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Mixed pyroxenite–peridotite sources for mafic and ultramafic dikes from the Antarctic segment of the Karoo continental flood basalt province

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ABSTRACT

Primitive rocks that are related to continental flood basalts are rare, but often reveal crucial information on the ultimate sources of these huge outpourings of mantle-derived magma. Here we present mineral chemical data for mafic and ultramafic dikes from the Antarctic extension of the Jurassic (~180 Ma) Karoo continental flood basalt province that was emplaced during the initial stages of the breakup of the Gondwana supercontinent. We concentrate on two previously recognized high-Ti dike rock suites (Group 3 and Group 4) that exhibit high MgO contents (up to 22 wt.%). Both groups are characterized by Mg-rich olivine phenocrysts (up to Fo_{90}) that are not mantle xenocrysts and indicate derivation from relatively Mg-rich parental magmas. Orthopyroxene is a common phenocryst and groundmass phase indicating emplacement at mid-crustal pressures (2–5 kbar; depth of ~10–20 km). The parental magmas of Group 3 and Group 4 dikes can be associated with pyroxenite sources on the basis of high olivine NiO, high whole-rock Zn/Fe, and low whole-rock CaO. In the case of Group 3 dikes, however, the samples that contain the most Mg-rich olivine also exhibit the mildest pyroxenite fingerprint and indications of an additional olivine-bearing (peridotitic) source component. We propose that the pyroxenite fingerprint of Group 3 and Group 4 dikes reflects relatively low-degree melting of fertile mantle at high pressures beneath the thick and cold Gondwanan lithosphere. Such conditions limited high-degree melting of peridotite sources which may have been more predominant in the generation of the Karoo low-Ti basalts within lithospheric thinning zones.

1. Introduction

The origins of continental flood basalts (CFBs) have divided scientists for decades, since these manifestations of large-scale mantle melting do not easily fit into accepted plate tectonic theory. A broad range of models have been proposed to explain their petrogenesis and geological characteristics (see Bryan and Ernst, 2008; Macdougall, 1988; Saunders, 2005). Many of the discussions have focused on the relative contribution of the deep mantle, i.e. mantle plumes (e.g., Campbell, 2005; Campbell and Griffiths, 1990; Richards et al., 1989), and lithospheric processes (e.g., Anderson, 1994, 2005; Coltice et al., 2007; Elkins-Tanton, 2005) in their generation. The debate on the origin of CFBs is largely fueled by the absence of detailed information on the parental magmas and the mantle sources involved. This stems from the fact that CFBs are generally fairly evolved ($MgO < 8$ wt.%) and contaminated by lithosphere, which can hinder the identification of their parental magma compositions and ultimate mantle sources (e.g., Jourdan et al., 2007a; Sano et al., 2001; Tommasini et al., 2005; Wooden et al., 1993). Some recent studies have suggested that pyroxenitic or "refertilized" mantle components, generated by the recycling of crustal materials back into the mantle, can be an important source component in CFB parental magmas (Gibson, 2002; Sobolev et al., 2007; Tuff et al., 2005).

Some rare and primitive ($MgO > 10$ wt.%) CFB-related lava and dike rocks show geochemical affinity to sublithospheric mantle sources and are crucial in understanding the mantle sources of the largest CFB provinces (e.g., Gibson et al., 2000; Heinonen et al., 2010; Lightfoot et al., 1993; Peate et al., 2003; Riley et al., 2005; Storey et al., 1997). Mineral chemistry of these primitive rocks has widely been used to estimate the composition of their primary melts and the mineral composition and thermodynamical properties of their mantle sources (e.g., Heinonen and Luttinen, 2008; Larsen and Pedersen, 2000; Sobolev et al., 2007; Thompson and Gibson, 2000).

The Jurassic (~180 Ma) Karoo large igneous province (LIP) was formed during the initial stages of break-up of the Gondwana supercontinent (Fig. 1). It is a typical CFB province in that the majority of the rocks are basalts that are characterized by geochemical affinity

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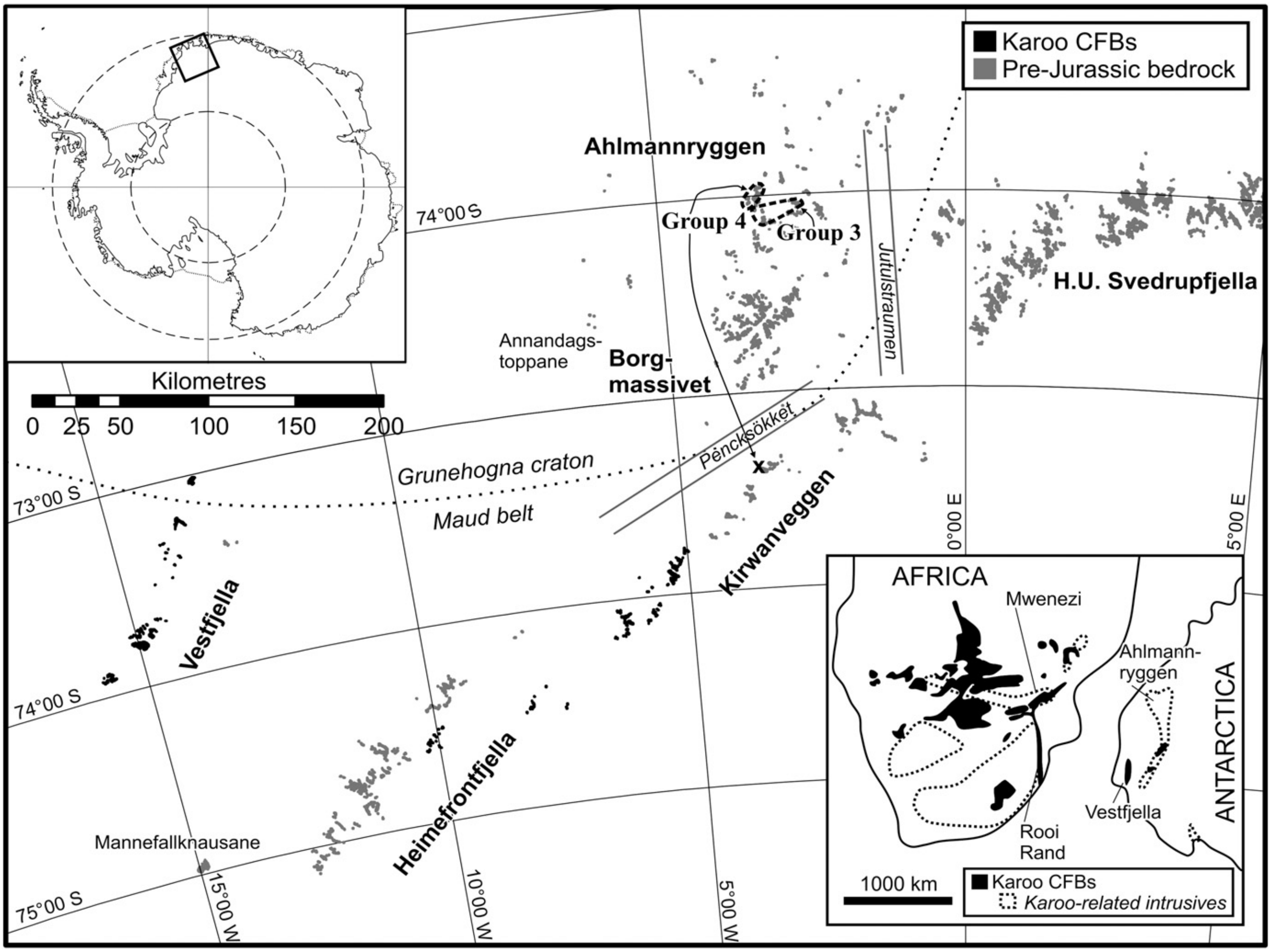

Fig. 1. Outcrop map of western Dronning Maud Land from Vestfjella to H. U. Svedrupfjella with distribution of Karoo flood basalts and Ahlmannryggen Group 3 and Group 4 dikes (one Group 4 dike is also known from Kirwanveggen). Lithospheric boundary between Grunehogna craton and Maud belt is after Corner (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.

to subcontinental lithospheric mantle (SCLM) and show evidence of variable degrees of contamination by the continental crust (e.g., Hawkesworth et al., 1984; Jourdan et al., 2007a; Luttinen et al., 1998; Sweeney et al., 1994). In the Antarctic segment of the Karoo LIP (Fig. 1), however, some primitive and nearly uncontaminated dike suites of sublithospheric geochemical character have been described (Heinonen and Luttinen, 2008; Heinonen et al., 2010; Luttinen and Furnes, 2000; Luttinen et al., 1998; Riley et al., 2005). At Ahlmannryggen, basaltic and picritic dikes crosscut the local Precambrian basement and have been sub-divided into four distinct geochemical groups (Groups 1–4; Riley et al., 2005). Two of the groups (3 and 4) include a subset of samples with MgO $>$ 12 wt.% (Harris et al., 1991; Riley et al., 2005). High-Fe (FeO_{tot} up to 14 wt.%) Group 3 dikes lack a notable lithospheric overprint and show a depleted mantle-like ε_{Nd} (from $+5$ to $+9$ at 180 Ma), whereas Group 4 shows more enriched incompatible-trace-element and isotopic signatures (e.g., ε_{Nd} = from -4.6 to $+2.4$ at 180 Ma) that may reflect the mixing of melts from both asthenospheric and lithospheric sources (Riley et al., 2005).

In order to estimate the primary melt compositions and the mantle sources of the Ahlmannryggen Group 3 and 4 dikes, we have performed a comprehensive mineral chemical analysis (~800 data points) on them. Most of the samples are relatively fresh and therefore suitable for such an approach. In addition, the variable mineral composition, including orthopyroxene as a phenocryst and groundmass phase, enables us to place constraints on the pressures of crystallization and depth of emplacement of the dikes.

2. Geological setting

2.1. Bedrock of western Dronning Maud Land

The bedrock of western Dronning Maud Land comprises igneous, sedimentary, and metamorphic rock types that range in age from Archean to Mesozoic (Wolmarans and Kent, 1982). The Jurassic Karoo CFBs are exposed at Vestfjella, Kirwanveggen, and Heimefrontfjella, and represent the uppermost stratigraphic unit (Fig. 1). Associated dikes that crosscut the local basement are more widespread and can also be found at Ahlmannryggen, Mannefallknausane, and H. U. Sverdrupfjella (Fig. 1). Below the CFBs, late Paleozoic sediments are known to sporadically overlie the Precambrian basement at Vestfjella, Heimefrontfjella, and southwest Kirwanveggen (e.g., Juckes, 1972; Wolmarans and Kent, 1982). The Precambrian basement of the area can be divided into the Archean Grunehogna craton and the Mesoproterozoic Maud Belt (Fig. 1) that, respectively, were juxtaposed with the temporally and spatially related Kalahari craton and Namaqua–Natal metamorphic belts of southern Africa prior to the Jurassic break-up of the Gondwana supercontinent (e.g., Jacobs et al., 1993, 2003, 2008). The Maud Belt is dominated by ortho- and paragneisses that are largely the result of high-grade metamorphism