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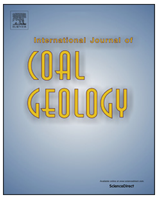

Numerical modelling of coal seam depressurization during coal seam gas production and its effect on the geomechanical stability of faults and coal beds

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ABSTRACT

This coupled geomechanical-fluid flow numerical modelling study investigates the geomechanical impact of depressurization of coal beds on fault and coal seam geomechanical stability during coal seam gas production, using a simplified 3D reservoir structure based on the Gloucester Basin, Eastern Australia. The model examines transient stress, pore pressure, and fluid flow patterns during gas production under three different background regional stress scenarios, with the aim of understanding possible geomechanical failure states in a fault and coal beds. The model results show that depressurization leads to shear stress increase in normal-faulting stress regimes, but decreases in reverse-faulting (dominant in eastern Australia) and strike-slip faulting stress regimes. This is in combination with an overall effective stress increase associated with pore pressure reduction. Depressurization-resultant fault failure appears to be possible only under normal-stress regimes. In addition, a critically-stressed fault segment is likely to be a precursor requirement for fault reactivation to occur as a result of depressurization/fluid depletion within normal-faulting stress conditions. Results further show fluid flow is dominated by lateral flow along coal beds, converging towards depressurization locations ("wells"). Fault permeability governs fluid transport along/across the fault and development of pore pressure compartmentalisation across the fault. Under all three background stress scenarios, flow velocities in coal beds are governed by coal permeability.

1. Introduction

Coal Seam Gas (CSG) resources are increasingly becoming an important global energy source, mainly because of its relatively low carbon footprint, its vast global reserve and the ability for gas fired power generation to integrate with variable generation renewable technologies (Underschultz, 2016). Australia has the second largest CSG reserve and production behind the USA (Hamawand et al., 2013). Extensive reserves, particularly in eastern Australia, have attracted extensive commercial interest in recent years for both domestic gas supply and for conversion to LNG for international export. Such commercial development has also raised public concerns about potential environmental impacts (Underschultz, 2016).

CSG resources are methane trapped in an unconventional reservoir by adsorption onto the coal matrix. Its extraction usually involves first producing water from the coal cleats (i.e. natural fractures in coals; Laubach et al., 1998) to de-pressure the coal seams such that the methane desorbs from the coal matrix and can be produced through the wellbore to surface (e.g. Moore, 2012; IESC, 2014; Espinoza et al., 2015). Details of how the coal reservoir responds geomechanically to depressurization remain uncertain. Since depressurization of a coal-seam reservoir will alter in-situ field stresses, it could lead to fault failure (fault reactivation) or be accompanied by failure in coal beds and other host rocks. Therefore, studying the possibility of fault reactivation and geomechanical stability of the whole coal-seam system under the conditions of depressurization is necessary to understand the risk under various in-situ geological conditions.

Previous works in mineral, petroleum and CO_2 geosequestration research fields show that coupled geomechanical and fluid flow numerical modelling is a powerful method to study fault reactivation and

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associated deformation in host rocks. For mineral systems, modelling studies demonstrated that faults can become reactivated in response to tectonic deformation (e.g. Schaubs and Wilson, 2002; Ord et al., 2002; Sorjonen-Ward et al., 2002; Zhang et al., 2008; Zhang et al., 2012). Such reactivation focuses shear strain-dilation and focus ore-forming fluids, and hence, lead to mineralization. For conventional petroleum and CO_2-storage reservoirs, previous modelling works focused on fault reactivation in response to extensional tectonic deformation (e.g. Gartrell et al., 2004; Zhang et al., 2009, 2011; Langhi et al., 2010), fluid injection (e.g. van Ruth et al., 2006; Rutqvist et al., 2015) and fluid depletion (e.g. Streit and Hillis, 2002; Hawkes et al., 2005; Nacht et al., 2010; Safari et al., 2013; Zhang et al., 2016). These studies showed that fault reactivation could occur under these conditions, and is a key risk to lead to seal breach, reduced integrity of hydrocarbon or CO_2 traps, and allow leakage from hydrocarbon accumulations or CO_2 storage reservoirs.

Coupled geomechanical-fluid flow numerical modelling studies on fault behaviour in coal-seam systems appear to be relatively limited. Some examples are (i) a numerical evaluation of the effects of impermeable faults on the production performance of degasification boreholes without geomechanics by Karacan et al. (2008), (ii) a BEM modelling study (boundary element method without fluid flow), explaining mining-induced fault reactivation associated with the main conveyor belt roadway by Islam and Shinjo (2009), and more recently (iii) a coupled thermal-hydrological-mechanical model simulation study on the processes (e.g. permeability and pore pressure changes) during CO_2-enhanced coalbed methane recovery in a simple generic structure without faults (Ma et al., 2017). A recent mathematical/analytical study on coal failure during methane production by Lu and Connell (2016) predicted coal failure associated with horizontal stress decrease, pore pressure reduction and volume shrinkage due to methane production and desorption. Such horizontal stress reduction associated with pore pressure reduction is consistent with but much greater than that predicted for generating fault reactivation in petroleum reservoirs (e.g. Zoback et al., 2001; Hawkes et al., 2005; Safari et al., 2013; Zhang et al., 2016).

This study aims to understand the geomechanical impact of depressurization on fault and coal stability during CSG production in a coal seam reservoir, using a 3D coupled geomechanical-fluid flow numerical modelling method. Based on a simplified 3D reservoir structure (geometry) based on the Gloucester Basin, Eastern Australia (Fig. 1), we examine stress alterations and geomechanical failure states of a fault and coal beds during depressurization under three different regional stress setting scenarios. Fluid flow patterns in the reservoir and its changes with fault and coal permeability changes are also analysed. This work is part of a three-year research program focusing on fault behaviour in the Gloucester Basin, Eastern Australia (Mallants et al., 2017). It should be emphasized that this study does not intend to investigate the sources of stresses and stress variations in the Australian continent, which was recently and comprehensively modelled by Rajabi et al. (2017a).

2. Modelling methodology

Geomechanical deformation and fluid flow modelling has been performed using FLAC3D (Itasca, 2006). FLAC3D is a very well tested mechanical modelling code from the Itasca Corporation in the USA. It is widely used in civil and mining engineering applications (e.g. Tulu et al., 2016; Sears et al., 2018). Its application to geological systems across a range of scales can be found in the literature (e.g. Sorjonen-Ward et al., 2002; Zhang et al., 2009, 2011; Liu et al., 2012; Khazaei and Chalaturnyk, 2017).

The code is capable of simulating the interactions between deformation and fluid flow in porous media. Modelled materials are represented by a 3D mesh representing the geometries of the observed geological structures. Each element in the mesh behaves according to prescribed mechanical and hydraulic laws and in response to the applied boundary conditions. For this study, rocks are simulated as isotropic elastic-plastic materials that require the specification of several geomechanical parameters, including Young's modulus, Poisson's ratio, cohesion, tensile strength, friction angle and dilation angle. Under deformation loading conditions, such elastic-plastic materials deform initially in an elastic manner up to a yield point (i.e. the maximum shear stress in the materials reaches a yield stress), and then after yield, they deform plastically resulting in irreversible plastic strain (e.g. Vermeer and de Borst, 1984; Ord, 1991) (Fig. 2a). The yield stress for the materials is governed by the Mohr-Coulomb failure criteria as described by the equation below:

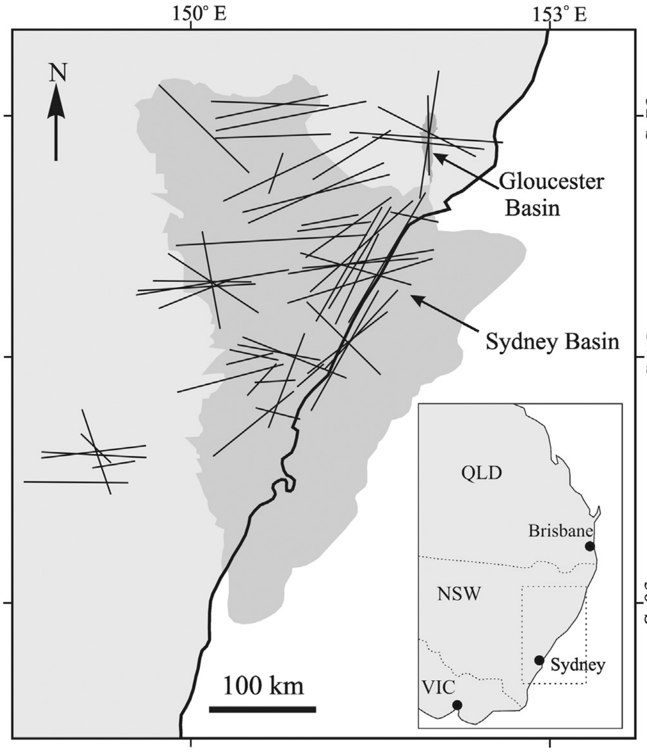

Fig. 1. Illustration of the locations of the Gloucester and Sydney Basins in New South Wales (NSW), Eastern Australia (inset). Black straight lines shows the orientation of the maximum horizontal stresses in the study area (based on Fig. 6 of Rajabi et al., 2016).

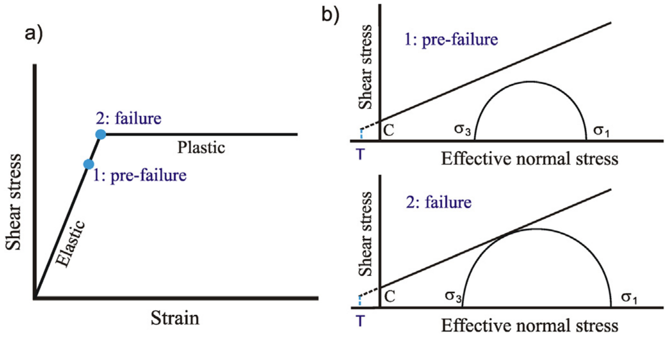

Fig. 2. (a) Schematic illustration of the stress-strain relationship for a Mohr-Coulomb elastic-plastic material. (b) Mohr's circle diagrams for point-1 (pre-failure) and point-2 (at failure) in (a). Mohr's circle will touch the failure envelope (straight line) when mechanical failure occurs. The vertical dashed line and T define the tension cut off (tensile failure) point, where the effective minimum principal stress is tensile and equal to the tensile strength of the fault. Note that the illustrations above are based on the established Mohr-Coulomb elastic-plastic theory (e.g. Ord, 1991).