Advanced Characterization of Unconventional Oil and Gas Reservoirs to Enhance CO_2 Storage Resource Estimates

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ABSTRACT

Although significant progress has been made globally to investigate the suitability of subsurface geologic sinks for CO_2 storage, there is a lack of detailed geologic data needed to develop improved volumetric equations for assessing CO_2 storage resources of unconventional formations. A key challenge in estimating the various parameters that affect CO_2 storage in unconventional formations is that the analytical techniques and instrumentation used to evaluate conventional reservoirs are often limited or even unsuitable when applied to shales and other tight rocks.

To improve our understanding of the key geologic factors that influence CO_2 storage resource estimates in unconventional formations and to better define the efficiency factors associated with each key parameter, the Energy & Environmental Research Center (EERC) recently began a collaboration with the U.S. Department of Energy (DOE) National Energy Technology Laboratory (NETL) and Hitachi High Technologies to develop analytical techniques to better understand and quantify the distribution of clay minerals, organics, porosity, and fracture characteristics in representative shale and tight rock samples. This effort, which is funded through the EERC–DOE Joint Program on Research and Development for Fossil Energy-Related Resources, will involve applying advanced image analysis techniques to imagery collected of unconventional rock samples using field emission scanning electron microscopy (FESEM).

A key goal of this project is to more efficiently identify and quantify key features that could affect CO_2 storage in unconventional formations. The project scope of work as well as previous EERC–DOE efforts that were precursors to this project will be summarized in this poster.

PROJECT GOALS & OBJECTIVES

Goal: Development of advanced characterization methods and procedures for studying the properties of organic-rich/tight rock formations, with the aim to improve assessment methods for estimating the CO_2 storage capacity.

Specific Objectives:

- Develop advanced FESEM and image analysis methods to better characterize sample composition in terms of clays, kerogen or organic content, and major minerals.
- Develop improved methods to better estimate porosity and pore-size distributions.
- Develop enhanced methods to improve the characterization of fracture networks.
- Collaborate with Hitachi R&D Division to improve data processing and image analysis protocols for enhanced quantification of desired features and their proportions.
- Collaborate with NETL's CT (computerizd tomography) scanning Laboratory in Morgantown to investigate the effects of CO_2 exposure on petrophysical properties of organic-rich shales at core scale.
- Utilize the acquired data to develop improved volumetric estimates of CO_2 storage potential in collaboration with Dr. Goodman's team at NETL.

SCOPE

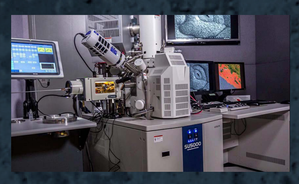
- The scope of work for this project is divided into the following tasks:
- Advanced compositional characterization to identify clay types, organics, major minerals, and proportions of each component.
- Improved porosity estimation for organic-rich shales.
- Determination of shale fracture characteristics.
- Development of advanced data analysis techniques for shales/tight rock characterization.
- Collaboration with NETL's CT scanning laboratory to investigate CO_2 effects on petrophysical properties.
- Development of an improved volumetric approach to estimate the CO_2 storage resource potential for shales in collaboration with NETL.

ADVANCED ANALYTICAL TECHNOLOGIES

FIELD EMISSION SEM

Hitachi's SU5000 field emission variable-pressure SEM has been ordered for this project.

- High resolution:
  - 1.2 nm at 30 kV; WD = 5 mm; 180,000x (secondary electron mode)
  - 3 nm at 15 kV; WD = 5 mm (backscatter electron mode)
- ZrO/W Schottky electron gun delivers small-beam spot sizes for enhanced energy dispersive spectroscopy (EDS) spatial resolution.
- Microanalysis system:
  - 6th-generation Bruker XFlash® silicon drift detector with 60-mm² area; Peltier cooled.
  - High x-ray throughput 1,000,000 cps!



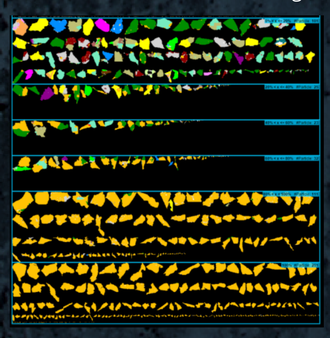
ION MILL POLISHER

- Hitachi's IM4000 Plus ion mill system for ultrasmooth sample polishing has been ordered for this project.
- Capabilities include polishing both cross sections and flat areas with dimensions:
  - 20 mm x 12 mm x 7 mm (cross section)
  - 50 mm x 25 mm (flat area)
- Additional capabilities of IM4000 Plus:
  - Air protection system to prevent unintended oxidation during milling.
  - Low-temperature cold block and/or liquid N_2 cooling unit for heat-sensitive materials.

SOFTWARE TECHNOLOGY: ESPRIT AND AMICS

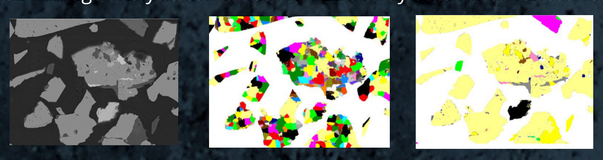
Bruker's **ESPRIT Software Suite** – is the latest Bruker software package for quantitative microanalysis, with mineral phase mapping.

Automated particle analysis and classification for drill cuttings.

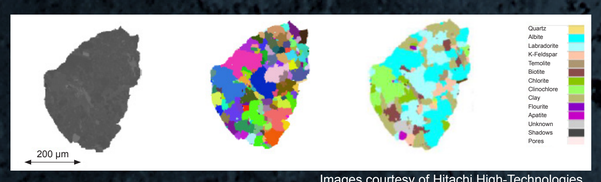


Hitachi's **Advanced Mineral Identification and Classification System (AMICS)** for automated mineralogy, particle/feature detection, and classification.

SEM image analysis combined with EDS x-ray data for advanced feature detection:



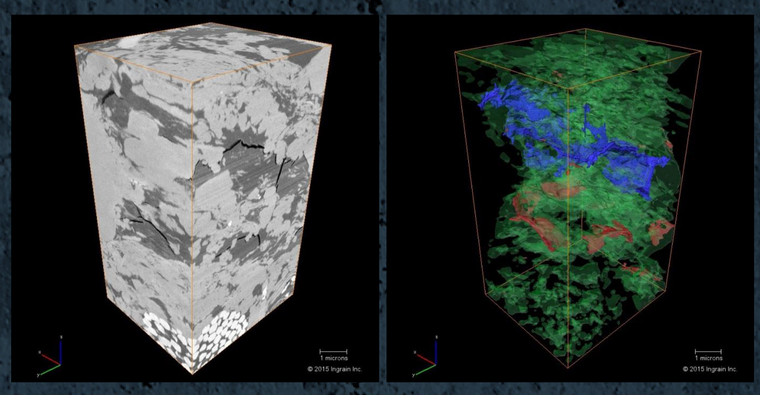
From rock particle detection to identification of individual mineral grains and automatic classification:



Images courtesy of Hitachi High-Technologies

PREVIOUS WORK

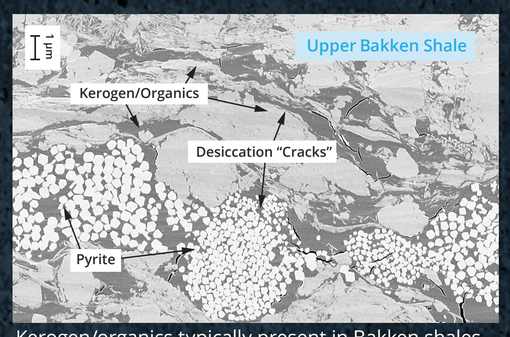
3-D FIB-SEM PORE AND ORGANIC MATTER DISPLAYS



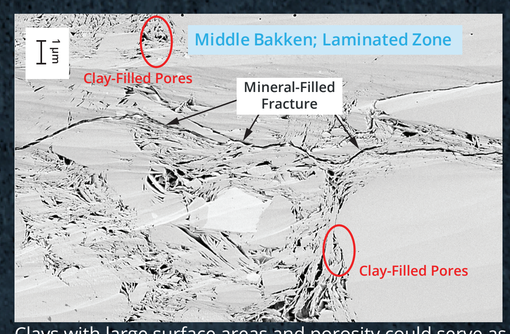
Note: Segmentation into various phases is based on grey scale values

CONNECTED POROSITY
NONCONNECTED POROSITY
ORGANIC MATTER

Focused ion beam (FIB)-SEM images show porosity types and organic matter content in core samples. These have implications for CO_2 migration, sorption, and storage. Various void volumes can be estimated from subsequent image analysis to enhance volumetric equations for CO_2 storage capacity.



Kerogen/organics typically present in Bakken shales could be potential CO_2 sorption/storage sites.



Clays with large surface areas and porosity could serve as both transportation conduits and storage/sorption sites.

SHALE CHARACTERIZATION CHALLENGES

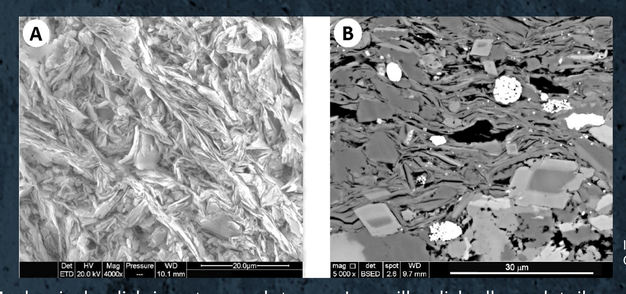
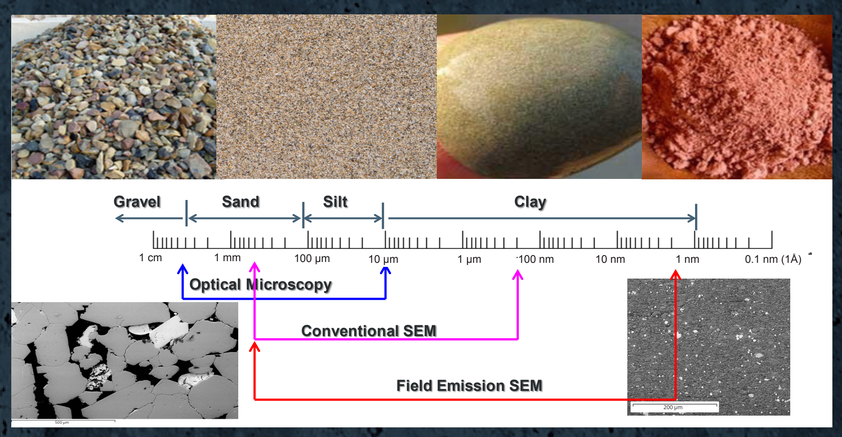


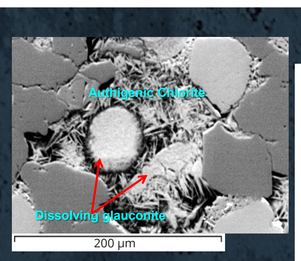
Image from Garcia et al., 2014.

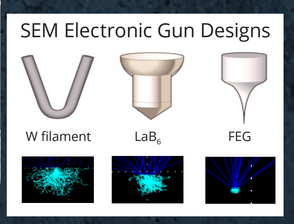
Mechanical polish is not enough to distinguish small features at high resolution.

Ion mill polish allows detail delineation of small features at high resolution.

Conventional Reservoir | Semiconventional Reservoir | Unconventional Reservoir







Smallest spot size and excitation volume at low kV is good for spatial resolution but bad for analysis!

PROJECT EXPECTATIONS AND IMPACTS

- The overall expectations of this project include development of better methods and/or protocols to identify and quantify the geochemical factors that affect CO_2 transport, migration, and sorption in tight rock, organic-rich reservoirs.
- This effort will be conducted in conjunction with other ongoing EERC projects to better understand how CO_2 migration and sorption are affected by kerogen type and thermal maturity as well as clay type and occurrence.
- The results of this project are expected to have significant implications for both CO_2-based EOR and CO_2 storage in unconventional reservoirs.
- The data generated will also be used to develop improved volumetric equations for estimating the CO_2 storage capacity for organic-rich and tight rock formations.

ACKNOWLEDGMENTS

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DISCLAIMER

REFERENCE

García, L., Ángel Caja, M., Tritlla, J., Sánchez, V., González, I., Gómez, F.J., and Quesada, S., 2014, State-of-the-art ion milling ablation applied to shale gas sample preparation: Search and Discovery Article #80389, www.searchanddiscovery.com/documents/2014/80389garcia/ndx_garcia.pdf (accessed August 2016).

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