Help and risk of seismicity induced by reservoir stimulations: physical fundamentals

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Abstract:

Experiments with borehole fluid injections are typical for stimulation and development of hydrocarbon or geothermal reservoirs. A new important branch here is the CO2 sequestration. The fact that fluid injection causes seismicity has been well-established for several decades. Current on going research is aimed at quantifying and control of this process. Understanding and monitoring of fluid-induced seismicity can help us to characterize rocks and estimates results of their stimulations.

The fluid induced seismicity covers a wide range of processes between the two following extremes. If the injection pressure exceeds the minimum principal tectonic stress, a hydraulic fracture will be created. Depending on the process of fracturing growth, seismicity with characteristic properties is generated. Propagation of a hydraulic fracture is usually accompanied by opening of a new fracture volume, fracturing fluid loss and its infiltration into reservoir rocks as well as diffusion of the injection pressure into the pore space of surrounding rocks and inside the hydraulic fracture. Some of these processes can be seen from features of spatial-temporal distributions of the induced micro seismicity.

Often, seismicity is also observed many hundreds of meters away from the injection source and even for experiments, where the injection pressure is smaller than the minimum principal stress (like in many geothermic systems). In these cases, pore pressure diffusion is assumed to be the dominant factor controlling the micro seismicity. Fluid induced seismicity typically shows several diffusion indicating features, which are directly related to the rate of spatial grow, to the geometry of clouds of micro earthquake hypocenters and to their spatial density. In some cases spontaneously triggered natural seismicity, like earthquake swarms, also shows such diffusion-typical signatures.

The magnitudes M of the fluid-stimulated seismicity are usually in the range from -3 till 2. Nevertheless, especially for long-term injections with durations of months or even years, earthquakes with larger magnitudes (M = 4 or even larger) have been observed. So far, little effort has been undertaken to estimate the probability for these events to occur. We explain a way how to calculate and control the probability of fluid-induced earthquakes. We show many examples of micro seismic datasets from different injection experiments including Fenton Hill and Paradox Valley (USA), Soultz (France) and Ogachi (Japan).

This 2.5hr lecture will include:

- An introduction into theory of wave phenomena in elastic and poroelastic media
- An introduction into physical fundamentals of earthquake seismology and micro seismic monitoring
- An overview of physics and applications of fluid-induced seismicity as described in the abstract above
- Examples of natural and artificially induced seismicity.