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Sleipner CCS site: velocity and attenuation model from seismic tomography

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The results of the travel-time and frequency shift tomographic inversion of the seismic data from one of the high-resolution lines acquired in 2006 on the Sleipner CO_2 geological storage site are here presented. The work has been performed within the European project CO_2ReMoVe, to produce an accurate model in-depth, of both seismic velocities and attenuation, to constrain better the quantification studies of the project's partners.
Tomographic techniques have the advantage of not assuming horizontal layering or uniform lateral velocities, and of enabling an easy comparison of models, even if resulting from seismic data acquired with different geometries, unavoidable in a time-lapse data set. Through an iterative process, the differences in travel-times between observed direct, reflected or refracted arrivals and the same, calculated on a discrete model, with a ray-tracing based on the Fermat's principle, are minimized. Other minimization procedures provide the reflector/refractor geometries in -depth. Analogously, in attenuation tomography, the minimization process takes into account the observed and calculated spectral-centroid frequency-shift, due to the loss of the highest frequency of the seismic wave, while crossing an attenuating medium. The result is a seismic quality factor (Q) model in-depth, and hence of the attenuation that is known to be more sensitive to subtle changes in physical properties than seismic velocity. The model is across the center of the CO_2 plume, on the in-line 1838, and is constituted by nine layers, four resulting by a preliminary analysis of the pre-injection 1994 data set, i.e. seabed, a strong reflection in the overburden and the top and bottom of the Utsira Sand, plus additional five horizons, four of which within Utsira Sands, and one just above the top of it. The layers within the reservoir are very close to each other and in some cases they merge together laterally. The accumulation of CO_2 in the uppermost layer of the reservoir, observed by other analyses, is confirmed by our analysis, whereas within the plume, lateral variations of both seismic velocity and Q values are observed. The presence of fine shale lenses, and their impact on the CO_2 distribution within the plume may be the reason for these lateral variations. The seismic velocity and Q tomographic values have been compared with the theoretical curves from petrophysics studies, so to give to the results an interpretation in terms of effective variations in CO_2 saturation and heterogeneity within the plume.