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A stress-dependent model for reservoir stimulation in enhanced geothermal systems

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We present a procedure for testing the interpretation of the induced seismicity. The procedure is based on Coulomb stress changes induced by deep fluid injection during well stimulation, providing a way to estimate how the potential for seismic failure in different volumes of a geothermal reservoir might change due to the water injection. Coulomb stress changes appear to be the main cause for the induced seismicity during the water injection. These stress changes do not only result from changes in the pore pressure, but also from the whole change in the stress tensor at any point in the medium, which results from the pressure perturbations. The numerical procedure presented takes into account the permeability increase that is due to the induced stress changes. A conceptual model that links the induced stress tensor and the permeability modifications is considered to estimate the permeability change induced during the water injection. In this way, we can adapt the medium behavior to mechanical changes, in order to better evaluate the effectiveness of the stimulation process for the enhancement of the reservoir permeability, while also refining the reconstruction of the Coulomb stress change patterns. Numerical tests have been developed that consider a physical medium and a geometry of the system comparable with that of Soultz EGS site (Alsace, France). Tests considering a fixed permeability, both isotropic and anisotropic, indicate a general decrease in the pressure changes when an anisotropic permeability was considered, with respect to the isotropic case. A marked elongation of the coulomb stress change patterns in the regional load direction was also retrieved. This effect is enforced when a stress-dependent permeability is taken into account. Permeability enhancement progressively enlarges the seismic volume in turns, while decreasing the pressure in the neighborhood of the bottom of the well (as it is inversely related to the permeability). This implies a better match with the observed seismicity pattern. The use of stress-dependent permeability also improves the reconstruction of the observed seismicity pattern. In particular, the large maximum of the coulomb stress changes at the point of injection, which was already mitigated by the consideration of anisotropic permeability, appears further decreased in the new data.
The improving of the correlation between the coulomb stress changes and the induced seismicity distribution supports the reliability and robustness of the main hypothesis of this study of the relationship between the induced stress tensor variation and the permeability enhancement. The use of stress-dependent permeability constitutes an important step towards the theoretical planning of stimulation procedures, and towards interpretation and mitigation of the induced seismicity.