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Seismic reflection structure of a high-temperature geothermal reservoir from Monte-Carlo inversion

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The K-Horizon is a well-known seismic reflection structure of regional extent in the Larderello area in Tuscany, Italy. The geological nature of the K-Horizon however is unknown. It is generally assumed to be a geothermal reservoir where possibly supercritical conditions prevail (∼450°C temperature). Investigation of its structure and geothermal potential is one of the main objectives of the collaborative DESCRAMBLE project of the European Union Horizon 2020 program.
Petrophysical laboratory data and geologic field observations suggest that the K-Horizon consists of alternating layers of fractured, fluid-containing (low seismic velocity) and unfractured rocks (high seismic velocity) that may seal a reservoir of superhot fluids. Indications on the low- and high velocity ranges are available from borehole samples from the area. We used this information as a starting point for modeling the seismic signature of the K-Horizon and for estimating its spatially variable structure from high-quality field seismograms from a 3D-seismic survey. For the seismic inversion we applied a Monte-Carlo approach:
In order to verify whether such a layered system would produce the dominating reflectors in the way they are observed throughout the 3D-seimic survey, we composed random models of alternating high- and low-velocity layers. The velocities were allowed to vary around a mean within a Gaussian distribution. The layer thicknesses were drawn from a Weibull distribution with a mode of 80 m and shape such that a minimum thickness of 20 m was ensured. This lower boundary corresponds to the theoretical resolution capacities of the survey instrumentation. Vertical incidence seismograms were produced by convolving the source signal (a vibro-sweep) with the reflectivity series and then correlated with the real time-migrated data. We computed more than one million models. For each input trace the models yielding the ten highest correlation coefficients were averaged to obtain a representative time-velocity model.
Adjacent traces show very consistent results in terms of layer thickness and velocity. Thus, the observed seismic time sections are very well represented by these time-velocity model traces. It turns out that the K-Horizon is well defined by at least one pair of thin high- (+10 to +25% against background) and low- (-10 to -25%) velocity layers. Moreover, the variation between all contributing models of a trace is lowest around the K-Horizon. Together with the enormous velocity contrasts, this strongly supports the idea of the alternating layer model. In addition, the large number of considered models enables a careful uncertainty analysis.