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Non-linear anisotropic Biot slow wave: a model of seismicity triggering by hydraulic fracturing?

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Fluid injection in rocks is one of the standard ingredients of the underground reservoir development. Productions of shale hydrocarbons or geothermal energy as well as massive disposals of saltwater or carbon dioxide require broad applications of this technology. The fact that a fluid injection causes seismicity has been well-established for several decades. Understanding and monitoring of fluid-induced seismicity is necessary for hydraulic characterization of reservoirs, for assessments of reservoir stimulation and for controlling of the related seismic risk. One can show that a linear pore-pressure relaxation corresponding to distant domains of enhanced geothermal systems and a hydraulic fracturing of shale reservoirs are two asymptotic end members of a set of non-linear diffusional phenomena responsible for seismicity triggering. These are special cases of a rather general non-linear pressure diffusion equation taking into account a strong enhancement of the hydraulic diffusivity tensor. This equation can be considered as a wave equation corresponding to an anisotropic propagation of a non-linear poroelastic Biot slow wave. This formulation provides descriptions of forward- and backward fronts of propagating pressure perturbations. They correspond to the triggering and back fronts of induced seismicity. Also the spacial density of microseismic clouds can be described by this wave. Real induced-seismicity data confirm adequacy of this model.