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Recent mantle degassing recorded by carbonic spring deposits along sinistral strike-slip faults, south-central Australia

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ABSTRACT

The interior of the Australian continent shows evidence for late Quaternary to Recent fault-controlled mantle ^{3}He and CO_2 degassing. A series of interconnected NW-striking sinistral faults, the Norwest fault zone (NFZ), in south-central Australia are associated with travertine mounds, the latter show a regular spacing of 50–70 km. U-series ages on 26 samples range from 354 ± 7 to 1.19 ± 0.02 ka (2σ errors) and suggest a clustering every ∼3–4 ka since ∼26 ka. Geochemical data demonstrate a remarkable mantle-to-groundwater connection. Isotopic data indicate that the groundwater is circulating to depths >3 km and interacting with Neoproterozoic/Cambrian basement and mantle volatiles. $^3He/^4He$ isotope ratios show that the He comes in part from the mantle. This demonstrates that the NFZ cuts through the entire crust and provides pathways for mantle degassing. Scaling relationships suggest that the series of sinistral faults that make up the NFZ are interconnected at depths and have a significant strike length of 60–70 km or more. The NFZ occurs where a major compositional boundary and a significant heat flow anomaly occurs, and a major step in lithospheric thickness has been mapped. We discuss a tectonic model in which recent stress field, heat flow and lithospheric structure in central Australia reactivated a set of steeply dipping Neoproterozoic faults, which may now be growing into a crustal/lithospheric-scale structure.

1. Introduction

Australia is the lowest and flattest of all continents, which is consistent with a stable, cratonic lithosphere far away from any plate boundary (Sandiford and Quigley, 2009) (Fig. 1). Yet, Australia is among the most active 'stable continental regions' (Braun et al., 2009). Some Australian sedimentary basins have substantially large CO_2 outgassing (Boreham et al., 2001), which is associated with mantle-derived He in parts of the Great Artesian Basin (Torgersen and Clarke, 1985), a phenomenon characteristic of seismically active zones (Kennedy et al., 1997). There are indeed zones of active seismicity in the interior of the Australian continent causing earthquakes with magnitudes of up to 7 (Hillis et al., 2008) (Fig. 2). Furthermore, numerous faults with Miocene to Quaternary displacements have been documented (Waclawik et al., 2008).

Another indicator of neotectonic activity in south-central Australia is the widespread occurrence of carbonic springs and travertine deposits along faults extending from the basement to the surface (Adlam and Kuang, 1988). Gold and Soter (1984) have noticed a correlation between major CO_2 seeps and zones of enhanced seismicity, and suggested that mantle or metamorphic CO_2 ascending through the crust along active faults triggers earthquakes. In the Flinders Ranges in south-central Australia, Balfour et al. (2015) showed that deeply sourced crustal fluids are associated with active faulting and that the focused seismicity there can only be explained by high pore–fluid pressure in the lower crust. Most faults associated with carbonic springs in south-central Australia strike NW–SE. Near Lake Eyre, calcite vein networks are prominent and occur in fracture zones associated with a neotectonic fault array, the Norwest fault zone (NFZ; Geological Survey of South Australia, 1992) (Fig. 2). Travertine deposits in seismically active

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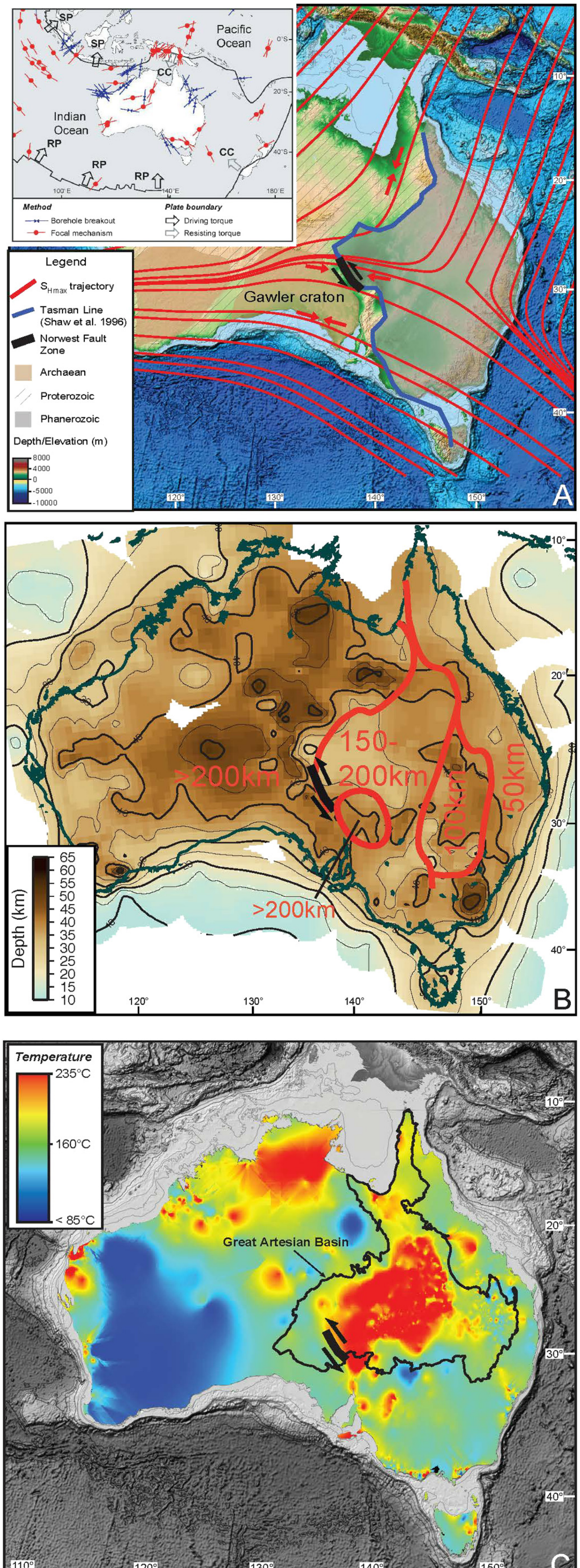

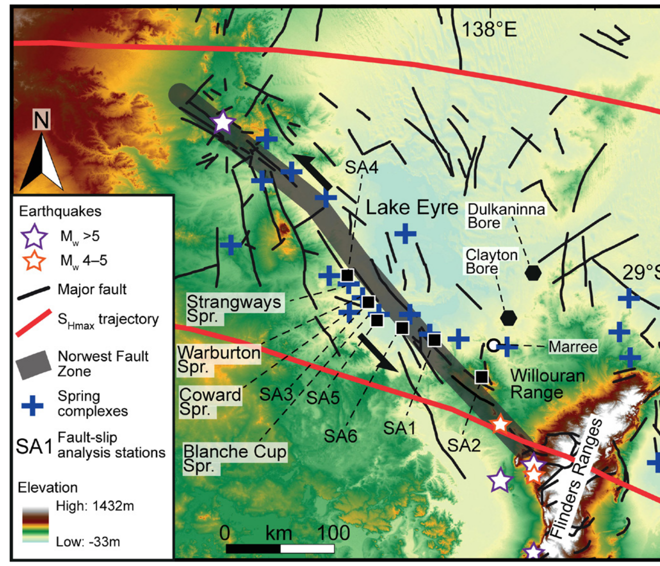

Fig. 2. Topographic map of northern south-central Australia showing NFZ near Marree, S_{Hmax} trajectories, carbonic spring complexes straddling NFZ at spacing of some 50–70 km, major earthquakes and localities for fault-slip analysis (SA1 through SA6); note uplift of N–S-trending Flinders Range subperpendicular to S_{Hmax} trajectories, subdued topography around NFZ and Lake Eyre basin. Base map from Geoscience Australia, national elevation data framework portal (http://nedf.ga.gov.au/geoportal/catalog/main/home.page); earthquake data from South Australian Government (South Australian Resources Information Geoserver, SARIG, https://sarig.pir.sa.gov.au/MapViewerJS/).

zones provide an important record of fault movement, as they can be dated precisely using U-series methods (Uysal et al., 2011; Kampman et al., 2012).

Although active tectonics has been known as the main process for transferring mantle volatiles into shallow crustal environments (Kulongoski et al., 2005; Kennedy and van Soest, 2007), a possible connection between recent fault movements and mantle degassing in Australia remained largely enigmatic. We show that the NFZ contains surface vents allowing mantle degassing in the Australian craton by examining the structure, geochronology, and isotope geochemistry of fault-controlled travertine deposits and dissolved and free gas samples. Specifically, we provide a solid data set on the exact timing of episodic ^3He and CO_2 degassing events and related late Quaternary to Recent fault activity.

2. Setting

Australia is the fastest moving continent since the Eocene (Sandiford et al., 2004) and has migrated more than 3000 km to the NNE as part of the Indo-Australian Plate (DeMets et al., 2010). Fast motion of Australia is controlled by the slab-pull force related

Fig. 1. (A) Topographic map of Australia (http://maps.ngdc.noaa.gov) with orientation of modeled maximum horizontal stress trajectories (S_{Hmax}, Hillis and Reynolds, 2000; Dyksterhuis and Müller, 2008); southern part of Australia characterized by E–W S_{Hmax} that swings into NNE direction subparallel to plate velocity vector in north; also shown are main crustal provinces, outlines of major cratons and Tasman Line proposed by Shaw et al. (1996) using geophysical signatures and locations of surface outcrop to define boundary. Inset: Indo-Australian Plate with in-situ stress data showing S_{Hmax} and plate boundary forces (RP: ridge push, SP: slab pull; CC: continental collision) (Sandiford et al., 2004). (B) Crustal thickness map (Kennett et al., 2011), note relatively thin crust in south-central Australia broadly coinciding with topographic low of Lake Eyre basin with altitude below sea level; lithospheric thicknesses also shown (Fishwick et al., 2008). (C) Heat flow map of Australia showing modeled crustal temperature at five kilometers depth (www.ga.gov.au). Surface trace of NFZ indicated on all maps; note that fault zone coincides with step in lithospheric thickness, relatively thin crust, transition from low to high heat flow in south-central Australia, and broadly also with swing in S_{Hmax} direction from E–W to NNE.