P. Morris (Computational Geosciences Group Leader, Lawrence Livermore National Laboratory); and Maria-Katerina Nikolinakou (Bureau of Economic Geology, University of Texas). Thanks were extended to retiring board members Bill Dershowitz, Mark Zoback, Mary MacLaughlin, and Rico Ramos. New officers were also seated: John McLennan, president; Laura Pyrak-Nolte, vice president; John Curran, treasurer. Kate Baker was re-elected secretary.

Outgoing president Antonio Bobet announced that Russ Ewy (Chevron Energy Technology Co.) would receive an ARMA Presidential Citation for his continuing contribution to the work of ARMA, including securing years of scholarship funding for students at the annual symposia.

Nine ARMA members were inducted in the fourth class of Future Leaders. This program recognizes motivated ARMA members of outstanding promise, relatively early in their careers, to ensure the continual development of ARMA. New future leaders are: Fiona Kwok (Assistant Professor, University of Hong Kong); Houman Bedayat (Postdoc Fellow, Bureau of Economic Geology, University of Texas); Ghazal Izadi (R&D Scientist, Baker Hughes); Qing Lin (Assistant Professor, China University of Petroleum); Mathew Ingraham (Technical Staff, Sandia National Laboratories); Kathy Kalenchuk (Senior Geomechanics Consultant, Mine Design Engineering, Inc.); Frank Zhang, (Computational Geomechanics Engineer, Itasca); Varun (Geomechanics Engineer, Itasca); and Ahmadreza Hedayat (Assistant Professor, Indiana University-Purdue University)

ARMA Future Leaders in San Francisco, June 2015. Photo: H. Montague

One of the highlights of the annual symposium is the announcement of the ARMA awards. At the ARMA Symposium in June, 2015, the following awards were made:

Chakra Rawal, Texas A&M University. Recipient of the Dr. N.G.W. Cook Ph.D. Dissertation Award, *3D Modeling of Coupled Rock Deformation and Thermoporo-Mechanical Processes in Fractures.* Nominated by Ahmad Ghassemi, Texas A&M University.

Lei, Q., Latham, J.-P., Xiang, J. and Lang, P. Rock Mechanics Research Award, *Representation of Large Scale Network Geometry with Realistic Apertures Determined by Mesoscale Geomechanical Modelling of a Natural Fracture System.* Published in the 48th US Rock Mechanics/Geomechanics Symposium, Minneapolis, MN, 1 - 4 June 2014. Nominated by Dr. John-Paul Latham, Imperial College.

Roy Pratanu, Wyatt L. Du Frane and Stuart D. C. Walsh; Lawrence Livermore National Laboratory. 2015 Symposium Best Paper Award, *Proppant Transport at the Fracture Scale: Simulation and Experiment.*

S. Akutagawa, Kobe University and Y. Machijima, LAZOC Corporation. 2015 Symposium Best Poster Award for the Paper, *A new optical fiber sensor for reading RGB intensities of light returning from an observation point in geo-materials.*

News Briefs

ARMA Technical Committees

By action of the Board of Directors, a number of subject matter committees have been established. Such committees were organized to support and conduct activities that contribute to the development and dissemination of knowledge in rock mechanics and geomechanics, to engage ARMA members in technical activities, and to support the vision of ARMA. These groups allow focus by members on areas of their particular interest. It was envisioned that symposium topics, newsletter articles, and exchange of professional information would be enhanced through the work of the technical committees. There are currently two active technical committees: Induced Seismicity (chaired by Azra Tutuncu) and Hydraulic Fracturing (chaired by Gang Han). A new technical committee is Rock Mechanics in the Built Environment (chaired by Mark Liebman).

Hydraulic Fracturing Committee

The goals of the Hydraulic Fracturing Technical Committee are to: (1) advance hydraulic fracturing technical development and to facilitate investigation and modeling of fundamental physics involved, and (2) promote environmentally responsible practice related to hydraulic fracturing. The committee consists of 15 members, including seven from academia, two from US national laboratories, and six from industry. Members are:

Gang Han (Chair), Aramco Services Company
Jon Olson, University of Texas-Austin
Thomas Doe, Golder Associates
Tony Settari, CGG/Taurus Reservoir
Maurice Dusseault, University of Waterloo
Mukul Sharma, University of Texas-Austin
Ahmed Ghasssemi, Oklahoma University
Mohamed Soliman, Texas Tech University
Mark Mack, Itasca/IMaGE
Hari Viswanathan, Los Alamos Nat. Lab.
John McLennan, University of Utah
Xiaowei Weng, Schlumberger
Nobuo Morita, Texas A&M
Sau-Wai Wong, Shell
Joe Morris, Lawrence Livermore Nat. Lab.

Several committee activities are unfolding, including participating and organizing hydraulic fracturing sessions at annual symposia, contributing to the ARMA e-Newsletter, and interacting and collaborating with other professional societies. Furthermore, the committee has begun planning a workshop with focus on the physics involved in the initiation, propagation, and closure of hydraulic fracturing. White papers from the modeling and environmental perspectives are also discussed. For more details, please follow the new committee webpage at the ARMA website, or directly contact Dr. Gang Han. (gang.han@aramcoservices.com).

Rock Mechanics in the Built Environment Committee

A number of issues faced by structures that employ structural, cladding or decorative architectural stone are analogous to those in the underground environment. While contemporary rock mechanics focuses on the engineering and material characteristics of a rock face, quarry, tunnel or mine, little attention is paid to the material that was excavated, quarried or mined, and used in construction. As such, it experiences a number of phenomena and environmental conditions which are detrimental to the stone. To address the issues related to rock mechanics in the built environment, the ARMA Board of Directors authorized the creation of a new technical committee.

Some of the topics planned for discussion and research by the committee include:

- Deterioration of load bearing stone in civil and structural engineering applications
- The implications of bedding plane on weather related exfoliation and delamination of stone
- Mining and quarrying of stone; microcracking and induced stress
- Rock engineering design to satisfy the requirements of structural reliability/limit state design
- Effects of stress relief, creep and other time dependent phenomena on cladding stone
- Rock mechanics based remediation techniques for spalling and deteriorated stone
- Finite element and boundary element analysis of stone monuments and structures
- New methodologies for evaluating and repairing stone in historic buildings
- Contemporary technologies for duplicating geologic conditions to create dimension stone using natural raw materials

The technical committee will provide a forum for the general discussion of these and other topics, and will form working groups to encourage further research on subjects of interest. Individuals are also welcome to pursue a particular area of interest within the framework of the committee. It is anticipated that in the future, peer-reviewed technical papers, technical sessions at the ARMA symposium, and standalone workshops will be the developed by the group for the rock mechanics community at large and to other academicians and researchers.

The chairman of the committee will use conference calls to facilitate discussions regarding topics of interest to the members, with follow up via email and phone to ensure members can pursue topics of mutual interest. A formal meeting of the technical committee will be held at the 50th US Rock Mechanics / Geomechanics Symposium in Houston in 2016.

Mark Liebman (CASE Forensics Corporation) will serve as the Chair of the committee. Please contact Mark to offer your thoughts regarding topics of interest and to participate as a member of the committee. He can be reached at (425) 785-5244 or mliebman@case4n6.com.