Multiscale assessment of claystone suitability for subsurface nuclear waste disposal

PI: Roman Y. Makhnenko, University of Illinois at Urbana-Champaign (UIUC)

Collaborators: Jonny Rutqvist, Lawrence Berkeley National Laboratory (LBNL)

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ABSTRACT:

The proposed work addresses the strategic focus goals of the DOE nuclear waste disposal program by (1) investigating the reliability of using rocks with different clay content as the host materials, (2) developing laboratory techniques for testing fluid flow and coupled thermo-hydro-mechanical (THM) processes in intact and fractured claystones, (3) combining micro- and lab-scale characterization with machine learning, (4) modeling the disposal options using the lab- and field-scale data, and (5) assessing the short- and longterm integrity of the repositories. The scope of this study is on evaluating generic results, as well as providing some preliminary recommendations for potential storage sites in the US. The objectives are to use lab-scale characterization with explicit parametric analyses to develop the methodology and techniques for the upscaling integration of the modeling and field scale testing that DOE is already actively pursuing. Claystones are abundant in the subsurface and can serve as effective barriers for deep geologic nuclear waste disposal. Yet, the large sensitivity of these low-permeable nanoporous materials to changes in degree of saturation, mechanical loading, pore pressure, and temperature convert their characterization into a very challenging task. Overcoming this challenge is a required step to reliably predict and model the short- and long-term response of the host formations that can be safely used for nuclear waste disposal.

The project consists of five major tasks. Task 1 includes a comprehensive experimental program that involves testing heterogeneous intact and fractured claystones at representative in-situ conditions to observe their hydro-mechanical response to thermal loading up to 100ºC and to characterize the sealing capacity and long-term integrity of the barrier systems. Task 2 is aimed at assessing the microscale properties through microimaging techniques (SEM, FIB SEM, EDX, and X-ray CT) and porosimetry (mercury intrusion and nitrogen adsorption). Tasks 3 and 4 are dedicated to development of empirically-based constitutive and numerical models combined with physics informed neural networks that utilize the material properties measured at different scales for enhanced predictions of material response. Task 5 deals with field scale experiments at the Mont Terri underground rock laboratory aimed at observing the response of a claystone with fractures at 10 m scale where hot and cold fluids will be injected into it for a few years. Combined with Tasks 3 and 4, and enhanced with data from Tasks 1 and 2, this should provide a reliable prediction tool for choosing the appropriate host formation and boundary conditions for storage.

This ambitious experimental approach leverages the PI's expertise and access to unique laboratory facilities and involves the introduction and calibration of constitutive models based on physical principles and information on microstructural properties. Despite the long duration of the characterization of coupled processes in claystones (weeks to months), this proposal will undertake these tasks enabling the building of realistic models and making accurate predictions for nuclear waste disposal. The PI is also involved in in development of neural networks to predict rock properties at lab- and field-scales based on the limited datasets. Contribution of the co-PI is mainly in numerical modeling, ensuring that the laboratory data collected at UIUC provide appropriate characterization of the host rock behavior that can be upscaled to the field applications. The co-PI will also ensure that the