# Interpreting the Strain Tensor During Injection into a Reservoir

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A suite of well tests was conducted to evaluate the feasibility of measuring and interpreting the strain tensor during injection. Water was injected at 1 liter/s for a few days to a few weeks into a well completed at a depth of 530 m in the Bartlesville sandstone in the North Avant Field in Oklahoma. The strain tensor was measured using strainmeters at a depth of 30m and a distance of 220m from the well. We used a Gladwin strainmeter, a state-of-the-art geodetic strainmeter, as well as novel borehole strainmeters developed for the project. After processing, the horizontal strains were tensile and the vertical strain was compressive during injection. The radial strain was less than the circumferential strain. Strain magnitudes increased during injection and recovered afterward. The strain rate was as fast as 100 nanostrain/d at the start of injection, and decreased to 10 nanostrain/d after a few days. The normal strain signals were approximately proportional to the log of time during the first few days of injection, and the semi-log slope was 50 to 75 nanostrain. Data from the Gladwin strainmeter were essentially identical to data from a strainmeter we developed using optical fiber sensors. Tilt was measured using two tiltmeters, but the tilts were erratic compared to the normal strain and were of limited value. Strain data were analyzed using a strain type-curve method, an analytical solution to a poroelastic inhomogeneity, and a stochastic inversion method. Poroelastic simulations explain the data well. Results from the interpretation methods are consistent with each other, and with independent information characterizing the area. The hydraulic diffusivity is approximately 0.5 $m^2$/s and the permeability is between 100 and 500 mD, according to analysis of the strain signals. This is consistent with measurements of permeability from cores, and with analyses of pressure transients. The analyses indicate that Young's modulus of the reservoir is between 2 and 6 GPa. Strain interpretations indicate the well intersects a permeable lens with a maximum dimension of 500 to 1,000 m. An isopach map of coarse-grained sand confirms a feature roughly 1,000 m in lateral extent. The results demonstrate that the strain signal measured at shallow (30m) depth can be used to infer properties and heterogeneities in an underlying reservoir or aquifer.

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