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On the impact of spatially heterogenous permeability on free convection in the Perth Basin, Australia

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ABSTRACT

We study the impact of spatially heterogeneous permeability on the formation and shape of hydrothermal porous flow convection in the Yarragadee Aquifer by modelling three simulation scenarios, each with differing permeability distributions.

In all scenarios, the southern part of the model is characterised by convection rolls, while the north is dominated by a stable region of decreased temperatures at depth due to hydraulic interaction with shallower aquifers.

This suggests that reservoir structure is a first-order controlling factor for the formation of the free convective system. The convective system adjusts to the spatially heterogeneous permeability distribution, yielding locally different convection patterns.

1. Introduction

Crucial prerequisites for successful geothermal energy exploitation are relatively high temperatures at depth and a sufficiently permeable reservoir body. By transporting hot fluid from greater depths to shallower depths, convective heat transfer increases temperatures locally. Those regions of up-flow are attractive targets for geothermal energy production. The Jurassic Yarragadee Aquifer is a target reservoir for geothermal energy use within the Perth Metropolitan Area (PMA), where temperature measurements from deep wells (e.g. Cockburn 1) of around 81 °C have been recorded at a depth of about 2.8 km. While the heat produced from deep aquifers within the Perth Basin may not suffice to generate electricity, it allows for direct heat use (e.g. St. Hilda's school geothermal well (Pujol, 2011)) for space heating, or cooling by chiller technology. In a recent review, the success rate of direct heat installations in the PMA was shown to be 100% (Pujol et al., 2015). This rate accounts for installations in shallow aquifers up to a depth of 1.15 km. Pujol et al. (2015) discuss that hydrothermal conditions in the deeper Yarragadee Aquifer are largely unknown. This uncertainty drastically increases in the presence of free convection.

Current numerical hydrodynamic flow models of the PMA clearly indicate that major aquifers within this sedimentary system are characterised by free convection (Sheldon et al., 2012; Schilling et al., 2013). These models show temperature variations at the same depth up to 40 °C. Such big temperature differences are relevant regarding geothermal direct heat use. Sheldon et al. (2012) and Schilling et al. (2013) estimated the potential for hydrothermal convection in the PMA addressing: 1) various homogeneous permeabilities within the Yarragadee Aquifer; 2) the role of faults regarding the flow field; 3) competition between advective and convective transport. These studies did not address the impact of spatially heterogeneous porosity and permeability in the Yarragadee Aquifer. Recently, Irvine et al. (2014) studied the influence of heterogeneous permeability on free convection in the Yarragadee Aquifer, by assessing simple 2D models based on stratigraphic forward modelling. Building up on the results of Schilling et al. (2013), we assessed the impact of spatially heterogeneous permeability on the development, shape and stability of free convection cells

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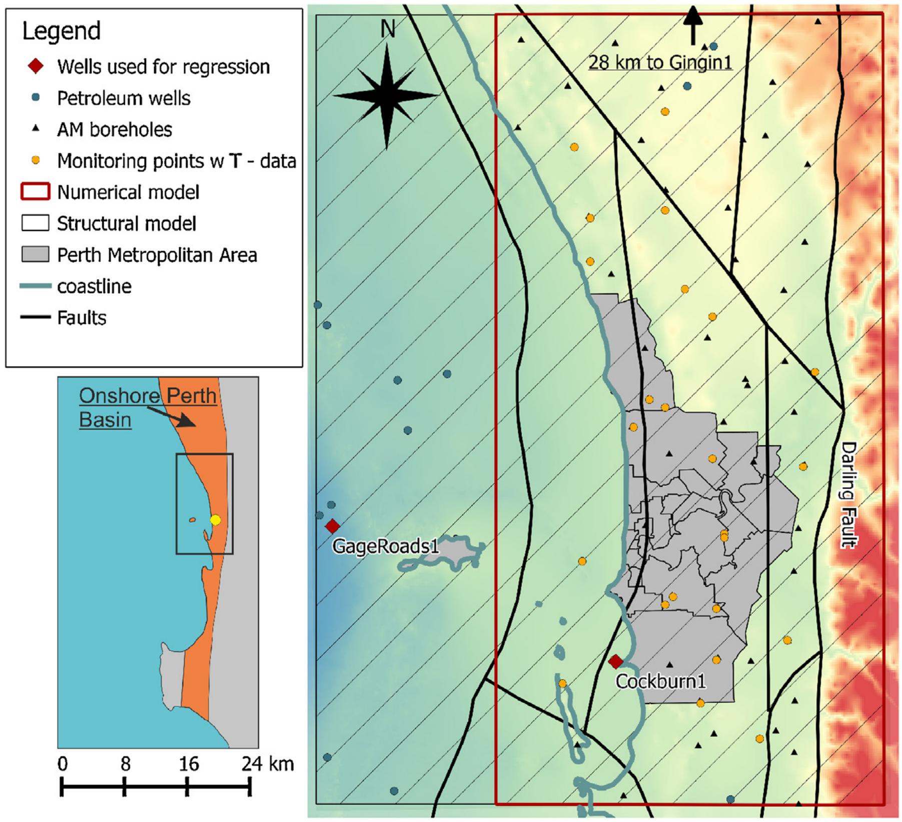

Fig. 1. Map of the study area in the Central Perth Basin (also termed Perth Metropolitan Area (PMA)) colour coded by topography. Faults and wells are indicated, as well as the boundaries of the structural and numerical model.

with time within the Yarragadee Aquifer in a 3D model of the Perth Metropolitan Area. For this purpose, we implement a calibrated relationship between porosity and permeability in order to generate a permeability distribution from a porosity distribution inferred from well-logs. Beyond the application of our modelling to the Yarragadee Aquifer, it also shows in a more general sense the influence of different realistic approaches of addressing the impact of heterogeneous permeability on the formation of free thermal convective circulation.

2. Geological background

The Perth Basin is a north-south-trending rift system and extends about 1300 km along the south-western continental margin of Western Australia, covering an area of about 172 300 km^2. Onshore, it is bounded by the Darling Fault to the east and gradually passes over into the continental shelf offshore to the west. The major Darling Fault offsets the sedimentary successions of the Perth Basin against the Proterozoic Yilgarn Craton to the east. Here we restrict our study to the central part of the Perth Basin including the Perth Metropolitan Area (Fig. 1).

In the context of increased exploration for hydrocarbon resources, the Perth Basin has been the subject of detailed geological studies (see, for example, Playford et al., 1976; Backhouse, 1984; Iasky, 1993; Cadman et al., 1994; Crostella and Backhouse, 2000). It is filled with Permian to Cenozoic sediments which are up to 15 km thick locally. The major lithological successions encountered within the Perth Basin are siliciclastic sediments, reflecting different rift phases from the Permian to the final break-up between Australia and Greater India in the Cretaceous. One main reservoir unit in the Perth Basin and intensively explored for its geothermal energy potential is the fluviatile Jurassic Yarragadee Aquifer (Crostella and Backhouse, 2000) (Fig. 2). In the study area, it is partially covered by the South Perth Shale. With low average permeabilities, the South Perth Shale acts as a seal for the Yarragadee Aquifer, while its absence (e.g. in the northern model area, PMA) enables

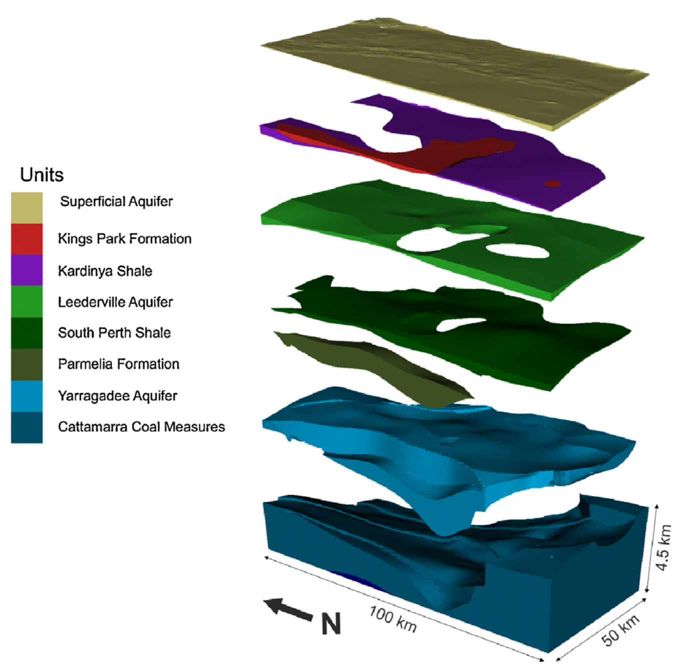

Fig. 2. Exploded view of the structural model (similar to presentation in Corbel et al. (2012a)). Main aquifers are the Yarragadee Aquifer (bright blue), the Leederville Aquifer (bright green) and the Superficial Aquifer (yellow). Vertical exaggeration is 4:1.