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Full-waveform Inversion of Crosshole GPR Data Collected in Strongly Heterogeneous Chalk: Challenges and Pitfalls

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Chalk is an important reservoir rock for hydrocarbons and for groundwater resources for many major cities. Therefore, this rock type has been extensively investigated using both geological and geophysical methods. Many applications of crosshole GPR tomography rely on the ray approximation and corresponding inversions of first break traveltimes and/or maximum first-cycle amplitudes. Due to the inherent limitations associated with such approaches, the resulting models tend to be overly smooth and cannot adequately capture the small-scale heterogeneities. In contrast, the full-waveform inversion uses all the information contained in the data and is able to provide significantly improved images. Here, we apply full-waveform inversion to crosshole GPR data to image strong heterogeneity of the chalk related to changes in lithology and porosity.

We have collected a crosshole tomography dataset in an old chalk quarry in Eastern Denmark. Based on core data (including plug samples and televiewer logging data) collected in our four ~15-m-deep boreholes and results from previous related studies, it is apparent that the studied chalk is strongly heterogeneous. The upper ~7 m consist of variable coarse-grained chalk layers with numerous flint nodules. The lower half of the studied section appears to be finer-grained and contains less flint. However, still significant porosity variations are also detected in the lower half. In general, the water-saturated (watertable depth ~2 m) chalk is characterized by high porosities, and thus low velocities and high attenuation, while the flint is essentially non-porous and has correspondingly high velocities and low attenuation. Together these characteristics form a strongly heterogeneous medium, which is challenging for the full-waveform inversion to recover. Here, we address the importance of (i) adequate starting models, both in terms of the dielectric permittivity and the electrical conductivity, (ii) the estimation of the source wavelet, (iii) and the effects of data sampling density when imaging this rock type. Moreover, we discuss the resolution of the bedding recovered by the full-waveform approach. Our results show that with proper estimates of the above-mentioned prior parameters, crosshole GPR full-waveform tomography provides high-resolution images capturing a high degree of variability that standard methods cannot resolve in chalk. This in turn makes crosshole full-waveform inversion a promising tool to support time-lapse flow modelling.