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Fluid-induced seismicity in volcanic and hydrothermal systems: numerical studies of the Tjörnes Fracture Zone, Iceland

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Pre-, co- and post-seismic fluid flow and fault behaviour in the seismically active region of the Tjörnes Fracture Zone, North of Iceland are the subject of this study. We run fluid flow (heat and mass transport) and fault-rupture simulations of a geological model which is based on multichannel seismic reflection data. We reconstruct geological structures (i.e. faults, unconformities and lens-shape layers) of the first 10 km of the Tjörnes Fracture Zone at great detail. Numerically we resolve geological processes occurring at vastly different time-scales. The conceptual model of the toggle switch mechanism has been applied to analyse seismicity-induced fluid flow and explain key geophysical and geochemical observations in the Tjörnes Fracture Zone. The data highlight the occurrence of four distinct over-pressured areas in the crust of the Tjörnes Fracture Zone, consistently with geophysical observations. At depth critical over pressures are reached while low over pressures prevail between 7 km depth and the top of the basement. Faults often have critical over pressures and are close to failure. During failure, faults can release over pressures in less than five minutes, which is accompanied by a sudden in permeability of over seven orders of magnitude. At this time, short-lived but extreme flow rates of more than 0.01 ms^{-1} occur. During the post-seismic phase (i.e. after failure), as the over pressure dissipates and the normal stress increases, fault permeabilities decay back to their pre-failure values in 2 to 3 years, consistently with geochemical data. Our model suggests that the permeability of seismically active hydrothermal systems is constantly evolving and can lead to short-lived catastrophic flow events. Our results show why hydrogeochemical monitoring of faults may be an important tool to improve the confidence in earthquake forecasting.