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Explanation of non-symmetric upward and downward diffusion during fluid injection

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Non-symmetric upward and downward pressure diffusion from the point of injection is an often observed phenomenon in fluid-triggered seismicity. It has been observed during hydraulic stimulation of deep geothermal reservoirs as well as during natural CO_2 triggered seismic swarms, like during the 2008 swarm and earlier ones in Bohemia / Vogtland area. In recent studies, a diverse set of models is used to describe this phenomenon; most commonly utilizing a stress and pressure-dependent permeability, causing higher permeability upwards than downwards. Though, such models often lead to unrealistic large permeability gradients. Besides a mechanical reason, also temperature and density contrasts are possible sources for a non-symmetric diffusion process. A temperature gradient in depth influences fluid properties with depth and salinity causes buoyancy.

In this work, we compare all these possible sources, to identify to which extend every one of them could cause such non-symmetric diffusion. We perform our simulations with water, and also derive conclusions for CO_2 as a triggering fluid. Although in reality, a mixture of all sources may occur, we find that temperature has by far the strongest influence on non-symmetric diffusion processes, especially considering that many regions in which this phenomenon was observed, exhibit a large temperature gradient. A stress dependent permeability also causes non-symmetric diffusion, but assuming realistic permeability gradients, the influence is limited. Salinity has been found to play only a minor role. Due to the even stronger temperature dependence of CO_2 properties, the effect of temperature on CO_2 driven seismicity is larger than on water. In the case of infiltrating CO_2, depending on the host rock situation, also buoyancy can become significantly large, assuming that the injection timescale is too short for CO_2 to dissolve in the pore water of the host system.

Our results indicate the importance of a realistic heat transfer model when simulating fluid injection in regions with strong thermal gradients as even during short time scales fluid motion is strongly influenced by the temperature gradient of the host system. Many models so far neglect this effect and therefore do not adequately represent the fluid motion.