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Subduction-modified oceanic crust mixed with a depleted mantle reservoir in the sources of the Karoo continental flood basalt province

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ABSTRACT

The great majority of continental flood basalts (CFBs) have a marked lithospheric geochemical signature, suggesting derivation from the continental lithosphere, or contamination by it. Here we present new Pb and Os isotopic data and review previously published major element, trace element, mineral chemical, and Sr and Nd isotopic data for geochemically unusual mafic and ultramafic dikes located in the Antarctic segment (Ahlmannryggen, western Dronning Maud Land) of the Karoo CFB province. Some of the dikes show evidence of minor contamination with continental crust, but the least contaminated dikes exhibit depleted mantle – like initial ε_{Nd} (+9) and $^{187}Os/^{188}Os$ (0.1244–0.1251) at 180 Ma. In contrast, their initial Sr and Pb isotopic compositions ($^{87}Sr/^{86}Sr = 0.7035$–0.7062, $^{206}Pb/^{204}Pb = 18.2$–18.4, $^{207}Pb/^{204}Pb = 15.49$–$15.52$, $^{208}Pb/^{204}Pb = 37.7$–37.9 at 180 Ma) are more enriched than expected for depleted mantle, and the major element and mineral chemical evidence indicate contribution from (recycled) pyroxenite sources. Our Sr, Nd, Pb, and Os isotopic and trace element modeling indicate mixed peridotite–pyroxenite sources that contain ∼10–30% of seawater-altered and subduction-modified MORB with a recycling age of less than 1.0 Ga entrained in a depleted Os-rich peridotite matrix. Such a source would explain the unusual combination of elevated initial $^{87}Sr/^{86}Sr$ and Pb isotopic ratios and relative depletion in LILE, U, Th, Pb and LREE, high initial ε_{Nd}, and low initial $^{187}Os/^{188}Os$. Although the sources of the dikes probably did not play a major part in the generation of the Karoo CFBs in general, different kind of recycled source components (e.g., sediment-influenced) would be more difficult to distinguish from lithospheric CFB geochemical signatures. In addition to underlying continental lithosphere, the involvement of recycled sources in causing the apparent lithospheric geochemical affinity of CFBs should thus be carefully assessed in every case.

1. Introduction

Continental flood basalts (CFBs) represent the most voluminous magmatic activity on the continents. They are commonly associated with the early stages of continental breakup, but whether they arise due to processes related to the continental lithosphere (e.g., thinning, delamination, and insulation) or instead derive from melting of a deep mantle plume, remains an issue of discussion (e.g., Anderson, 2005; Beccaluva et al., 2009; Campbell, 2005; Coltice et al., 2009; Elkins-Tanton and Hager, 2000; Jourdan et al., 2007; Sobolev et al., 2011b). CFBs generally show highly variable trace element and isotopic compositions, often attributed to assimilation with, or derivation from, continental lithosphere (e.g., Carlson et al., 1981; Hawkesworth et al., 1992; Jourdan et al., 2007; Lightfoot et al., 1990; Luttinen and Furnes, 2000; Molzahn et al., 1996; Pik et al., 1999; Sano et al., 2001).

The role of sublithospheric mantle sources in CFB petrogenesis remains poorly constrained. On some occasions, Mg-rich melts derived from the convecting mantle have risen within thick continents so rapidly or through such cold or infertile material that they have preserved their primary geochemical signatures. Lavas and dikes crystallized from such melts have been recognized on the basis of anomalous compositional characteristics (e.g., high initial ε_{Nd}) that are not compatible with continental lithospheric sources. Instead, depleted MORB mantle (DMM), recycled oceanic lithosphere, and hotspot-related geochemical reservoirs such as

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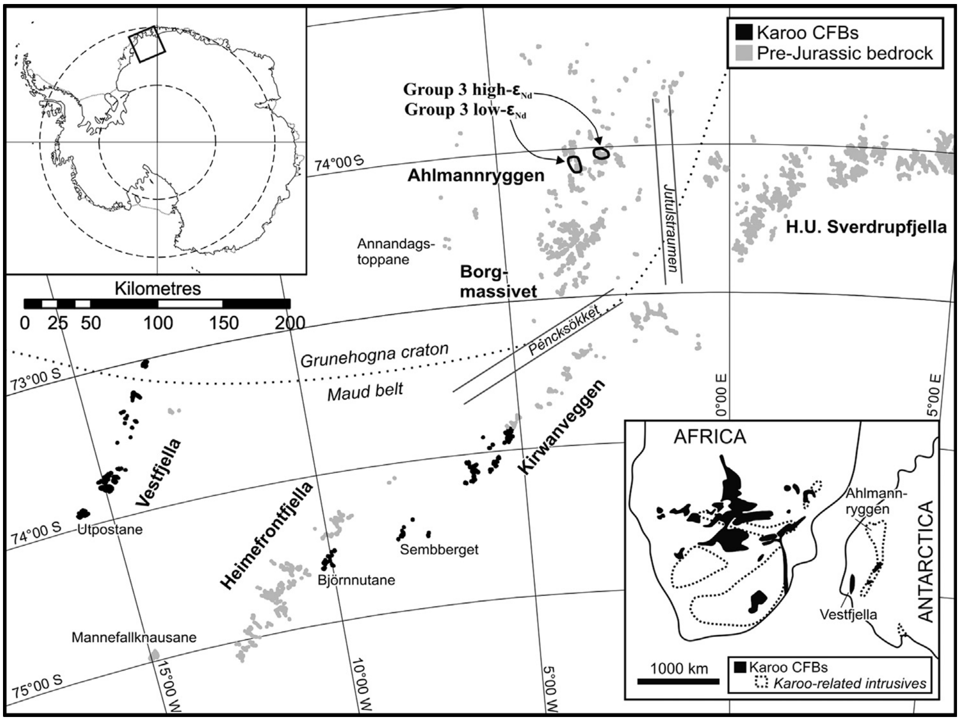

Fig. 1. Outcrop map of western Dronning Maud Land from Vestfjella to H.U. Sverdrupfjella. Distribution of Karoo flood basalts and Ahlmannryggen Group 3 dikes is shown. Lithospheric boundary between Grunehogna craton and Maud belt is after Corner (1994). Distribution of Karoo flood basalts and related intrusive rocks (outside the flood basalt areas) in reconstructed Gondwana supercontinent (cf. Heinonen et al., 2010) is shown in the inset.

non-chondritic primitive mantle have been suggested to be possible source components (e.g., Carlson et al., 2006; Day et al., 2013; Fram and Lesher, 1997; Heinonen et al., 2010; Jackson and Carlson, 2011; Lightfoot et al., 1993; Storey et al., 1997; Thompson and Gibson, 2000). Some studies have also suggested that recycled crustal components were involved in CFB genesis, but such analyses have often been based on a limited number of chemical or physical variables (e.g., Cordery et al., 1997; Day, 2013; Gibson, 2002; Horan et al., 1995; Kent et al., 2002; Leitch and Davies, 2001; Luttinen et al., 2010; Rocha-Júnior et al., 2012; Shirey, 1997; Sobolev et al., 2007).

The Jurassic Karoo large igneous province, located in southern Africa and Antarctica (Fig. 1), is a typical CFB province as it is characterized by basalts that are highly evolved and/or show strong geochemical affinity to the lithosphere (e.g., Ellam, 2006; Hawkesworth et al., 1984; Jourdan et al., 2007; Luttinen and Furnes, 2000; Luttinen et al., 1998; Riley et al., 2005; Sweeney et al., 1994). This has led some researchers to propose that the Karoo CFB parental melts were generated solely within the Gondwanan lithosphere (e.g., Ellam and Cox, 1989; Jourdan et al., 2007). On the other hand, the high initial $^{187}Os/^{188}Os$ of some Karoo picrites indicate involvement of plume-like enriched mantle sources (Ellam et al., 1992). In addition, some recent studies in Antarctica (Fig. 1) have revealed several Karoo magma types that show isotopic and trace element characteristics indicative of sublithospheric sources (Heinonen and Luttinen, 2008, 2010; Heinonen et al., 2010, 2013; Luttinen et al., 1998; Riley et al., 2005). High-Mg dikes from the Vestfjella mountain range (Fig. 1) can be divided into depleted and enriched ferropicrite suites that show Sr, Nd, Pb, and Os isotopic compositions similar to those of Southwest Indian Ridge mid-ocean ridge basalts (SWIR MORBs) and ocean island basalts (OIBs), respectively (Heinonen et al., 2010). In addition, the Ahlmannryggen mountain range (Fig. 1) hosts a previously recognized suite of mafic and ultramafic dikes (Group 3 of Riley et al., 2005) that crosscut Precambrian basement and are characterized by notably high ε_{Nd} (from +5 to +9 at 180 Ma) and MgO (8–22 wt%) indicating their crystallization from primitive melts derived from sublithospheric sources (Riley et al., 2005). They also show slightly elevated $^{87}Sr/^{86}Sr$ (0.7035–0.7062 at 180 Ma) and geochemical (low CaO and high Ti and Zn/Fe) and mineral chemical (high-Ni olivine) evidence for derivation from pyroxenite-bearing sources (Riley et al., 2005; Heinonen et al., 2013).

High-Mg rocks related to CFBs are rare but important carriers of petrogenetic information on the sources and origin of these massive volcanic phenomena. In this study, we present Pb and Os isotopic data on the Group 3 dikes of Ahlmannryggen and, in conjunction with previously published major element, trace element, mineral chemical, and Sr and Nd isotopic data, evaluate the role of lithospheric contamination on their parental magmas and attempt to decipher the composition and nature of their mantle sources. Finally, we evaluate the implications of our findings in relation to Karoo magmatism, and to CFB magmatism in general.

2. Geological and geochemical context

The Karoo CFBs erupted on the landmasses of Africa and Antarctica, both then part of the Gondwana supercontinent, at 184–178 Ma (Fig. 1; Jourdan et al., 2005). The magmas intruded through thick continental lithosphere that consists of a variety of Archean to Paleozoic rocks.

2.1. Pre-Jurassic geology of western Dronning Maud Land

In western Dronning Maud Land, the NW portion of the area is dominated by the Archean Grunehogna craton (Fig. 1; Krynauw et al., 1991; Wolmarans and Kent, 1982). The Archean basement is only exposed at Annandagstoppane (Fig. 1; Marschall et al., 2010) and elsewhere is covered by metamorphosed Mesoproterozoic supracrustal rock types belonging to the Ritscherflya Supergroup and/or by Borgmassivet mafic intrusions (Krynauw et al., 1988, 1991; Riley and Millar, 2014; Wolmarans and Kent, 1982). The southern and eastern parts of the Precambrian basement of