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Quantification of fluid migration via faults requires two-way coupled hydromechanical simulations

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Abstract

Subsurface storage of fluids triggers pressure and volume changes in reservoirs, caprocks and faults. In this context, hydraulic fault conductivity can increase by several orders of magnitude, promoting upward migration of reservoir fluids into shallow freshwater aquifers. In the present study, we compared one-way and two-way hydromechanical couplings to quantify the impacts of subsurface fluid storage on fluid migration via a fault. Our simulation results emphasize the requirement of two-way coupled hydromechanical simulations, since neglecting petrophysical changes in the one-way coupling leads to an underestimation of fault pressure gradients, and thus fluid migration.

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Keywords: Subsurface fluid storage; fault fluid migration; fault reactivation; hydromechanical simulations; one-way coupling; two-way coupling

1. Introduction

Utilization of the geological subsurface for greenhouse gas storage is practiced for many decades worldwide at pilot- to industrial-scale, e.g., [1-3], and is likely to become even more important in the near future to meet current climate and energy policy objectives [4]. However, fluid injection into the subsurface, e.g., into a saline aquifer for long-term storage induces pressure elevation, and thus spatial and temporal changes in the recent stress field. These in turn can adversely affect the mechanical behavior of reservoirs, caprocks and faults. Effective stresses altered by

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pore pressure changes in a fault and its vicinity can facilitate fault slip and dilation, and hence enhance or establish new hydraulic flow paths for formation fluids as a result of porosity and associated permeability increases [5-7]. In the present study, we set up a 2D structural model based on the geology of a prospective storage site in the German Federal State of Brandenburg, and applied one-way and two-way hydromechanical coupled simulations to assess the impacts of geological subsurface storage on fault integrity and fault fluid flow (Fig. 1).

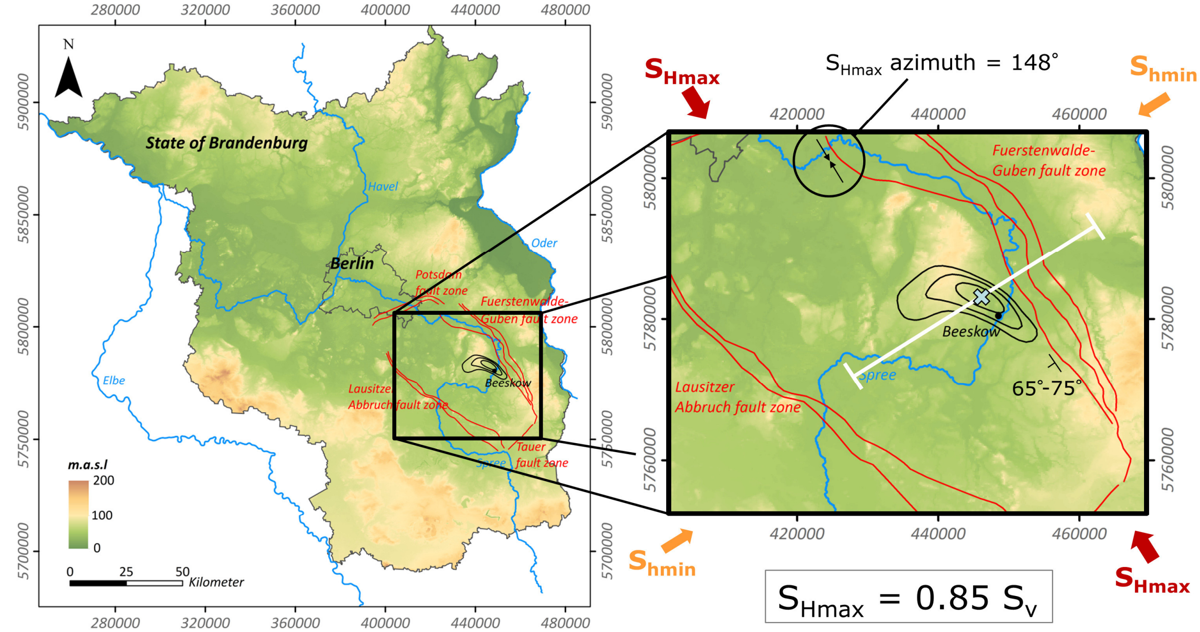

Fig. 1. Model set up based on a prospective storage site in the German Federal State of Brandenburg (left). White cross-section in the right figure indicates the extent of the 2D structural model used in our coupled hydromechanical simulations. Fluid injection (white cross) occurs into the top of a Mesozoic anticline structure (outlines indicated). Maximum horizontal stress orientation is derived from wellbore breakout analyses at the Fuerstenwalde-Guben fault zone [8]. A classical normal faulting regime was assumed in all simulations. Axis labels show UTM-coordinates (spatial reference: EPSG projection 32632 - WGS84 / UTM zone 33N). National borders, isolines and rivers derived from [9], digital terrain model from [10].

In both coupling approaches, two independent simulators calculate either fluid or rock dynamics, whereby the information exchanged between both depends on the chosen coupling method. Our one-way coupling implementation considers pore pressure changes calculated by the flow simulator as input to the hydromechanical simulator to determine effective stresses and calculate grid point velocities. In our two-way coupling implementation, the flow simulator receives a feedback from the hydromechanical simulator in case of altered hydraulic properties due to volumetric strain increments [6, 11-13]. One-way coupled simulations generally reduce the complexity of the computational implementation; however, hydromechanical effects on fluid flow are likely to be underestimated without taking into account mechanically induced porosity and permeability changes, affecting fluid flow and pore pressure propagation.

2. Model setup and parameterization

The 2D structural model used in our coupled one-way and two-way hydromechanical simulations has a total lateral extent of 40 km and a thickness of 5 km. It is set up along a cross-section in the southeastern part of the Federal State of Brandenburg, running through the top of a Mesozoic anticline structure and perpendicular to the Fuerstenwalde-Guben fault system, representing a major fault system in this region (Fig. 1). The model consists of five geological units, including one saline storage aquifer (Detfurth Formation in the Middle Buntsandstein), an