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Density parameter estimation in full waveform well-to-well tomography

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The importance using the full waveform is widely recognized in seismic explorations. Especially, seismic full waveform inversion (FWI) can detect the high-resolution physical properties in the subsurface. Since the seismic wave propagation cannot be controlled by not only P-wave and S-wave velocities but the density of the medium, it is necessary to include all three parameters in the modeling and inversion (Vireux and Operto, 2009). However, multi-parameter FWI is a challenging problem because parameters are coupled with each other, and the coupling effects prevent from the appropriate estimation of the elastic parameters. Especially, the estimation of density is a very difficult issue because plural elastic parameters including density increases the dimension of the solution space, so that any minimization could be easily trapped in local minima. Therefore, the density is typically estimated using an empirical formula such as the well-known Gardner's relationship (Gardner et al., 1974) or is fixed to a constant value. Since the density parameter is directly included in the elastic wave equation, it is necessary to check whether it is possible to estimate density value exactly or not. Moreover, the Gardner's relationship is an empirical equation and could not always show the proper relation between Vp and density(e.g., in the salt dome). Pre-salt exploration conducted in recent decades could accordingly be influenced.

The objective of this study is to investigate the feasibility of the estimation of density structure when the density is inverted with the other elastic parameters and to assess if density is separable from the other parameters. We perform 2D numerical simulations in order to investigate the most important factor in the inversion of density structure as well as Vp and Vs. We conducted four numerical experiments with different inversion strategies; i.e. we invert 1) Vp and density simultaneously, 2) Vs and density simultaneously, 3) Vp, Vs and density simultaneously, and 4) only density. Considering these results, the density inversion results are affected by the other parameters and inversion results are worse than the result of inverting solely density. Compared with the other parameters, the density has a little influence on the waveform, and it is likely to be ignored in the inversion. Moreover, we conducted grid analysis of misfit function (Gholami et al., 2013) to estimate the contribution of each parameter to misfit function. These results suggest that solely inversion of density is the most effective to estimate the reliable value, on the other hand to estimate density with the other parameters is captured in the local minima.

Keywords: full waveform inversion, density