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Insights into mantle-type volatiles contribution from dissolved gases in artesian waters of the Great Artesian Basin, Australia

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ABSTRACT

The geochemical features of the volatiles dissolved in artesian thermal waters discharged over three basins (Millungera, Galilee and Cooper basin) of the Australian Great Artesian Basin (GAB) consistently indicate the presence of fluids from multiple gas sources located in the crust (e.g. sediments, oil reservoirs, granites) as well as minor but detectable contributions of mantle/magma-derived fluids. The gases extracted from 19 water samples and analyzed for their chemical and isotopic composition exhibit amounts of CO_2 up to about 340 mlSTP/L_{H2O} marked by a $\delta^{13}C_{TDC}$ (Total Dissolved Carbon) ranging from −16.9 to +0.18‰ vs PDB, while CH_4 concentrations vary from 4.4×10^{-5} to 4.9 mlSTP/L_{H2O}. Helium contents were between 9 and >2800 times higher than equilibrium with Air Saturated Water (ASW), with a maximum value of 0.12 mlSTP/L_{H2O}. Helium isotopic composition was in the 0.02–0.21 Ra range (Ra = air-normalized $^3He/^4He$ ratio). The three investigated basins differ from each other in terms of both chemical composition and isotopic signatures of the dissolved gases whose origin is attributed to both mantle and crustal volatiles. Mantle He is present in the west-central and hottest part of the GAB despite no evidence of recent volcanism. We found that the partial pressure of helium, significantly higher in crustal fluids than in mantle-type volatiles, enhances the crustal He signature in the dissolved gases, thus masking the original mantle contribution. Neotectonic activity involving deep lithospheric structures and magma intrusions, highlighted by recent geophysical investigations, is considered to be the drivers of mantle/magmatic volatiles towards the surface. The results, although pertaining to artesian waters from a vast area of >542,000 km^2, provide new constraints on volatile injection, and show that fluids' geochemistry can provide additional and independent information on the geo-tectonic settings of the Great Artesian Basin and its geothermal potential.

1. Introduction

The Great Artesian Basin (GAB) of Australia is unique not only because it is the largest and deepest artesian basin in the world, but also because it experiences conspicuously elevated crustal and mantle degassing in association with high heat production (Torgersen et al., 1992; Habermehl and Pestov, 2002). Highly radioactive crust in the central-western part of the GAB is responsible for an increase in heat flow and regional ^4He flux, whereas the reduced heat flow with enhanced ^3He flux is attributed to young volcanism in its eastern part (Sass and Lachenbruch, 1978; Torgersen and Clarke, 1985; Duncan and McDougall, 1989; Torgersen et al., 1992; Bethke et al., 1999)). Eastern Australia has been the site of both hotspot volcanism and intraplate lava flow fields since the late Cretaceous (Wellman and McDougal, 1974). Hotspot volcanism occurs as a response to the northward migration of Australia away from Antarctica, and is currently centred in Bass Strait in southeast Australia. Intraplate lava flow fields are distributed across the east coast in time and space, but the most recent activity (<5 Ma) is concentrated in northeast Queensland and southern Victoria (Johnson, 1989; Vasconcelos et al., 2008). A ^3He-rich gas component indicating a mantle contribution of up to 7% in the GAB groundwater was observed at localities (at ~20.5 S° 144° E, ~25.5 S° 146° E, and ~27 S° 144.5° E) in close proximity to Cenozoic lava flow fields (Torgersen et al., 1987; Torgersen et al., 1992), however to date there has been no evidence suggesting a mantle helium input to the groundwater further west, in the central and hottest part of the GAB. Natural gases from the Eromanga and Cooper Basins underlying the central-western part of the GAB, however, have extremely high CO_2 contents of more than 50%, although gases from most Australian basins

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contain CO_2 of <5% (Boreham et al., 2001). Gases with CO_2 contents >5% in association with narrowly ranging $\delta^{13}C$ values between −3 and −10‰ in the Eromanga and Cooper Basins are considered to be originated from a mantle source (Boreham et al., 2001). Although no surface manifestation of volcanic activity is present in this region, it has been demonstrated elsewhere that mantle volatiles can be transferred into the shallow crust following extensional tectonic activity (Oxburgh and O'Nions, 1987; Kennedy and van Soest, 2006; Banerjee et al., 2011). The injection of mantle-derived fluids into geothermal reservoirs and groundwaters can be detected by using the He isotope geochemistry of volatiles even in regions where there is no active volcanism (e.g., Italiano et al., 2000; Güleç et al., 2002; Kulongoski et al., 2005; Italiano et al., 2013). The aims of this article are to evaluate the chemical and isotopic composition of the whole gas phase dissolved in deep artesian waters to explore whether a mantle fluid flux occurs in the central part of the GAB, and to discuss implications for active tectonics, and heat source and geothermal potential in the central GAB. A broad scale survey was conducted to collect gases dissolved in artesian thermal waters throughout the Galilee and Millungera Basins, and the northern part of the Cooper Basin in SW Queensland (Fig. 1). Water samples were taken from 19 deep artesian wells mostly in areas that have not been sampled by previous investigators (Torgersen et al, 1987; Torgersen et al., 1992), and analyzed for dissolved gas contents (He, CO_2, CH_4, N_2 and O_2), and He, Ar and C isotopes.

2. Geological background and hydrology

The GAB comprises the Mesozoic Eromanga, Surat and Carpentaria Basins and parts of the Permian Bowen and Galilee Basins (Habermehl, 2001, and references therein). The confined aquifers occur in quartzose sandstones of continental origin and mostly Triassic, Jurassic and Cretaceous ages. The most productive aquifers in the GAB are the Lower Cretaceous–Jurassic sequences, with about 500–1500 mg/L total dissolved solids and bore yields over 5 L/s. A thick Early Cretaceous argillaceous sequence of marine origin is the main confining unit. The groundwater recharge zone is located primarily along the eastern margin of the basin, and the large-scale regional groundwater flow direction is from the east towards the southwest.

The geology of the GAB consists of several broad synclinal structures trending north and northeast, overlying sedimentary, metamorphic and igneous rocks of pre-Jurassic or pre-Triassic ages. The Mesozoic sedimentary sequence in the central part of the basin reaches a maximum total thickness of about 3000 m (Habermehl, 2001). Parts of the

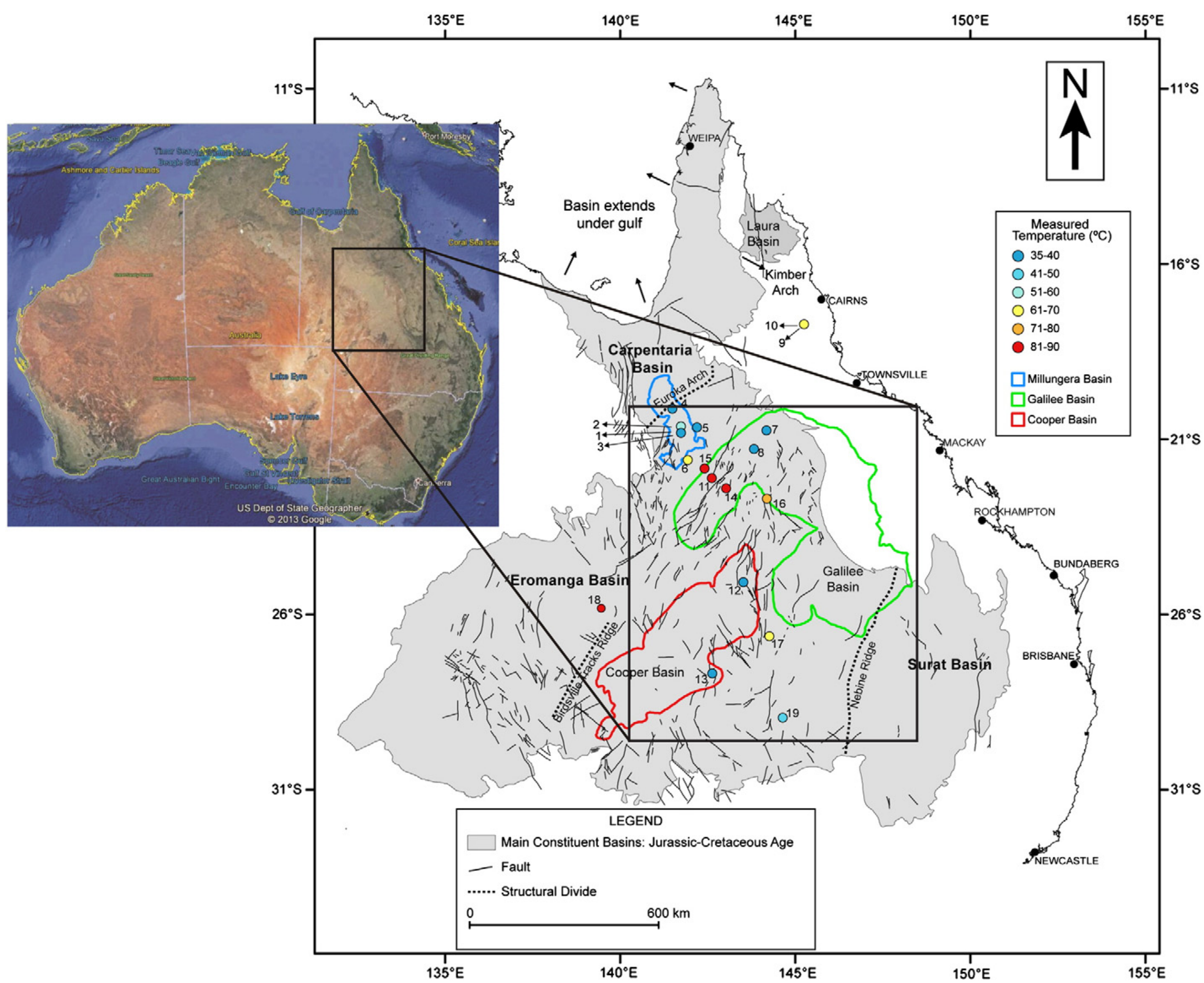

Fig. 1. Sample locations over the investigated Millungera, Galilee and Cooper Basins. The sampling sites are spread over an area marked by significant heat-flow anomalies (after OzTemp-Interpreted Temperature at 5 km depth, Commonwealth of Australia – Geoscience Australia, 2010). Sample ID shown as open circles in various colours compatible with water temperatures at the well head (see legend).