Geothermics 53 (2015) 46–56

Contents lists available at ScienceDirect

Geothermics

journal homepage: www.elsevier.com/locate/geothermics

Seismic mapping and geomechanical analyses of faults within deep hot granites, a workflow for enhanced geothermal system projects

H. Abul Khair[a,*], D. Cooke[a], M. Hand[b]

[a] Centre for Tectonics, Resources and Exploration (TRAX), Australian School of Petroleum, University of Adelaide, North Terrace, Adelaide, SA 5005, Australia
[b] South Australian Centre for Geothermal Energy Research, University of Adelaide, North Terrace, Adelaide, SA 5005, Australia

ARTICLE INFO

Article history:
Received 30 September 2013
Received in revised form 27 March 2014
Accepted 18 April 2014
Available online 14 May 2014

Keywords:
Enhanced geothermal system
Seismic
Fault and fracture network
Geomechanics

ABSTRACT

Areas with deep seated radioactive granites are considered targets for enhanced geothermal system (EGS) projects. These areas normally exhibit high heat flow and temperature anomalies related to granitic bodies. High concentrations of uranium within the granites are the most likely cause of the anomalous temperatures. Elevated temperatures are also resulted to high heat flow and thick sedimentary rock cover that includes insulating materials such as coals and gas reservoirs.

In this study we investigated the use of 3D seismic amplitudes and attributes to map deep granitic bodies and faults in the Cooper Basin of South Central Australia. We established a workflow for possible geomechanical fluid flow susceptibility analyses for faults that intersect granites. The far field stress tensor must be interpreted through analyses of image logs and formation tests. Our geomechanical analyses models show how this stress tensor affects basement faults interpreted from 3D seismic surveys. Normal stresses, shear stresses, slip tendency, and distance to failure should be modelled for the faults that cut the granites. The optimal orientation of faults that can be possible conduits are then located. We suggest that the optimal injection and production wells should be located at tips of shallow faults that penetrate the granites. We anticipate that short horizontal faults that are located far from other faults will form a more secure fluid conduit. Finally, this study can be a workflow to evaluate the relative merit of future enhanced geothermal system projects.

1. Introduction

Most geothermal power generating systems are located where naturally occurring hot water and highly permeable rocks are capable of carrying the heat to the surface (Tester, 2006; Lund, 2007; Meixner et al., 2011). However, potentially large geothermal energy resources are within reach of conventional drilling techniques in hot, dry and low permeability rocks (HDR) (Duchane and Brown, 2002; Tester, 2006). The unconventional geothermal reservoirs, which are also called enhanced geothermal systems (EGS) reservoirs, are geothermal systems without natural convection. These systems can be enhanced by pumping water through pre-existing faults and fractures causing them to hydro-shear (Legarth et al., 2005). Thus, success of EGS development requires high heat flows and conductive subsurface corridors, which may include optimally oriented pre-existing, open faults or fractures.

The case study used to establish the workflow for EGS development in the current research is the Cooper Basin in south-central Australia. This is a region of high geothermal gradients and high surface heat flow (Cull and Denham, 1979; Cull and Conley, 1983; Somerville et al., 1994; Gerner and Holgate, 2010) (Fig. 1A–C). This anomalous area is part of a regional high heat flow anomaly that was attributed by some researchers to the enrichment of radiogenic elements within the Proterozoic basement (e.g. Sass and Lachenbruch, 1979; McLaren et al., 2003). In contrast, others attributed the anomaly to the Middle Carboniferous high-heat-producing granitic bodies of the Big Lake Suite (BLS) underlying the Cooper Basin sediments (e.g. Beardsmore, 2004). Beardsmore (2004) found that the average vertical heat flow is over 100 mW/m^2 in the Moomba-Big Lake area above the granites and drops significantly beyond the edges of the BLS granites. Meixner et al. (2011) suggested that high mantle heat flows coupled with an insulating sedimentary blanket might also be the reason behind the high temperatures. Meixner et al. (2012) used 3D gravity and magnetic data to model the depth of these granitic bodies and coupled these results with potassium and heat flow measurements to create a thermal map of the Cooper Basin. Many authors propose that the combination of high heat flows and high temperature gradients

* Corresponding author. Tel.: +61 414183481.
E-mail addresses: hani.abulkhair@adelaide.edu.au, hani.abulkhair@yahoo.com.au (H. Abul Khair).

http://dx.doi.org/10.1016/j.geothermics.2014.04.007
0375-6505/

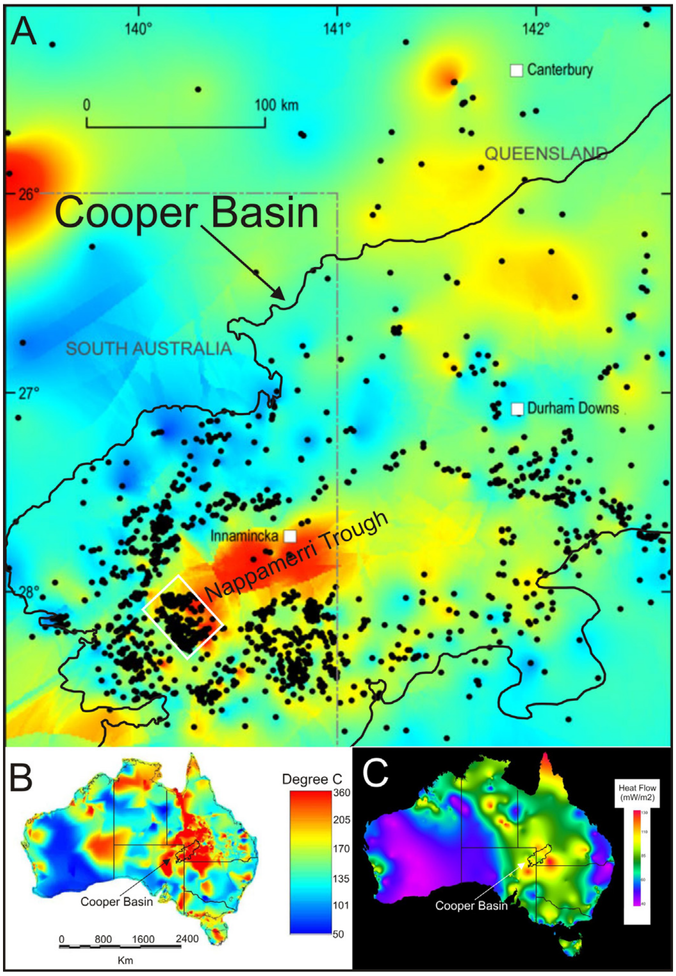

Fig. 1. Map of predicted temperatures at 5 km depth in the Cooper Basin (A), and across Australia (B) (Gerner and Holgate, 2010). Colour legend in B applies to the main image. Scale bar in B applies to C, Black dots are wells from which temperature measurements were taken. White rectangle represents the location of the 3D seismic survey. Surface heat flow across Australia (C) is also shown (from Hot Dry Rocks Pty Ltd).

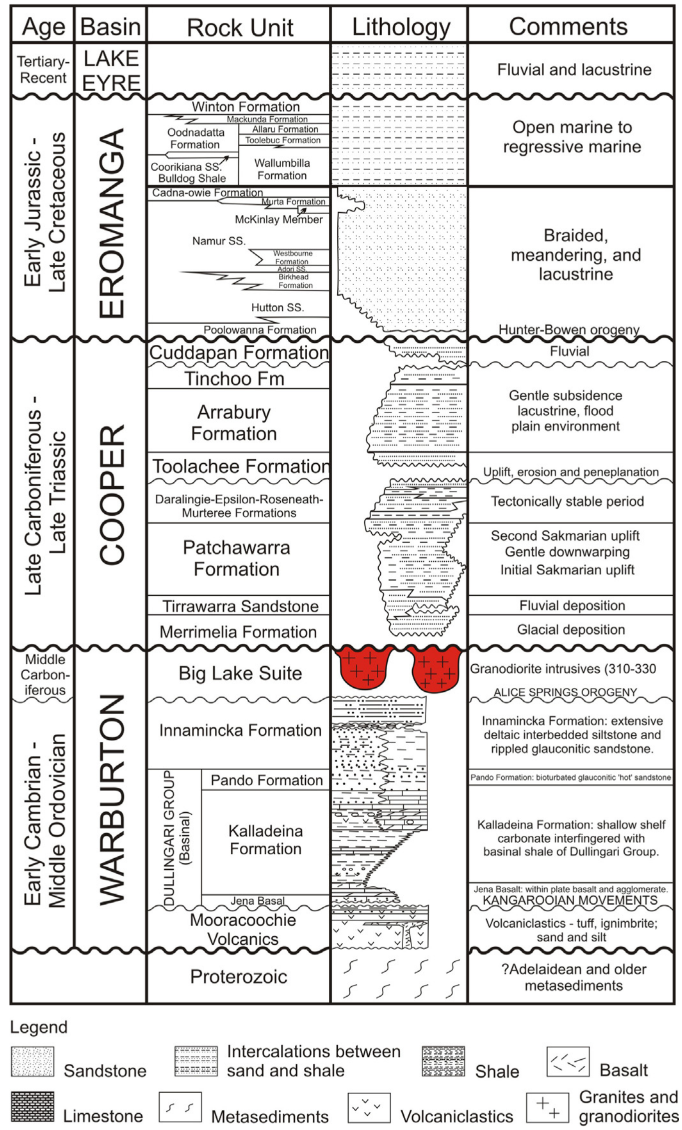

Fig. 2. Geological summary of the Cooper region (modified after Cotton et al., 2006). The red colour represents the granitic intrusion of heat source in the Cooper Basin.

over the BLS form a potential geothermal energy resource (e.g. Middleton, 1979; Gallagher, 1988; Beardsmore, 2004).

A thick clastic sedimentary sequence ~3 km covers the BLS in the Cooper Basin, with intercalations of coal beds. This sequence provides good thermal insulation which, combined with the high heat flows and thermal gradients, result in temperatures up to 250 °C at depths 4–5 km (Holgate, 2005). Image logs from wells penetrating the granites in the Moomba area (e.g. Moomba 73), showed fracture densities averaged 0.2 fracture/m (Abul Khair et al., 2013). Seismic interpretation of the 3D Moomba-Big Lake survey identified more than 300 faults penetrating the basement rocks. Thus, the geothermal system in the Cooper Basin contains all the required elements of high heat flows and high temperature gradients to the faults and fractures needed for EGS development.

The aim of this study is to generate a workflow for EGS projects. It will include the use of: (1) seismic amplitudes and attributes to map the granitic bodies; (2) maps of faults and fractures at the BLS surface; and (3) geomechanical fluid flow susceptibility analyses to model the potential fluid conduits within these rocks.

2. Geology and tectonic setting of the Cooper Basin area

The basement in the Cooper Basin is composed of metasediments associated with the formation of the South Australian craton during Proterozoic time (Fig. 2) (Cawood and Korsch, 2008). They include protomylonitic pegmatitic gneiss to the north of Cooper Basin (Rankin and Gatehouse, 1990), highly sheared and folded quartz-sericite schist (Willis et al., 1983; Gatehouse, 1986) to the south, and steeply dipping ortho-quartzite (Gravestock et al., 1995), in the south-west.

The Early Palaeozoic Warburton Basin units that underlie a large portion of the Cooper Basin are composed of ~1800 m of volcanic tuff and marine carbonate and clastic sediments intercalated with basaltic volcanic rocks (Fig. 2) (Gatehouse, 1986). At least three unconformities can be defined within the Early to Middle Cambrian Warburton sediments associated with the basalts. Following the deposition of the Cambrian-Ordovician sequences in the Warburton Basin, north west–south east compression caused a partial inversion of the Warburton Basin, deformation of the pre-existing sequence and the subsequent intrusion of Middle to Late Carboniferous granites (Gatehouse et al., 1995; Gravestock and Flint, 1995; Alexander and Jensen-Schmidt, 1996). This tectonic event is coeval with the Alice Springs and Kanimblan Orogenies, which affected central Australia and the eastern Australian basins. All published