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Injection-induced earthquakes rupture subcritically in regimes controlled by stress symmetry breaking

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Characterizing time-dependent deformation and fracturing in rocks is crucial for assessing seismic hazards and related risks. An important aspect of this process is subcritical fracture growth (SFG) and its properties. Under SFG, fractures can grow at stress values lower than the critical fracture toughness. Many laboratory studies have focused on tensile SFG, and some have assessed shear SFG in rocks. Here, we provide evidence for mixed-mode (tensile and shear) SFG in injection-induced seismicity in a geothermal field. We study a relationship between the SFG parameters and the rate of water injection into the reservoir. We analyse the injection rate with the degree of 3D stress anisotropy and find that the SFG regime may be controlled by the degree of the stress asymmetry, i.e. how close intermediate stress is to a transversely anisotropic condition. We observe that a critical rupture occurs when both SFG parameter is higher than 2 and the principal stresses are symmetric. We present a possibility of using these results in the operational reservoir to manage the seismic hazard.
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