DGMK/ÖGEW-Frühjahrstagung, Fachbereich Aufsuchung und Gewinnung
Celle, 5./6. April 2017

Coupled Thermo-hydro-mechanical simulation of the induced seismicity during the geothermal energy production in Unterhaching

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Abstract

The induced seismicity is a common issue by producing the underground energy and resources. For the deep geothermal energy development, it is normally associated with the reservoir stimulation, by which a large amount of water is injected into underground to create high-conductive flow path as well as enhance the formation permeability. However, in the South German Molasse Basin, induced seismicity is also observed at the operation stage of the geothermal system Unterhaching, which has never been stimulated. The objective of this study is to investigate the mechanisms with coupled thermo-hydro-mechanical simulations.
The numerical simulations were carried out with the coupled simulator TOUGH2MP-FLAC3D. In order to consider the behavior of fault zones, a coupled THM-model based on crack tensor and elastoplasticity theory is implemented in the simulator. In this model the fault slip is treated as elastoplastic deformation with the assumption that the elastic deformation is aseismic, while such plastic deformation is seismic. The enhancement of fault permeability after fault slip is taken into account. With this model the stress drop during the micro-earthquake can be simulated. The seismic moment tensor and moment magnitude can also be evaluated.
A full 3D underground model of the geothermal system Unterhaching is generated based on the measured structure and facies data from Bavarian State Office of the Environment (BLfU). The whole model covers an area of 8.44 km x 10.21 km and lies at the depth between -2.360 m and -4.360 m, containing the tertiary caprock, the main target formation Purbeck and Malm, as well as crystalline basements. It includes 15 fault segments. The hydro-mechanical parameters are determined from labor experiments and literatures. The initial temperature is matched with in-situ measurements. The primary stress state is estimated from the regional stress state of Molasse basin.
The simulation results show that large stress reduction occurred near the injection zones due to the cold water injection. The decrease of the stress components is not the same, which leads to reorientation of the stress tensor. The maximal shear stress appeared near the faults where the injection took place. However, it located not always at the injection zone but moved away from it as time goes by. Since the pore pressure is almost not changed, it could be concluded that the temperature reduction could be the dominant mechanism for the induced seismicity. The further variation study shows that the seismicity could occur if the initial stress is already critical or nearly critical.