Quantification of the Crack Evolution Process by Extracting Relevant Signal Components from Wave Propagation and Diffusive Transport Front Measurements

Dr. Siddharth Misra, Assistant Professor
Mewbourne College of Earth and Energy
The University of Oklahoma
Norman, OK 73019

The project will measure new signals and develop new machine learning algorithms/codes to understand and predict the micromechanics of mechanical discontinuities (cracks) in geological porous material under shallow crustal conditions. In alignment with DOE Geosciences Research grand vision, this research will provide the foundation for improved visualization of the spatiotemporal evolution of crack clusters and fracture networks in the subsurface earth. The spatiotemporal evolution of micromechanical discontinuities (cracks) influences the wave propagation and diffusive transport phenomena in the medium. During the evolution of the crack clusters from initiation to coalescence, different wave/diffusion phenomena, such as sonic propagation, pressure diffusion, and acoustic emission, to name a few, are sensitive to different elements of the micromechanical discontinuities. Sonic propagation, acoustic emission, and pressure diffusion monitoring have the potential to assess, monitor, and map the crack-driven micromechanical alterations in the rock because the transmitter-receiver arrays can be designed, arranged and tuned to (*1*) achieve maximum recovery of the scattered waveforms and traveltimes, (*2*) capture the later arrivals and multiple reflections, and (*3*) illuminate large volume of the media. However, the structural/topological complexities of the mechanical discontinuities, complex distribution of the stress fields, complex mechanical alterations in media, and fluid redistribution in the crack system pose serious challenges for the detection and modeling of the crack evolution process. The crack evolution process depends on the mineralogy, pore structure, rock fabric, effective mechanical moduli, fluid saturation, and pre-existing microcracks in the rock, and also on the strain rate and the thermal, chemical, and stress histories. For purposes of accurately accounting such complexities and heterogeneities in the absence of reliable physical laws, simulation methods, and signal processing techniques, novel data-driven machine learning methods will be developed and applied on the six aforementioned laboratory-based signals acquired during the crack evolution process. Overall, in the next five years of the project, eight important tasks will be accomplished: (*1*) multipoint, concurrent and continuous measurements of sonic waveform, sonic traveltime, pressure diffusion traveltime, pressure transient, acoustic emission signal, and stress-strain curves during the spatiotemporal evolution of crack clusters; (*2*) development of an improved micromechanical model of spatiotemporal crack evolution process; (*3*) development of a 3D fast-marching solver to simulate the wave propagation and diffusive transport fronts influenced by the spatiotemporal evolution of crack clusters; (*4*) novel training of machine learning and deep learning models with the fast-marching solver and measured dataset; (*5*) extraction of signal components relevant to the various phases of crack evolution by jointly processing the six aforementioned laboratory measurements using the machine learning and deep leaning methods; (*6*) generation of a 2D visual map of the crack evolution process; (*7*) creation of a database of crack-driven signals and extracted signal components, and (*8*) development of an open-source machine-learning-centric software suite to process the signals associated with brittle processes. The research work will facilitate the development of high-quality graduate/undergraduate educational material and will promote public understanding of brittle processes through datasets, publications, software, infographics, and videos.