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Seismicity induced by hydraulic stimulation – seismic efficiency of injection and spatiotemporal analysis

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Fluid injection into the rock formations represents a valuable analog to study the role of high-pressurized fluids in the seismogenic process. It is often carried out in depths of first thousands of meters in order to increase the permeability of rock formation for better exploitation of hydrocarbons and geothermal energy. The increased fluid pressure results in decrease of the strength of fractures and faults which causes their brittle failure that is observed in the form of microearthquakes and enables imaging of the stimulated rock volume. Besides this positive role, seismicity sometimes increases to the level that can be felt by the population, which can cause concerns about the seismic risk of these industrial operations. Thus, one of the main interests focused by recent studies deals with the maximum earthquake that can be triggered by hydraulic stimulations. One of the most important factors for better understanding of the role of fluid injection is the relation between the hydraulic energy and released seismic energy. To quantify this we introduce the parameter seismic efficiency of injection which is proportional to the ratio of the seismic moment and hydraulic energy. We test this parameter by analyzing seismicity in two geothermal reservoirs and two gas reservoirs. We find that for our four different data sets, the seismic efficiency of injection encompasses a broad range of values from about 1e-6 to 1 and it depends on the geology and most probably also on stress state of the stimulated volume. During the hydraulic stimulation, seismic efficiency of injection seems to be stable in time, which makes possible to use it for assessment of seismic risk even from a short-term injection test. As a parameter which is sensitive to the released tectonic energy, seismic efficiency of injection could be used also for distinguishing induced and triggered seismicity. We also analyze the relation between the spatiotemporal characteristics of the activity and injection regime in order to identify areas with higher potential of seismic moment release.