Field Testing of Hybrid Brillouin-Rayleigh Distributed Sensing System for Subsurface Water Injection Monitoring

*Yankun Sun[1,2], Ziqiu Xue[1,2], Tsutomu Hashimoto[1,2], Xinglin Lei[3], Yi Zhang[1,2]

1. Geological Carbon Dioxide Storage Technology Research Association, 2. Research Institute of Innovative Technology for the Earth, 3. National Institute of Advanced Industrial Science and Technology

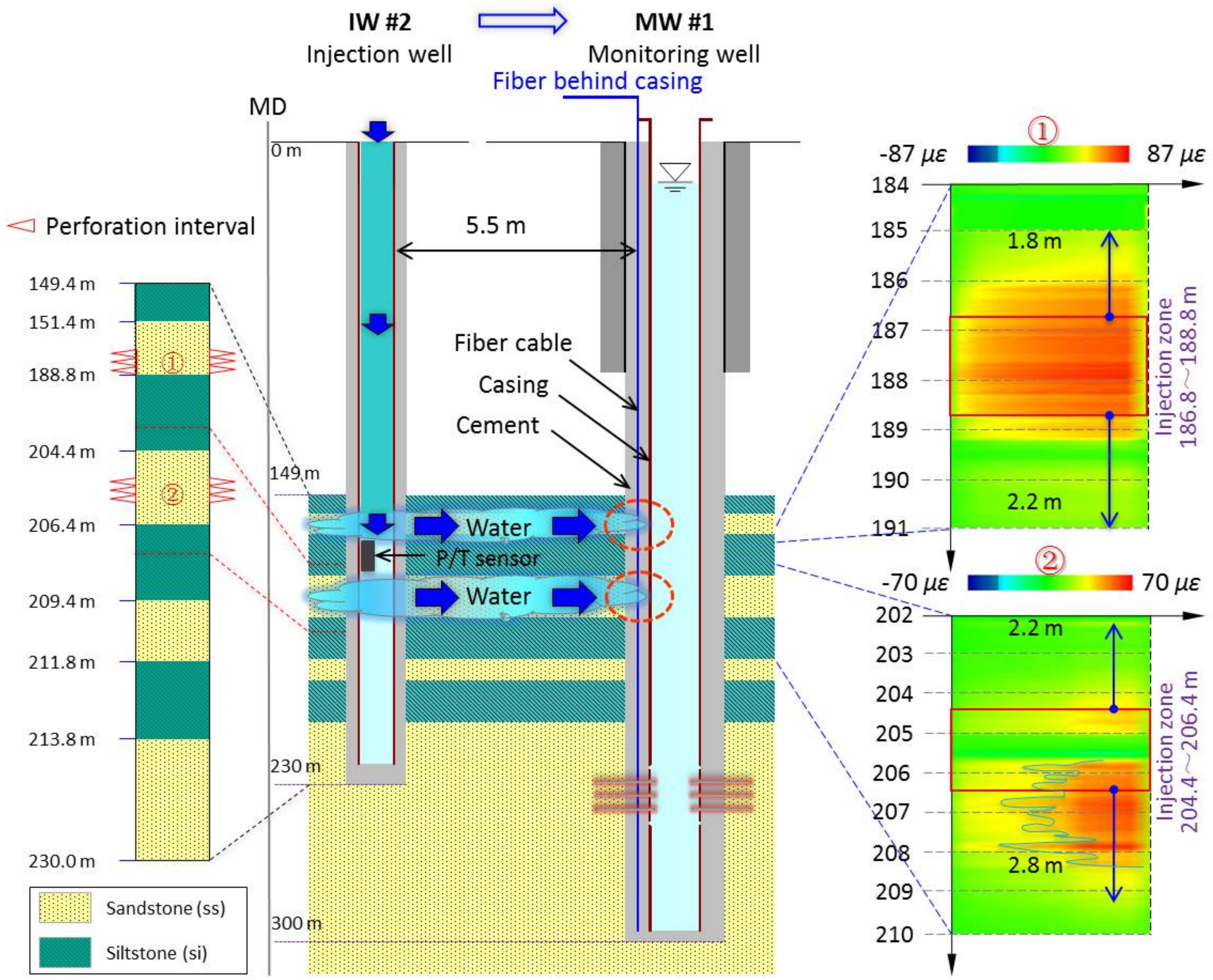
Massive fluid injections into underground formations inevitably alter stress state and even induce damaging earthquakes, so robust high-resolution monitoring technologies are urgent to track geomechanical behaviors of injected fluids. Here we present one of the first case studies demonstrating the use of distributed fiber optic sensing (DFOS) technique based on hybrid Brillouin-Rayleigh backscattering for well-based monitoring of geomechanical deformations induced by field water injection. Injection tests were conducted with different injection scenarios between injection well (230 m, IW #2) and 5.5 m away from fibered monitoring well (300 m, MW #1) deployed cable behind casing in Mobara, Japan. Geomechanical responses were real- time recorded using DFOS approach; the resulting strain profiles were used to capture fluid evolution behaviors; thus evidencing that induced strains significantly depend on injection rate, injection pressure and lithological heterogeneity using this approach. Concurrent borehole logging was utilized to detect injection-induced variation of near- wellbore formations, which results agreed reasonably well with DFOS readings. This field application of hybrid DFOS technology conclusively enables speedy improvement of finely monitoring subsurface geoscience engineering activities, such as CO_2 storage.

Based on this methodology, some conclusions in this study can be drawn below:
1. An advanced DFOS system based hybrid Brillouin-Rayleigh backscattering is successfully applied to real-time monitor water injection tests between two adjacent wells. Two different injection formations ① and ② are investigated.
2. Field testing demonstrates that induced geomechanical deformation (i.e., strain) is mainly dependent on injection volume rather than injection temperature, which has no significant effect on the strain changes.
3. Geomechanical deformations harmoniously emerge and eliminate with injection schemes, although the effect of packers on the strain profile results in slight emergency of strain leaps. The impacted zones expand along vertical direction beyond corresponding injection sections.
4. Formation heterogeneity results in lateral transport of injected water and its pressure propagation in the pore space. Compared with *V*sh -GR and BH, the lower *V*sh related to formation is easier for strain accumulation. In addition, although the impact acting on clay-rich formations is relatively small, the existence of shale just weakens the induced deformation intensity rather than completely stops the strain expansion.
5. According to open-hole resistively logs of IW and MW, simplified simulation result further confirms strong small-scale formation heterogeneity and discontinuities of shale-sand distribution in the injection formations.
6. Testing results also reveal that there are two main reasons accounting for vertical expansion of impacted zones during water injections. First reason is formation heterogeneity, which is quantified by open-hole resistivity logging and GR data, largely affecting fluid behaviors, including migration, evolution and diffusion in subsurface. Second reason is that due to poroelastic deformation, different injection scenarios can generate different injection pressure, which will ultimately lead to different geomechanical deformation responses and first-arrival pressure front patterns of injected water propagating to the

fibered well.

References
Xue, Z., Hashimoto, T., 2017. Geomechanical Monitoring of Caprock and Wellbore Integrity Using Fiber Optic Cable: Strain Measurement from the Fluid Injection and Extraction Field Tests. *Energy Procedia* 114, 3305–3311.
Sun, Y., Li, Q., Fan, C., 2017. Laboratory core flooding experiments in reservoir sandstone under different sequestration pressures using multichannel fiber Bragg grating sensor arrays. *International Journal of Greenhouse Gas Control.* 60, 186–198.
Sun, Y., Xue, Z., Hashimoto, T., 2018. Fiber optic distributed sensing technology for real-time monitoring water jet tests: Implications for wellbore integrity diagnostics. *Journal of Natural Gas Science and Engineering.* 58, 241–250.
Sun, Y., Xue, Z., Hashimoto T., Zhang, Y., 2019. Hybrid Brillouin-Rayleigh Sensing System for Cross-well Monitoring Fluid Injection Tests—A Geomechanical Responses Perspective. *Water Resource Research.* (Under review).

Keywords: Distributed fiber optic sensing, Fluid injection and storage, Hybrid Brillouin-Rayleigh backscattering, Real-time monitoring, Strain responses, Geomechanical deformation



A schematic for fiber optic sensors deployment (left) and the mapped strain by the fiber optic cable (right).