Analysis of the seismic response to reservoir development and long-term operation at the Rittershoffen deep geothermal site

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In a geothermal reservoir, seismicity may be induced due to changes in the subsurface as a result of drilling, stimulation or circulation operations. The induced seismic events are therefore strongly linked to the fluid flow, the mechanical state of the reservoir and the geological structures that impact the stress field and make this fluid flow possible. Here, the study is based on the monitoring of the development and operation of the deep geothermal site at Rittershoffen (Alsace, France) using different seismic networks covering various operational periods from September 2012 to present, including the drilling of the well doublet GRT1/GRT2, stimulation of GRT1 and well testing. The seismicity induced by these operations has the potential to give valuable insight into the geomechanical behaviour of the reservoir and the geometry of the fracture network. The present study gives an overview of the spatial and temporal development of the induced seismicity and the magnitudes of the events to provide insights into active structures in the reservoir.

To improve the level of detection, we first apply a template matching algorithm to the continuous waveforms recorded by the seismic networks. After running the detection with the template matching, the relative locations of all detected events are calculated as well as relative magnitudes. This workflow is applied to the whole time period from the start of the drilling in 2012 up to 2017. The spatial and temporal evolution of the events and their magnitudes shows how the different operations during reservoir development influence the seismogenic development of the reservoir and the seismic activity during continuous operation of the site. Further analysis like b-value computation, estimation of the best-fitting planes to the seismic clouds and evaluation of the waveform correlation between the seismic events give insight into the processes that induced the seismicity and the relation between different seismic intervals.

Focus of the present study is on the similarities and differences in the seismic response of the reservoir to the three subsequent stimulations of GRT1, called thermal, chemical and hydraulic stimulation. Results show that the seismicity induced during the hydraulic stimulation is much
stronger in terms of seismicity rate and magnitudes than seismicity induced during thermal stimulation and migrates further into the reservoir. Noticeably, after a seismically quiet period of four days after the hydraulic stimulation a short burst of seismicity occurred unrelated to any operations on site. Seismicity during this delayed interval proved to have quite distinct characteristics from the seismicity induced during injection. While no significant seismicity was induced during chemical stimulation, the operation may have had an important influence on the seismic response of the reservoir during hydraulic stimulation by changing the state of the present fracture network.