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Review of plausible chemical migration pathways in Australian coal seam gas basins

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ABSTRACT

Coal seam gas (CSG) or coal bed methane production has grown exponentially in Australia over the last two decades with currently nearly 7000 productive wells and another 18,750 wells planned over the next five to ten years. To address concerns over environmental contamination by hydraulic fracture fluids (HFF) attributed to (i) incidents involving poor surface handling of HFF and other fluids with potential migration pathways in soil and shallow groundwater, and (ii) leakage pathways arising from HFF injection into coal seams and unintended migration of these chemicals, the *National assessment of chemicals associated with coal seam gas extraction in Australia* (the *Assessment*) was undertaken. The *Assessment* included a review of international studies on unconventional gas migration pathways to provide prior knowledge and comparison for use in the Australian study. The international literature highlighted that accidents with HFF were mainly due to surface operations and included leaking equipment and spills. Contamination risks of groundwater from hydraulic fracturing itself were found to be very small based on analysis of micro-seismic and groundwater hydrochemistry data; geologic modelling of vertical fracture growth further reveals a low risk of leakage pathways developing in aquifers confined by deep shale formations. This is due to limitations on the fracture growth vertically across aquitards often hundreds of meters thick, retention within the shale of limited amounts of injected fluid, and preferential fracture growth at shallow depths in the horizontal direction. These arguments are broadly applicable to Australian CSG basins. However, important differences exist, such as the reduced thickness in Australia of the aquitards that separate the targeted gas resource from groundwater. Also, hydraulic fracturing in Australian coal seams is practised only when permeabilities are too low for gas extraction to be economical without stimulation. From the nearly 10,000 CSG wells drilled in the Bowen and Surat Basins in Queensland, only 6% have received hydraulic fracturing to date. The reduced risk of leakage pathways developing during CSG production in Australian basins is further corroborated by geologic criteria based on modelling and observations. Criteria include encountering certain favourable conditions during drilling/injection, i.e. (i) interfaces, such as natural fractures, faults, and bedding planes, which promote offsetting and branching, or rock layers with higher fracture toughness causing the cessation or reduction in fracture growth, (ii) narrow fractures due to a relatively higher elastic modulus, leading to higher viscous flow loss, (iii) high permeability layers, and (iv) overlying layer(s) with a higher confining stress. In addition to the leakage pathways considered in North American shale gas basins involving (i) pre-existing fractures and faults, or (ii) flow up the production well due to poor casing or cementing, plausible chemical migration pathways in Australian CSG basins are due to (iii) connectivity via a fracture in or extended out of the coal seam formation between CSG wells and water bores co-located in the same formation, and (iv) poor integrity water bores enhancing inter-aquifer connectivity. These plausible pathways are described and used in subsequent work as the basis of risk assessments for contamination at the local- and regional scale.

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1. Introduction

Coal seam gas (CSG) or coal bed methane production has grown exponentially in Australia over the last two decades with currently nearly 7000 productive wells and another 18,750 wells planned over the next five to ten years (OGIA, 2016) (Fig. 1). There are concerns over environmental contamination by hydraulic fracture fluids (HFF) due to (i) incidents involving poor surface handling of HFF and other fluids with potential migration pathways in soil and shallow groundwater, and (ii) leakage pathways arising from HFF injection into coal seams and unintended migration of these chemicals.

Hydraulic fracturing for CSG production has a 40-year history, with > 20 years of commercial experience in North America prior to the more recent development of the Australian CSG industry (McGowen et al., 2007; Murray, 1996). There has been a commensurate development of modelling approaches and collection of relevant experimental and field data to understand and predict hydraulic fracture growth (for a review, see Jeffrey et al., 2016a, 2016b, 2017). Many of the recent published studies are from US shale gas areas where horizontal drilling is combined with creating multiple vertical fractures (Brantley et al., 2014). In Australian coal formations production from vertical wells is more common, with fracturing operations aimed at producing mainly vertical fractures, although some horizontal exploration wells have been drilled in the Gunnedah basin in New South Wales (Rutovitz et al., 2011; NSW Chief Scientist and Engineer, 2014) and horizontal production wells are in use in the northern Bowen Basin (Moranbah gas field; Towler et al., 2016); these horizontal wells have not been hydraulically fractured.

In CSG hydraulic fracturing design, one of the most important considerations for the effectiveness of the treatment is preventing unwanted vertical hydraulic fracture growth out of the CSG production interval into the overburden geological barrier, typically referred to as seal, caprock or aquitard. Such height growth is ineffective and inefficient from a production viewpoint and therefore the topic has received much attention (King, 2012 and references therein).

Because of these fundamentally different fracturing operations, and because US shale-gas fields are at much greater depth (average depths for the largest gas-producing reservoirs range from 2000 to 3700 m – US EPA, 2016) than the Australian CSG fields (generally between 300 and 1000 m below ground, see further), extrapolation of results from the US shale-based studies to Australian CSG conditions has to be done with great care. Nevertheless, the shale gas studies provide useful insights and background information for the review of potential migration pathways in the Australian coal basins.

More relevant for appreciating potential migration pathways linked to CSG activities in Australia are findings from the US coalbed methane fields, although the number of US coalbed methane wells are only a fraction of the US shale wells (based on 2015 data total coalbed methane production was 1.24 trillion cubic feet or about 5% of the total US onshore unconventional gas production (EIA, 2016)), with coalbed methane wells comprising 15% of all hydraulically fractured wells. Coalbed methane wells drilled between 2000 and 2013 totalled 159,250 (US EPA, 2016). The approximate depth of the main four US coalbed methane basins is similar to those in Australia: Black Warrior (0–1100 m), Powder River (140 - > 2000 m), Raton (< 200 - > 1300 m), and San Juan (170–1000 m) (US EPA, 2016). Some similarities also exist in the stress regime: the Bowen-Surat Basins in Queensland have a strike-slip or thrust faulting regime (in both cases the maximum horizontal stress exceeds the vertical stress) (Rajabi et al., 2017a), while the US coalbed methane basins are characterized by strike-slip (Powder River; Morin, 2005), strike-slip and thrust faulting (San Juan; Lorenz and Cooper, 2003), normal faulting (Raton; Rubinstein et al., 2014), and normal and strike-slip faulting (Black Warrior; Groshong et al., 2009). One of the plausible fluid pathways into a drinking water resource that was found especially relevant for the shallower coalbed methane basins is through fracture networks created

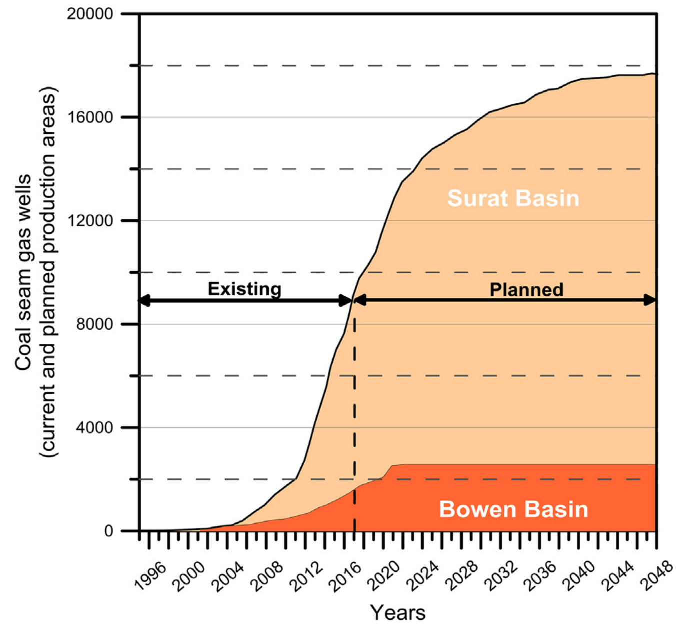

Fig. 1. Existing and projected future CSG wells in current and planned production areas in Surat and Bowen Basins, Queensland (Modified from OGIA, 2016).

from directly fracturing into a drinking water resource, i.e. when the gas formation is co-located with the drinking water resource (US EPA, 2016).

The Australian Federal Government project *National assessment of chemicals associated with coal seam gas extraction in Australia* (henceforth referred to as the *Assessment*) has recently been completed.[1] The *Assessment* focussed on risks to human health and the environment from surface handling of chemicals used in CSG extraction. Additional research considered potential risks from chemicals entering deeper groundwater through drilling or hydraulic fracturing operations. This is the first in a series of research papers that reviews and summarizes methods and findings in regards to soil and groundwater migration pathways of chemicals used in drilling and hydraulic fracturing.

The first commercial CSG production from vertical hydraulically fractured wells in Australia commenced in 1996 (Geoscience Australia, 2001). CSG extraction in Australia occurs predominantly in Queensland (Surat and Bowen Basins), with some smaller production areas in New South Wales (ongoing production in the Sydney Basin with planned production in the Gunnedah Basin) (Fig. 2 and Table 1). Since the typical life of a gas field is about 25 years, substantial production is expected to cease by 2060.

A review of CSG practices in Australia showed that hydraulic fracturing is practised only for coal measures that have permeabilities that are too low for gas extraction to be economical without stimulation. For example, from the nearly 10,000 CSG wells (3000 exploration/pilot/appraisal wells and 7000 production wells) drilled in the Bowen and Surat Basins in Queensland, only 6% have received hydraulic fracturing (based on data until December 2017, Fig. 3). This percentage could increase to 10 to 40% over time (DEHP, 2014a). Coal seams in the Bowen Basin have much lower permeability than, for example, the Surat Basin and are therefore likely to require increased levels of hydraulic fracturing (Helmuth et al., 2008). For New South Wales, hydraulic fracturing has been applied to 12% of all wells (based on 123 out of 159 wells at Camden and none at the Narrabri site).

The depths of Australian coal seams are generally shallower than

[1] https://www.environment.gov.au/water/coal-and-coal-seam-gas/national-assessment-chemicals.