## Reservoir Dynamics and Injection-Induced Seismicity in the Permian Basin

Peter Hennings
Senior Research Scientist and Lecturer
Principal Investigator – Center for Injection and Seismicity Research (CISR)
Bureau of Economic Geology
The University of Texas at Austin

The TexNet Earthquake Monitoring Network and its partner seismic networks have been providing detailed information on seismicity in Texas for over six years. CISR research using this data has shown that induced seismicity has occurred within three distinct geological systems in the Permian Basin region. Two of these systems are the injection-induced ruptures of basement-rooted faults in the northern Delaware Basin and the central Midland Basin. The inducement mechanism for these systems is an increase in pore pressure, and therefore stress, from injection into strata above basement. Because basement faults host these ruptures, the local magnitudes can be relatively large, with events of $M_L$5.0+ recorded. For earthquakes associated with basement ruptures, we find pore pressure increases of up to 450 psi proximal to large-scale injection and strongly variable temporal variations in injection rate. The most active sets of ruptures in this system are within the Culberson-Mentone zone, which sits distally from areas of large-scale injection, and where changes in pore pressure are on the order of 0-75 psi. This implies that poroelastic stressing must play a role, acting at greater distances than pore pressure change alone. This mix of proximal and distal inducement in the northern Delaware Basin and the Midland Basin is like that observed for inducement in northern Oklahoma, Kansas, and in the Fort Worth Basin of Texas.

The third induced seismicity system is within Permian-age shales and shallower strata in the southcentral Delaware Basin and is caused by rupture of strata-bound faults that do not extend into basement. This geomechanically complex inducement is caused by injection into the Delaware Mountain Group (DMG), hydraulic fracturing (HF) of the underlying shales, and variable depletion and compaction of the shales associated with production. Host formation lithology and the strata-bound nature of these fault ruptures reduces the observed maximum magnitude to $<M_L$3.5, with rare exceptions. Many of these seismogenic faults have been made neotectonically active and deform the ground surface due to both injection and production. Some of these shallow faults have tips that extend downward into underlying shale formations where HF rupture can be facilitated by natural overpressure conditions. In this system there has been a transition from seismogenic rupture to aseismogenic slip as HF-inducement gives way to faulting due to differential subsidence of the deeper shales and pore pressure increase of the shallow strata by injection.

In the Delaware Basin, petroleum operations are causing accelerating subsidence and uplift, and their implications must be understood to protect surface environment and the sustainability of energy production. We use Sentinel-1 satellite radar data to analyze the widespread deformation patterns we observe across the entire basin spanning 2015-2021. Through an integrated analysis of the observed deformation patterns with comprehensive subsurface data, we show that the rapidly accelerated deformation rates since 2018 dynamically relate to massive increases in production, injection, and activation of faults that deflect the ground surface, coseismic deformation, and induced earthquakes. Understanding these changes is a pressing concern for safeguarding the surface environment in the basin and its tens of thousands of old petroleum wellbores.