Critical Issues in the Subsurface: Using Field Observatories and Data toAdvance Understanding of Rock Behavior

Joint Meeting of the
Committee on Earth Resources and
Committee on Geological and Geotechnical Engineering

October 23, 2014 | Keck Center | Washington, DC

The National Research Council’s Committee on Earth Resources (CER) and Committee on Geological and Geotechnical Engineering (COGGE) organized a meeting on October 23, 2014 at the suggestion of the Department of Energy (DOE) to explore and identify questions related to (1) key aspects of subsurface rock physics, the understanding of which could lead to better prediction of rock mechanical response to engineered applications; (2) existing or new data and information that may lead to better rock mechanical predictions, as well as characteristics of existing well sites or fields that provide those data; and (3) characteristics of a “virtual field observatory” where those data are collected and retrieved to study rock mechanical behavior in a variety of subsurface environments and a range of applications. The DOE proposes to develop such a virtual field observatory under the umbrella of the DOE Subsurface Technology and Research Development (SubTER) crosscut that would benefit multiple DOE offices as well as other federal agencies engaged in issues related to subsurface engineering.

The meeting included four presentations followed by group discussion. Presentations were given by Mr. Mark Ackiewicz (Director of Carbon Capture and Storage research at DOE), Dr. Austin Holland (Oklahoma Geological Survey), Dr. Roberto Suarez-Rivera (W.D. Von Gonten Laboratories), and Dr. Josh White (Lawrence Livermore National Laboratory). Members of COGGE and CER contributed to subsequent discussion, as did meeting participants that included individuals from various federal agencies and professional organizations as well as congressional staff. The meeting agenda and speaker presentations and biographies are available at http://dels.nas.edu/global/besr/CER-Events.

The speakers represented different sectors and areas of professional expertise in rock mechanics. Each was asked to present their perspectives on the needs a virtual field observatory might fill as well as challenges in establishing such an observatory.

Mark Ackiewicz introduced the DOE SubTER collaborative model to facilitate innovation and address the challenges in discovering, characterizing, predicting, accessing, engineering, sustaining, and monitoring the subsurface for a safe and effective energy future (see Figure 1). Urgent and well-documented needs to improve subsurface capabilities were highlighted including those associated with increased hydrocarbon...
and geothermal energy recovery, CO₂ and energy storage, waste disposal, high-resolution imaging, safety, reliability, and mitigation of environmental effects. Mr. Ackiewicz emphasized the need to validate different multi-faceted, multi-functional modeling and technological approaches through data derived from field observatories.

Austin Holland presented state-level interests and issues and described the increase in magnitude and frequency of felt earthquakes in Oklahoma, including those of (M₁) 3 and M 4+, which have been attributed to waste water disposal and in a few instances, to hydraulic fracturing (see Figure 2). These kinds of activities may result in increases in pore fluid pressure in the presence of faults in critical states of stress which may cause a fault to slip and generate an earthquake large enough to be felt at the surface. Many of these earthquakes are occurring in the crystalline basement, beneath the zone of subsurface engineering activity in the sedimentary basins. The location and orientation of faults, and the orientation and variation of stresses on those faults are largely unknown. Lack of information on those fault properties and the reasons for changes in pore pressure and stress orientations in response to engineering activity make predicting the occurrence of and risk associated with induced seismicity difficult. Well log and industry data, according to Dr. Holland, could be used to help advance current models of stress orientations, and hydraulic fracturing operations monitored for microseismic activity could be a good source of information for virtual field observatories if data and database formats could be standardized for exchange among researchers and stakeholders.

Roberto Suarez-Rivera from WD Von Gonten Laboratories described heterogeneities as a key component of rock mechanical behavior as evidenced by microseismic monitoring, oilfield production data, and log and seismic data. Wells within hundreds of feet of other wells have large variation in unconventional reservoir productivity. Variability includes natural changes in geologic systems from the micro to regional scales that affect rock behavior and reservoir productivity. Dr. Suarez-Rivera used several examples including

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1 “M” refers to ‘moment magnitude’

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FIGURE 1. SubTER Tech Team within the U.S. Department of Energy. SubTER facilitates innovation and addresses challenges in assessing the subsurface for future energy development. Source: Adapted from PowerPoint Presentation by Mark Ackiewicz.
borehole breakouts, hydraulic fracturing, and fracture experiments to demonstrate how rock heterogeneity affects reservoir interconnectedness, characterization, reserves in place, and production (see Figure 3). In this way, lack of ability to characterize heterogeneity, even in the most controlled of settings, prevents understanding cause and effect relationships in rock behaviors, and results in inefficient production procedures and increase in risk and cost.

Joshua White, a researcher and data modeler with Lawrence Livermore National Laboratory, described the advantages of a strong virtual observatory in its capacity to draw together the right expertise to develop a comprehensive site characterization plan, to design targeted field and laboratory experiments, to tightly integrate modeling efforts, and to focus research through multi-institution partnerships. His presentation included a case study from a multi-institution field project, the In Salah industrial-scale carbon capture and storage project in Algeria, as a potential model for developing a successful field observatory. The strengths of this field “laboratory” are related to its success characterizing, monitoring, and developing integrated modeling of geomechanical processes and behavior. In particular, Dr. White outlined six “lessons learned” from the experiences with this field site: (1) the value of leveraging existing infrastructure and characterization data; (2) the informative nature of making direct measures of geomechanical deformation (e.g., InSAR measures of surface deformation that provide clues to subsurface causes; see Figure 4); (3) the need for monitoring to include multiple data streams to fill data gaps and constrain models of temporal and spatial subsurface behavior; (4) the value of comparing the cost of acquiring data with the short- and long-term usefulness of the data (i.e., identify small investments with big

FIGURE 2. Oklahoma Earthquakes from 2009 to September 2014. Increased seismic activity has been attributed to waste water disposal and in a few cases, to hydraulic fracturing. Source: Adapted from PowerPoint Presentation by Austin Holland.

FIGURE 3. Examples of rock heterogeneity when fractured, which affects oil reservoir interconnectedness, characterization of reserves in place, and production. Source: Adapted from PowerPoint Presentation by Roberto Suarez-Rivera.
impacts); (5) the need to measure and constrain stress states as much as possible (e.g., through leak-off tests, wellbore and wellbore failure information); and (6) the need for clear and effective data sharing.

Discussions expanded on speaker presentations and focused on issues of heterogeneities in rock structures and lithology, whether at a single locality or when comparing one region or field to another. The spatial and temporal scales at which data are collected was another topic suggested by some of the participants as needing quantification—determining what data are collected and when may require discussions among the observatory participants. Some data that would be of longer-term benefit but perhaps less useful at present could be worth collecting. The need to use multiple existing technologies and techniques to better characterize the subsurface, as well as determining the feasibility of innovative uses of existing and new technologies, was also discussed. Several participants suggested that the breadth and value of virtual observatory sites may be enhanced by supplementing already available data from federal or private sources or energy production sites with other kinds of sites with direct access to the subsurface (e.g., underground construction sites and facilities; mines). The ultimate aim, according to many of the participants, is to develop models that are useful to scientists, industry, regional stakeholders, and decision makers. Several meeting participants indicated that collaborative development of a functioning virtual field observatory, despite inherent challenges and if implemented successfully, could benefit many DOE programs and other programs across the federal family, and inform better adaptive engineering of the subsurface.

FIGURE 4. Direct measurement of geomechanical deformation using InSAR can be very informative during the course of injection in a CCS project. Source: Adapted from PowerPoint Presentation by Joshua White.

Hypothesis 1: Reservoir-Only Behavior
The first hypothesis is that all monitoring observations are consistent with excess pressure and CO$_2$ reservoir interval. That is, there has been no vertical migration of fluids into the caprock. As suggested by Vasco and colleagues (20), it is possible that the observed surface deformations above KB-502 could result from a heterogeneous permeability distribution in the reservoir interval alone. A low-permeability zone intersecting the injector and extending to the northwest could partition the reservoir pressurization into two zones, each responsible for one of the uplift lobes. Although inversion models including a vertical dilation zone provide a better fit to the data, one can conclude that InSAR data alone are ambiguous on whether fluid migration has been contained in the reservoir. The observed velocity anomalies, however, make hypothesis 1 less plausible. The anomalies require a mechanism to change the velocity structure of the lower caprock (i.e., pressure, saturation, and/or mechanical changes). The reservoir-only hypothesis implies the only significant changes to the caprock that have occurred are far-field geomechanical deformations. The diffuse nature of such