# Visualizing and measuring flow in shale matrix using *in situ* synchrotron X-ray microtomography

A.H. Kohli[1,2], A.M. Kiss[1], T. Kovscek[2], J.R. Bargar[1]

[1] SLAC National Accelerator Laboratory
[2] Stanford University

Natural gas production via hydraulic fracturing of shale has proliferated on a global scale, yet recovery factors remain low because production strategies are not based on the physics of flow in shale reservoirs. In particular, the physical mechanisms and time scales of depletion from the matrix into the simulated fracture network are not well understood, limiting the potential to optimize operations and reduce environmental impacts.

Studying matrix flow is challenging because shale is heterogeneous and has porosity from the µm- to nm-scale. Characterizing nm-scale flow paths requires electron microscopy but the limited field of view does not capture the connectivity and heterogeneity observed at the mm-scale. Therefore, pore-scale models must link to larger volumes to simulate flow on the reservoir-scale. Upscaled models must honor the physics of flow, but at present there is a gap between cm-scale experiments and µm-scale simulations based on *ex situ* image data. To address this gap, we developed a synchrotron X-ray microscope with an *in situ* cell to simultaneously visualize and measure flow.

We perform coupled flow and microtomography experiments on mm-scale samples from the Barnett, Eagle Ford and Marcellus reservoirs. We measure permeability at various pressures via the pulse-decay method to quantify effective stress dependence and the relative contributions of advective and diffusive mechanisms. Images at each pressure step document how microfractures, interparticle pores, and organic matter change with effective stress. Linking changes in the pore network to flow measurements motivates a physical model for depletion. To directly visualize flow, we measure imbibition rates using inert, high atomic number gases and image periodically with monochromatic beam. By imaging above/below X-ray adsorption edges, we magnify the signal of gas saturation in µm-scale porosity and nm-scale, sub-voxel features. Comparing vacuumed and saturated states yields image-based measurements of the distribution and time scales of imbibition. We also characterize nm-scale structure via focused ion beam tomography to quantify sub-voxel porosity and connectivity. The multi-scale image and flow data is used to develop a framework to upscale and benchmark pore-scale models.