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Joint petrophysical full-waveform inversion of the shallow-seismic and multi-offset GPR data

Tan Qin, Thomas Bohlen, and Yudi Pan
Geophysical Institute, Karlsruhe Institute of Technology, Karlsruhe, Germany (tan.qin@student.kit.edu)

Shallow-seismic surface wave and ground penetrating radar (GPR) are employed in a wide range of engineering and geosciences applications. Full-waveform inversion (FWI) of either seismic or multi-offset GPR data are able to provide high-resolution subsurface characterization and have received particular attention in the past decade. Those two geophysical methods are involved in the increasing requirements of comprehensive site and material investigations. However, it is still challenging to provide an effective integration between seismic data and electromagnetic data. In this paper, we investigated the joint petrophysical inversion (JPI) of shallow-seismic and multi-offset GPR data for more consistent imaging of near surface. As a bridge between the seismic parameters (P-wave velocity, S-wave velocity, and density) and GPR parameters (relative dielectric permittivity and electric conductivity), the petrophysical relationships with the parameters namely porosity and saturation are employed to link two data sets. We first did a sensitivity analysis of the petrophysical parameters to the seismic and GPR parameters and then determined an efficient integration of using shallow-seismic FWI to update porosity and GPR FWI to update saturation, respectively. A comparison of several parameterisation combinations shows that the seismic velocity parameterisation in shallow-seismic FWI and a modified logarithm parameterisation in GPR FWI works well in reconstructing reliable S-wave velocity and relative dielectric permittivity models, respectively. With the help from the petrophysical links, we realized JPI by transforming those well recovered parameters to the petrophysical parameters and then to other seismic and GPR parameters. A synthetic test indicates that, compared with the individual petrophysical inversion and individual FWI, JPI outperforms in simultaneously reconstructing all seismic, GPR, and petrophysical parameters with higher resolution and improved details. It is proved that JPI would be a potential data integration approach for the shallow subsurface investigation.