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Anomalous diffusion of seismicity induced by the stimulation of an enhanced geothermal system below Basel, Switzerland

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Anthropogenic activities, associated with fluid or gas injections or extractions from the Earth's crust, geothermal exploitation, the impoundment of water reservoirs and mining activities can induce earthquakes. Such earthquakes can ever occur in zones of low deformation, posing a higher seismic risk than the one expected in the conventional hazard models. Although the failure condition of a fault in the presence of pressurized fluids seems relatively simple, a complication emerges from the diffusion of the pore-pressure triggering front that can trigger earthquakes at great distances away from the initial site of the pore-pressure perturbation and at time scales that may vary from days, up to months or even years. A characteristic example is the development of an enhanced geothermal system (EGS) below Basel, Switzerland, in 2006. The water injection under high pressures into the impermeable crystalline basement induced more than 10,000 earthquakes during the 6-days injection phase, which reached magnitudes that required the reduction of the injection flow rates, the eventual well shut-in and the abandonment of the project. The spatiotemporal properties of the induced seismicity indicate the migration of the seismic front away from the borehole cashing shoe, which is more likely associated with pore-pressure diffusion into a complex network of fractures. During the first three days of the injection phase, seismicity diffuses away from the cashing show at slow diffusion rates, which can be described by a slow sub-diffusive process. The diffusion process changes dramatically following the increase of the injection flow rates and the wellhead pressure, where a fast migration of seismicity and super-diffusion is observed. After the reduction of the injection rates and the eventual well bled-off, the induced seismicity rates decreased drastically and the earthquake diffusion process turned back to slow sub-diffusion, which persisted for a 100-days period. Overall, the spatiotemporal properties of seismicity demonstrate the complex propagation and the anomalous diffusion of the pore-pressure triggering front (e.g., Vallianatos et al., 2016) during the stimulation of the EGS in Basel, a process that may be expected in most cases of induced seismicity in the highly heterogeneous and multi-fractured crust.

References

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