the ENERGY lab

PROJECT FACTS

Carbon Storage

Advanced Technologies for Monitoring CO_2 Saturation and Pore Pressure in Geologic Formations: Linking the Chemical and Physical Effects to Elastic and Transport Properties

Background

Through its core research and development program administered by the National Energy Technology Laboratory (NETL), the U.S. Department of Energy (DOE) emphasizes monitoring, verification, and accounting (MVA), as well as computer simulation and risk assessment, of possible carbon dioxide (CO_2) leakage at CO_2 geologic storage sites. MVA efforts focus on the development and deployment of technologies that can provide an accurate accounting of stored CO_2, with a high level of confidence that the CO_2 will remain stored underground permanently. Effective application of these MVA technologies will ensure the safety of geologic storage projects with respect to both human health and the environment, and can provide the basis for establishing carbon credit trading markets for geologically storing CO_2. Computer simulation can be used to estimate CO_2 plume and pressure movement within the storage formation as well as aid in determining safe operational parameters; results from computer simulations can be used to refine and update a given site's MVA plan. Risk assessment research focuses on identifying and quantifying potential risks to humans and the environment associated with geologic storage of CO_2, and helping to ensure that these risks remain low.

Project Description

This four-year project—performed by Stanford University's Stanford Rock Physics Laboratory in partnership with ExxonMobil and Ingrain, Inc.—is providing robust methodologies for using seismic data to quantitatively map the movement, presence, and permanence of CO_2 relative to its intended storage location. Optimized rock-fluid models incorporate the seismic signatures of (1) saturation scales and free vs. dissolved gas in a CO_2-water mixture, (2) pore pressure changes, and (3) CO_2-induced chemical changes to the host rock (Figure 1). Work products from this project include an innovative dataset, methodologies, and algorithms for predicting the seismic response of multiphase and reactive fluids in CO_2 storage programs.

CONTACTS

John Litynski
Carbon Storage Technology Manager
National Energy Technology Laboratory
626 Cochrans Mill Road
P.O. Box 10940
Pittsburgh, PA 15236-0940
412-386-4922
John.Litynski@netl.doe.gov

Robert Noll
Project Manager
National Energy Technology Laboratory
626 Cochrans Mill Road
P.O. Box 10940
Pittsburgh, PA 15236-0940
412-386-7597
Robert.Noll@netl.doe.gov

Gary Mavko
Principal Investigator
Stanford Rock Physics Laboratory
Stanford University
340 Panama Street
Stanford, CA 94305-6203
650-723-9438
Mavko@stanford.edu

PARTNERS

ExxonMobil Corporate Strategic Research
Ingrain, Inc.

PROJECT DURATION

Start Date	**End Date**
10/01/2009	09/30/2013

COST

Total Project Value
$1,498,489

DOE/Non-DOE Share
$1,183,355 / $315,134

PROJECT NUMBER

DE-FE0001159

U.S. DEPARTMENT OF ENERGY

In spite of advanced techniques for geophysical imaging, current methods for interpreting CO_2 saturation from seismic data can be fundamentally improved. Until now, Gassmann's equations, which relate pore fluid compressibility and the rock frame to overall elastic properties, have been the primary tool for interpreting CO_2 plumes from time-lapse seismic data. Gassmann's model is purely mechanical, and is best suited for conditions of single-phase fluid saturation in relatively inert systems. Yet, CO_2-rich fluid-rock systems can be chemically reactive, altering the rock frame via dissolution, precipitation, and mineral replacement. Furthermore, CO_2 systems are multiphase, with uncertainties in scales of phase mixing in the pore space and solution of one phase in another. Errors from ignoring the physicochemical factors during CO_2 injection can affect predicted seismic velocity changes, resulting in compromised estimates of saturation and pressure of CO_2-rich fluids.

Goals/Objectives

The primary objective of the DOE's Carbon Storage Program is to develop technologies to safely and permanently store CO_2 and reduce Greenhouse Gas (GHG) emissions without adversely affecting energy use or hindering economic growth. The Programmatic goals of Carbon Storage research are: (1) estimating CO_2 storage capacity in geologic formations; (2) demonstrating that 99 percent of injected CO_2 remains in the injection zone(s); (3) improving efficiency of storage operations; and (4) developing Best Practices Manuals (BPMs).

The primary goal of this research is to provide robust methodologies for quantitatively interpreting subsurface CO_2 saturation and state from seismic data. These methodologies will allow quantitative mapping of the movement, presence, and permanence of CO_2 relative to its intended storage location at injection sites to help meet the Carbon Storage Program's goal of estimating storage capacity, improving storage efficiency, and demonstrating subsurface CO_2 storage permanence. Specifically, the research aims to provide CO_2-optimized rock-fluid models that incorporate the seismic signatures of (1) saturation scales and free vs. dissolved gas in a CO_2-water mixing, (2) pore pressure changes, and (3) CO_2-induced chemical changes to the host rock.

Accomplishments

To date, researchers have performed a series of laboratory experiments and high-resolution images assessing the changes in microstructure, transport, and seismic properties of fluid-saturated sandstones and carbonates injected with CO_2. The following summarizes the results to date:

- Injecting CO_2-rich brine into carbonate rocks results in decreased ultrasonic P- and S-wave velocities and increased porosity and permeability. Initial measurements on carbonate samples reveal as much as 30% decrease in elastic velocity, 5% increase in porosity, and 4,000 mD increase in permeability, all associated with permanent dissolution of minerals and flushing of mineral fines. Experiments illustrate that the magnitude of the changes correlates with the rock microtexture – tight, high surface area samples showed the largest changes in permeability and smallest changes in porosity and elastic stiffness compared to those in rocks with looser texture and larger intergranular pore space. In contrast, computer simulations show that mineral precipitation in the pore space can cause significant decreases in porosity and permeability and increases of elastic moduli.

- Injecting CO_2 into brine-saturated-sandstones induces salt precipitation primarily at grain contacts and within small pore throats (Figure 2). High porosity samples exhibited less permeability change with precipitation than the low porosity samples. In rocks with porosity lower than 10%, salt precipitation reduces permeability and increases P- and S-wave velocities of the dry rock frame. High resolution images revealed that salt precipitated preferentially in thin cracks and grain boundaries, leading to relatively large increases in elastic stiffness.

- Injecting CO_2-rich water into micritic carbonates induces dissolution of the microcrystalline matrix, leading to porosity enhancement and chemo-mechanical compaction under pressure. In this situation, the elastic moduli of the dry rock frame decreased.

- Injecting CO_2-rich brine into a sample of the Lower Tuscaloosa sandstone of Cranfield, Mississippi affected the formation's elastic and transport properties. Iron concentration, compressional and shear wave velocities were measured before and after injecting the sandstone sample with carbon dioxide rich synthetic Tuscaloosa brine at various confining pressures.

- Studying the heterogeneities of microstructure in several rock types to understand distributions of flow paths and pore surface area yielded fairly uniform pore size distributions within each rock sample but variation from one sample to the next on the core plug scale. Sandstones had the narrowest range of pore sizes, carbonates had a broader range of sizes, and the tightest carbonate had a very broad distribution of sizes.

- Injecting CO_2 into oil-bearing sandstones and carbonates demonstrated that oil coating reduces the overall reactivity associated with CO_2 injection. The increases in porosity and decreases in ultrasonic velocity were smaller in an oil-bearing sample than in a very similar clean sample.

- Developed a preliminary model that theoretically predicts the changes in rock elastic bulk modulus upon replacement of one pore fill with another. The computational work used finite element methods to predict the frequency-dependent stiffness of rocks containing mixtures of free CO_2 and brine. The model is an important step towards understanding the seismic signature of dissolved and precipitated minerals. It is anticipated that the model will provide a framework that can include chemical changes to the pore space.

Benefits

It will be necessary to improve existing monitoring technologies, develop novel systems, and protocols to satisfy regulations to track the fate of subsurface CO_2 and quantify any emissions from reservoirs. The Carbon Storage Program is sponsoring the development of technologies and protocols by 2020 that are broadly applicable in different geologic storage classes and have sufficient accuracy to account for greater than 99 percent of all injected CO_2. If necessary, the tools will support project developers to help quantify emissions from carbon capture, utilization, and storage (CCUS) projects in the unlikely event that CO_2 migrates out of the injection zone. Finally, coupled with our increased understanding of these systems and reservoir models, MVA tools will help in the development of one of DOE's goals to quantify storage capacity within ± 30 percent accuracy.

The proposed technology for the analysis of seismic data will provide the necessary advancement for tracking the location of injected CO_2, ensuring that injection fields and abandoned wells are not leaking, and verifying the quantity of CO_2 that has been injected underground. Results of this research will help to advance a scientific understanding of carbon storage options, increase storage efficiency, and to provide cost-effective, environmentally sound technology options that ultimately may lead to a reduction in CO_2 emissions.

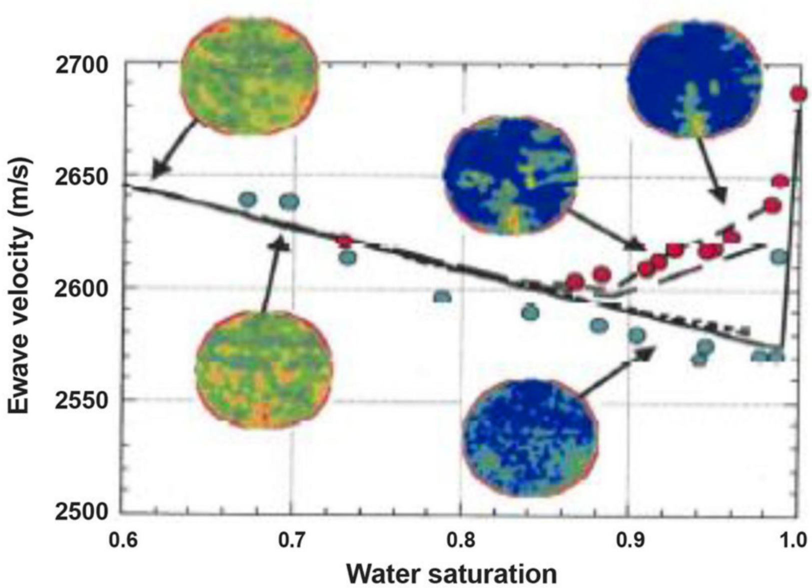

Figure 1 - Resonant bar extensional wave velocity (~900Hz) vs. gas-water saturation in limestone (Cadoret et al,. 1997). Colored circles are x-rayCT images of water distribution (blue=water). Increasing water saturation leads to fine-scale gas-water mixing and low velocities (blue dots), while increasing gas saturation.

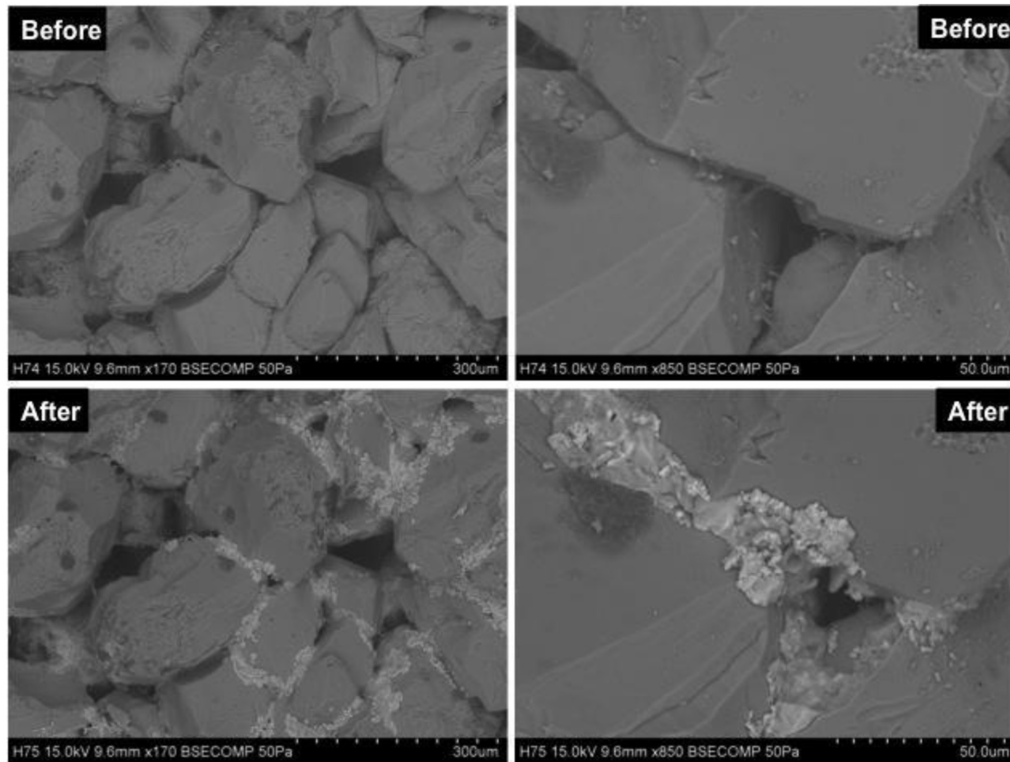

Figure 2 - Time-lapse SEM images monitoring the effects of salt precipitation within the pore microstructure of Fontainebleau sandstones.