Interpreting strain tensor data to characterize and monitor reservoirs for CO2 storage and other applications

Recent advances in instrumentation have made it feasible to measure the transient strain tensor caused by small changes in fluid volume or pressure in the subsurface and this has opened the door to new opportunities for characterization and monitoring. We have deployed strainmeters and then conducted injection well tests in an underlying reservoir at 530m depth. The resulting data indicated that the horizontal strain at shallow strainmeters (30 to 40m depth) was tensile and the vertical strain was compressive. The radial strain was less than the horizontal strain, and the strain rates decreased from 100 nanostrain/day to roughly 10 nε/d over a few days. The signal at two strainmeters at shallow depth were consistent, although the magnitude of the horizontal strains were different reflecting the different radial directions from the well. The signal at a deep strainmeter deployed at reservoir depth was much different, with tensile vertical strains and compressive horizontal strains.

These data can be interpreted by inverting poroelastic forward models developed using numerical and analytical methods. The average horizontal strain in the caprock resembles the transient pressure in the underlying reservoir and classic type-curve methods from transient well testing can be used for preliminary interpretations of strain data. We have developed closed-form analytical solutions to a pressurized poroelastic inclusion and inhomogeneity in a half-space. This model is fast and can be inverted to estimate reservoir stiffness and geometry. Numerical models developed using finite element methods allow more details of the subsurface to be included in the inversion, but they require much longer run times and this makes inversion cumbersome using standard methods. We have developed an inversion approach that uses a proxy model created using machine learning to do most of the forward calculations. The proxy model is periodically updated and refined using the finite element model to ensure accuracy. This approach significantly reduces the computational requirements and makes it feasible to use Bayesian inversion with large numerical models.

We have shown that the strain tensor in the caprock is sensitive to pressure in the reservoir, boundaries in the reservoir, and pressure in the caprock caused by leaks. These results indicate that coupling strain tensor data with inversion has the potential to help evaluate reservoirs during initial characterization, and to monitor them during the CO_2 injection and storage process.