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Variable sources for Cretaceous to recent HIMU and HIMU-like intraplate magmatism in New Zealand

Q.H.A. van der Meer [a,b,*,1], T.E. Waight [a], J.M. Scott [b], C. Münker [c]

[a] Department of Geosciences and Natural Resource Management (Geology Section), Copenhagen University, Øster Voldgade 10, 1350 Copenhagen K, Denmark
[b] Department of Geology, University of Otago, Leith Street, Dunedin 9054, New Zealand
[c] Institut für geologie und Mineralogie, Universität zu Köln, Zülpicher Str. 49b, 50674 Köln, Germany

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ABSTRACT

Continental intraplate magmas with isotopic affinities similar to HIMU are identified worldwide. Involvement of an asthenospheric HIMU or HIMU-like source is contested because the characteristic radiogenic Pb compositions coupled with unradiogenic Sr and intermediate Nd and Hf compositions can also result from in-situ ingrowth in metasomatised lithospheric mantle. Sr–Nd–Pb–Hf isotopic compositions of late Cretaceous lamprophyre dikes from Westland, New Zealand, provide new insights into the formation of a HIMU-like alkaline intraplate magmatic province under the Zealandia continent. The oldest (102–100 Ma) calc-alkaline lamprophyres are compositionally similar to the preceding arc-magmatism ($^{206}Pb/^{204}Pb_{(i)} = 18.6$, $^{207}Pb/^{204}Pb_{(i)} = 15.62$, $^{208}Pb/^{204}Pb_{(i)} = 38.6$, $^{87}Sr/^{86}Sr_{(i)} = 0.7063–0.7074$, $\varepsilon Nd_{(i)} = -2.1 - +0.1$ and $\varepsilon Hf_{(i)} = -0.2 - +2.3$) and are interpreted as melts originating from subduction-modified lithosphere. Alkaline dikes erupted on the inboard Gondwana margin shortly after cessation of subduction (92–84 Ma) have heterogeneous isotopic properties: $^{206}Pb/^{204}Pb_{(i)} = 18.7$ to 19.4, $^{207}Pb/^{204}Pb_{(i)} = 15.60$ to 15.65, $^{208}Pb/^{204}Pb_{(i)} = 38.6$ to 39.4, $^{87}Sr/^{86}Sr_{(i)} = 0.7031$ to 0.7068, $\varepsilon Nd_{(i)} = +4.5$ to $+8.0$ and $\varepsilon Hf_{(i)} = +5.1$ to $+8.0$. Melt compositions point to an amphibole-bearing spinel facies lithospheric mantle source enriched by metasomatism that introduced, amongst many elements, U + Th which lead to rapid ingrowth to HIMU-like compositions. Importantly, this HIMU-like source enrichment appears to have completely originated from the complex local subduction history. A coeval episode of alkaline magmatism (mainly 98–82 Ma) occurred outboard of Gondwana's former active margin and on the Hikurangi oceanic plateau (accreted to Zealandia in the Early Cretaceous) with compositions closer to true HIMU ($^{206}Pb/^{204}Pb_{(i)} \approx 20.5$, $^{207}Pb/^{204}Pb_{(i)} \approx 15.7$, $^{208}Pb/^{204}Pb_{(i)} \approx 40.0$, $\varepsilon Nd_{(i)} \approx 4.5$ and $\varepsilon Hf_{(i)} \approx 4.0$). In contrast to the inboard HIMU-like magmas, the radiogenic $^{207}Pb/^{204}Pb$ and relatively unradiogenic Nd and Hf require an ancient enriched source component. This magmatism is interpreted to represent melting of a fossilised HIMU source that resided under the Hikurangi Plateau. These genetically distinct but isotopically similar intraplate reservoirs were separated by the down-going slab under Gondwana's former active margin. Ancient HIMU magmatism was locally replaced by the young HIMU-like type which became dominant across Zealandia during the Late Cretaceous. Our research suggests that the sources for alkaline intraplate magmas with compositions similar to ocean island basalts can be formed either with or without the involvement of a plume-derived component.

1. Introduction

The petrogenesis of continental intraplate magmatic provinces (e.g., East Africa (Rooney et al., 2014) and the Mediterranean (Duggen et al., 2005)) remains a contested but essential topic for our understanding of mantle melting and dynamics, in particular evaluating whether melts are sourced in the asthenosphere, lithosphere or both. Chemical and isotopic similarities exist between alkaline continental and oceanic intraplate magmas with HIMU (high $^{238}U/^{204}Pb$ or μ) or HIMU-like affinities (e.g. Hoernle et al., 2010). While oceanic lithosphere is formed through melt extraction from convecting asthenosphere, continental lithosphere is predominantly formed through subduction and often has a complex multi-stage pre-history of depletion and enrichment (e.g. Pearson et al., 2003). HIMU compositions are commonly interpreted to originate from the melting of ancient subducted hydrothermally altered oceanic crust that rises to the surface in mantle plumes

* Corresponding author.
E-mail address: qvandermeer@gmail.com (Q.H.A. van der Meer).
[1] Current address: Department of Geological Sciences, University of Cape Town, 13 University Avenue, Rondebosch 7701, South Africa.

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(e.g. Stracke et al., 2003). HIMU-like melts have many isotopic similarities to HIMU but, most importantly, lack highly radiogenic $^{207}Pb/^{204}Pb$ and could therefore represent younger enriched sources. Detailed investigations of melts potentially originating from the lithospheric mantle are required to better understand the affinities of enriched mantle reservoirs underlying the continental and oceanic crust, and to determine whether source enrichment is ultimately derived from deep recycled plume materials or shallower subduction-related enrichment.

New Zealand contains a prolonged record of repeated continental alkaline intraplate volcanism erupting over the last ∼100 Ma (e.g., Timm et al., 2010; van der Meer et al., 2016). This time period spans from when the now largely undersea continent of Zealandia was part of the Gondwana margin, through Late Cretaceous extension and separation from Antarctica and Australia, up to the present day (Fig. 1). The Zealandia intraplate alkaline basalts have long been recognised to have OIB elemental and Sr, Nd ± Pb isotopic signatures that indicate a HIMU-like source component (e.g. Barreiro and Cooper, 1987; Baker et al., 1994; Hoernle et al., 2006; Panter et al., 2006; Sprung et al., 2007). There is, however, no consensus on the origin of this HIMU-like source, where it resides, and why it is repeatedly tapped.

A suite of Sr–Nd–Pb–Hf isotope data from the most geographically extensive – but least studied – intraplate occurrence in New Zealand (the Cretaceous Westland Dike Swarm, Waight et al., 1998a; van der Meer et al., 2013, 2016), coupled with published data from elsewhere in Zealandia, is used here to examine the mantle sources for these intraplate alkaline magmas. Our dataset comprises 49 new samples and >150 published samples and is the first to be compared against the Zealandia peridotite mantle Sr–Nd–Pb–Hf isotope reference frames recently established by Scott et al. (2014a, 2014b, 2016), Czertowicz et al. (2016), McCoy-West et al. (2016) and Dalton et al. (2017). This dataset permits analysis of the temporal and spatial isotopic variability of intraplate magma sources on a continental-scale. The results (1) reveal that Cretaceous subduction termination and associated changes in tectonic regime played a role in influencing the Gondwana margin lithospheric mantle composition; (2) identify the presence of isotopically distinct alkaline intraplate reservoirs that are related to the presence of a collided oceanic plateau; and (3) enable construction of a model that accounts for the generation of HIMU (-like) intraplate magmatism on continental as well as adjacent oceanic crust.

2. Geological setting

2.1. Zealandia crustal structure

The basement geology of Zealandia consists of the Eastern and Western Provinces. The former comprises Palaeozoic to Mesozoic arc-related terranes accreted to the Gondwana subduction margin and variably metamorphosed in the Mesozoic (e.g., Mortimer, 2004). The Western Province is made up of a Cambrian volcanic arc and a series of Palaeozoic metamorphosed sedimentary strata cut by several episodes of granitic plutonism (e.g. Mortimer, 2004). The suture zone between the two provinces occurs within the long-lived Cordilleran-style Median Batholith (e.g. Mortimer et al., 1999; Scott, 2013). The latest arc-related I-type plutons were emplaced in the Western Province between ∼110 to 105 Ma, during which time subduction ceased and the Zealandia Gondwana margin began to undergo crustal thinning (e.g. Gibson et al., 1988; Waight et al., 1998b) leading to formation of the Tasman Sea at ∼84 Ma (Gaina et al., 1998). Cessation of subduction has been related to collision of the oceanic Hikurangi Plateau in the Early Cretaceous (e.g. Davy et al., 2008), remnants of which are jammed in the Cretaceous trench (Fig. 1).

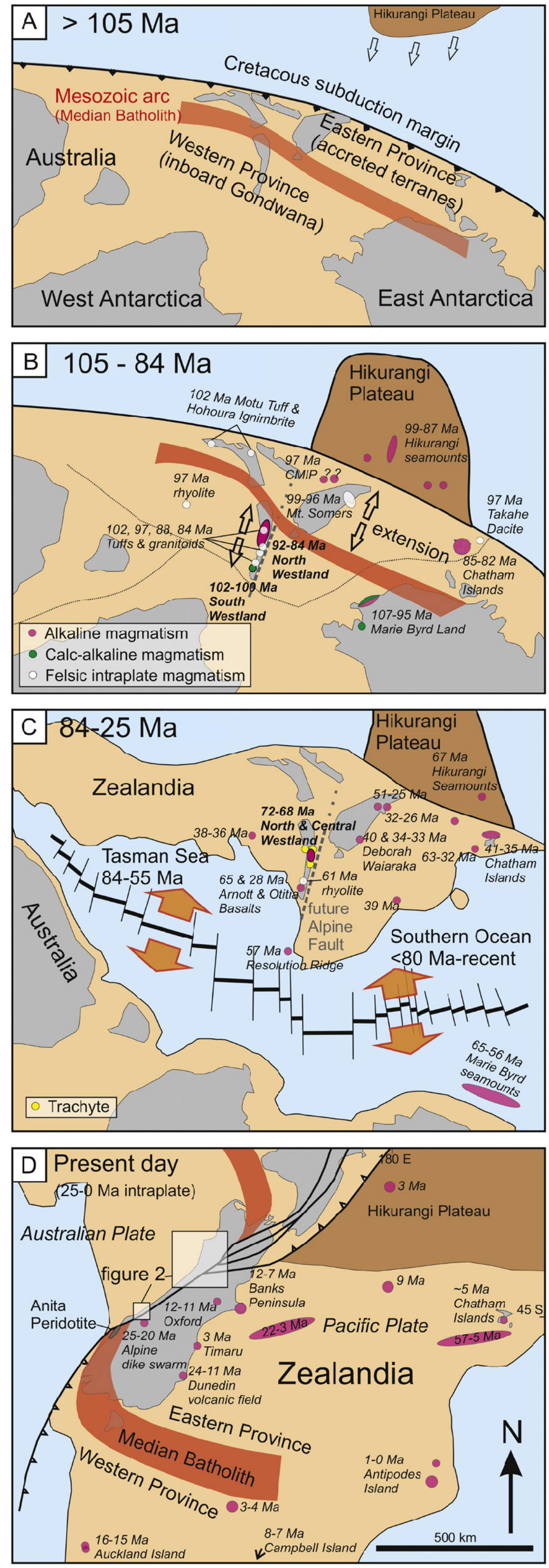

Fig. 1. Palaeogeographic reconstruction of Zealandia from a Gondwana margin setting (A) through collision of the Hikurangi Plateau (Davy et al., 2008) and the onset of extension (B), continental rifting (C) and the current setting of transpression (D). Locations of intraplate magmatic activity are indicated with colour corresponding to type, see legend. After Storey et al. (1999), Tulloch et al. (2009), Hoernle et al. (2010), Timm et al. (2010) and van der Meer et al. (2016). CMIP: Central Marlborough Igneous Province, a location of alkaline intraplate magmatism in the Eastern Province, Cretaceous location is uncertain. Note outline of present-day New Zealand in figures A, B and C for approximate scale. (For interpretation of the colours in this figure, the reader is referred to the web version of this article.)