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Understanding the active tectonics in Australia: Implications of geothermal resources

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ABSTRACT

Great Artesian Basin (GAB) in east-central Australia has a significant potential for geothermal resource, which is believed to be due to radiogenic heat production in basement granitic rocks. We examine an alternative hypothesis proposing that the mantle degassing may be the heat source (at least partly) in association with active tectonics. This study applies methodologies in geochronology, isotope geochemistry and structural geology to assess the role of neotectonic reactivation of Phanerozoic faults in permeability creation and mantle degassing in generation of geothermal resources. Isotopic dating results and stable isotope geochemistry of hydrothermal minerals in basement rocks are interpreted as indicating that Cretaceous extensional tectonic events controlled the thermal history of central-eastern Australian basins and distribution of fracture zones allowing recent uprise of hot mantle fluids.

1. INTRODUCTION

The high heat flow in the GAB has been attributed to the radioactive decay of U, Th, and K stored in the basement granitic rocks below the thermally insulating sedimentary rocks of the Eromanga, Cooper, Galilee and Millungera Basins. The Big Lake Suite granite underlying the Cooper Basin is regarded as the primary source of heat in NE South Australia and SW Queensland (Middleton, 1979), having a substantially high heat production at a rate of up to 10 $\mu W/m^3$. Other basement granites in this region, however, have much lower heat production values ranging from 1.5 to 4 $\mu W/m^3$ (Radke, 2009). In addition, the majority of existing wells (~750) drilled up to a depth of about 4 km intersect metasediments, and only a very small proportion (~40) intersects granitoid rocks. Therefore, existing surface and subsurface geological data suggest that the total mass of high heat producing granites across the GAB is no larger than in other parts of the continent that do not show any significant heat anomalies.

Australian sedimentary basins, particularly the Cooper and Galilee Basins have substantially high subsurface CO_2 content with mantle-like carbon isotope signatures (Boreham et al., 2001; Italiano, in review). This feature and results of our recent He isotope studies (Italiano, in review), together with the relatively low abundance of basement granites with high heat production, raises the question of whether high thermal gradients in the GAB can be related, at least partly, to a mantle-derived heat flux, which will be investigated in this project. In regions void of active or recently active volcanism, as is the case in the study area, amagmatic flow of mantle fluids through the ductile lower crust can occur due to the creation of permeable pathways as a result of crustal deformations (Kulongoski et al., 2005; Kennedy and van Soest, 2007). The Australian continent is one of the seismically active intraplate regions in the world. The northward movement of Australia resulted in collision with Eurasia in the Timor and Papua New Guinea regions, with plate boundary forces acting upon the Australian Plate, which is expressed in a compressional stress regime in central Australia. Previous studies have documented a number of major recent reverse fault earthquakes that caused surface fault ruptures with many pre-historic fault scarps in Australia. Crustal deformations and associated seismic activities in continental intraplate regions occur commonly through reactivation of pre-existing zones of weakness such as the regions of extended continental crust. In conjunction with isotopic data of the volatiles (Italiano et al., in review), our structural geological field observations suggest that geothermal systems in central Australia preferentially occur in areas of deformation-enhanced permeability and deep mantle fluid production. To this end, we performed comprehensive isotopic dating studies (Rb–Sr, Ar–Ar and U-series) to understand the role of Phanerozoic and neotectonic deformations in permeability production and stable isotope tracing to determine the source of fluids in the geothermal reservoirs.

2. RESULTS AND DISCUSSION

2.1 Thermal history and fault reactivation

Our recent studies of Rb–Sr and Ar–Ar dating in combination with stable isotope and trace element geochemistry of hydrothermal minerals in the basement rocks indicate that Mesozoic extensional tectonic events controlled the thermal history of eastern Australia, which also determine the distributions of fracture zones allowing the recent uprise of hot mantle fluids (Middleton et al., in review). We conducted a comprehensive Rb–Sr and Ar–Ar age dating of hydrothermal illite minerals from basement cores in the Cooper, Galilee and Millungera Basins. Some particular samples provide well-defined Cretaceous ages of ~127 Ma, ~100 Ma, ~95 Ma, and ~60 Ma, which represent the areas characterised by significantly high-inferred temperatures (>250°C;) at 5 km depth (Chopra and Holgate, 2005), distinctively low gravity anomalies (GSQ data), and zones of low seismic velocities (Saygin and Kennett, 2010; Saygin and Kennett, 2012; Saygin et al., 2013). All these ages coincide with episodes of break-up of Australia from India, Antarctic, and Coral Sea as well as tectonic movements created cratonic basins in central Australia (e.g., Eromanga Basin) (Veevers et al., 1991). Hydrogen and oxygen stable isotope values of these Cretaceous illites are conspicuously low, characteristic for extension-related meteoric-hydrothermal process (e.g., Uysal et al., 2000). By contrast, authigenic illite samples from cores representing areas of lower inferred temperatures at 5 km, high gravity and seismic velocities were formed from more evolved basinal fluids during earlier (Proterozoic, Paleozoic and early Mesozoic) tectonic events.

2.2 Neotectonics and mantle degassing

We noticed during our fieldwork that silica and carbonate minerals deposited at the surface, commonly along elongate fracture zones. Most interestingly, the silica and carbonate sinter deposits show evidence of deformations such as faulting and fracturing. The fractures in sinters were filled by younger silica and carbonate deposits (veining). Our field studies confirm that pre-existing faults were reactivated neotectonically and controlled the formation of late Quaternary carbonate vein and breccia deposits, which formed as hydro-fractures as a result of CO_2-rich fluid overpressure, a process observed in seismically active geothermal systems worldwide (Chiodini et al., 2008; Uysal et al., 2007; Uysal et al., 2009). Thus, clusters of carbonate-rich groundwaters may highlight areas characterized by high fluxes of volatiles that normally have a deep mantle origin and cannot be generated solely by degassing granite. $\delta^{13}C$ values of the carbonates are consistent with CO_2 derived from a mantle source. High precision U-series dating of carbonate veins show that release of the pressurised CO_2 occurred intermittently from 35.9 ± 0.15 ka to 1.2 ± 0.02 ka, possibly in association with mantle degassing in response to seismicity.

2.3. Mantle fluids as potential for geothermal resources in the GAB

The released mantle-derived volatiles imply not simply a large amount of CO_2, but also the supply of significant amounts of thermal energy to crustal fluids including ground waters and oil reservoirs. The release of conductive thermal energy by granites at shallow crustal levels (upper crust) differs from the typically convective thermal energy of mantle origin released at the level of the lower crust (or deeper).

Recent seismic tomography studies are consistent with our gas-geochemistry results, suggesting that deep crustal fracturing and degassing, and hence heat released from the mantle, occur at a scale smaller than the whole GAB. Volatiles from different sources (both shallow and deep) contribute to feed the circulating waters that move across tectonic structures and discontinuities, generating a wide array of geochemical signatures. The geochemical features of dissolved He and CO_2 (Italiano et al., in review) fully agree with the proposed presence of mantle-derived CO2 over the Cooper Basin (Boreham et al., 2001) and is consistent with the area's anomalously high heat flow (Chopra and Holgate, 2005).

3. Conclusion and recommendations

On the basis of our preliminary results, we propose that there are semi conventional geothermal systems in outback Queensland/SA from which the intensity is controlled by deformation-enhanced permeability and deep mantle fluid production. This hypothesis need to be tested through further research by conducting small-scale studies, which are needed to better understand the relationships between circulating/upwelling mantle-derived volatiles and the active faulting, buried under thick sedimentary covers. Particularly, the new conceptual model for the GAB needs to incorporate individual sub-basins with varying chemistry, flow paths and mixing dynamics and temperature conditions.

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