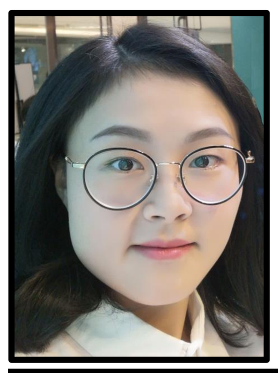

High-resolution Mapping and Characterization of Shale Fractures Hydraulically Induced in the Laboratory

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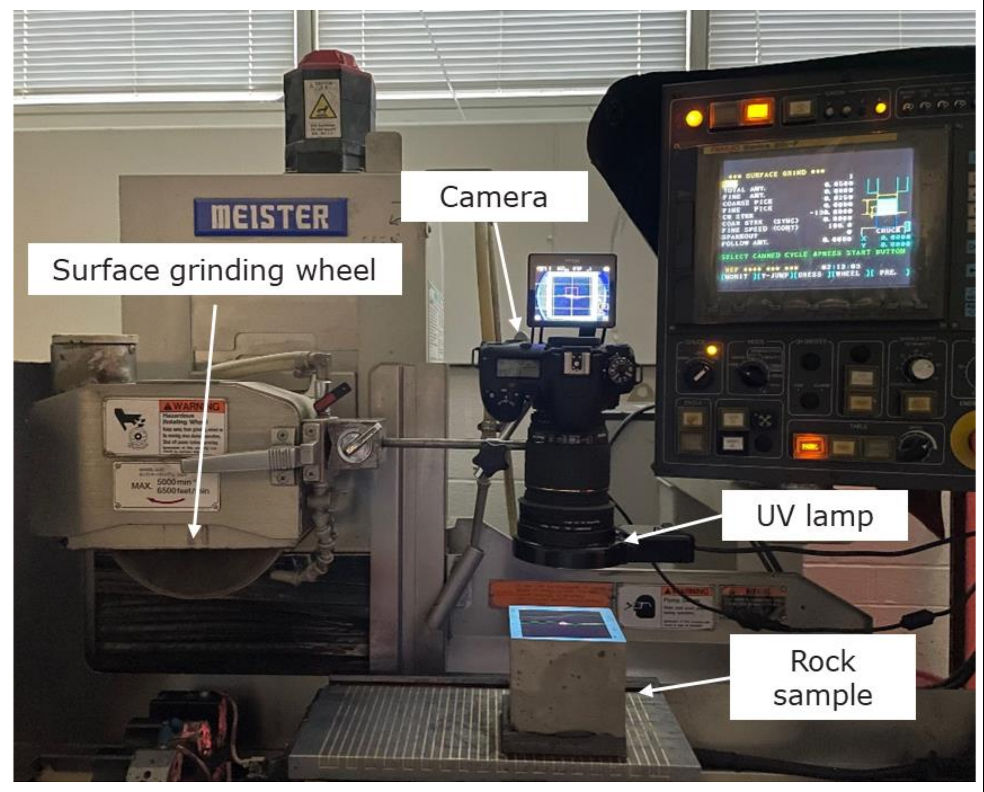
BACKGROUND

A wide range of subsurface activities, including oil and gas exploitation of hydrocarbon reservoirs, resource extraction from geothermal energy systems, and storage of carbon dioxide, rely on the transport of fluids in rock. As a reservoir stimulation technique, hydraulic fracturing is widely used to enhance fluid injection/production by creating highly conductive flow channels in rock formations. For fractured laminated rock formations such as shale, the presence of natural fractures and bedding planes make it possible for hydraulic fracturing to generate complex fracture networks in these formations. However, it remains unclear how fluid-driven fractures propagate and interact with the pre-existing fractures. Reliable high-resolution imaging and quantitative characterization of the geometry and fluid transmissivity of the fracture network is essential for the understanding of failure mechanisms and fluid flow behavior.

METHODOLOGY

Fracture mapping – 3D reconstruction from serial cross-section images

The imaging approach uses a surface grinder and a digital camera to successively collect high-resolution images of surfaces serially exposed by grinding, where fluorescence imaging is used to achieve a high intensity contrast between fractures and rock matrix. From the collected images, a digital 3D representation of the fracture network in an 8 cm shale cube is reconstructed at a spatial resolution of 39 × 39 × 50 μm³. Using this approach, a similar resolution can be achieved for a variety of rocks ranging from centimeters to tens of centimeters in size.

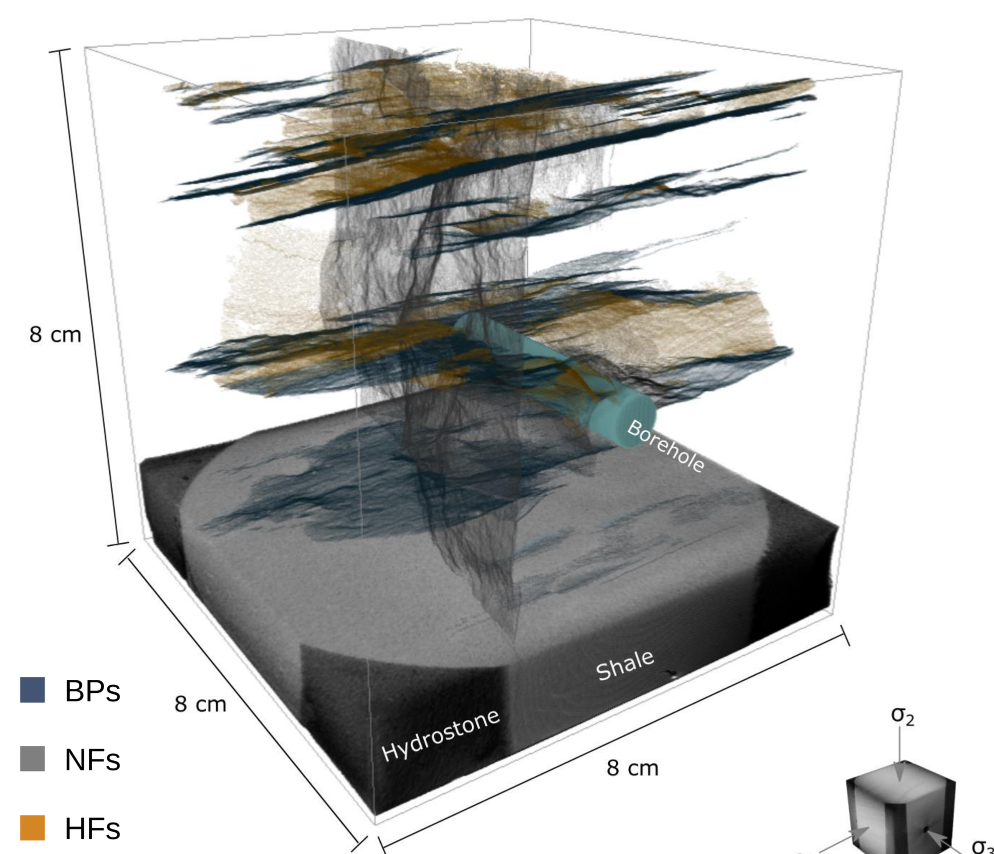


Deep-learning based fracture region segmentation

The fracture network constituted by parted bedding planes (BPs), natural fractures (NFs), and hydraulic fractures (HFs) is segmented into three regions of interest using a deep-learning based approach, which is more efficient and produces more consistent results compared to human-guided manual segmentation.

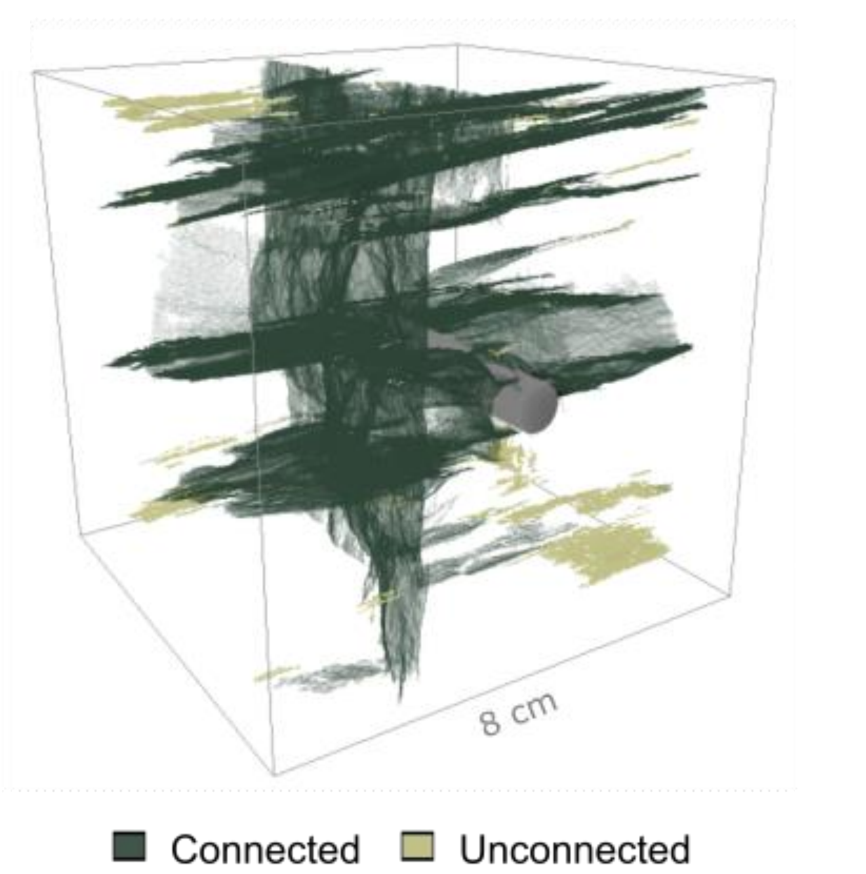
Quantitative characterization

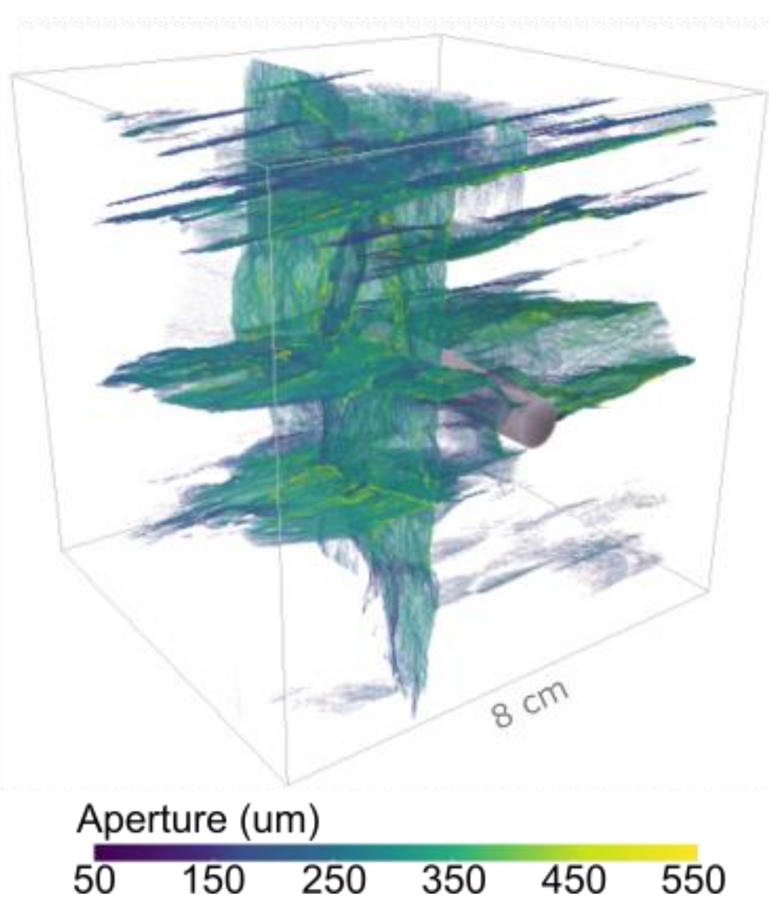
- Fracture geometry is assessed by fracture connectivity, volume fraction, aperture, surface area, dip direction, and dip angle.
- Fluid producibility of the fracture network is numerically simulated using the finite volume method.



[Li et al., 2022]

FRACTURE FEATURE MAPS

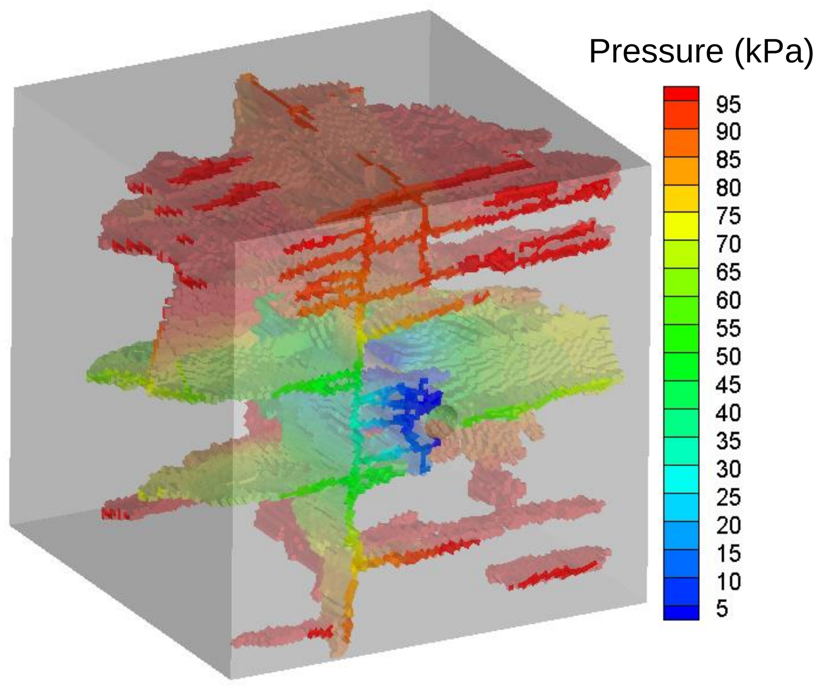




Properties of the fracture network

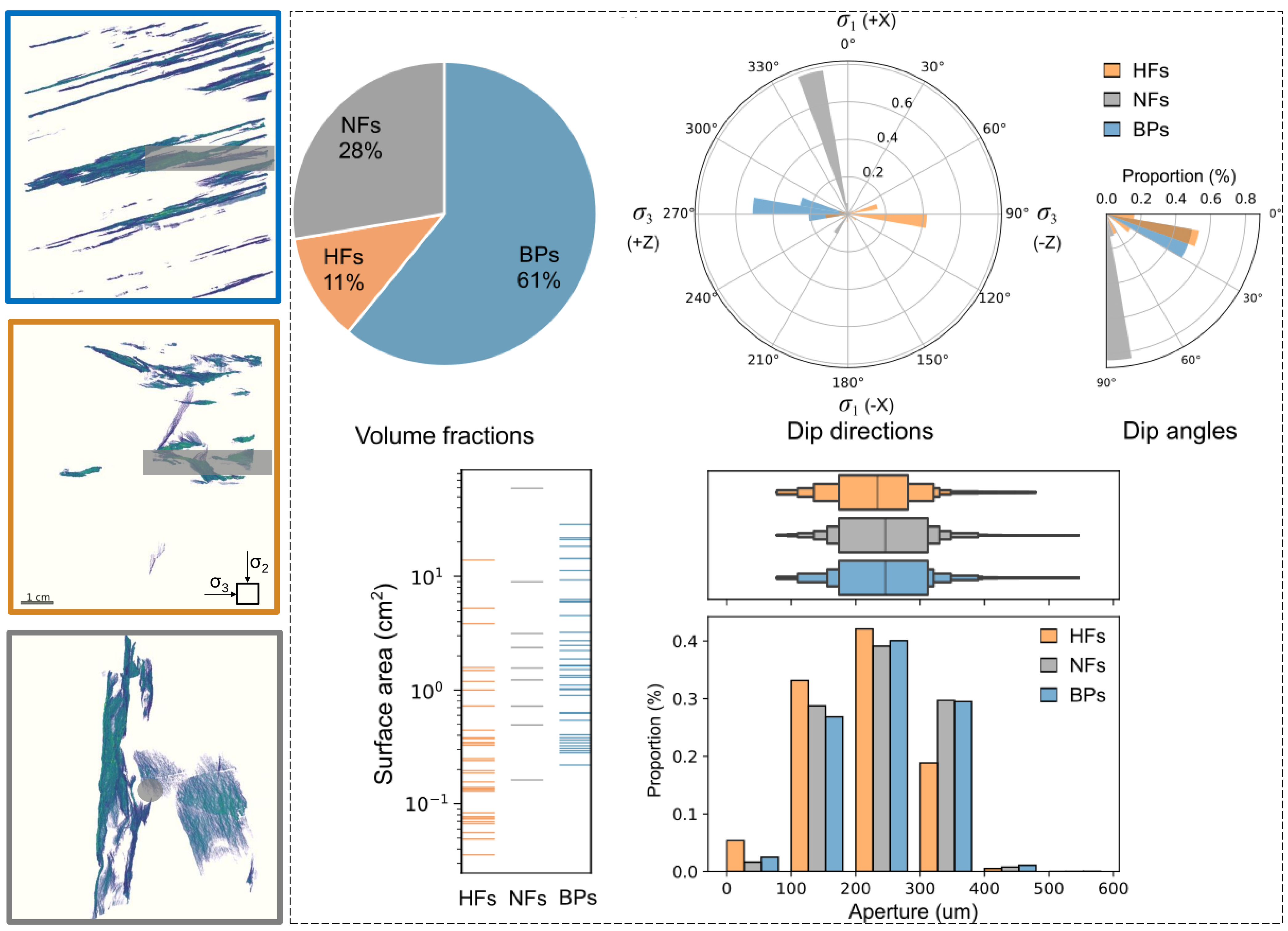
Parameters	Values
Fracture porosity (%)	1.69
Fracture connectivity (%)	97.0
Surface area to volume ratio (cm^{-1})	0.64
Average aperture (μm)	245.5

Fluid production pressure map



- The fluid-driven fracture network is highly interconnected, where the fractures unconnected to the borehole are mainly parted bedding planes.
- The area/volume ratio is orders of magnitudes higher than that normally observed in shale formations implying that the hydraulic fracturing testing highly improved its fluid recovery potential.
- The horizontal fluid drainage is much faster than in the vertical direction indicating strong fluid flow anisotropy.

GEOMETRICAL CHARACTERIZATION



- 89% of the hydraulically induced fracture network result from opening/extension along the pre-existing discontinuities, demonstrating their controlling role on the fracture network geometry.
- The tendency of HFs dipping towards σ_3 with low dip angles implies the strong influence of BPs, in addition to principal stress orientations, on HFs propagation.
- The rock fabric being, on average, wider than HFs may indicate that the opening of rock fabric is easier than HFs.
- Lateral fracture network growth along rock fabric is favored under the prescribed stress-state.

The geometry and characteristics of the fracture network may be indicative of near wellbore fracture complexity at field scale.

- Li M, Magsipoc E, Abdelaziz A, Ha J, Peterson K, Grasselli G (2021) Mapping Fracture Complexity of Fractured Shale in Laboratory: Three-dimensional Reconstruction From Serial-section Images Rock Mechanics and Rock Engineering. 55:2937-2948
- Li M, Magsipoc E, Abdelaziz A, Ha J, Peterson K, Grasselli G (2022) Fracture network in laboratory hydraulic fracturing tested shale cube. In: Album of Porous Media Structure and Dynamics.