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Numerical investigation of thermoelastic effects on fault slip tendency during injection and production of geothermal fluids

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Abstract

This study deals with numerical analysis of fault slip behaviour within deep faulted geothermal reservoirs during injection and production of fluid. A coupled approach for thermo-hydro-mechanical process modelling is used to describe and quantify the effects of thermoelastic stress on the slip tendency. The results show that the slip tendency of a fault can increase when the cold fluid front reaches the fault due to thermal stress enhancement. Magnitudes of increase in slip tendency depend on the injection temperature and the dip angle of the fault, and under specific configurations, may lead to a reactivation of the fault.

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1. Introduction

Understanding processes controlling slip behaviour of faults as induced by man-made activities is of interest for several geo-energy related studies such as geothermal power production, energy storage and enhanced oil and gas recovery. Injection-induced reactivation of faults or fracturing can indeed lead to notable micro-earthquakes [1,2,3,4]. Correlations between pore pressure changes as those induced by injection and production of fluid and the in-situ stress field within a reservoir play a major role in coupled hydraulic and deformation processes [5,6,7]. These poroelastic effects have been identified as part of the processes controlling faults slip behaviour [8,9,3,4]. Furthermore, changes in temperature can also affect the in-situ stress-field [10,11,12,13]. Although the ratio between thermoelastic and poroelastic stresses ($\sigma^{Thermo}/\sigma^{Poro} = K\beta\Delta T/\alpha\Delta p_f$) has been reported to increase with rock stiffness and therefore depth [14], thermoelastic effects are often not considered when analysing slip tendency and possible reactivation of faults in geothermal reservoirs.

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Nomenclature

$c_{f,s,b}$	fluid, solid or bulk heat capacity
E	Young's modulus
$\boldsymbol{g}$	gravitational force
G	shear modulus
$\boldsymbol{I}$	identity matrix
$\boldsymbol{k}$	permeability tensor
K	bulk modulus
L	first Lamé parameter
$n_{x,y,z}$	direction cosines
p_f	pore pressure field
$\boldsymbol{q_f}$	specific discharge or Darcy's velocity
$Q_{f,T}$	fluid (subscript f) or thermal (subscript T) source term
S_s	specific storage
t	time
T	temperature field
T_0	initial temperature
T_s	slip tendency
$\boldsymbol{v_f}$	fluid velocity
α	Biot's elastic coefficient
β	thermal expansion coefficient
γ	dip angle
δ_{ij}	Kronecker-delta
$\boldsymbol{\epsilon}$	strain tensor
$\lambda_{b,s}$	bulk or solid thermal conductivity
μ_f	fluid dynamic viscosity
μ_s	solid frictional coefficient
ν	Poisson's ratio
$\rho_{f,s,b}$	fluid, solid or bulk density
$\boldsymbol{\sigma}$	Cauchy's stress tensor
$\boldsymbol{\sigma'}$	effective stress tensor
σ_N	normal stress
τ	shear stress
$\mathbb{C}$	elastic material tensor

This contribution presents a numerical evaluation of the impacts of thermoelastic stresses on the slip behaviour of faults within deep geothermal reservoirs as based on a frictional sliding resistance formulation. A coupled approach for thermo-hydro-mechanical process modelling has been integrated in the open-source finite element method based simulator OpenGeoSys [15] following theory of coupled thermo- and poroelasticity.

The reactivation potential of a fault is evaluated during injection and production of geothermal fluid as a function of the ratio of shear to normal stress on the fault plane. First, a simple geometry model is considered with different configurations, by changing the dip angle of the fault. Thermoelastic stress enhancement comes from the temperature anomaly of the cold injected geothermal fluid propagating within the relative warmer fluid-bearing reservoir. This simple model serves as an introduction to a real-case application of the Groß Schönebeck geothermal research site, which is discuss further in the manuscript.