Lithos 302–303 (2018) 341–358

Contents lists available at ScienceDirect

Lithos

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

# Temporal constraints on magma generation and differentiation in a continental volcano: Buckland, eastern Australia

Tracey J. Crossingham [a,*], Teresa Ubide [a], Paulo M. Vasconcelos [a], Kurt M. Knesel [a,b], Guilherme Mallmann [a,c]

[a] School of Earth and Environmental Sciences, The University of Queensland, Brisbane, QLD 4071, Australia
[b] Department of Geosciences, Trinity University, San Antonio, TX 78212, USA
[c] Research School of Earth Sciences, The Australian National University, Canberra, ACT 2601, Australia

ARTICLE INFO

*Article history:*
Received 15 August 2017
Accepted 13 January 2018

*Keywords:*
$^{40}Ar/^{49}Ar$ geochronology
Continental volcanism
Eastern Australia
Magma differentiation
Radiogenic isotopes

ABSTRACT

The eastern margin of the Australian continent hosts a large number of Cenozoic intraplate volcanoes along a 2000 km long track. Here, we study mafic lavas from the Buckland volcano, Queensland, located in the northern (older) segment of this track, to assess magma generation and differentiation through time. The rocks are aphanitic to microporphyritic basalts, trachy-basalts and basanites. Incompatible element geochemistry together with Sr-Nd-Pb isotope ratios indicate that magmas formed from an enriched mantle I (EMI)-like garnet-bearing source with variable degrees of crustal contamination. Whole rock elemental variations suggest fractionation of olivine, plagioclase, clinopyroxene and/or magnetite. There is no petrographic or geochemical evidence of magma mixing in the studied rocks (e.g., lack of recycled minerals), suggesting a relatively quick ascent from the source to the surface without major storage at shallow levels.

$^{40}Ar/^{39}Ar$ geochronology reveals two stages of volcanism: 30.3 ± 0.1 Ma and 27.4 ± 0.2 Ma. The Old Buckland (30.3 ± 0.1 Ma) melts have negative K anomalies, and incompatible element ratios suggest the occurrence of residual hydrous minerals in a metasomatised mantle source. We therefore infer that at the onset of volcanism, deep-mantle-derived magmas interacted with metasomatised sub-continental lithospheric mantle (SCLM). Major and trace element data, clinopyroxene thermobarometry and thermodynamic modelling indicate magma evolution by assimilation and fractional crystallisation (AFC) during ascent through the crust. Following a hiatus in volcanic activity of ~2.5 Ma, eruption of Young Buckland (27.4 ± 0.2 Ma) lavas marked a shift towards more alkaline compositions. Trace element compositions indicate lower degrees of partial melting and a lack of interaction with metasomatic components. Young Buckland lavas become progressively more $SiO_2$-saturated up stratigraphy, suggesting an increase in the degree of partial melting with time. Young Buckland lavas also have more radiogenic $^{87}Sr/^{86}Sr$ and $^{207}Pb/^{204}Pb$ ratios and less radiogenic $^{143}Nd/^{144}Nd$ ratios up stratigraphy. These isotopic variations, together with coupled increases in Pb and K and decreases in Ce/Pb (27.22 to 11.09) and Nb/U (68.30 to 29.96), suggest that crustal contamination also increased with time.

By placing absolute age and stratigraphic constraints on the Buckland lavas, we have been able to ascertain differentiation signatures imposed on mantle-derived melts during ascent through the continental lithosphere over 3 Ma. Our study provides new constraints on magma generation and differentiation in continental intraplate volcanic systems.



## 1. Introduction

Intraplate volcanism, particularly flood basalts and hotspot tracks, record important information on thermal and geochemical anomalies in the mantle (e.g., Kamenetsky et al., 2017; Leeman, 1982; Sheth et al., 2013). Magmas derived from a depleted upper mantle (DM) or variously enriched lower mantle source components (e.g., high μ (HIMU), enriched mantle I (EMI), enriched mantle II (EMII)) inherit the geochemical characteristics unique to these sources (e.g. Hofmann, 1997; Zindler and Hart, 1986). However, understanding the source characteristics of continental intraplate volcanoes can be a challenging task, as most magmas that erupt on the surface cannot be considered primary melts (e.g. Carlson et al., 1981; Kamenetsky et al., 2017; Ma et al., 2013). This is largely because the thickness of the continental lithosphere enhances magma differentiation processes (e.g., Ma et al., 2013), including interaction with the sub-continental lithospheric mantle (SCLM), and contamination by crustal components, fractional crystallisation and magma mixing (e.g., DePaolo, 1981; Devey and Cox, 1987; Ma et al., 2013; Pilet et al., 2005; Putirka, 2017; Spera and Bohrson, 2001).

* Corresponding author at: Level 2, Room 210, Steele Building, The University of Queensland, St. Lucia, QLD 4072, Australia.
*E-mail address:* tracey.crossingham@uqconnect.edu.au (T.J. Crossingham).

https://doi.org/10.1016/j.lithos.2018.01.009

Timescales of magma generation and differentiation through to eruption have been well documented (e.g. Cooper, 2015; Hawkesworth et al., 2004) and the life span of an individual polygenetic volcano can be on the order of millions of years (e.g. Christiansen, 2001; Wellman and McDougall, 1974). Timing relationships of the processes controlling the evolution of intraplate volcanism have been recently explored by combining $^{40}Ar/^{39}Ar$ geochronology with stratigraphic and geochemical data, establishing, for example, distinct stages of volcanism at the Sunlight volcano, Wyoming (Feeley and Cosca, 2003) and at Mt. Rouse of the Newer Volcanics Province, southeastern Australia (Boyce et al., 2015). Such geochronological-geochemical approaches have the potential to place temporal constraints on magma generation and evolution in individual volcanic centers.

The east coast of the Australian continent hosts a 2000 km long track of Cenozoic volcanoes (Fig. 1) offering a unique opportunity to investigate magma source and differentiation processes in an intraplate continental setting. Early research on the age-progressive central volcanoes (~34–6 Ma from north to south: Wellman and McDougall, 1974) highlighted the importance of differentiation processes in producing magmas with diverse compositions (e.g. Ewart et al., 1977; Middlemost, 1981; Stolz, 1985). Fractional crystallisation was considered the dominant differentiation process, often accompanied by crustal assimilation (Ewart et al., 1988). More recently, interaction with the SCLM has also been proposed to play a major role in the formation of the diverse range of eastern Australian Cenozoic lavas (Davies et al., 2015; O'Reilly and Zhang, 1995; Van Otterloo et al.,

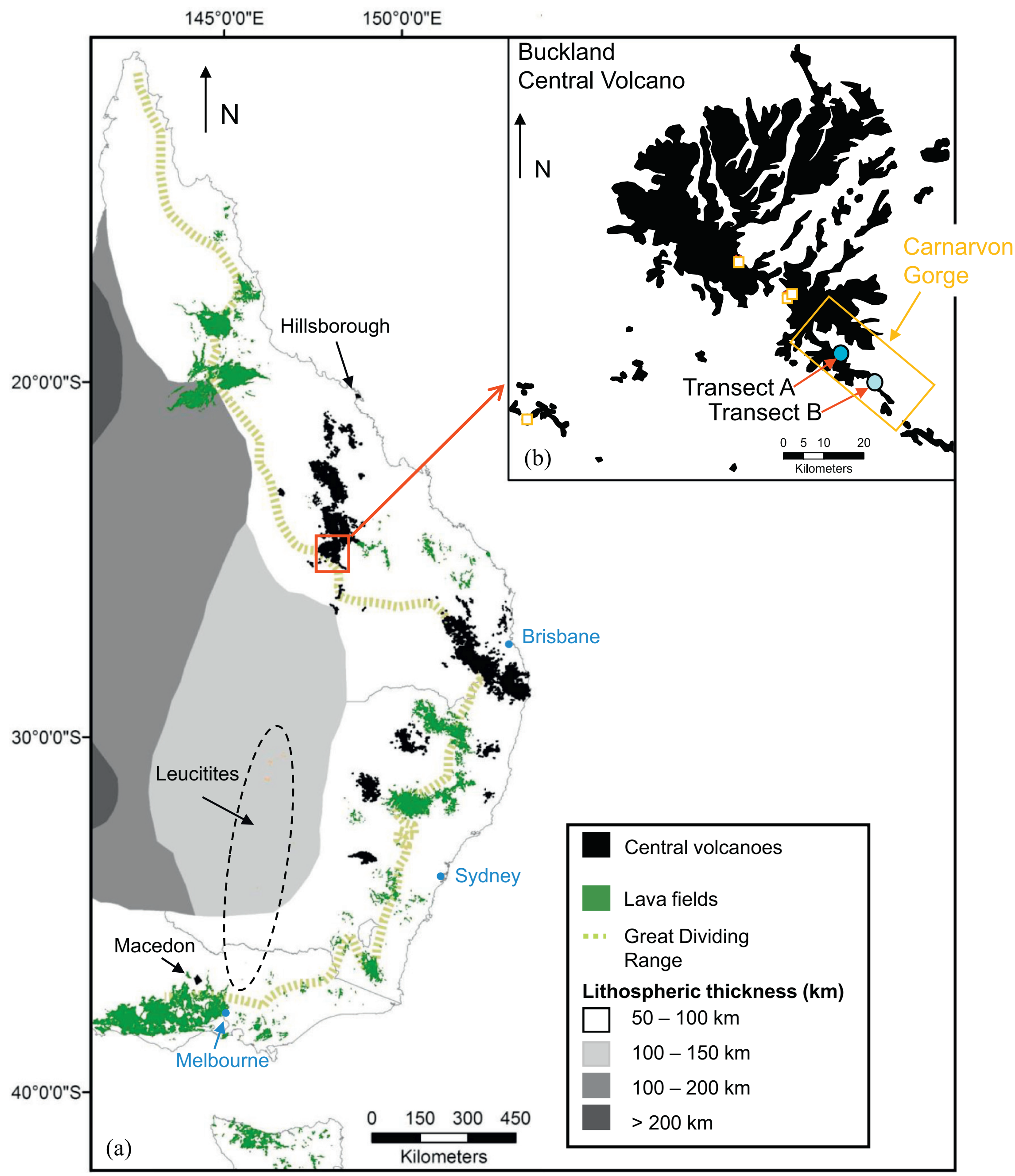


**Fig. 1.** (a) Distribution of the Cenozoic lavas along the eastern margin of Australia. (b) The Buckland central volcanic province, highlighting the location of Carnarvon Gorge, where the mafic lavas were collected, in two transects, for this study (dark blue and light blue circles). The white and yellow squares represent the location of samples previously dated by Cohen (2007) via $^{40}Ar/^{39}Ar$ geochronology. Modified after Johnson (1989) and Fishwick et al. (2008).