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The longevity of Archean mantle residues in the convecting upper mantle and their role in young continent formation

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ABSTRACT

The role played by ancient melt-depleted lithospheric mantle in preserving continental crust through time is critical in understanding how continents are built, disrupted and recycled. While it has become clear that much of the extant Archean crust is underpinned by Archean mantle roots, reports of Proterozoic melt depletion ages for peridotites erupted through Phanerozoic terranes raise the possibility that ancient buoyant lithospheric mantle acts as a "life-raft" for much of the Earth's continental crust. Here we report the largest crust–lithospheric mantle age decoupling (∼2.4 Ga) so far observed on Earth and examine the potential cause for such extreme age decoupling.

The Phanerozoic (<300 Ma) continental crust of West Otago, New Zealand, is intruded by Cenozoic diatremes that have erupted cratonic mantle-like highly depleted harzburgites and dunites. These peridotites have rhenium depletion Os model ages that vary from 0.5 to 2.7 Ga, firmly establishing the record of an Archean depletion event. However, the vast range in depletion ages does not correlate with melt depletion or metasomatic tracer indices, providing little support for the presence of a significant volume of ancient mantle root beneath this region. Instead, the chemical and isotopic data are best explained by mixing of relict components of Archean depleted peridotitic mantle residues that have cycled through the asthenosphere over Ga timescales along with more fertile convecting mantle. Extensive melt depletion associated with the "docking" of these melt residues beneath the young continental crust of the Zealandia continent explains the decoupled age relationship that we observe today. Hence, the newly formed lithospheric root incorporates a mixture of ancient and modern mantle derived from the convecting mantle, cooled and accreted in recent times. We argue that in this case, the ancient components played no earlier role in continent stabilization, but their highly depleted nature along with that of their younger counterparts now represents a highly viscous, stable continental keel. This model could account for the large spectrum of ages observed in fertile to moderately depleted peridotites sampled from lithospheric mantle beneath SE Australia, W Antarctica and other locations in Zealandia, as well as the oceanic mantle. Our data confirm the longevity and dispersal of ancient depleted mantle domains in the convecting mantle and their re-appearance beneath young continents.

1. Introduction

Earth's continents are underlain by melt-depleted lithospheric mantle that protects them from the disruptive effects of asthenospheric mantle convection. The role that buoyant, viscous, highly depleted mantle has played in preserving Archean cratonic crust through to the present day has become clear through Os isotope studies of peridotite xenoliths erupted by kimberlites (Walker et al., 1989; and more recent studies reviewed by Pearson and Wittig, 2014). Less clear is the relationship between post-Archean crust and its underlying lithospheric mantle. For example, could ancient lithospheric mantle act as a "life-raft" that promotes attachment of younger crust (Carlson, 1995; McBride et al., 1996; Handler et al., 1997, 2003; Peslier et al., 2000a, 2000b; McCoy-West et al., 2013; Mundl et al., 2015)? Or are the relicts of ancient melting events entrained in the convecting mantle flow and later sampled by volcanic or orogenic events, as interpreted for oceanic settings (Parkinson et al., 1998; Brandon et al., 2000; Meibom and Frei, 2002; Harvey et al., 2006; Bizimis et al., 2007; Pearson et al., 2007; Liu et al., 2008; Simon et al., 2008; Dijkstra et al., 2010; Stracke et al., 2011; Rampone and Hofmann, 2012; Lassiter et al., 2014)?

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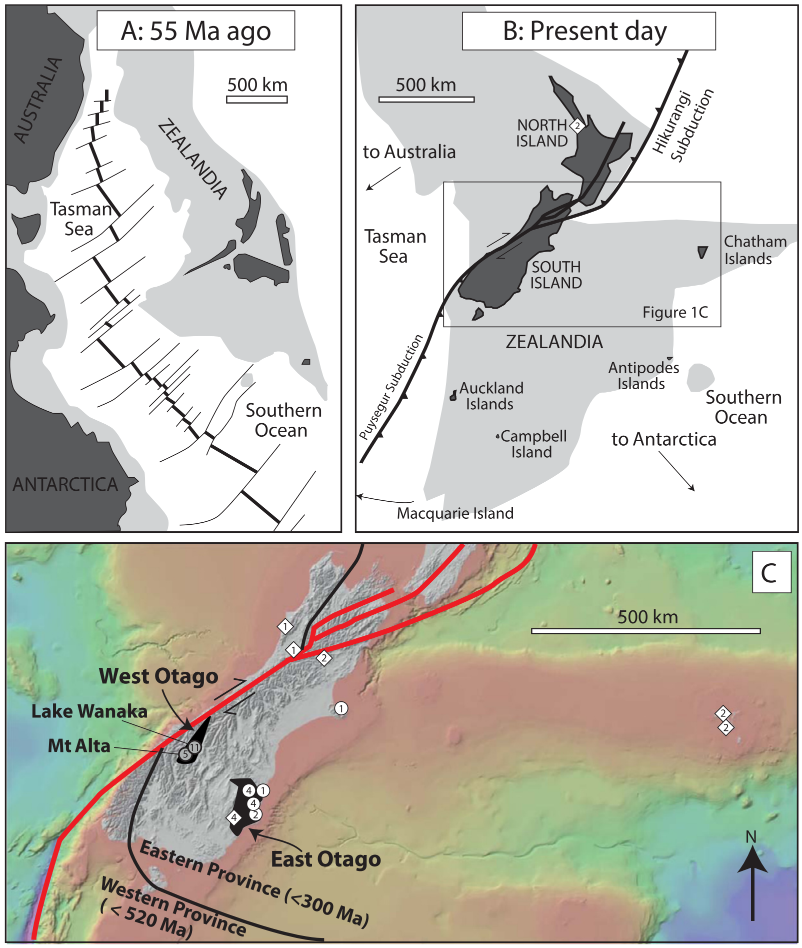

Fig. 1. A) Reconstruction of the Australia–Antarctica–Zealandia at 55 Ma, modified from Mortimer et al. (2012). This time period represents the extent of seafloor spreading between New Zealand and Australia and formation of the Tasman Sea. The elongate eastern edge of Zealandia represents the position of the former Early Cretaceous subduction trench on the paleo-Pacific margin of Gondwana. B) Present-day map of Zealandia showing portions of continental crust above sea level (dark gray) and portions below sea level (light gray), as well as oceanic crust (white), and the Australia–Pacific boundary (prominent fault line that traverses through Zealandia), modified from Scott et al. (2014a). C) A satellite gravity map of central–southern Zealandia shows the distribution of peridotite xenolith locations for which there is Re–Os isotope data, modified from Scott et al. (2014a). White symbols are data from McCoy-West et al. (2013) where the circles define their "Waitaha domain"; gray symbols are from our study. The number inside each symbol indicates the number of samples analyzed from each location. Dark fields show the extent of xenolith-bearing magmatism in West Otago and East Otago (Reay and Sipiera, 1987; Scott et al., 2014a). The Australia–Pacific plate boundary is shown in red. The thick black line shows the important Zealandia geological subdivision between the Eastern Province (Carboniferous and younger terranes <300 Ma) and the Western Province (Cambrian–Early Paleozoic terranes <520 Ma) (Scott, 2013). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

Peridotite xenoliths in Cenozoic volcanic complexes in New Zealand (Fig. 1) provide an opportunity to investigate the nature of the lithospheric mantle in Earth's youngest continent, Zealandia, where no crust older than 520 Ma has so far been recorded. Osmium and hafnium isotope data from a small selection of fairly fertile to moderately depleted peridotite xenoliths on the eastern side (East Otago) of New Zealand (Fig. 1) reveal that portions of the sampled lithospheric mantle experienced Paleoproterozoic melt depletion (McCoy-West et al., 2013; Scott et al., 2014a). This has led to the suggestion that this young continent is underlain by an ancient lithospheric mantle that has provided a stable platform, since the Paleoproterozoic, onto which various fragments of continental materials were accreted (McCoy-West et al., 2013).

A suite of newly discovered peridotite xenoliths from the western side (West Otago) of New Zealand (Fig. 1) has been shown to have strong compositional affinities to cratonic mantle (Scott et al., 2014a) supporting the possibility of an Archean mantle root beneath much younger (<300 Ma) crust. However, this inference lacks geochronological evidence. The ^{187}Re–^{187}Os isotopic system in mantle peridotites has been extensively used as providing a reliable means of dating formation of lithospheric mantle (see review in Pearson and Wittig, 2014), while platinum group element (PGE) systematics can be applied to investigate the extent of melt depletion and potential subsequent alteration in the peridotites (Pearson et al., 2004; Liu et al., 2011). Using whole-rock Re–Os isotopes and PGE we examine the timing and extent of melt depletion processes in the lithospheric mantle beneath this region to try to establish the temporal relationships between crust and lithospheric mantle and evaluate the role of ancient depleted lithospheric mantle in the formation of a much younger continent.

2. Geological setting and samples

Prior to 85 Ma, Zealandia, East Australia and West Antarctica were a contiguous continental mass, acting as the paleo-Pacific margin of Gondwana (Fig. 1A; Mortimer, 2004). Cretaceous rifting opened the Tasman Sea between Zealandia and Australia and the Southern Ocean between Zealandia and West Antarctica, and has subsequently transported New Zealand more than 3000 km northwards (Fig. 1B; Bradshaw, 1989). Although ~90% of Zealandia remains underwater, the exposed rocks indicate that it is constructed of two broad geological subdivisions: the Western Province, which is dominated by Early Paleozoic rocks, and the Eastern Province, which comprises Carboniferous to Cretaceous fore-arc sedimen-