PRF# 57449-DNI9
Flow and Geomechanics in Fractured Black Shale

Joachim Moortgat
School of Earth Sciences, The Ohio State University

Narrative Progress Report

This project aims to advance our capabilities to model the dynamic behavior of both fluids and rocks in fractured black shale formations. In this first period, progress has been made in two key areas: 1) characterizing the pore structures of nano-porous shale matrices, and 2) initiating the modeling of coupled multiphase fluid flow and geomechanical responses through an efficient and robust finite element and operator splitting scheme. Further details are provided below.

Relationship between Rock Composition and Pore Structure

In order to even estimate the initial amount of gas-in-place (GIP) in a macroscopic rock sample or entire formation, one essentially needs to predict their respective pore size distributions (PSD) and specific surface areas (SSA). This is because, unlike in conventional reservoirs, a large fraction of gas can be adsorbed onto the walls of (nano- and meso-) pores, some of which have sizes comparable to the radii of the gas molecules. Measuring pore structures involves challenging, expensive, and time-consuming experiments. The objective of PhD student Fengyang Xiong's research is to use such experiments systematically to correlate pore architectures to geochemical and petrophysical properties that are easier to measure, e.g., along a bore hole.

Xiong has measured low-pressure carbon dioxide and nitrogen adsorption isotherms on 42 samples from deep (> 3000 m) shales to measure their PSD (Figure 1) and SSA and relate those to his measurements of total organic carbon, thermal maturity, and mineralogy (mainly clays and quartz). In addition, he has performed a range of high-pressure methane adsorption experiments to determine the amount of adsorbed gas in the same samples, as well as 'canister desorption experiments' that attempt to measure GIP directly on site. In the past two years, this work has involved collaborations (including a visit and several first- and co-authored journal publications) with fellow students and previous advisors at the State Key Laboratory of Petroleum Resources and Prospecting, at the China University of Petroleum in Beijing, where Xiong obtained his MSc degree.

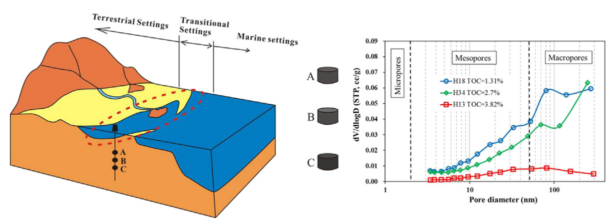

Figure 1: Depositional setting of transitional shales (left) and measured pore size distributions (right) for three representative samples (from: Xiong et al. 2017, *Fuel*, **206**:504–515).

We were fortunate, though, to recently receive generous access to an underutilized Rubotherm gravimetric high-pressure sorption analyzer in Chemical and Biomolecular Engineering at The Ohio State University (few labs worldwide have these expensive instruments). Using this unique opportunity, Xiong has embarked on an ambitious schedule of experiments for the coming period (academic year 2018-2019) to accurately measure methane adsorption on a range of natural shale samples from both the US and China, as well as a suite of samples consisting of pure minerals, with the goal of predicting GIP from basic measured rock properties.

Macroscopically meaningful equivalent descriptions of the 'porosity' and 'fluid density' (including both free and adsorbed gas) are essential inputs for any reservoir simulator for black shales.

Coupled Multiphase Fluid Flow and Geomechanics

The main focus of this PRF project is to model the poro-elastic behavior of rock in response to multiphase multi-component flow in (natural or induced) fractured shale formations.

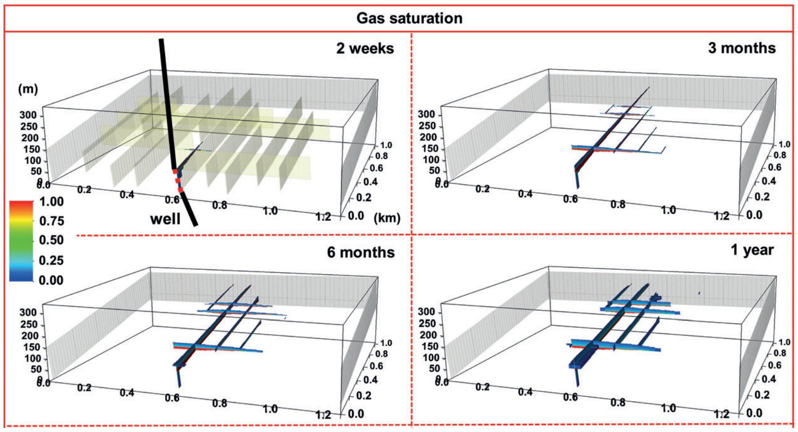

Figure 2: Methane transport in tilted discrete fracture network (from: Moortgat et al. (2018) *Groundwater*, **56**(2):163-175).

Because this is a new research direction, PhD students William Eymold and Amin Amooie spent the first half of this period on a comprehensive review of existing approaches. This has been important because 1) flow-plus-geomechanics models are challenging to implement and multiple schemes have recently been demonstrated to have poor convergence properties, and 2) the vast majority of past research has only considered rocks saturated with single-phase incompressible fluids. The corresponding mathematical frameworks and numerical discretizations under the latter assumptions can not be readily extended to problems with strong compressibility or capillary effects, as are involved in the flow of brines and methane-rich gas in fractured shales.

Building on the current state-of-the-art, we are adopting the unconditionally stable 'fixed-stress scheme.' Flow and geomechanics are updated with an operator-splitting approach that takes advantage of the optimal numerical methods for each sub-problem. Sequentially coupled schemes are more computationally efficient than monolithically fully coupled ones, yet can achieve the same accuracy through iterations. We follow a method developed for multiphase compressible, but immiscible, fluid mixtures in the context of geological CO_2 sequestration.[1] Similar to that work, we are in the process of modifying an open source finite element (FE) code for elastic deformation and developing an interface to our in-house reservoir simulator for flow and transport in fractured media, but with different accumulation terms to account for partially miscible systems. Both problems use complementary finite element methods on the same mesh.

The implementation of this coupled simulator and applications to discrete fracture networks with realistic orientations in a prevailing stress field (Figure 2) will continue in the next period.

Summary of Support and Outcomes

The support provided by the ACS PRF has helped to diversify my research group's work into the areas of geochemistry and geomechanics. This broadening of expertise has already opened up unexpected collaborative opportunities with colleagues in other Earth Sciences subfields and led to two large funding proposals on basin scale fluid migration and fracture mechanics that are currently pending.

Direct funding has been provided for the last year of PhD research for Mohammad Amin Amooie, who has worked closely with my postdoc Mohamad Reza Soltanian. Their efforts have been awarded by a prestigious postdoc position at the Massachusetts Institute of Technology (MIT) for Amooie, and a tenure track faculty position at the University of Cincinnati for Soltanian. The bulk of the geomechanics modeling is performed by (currently pre-candidacy) PhD student William Eymold, while (post-candidacy) PhD student Fengyang Xiong is involved in the experimental characterization of pore-structures in nano-porous black shales in relation to mineralogy, organic carbon, and other geological controls. Both will be (partially) supported by the PRF grant during the 2018-2019 academic year, while Eymold was awarded a competitive (OSU) University Fellowship during the past period and Fengyang was supported through other means. Journal publications by Amooie, Soltanian, and Xiong are currently in press and will be reported next year.

[1] Jha, B. & Juanes, R. (2014). Coupled modeling of multiphase flow and fault poromechanics during geologic CO_2 storage. Energy Procedia, 63, 3313-3329.