Lithos 198–199 (2014) 153–171

Contents lists available at ScienceDirect

Lithos

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

Lead isotope signatures of Kerguelen plume-derived olivine-hosted melt inclusions: Constraints on the ocean island basalt petrogenesis

Anastassia Y. Borisova [a,b,*], François Faure [c], Etienne Deloule [c], Michel Grégoire [a], Frédéric Béjina [d], Philippe de Parseval [a], Jean-Luc Devidal [e]

[a] *Géosciences Environnement Toulouse, Université de Toulouse, UPS, OMP-, CNRS, IRD, 14 Avenue E. Belin, 31400 Toulouse, France*
[b] *Geological Department, Lomonosov Moscow State University, Vorobievu Gory, 119899 Moscow, Russia*
[c] *Centre de Recherches Pétrographiques et Géochimiques, UMR 7358 CNRS, Université de Lorraine, 15 rue Notre Dame des Pauvres, 54501 Vandoeuvre les Nancy, France*
[d] *CNRS, Institut de Recherche en Astrophysique et Planétologie, IRAP, Université de Toulouse, UPS, OMP, Toulouse, France*
[e] *Clermont Université, Université Blaise Pascal, Laboratoire Magmas et Volcans, CNRS UMR 6524, F-63038 Clermont-Ferrand, France*

ARTICLE INFO

Article history:
Received 8 February 2013
Accepted 21 March 2014
Available online 3 April 2014

Keywords:
Ocean island basalt
Kerguelen plume
Melt inclusions
Crustal assimilation
Melt mixing
DUPAL isotope anomaly

ABSTRACT

The nature of magmatic sources reflected by isotopic composition of the ocean island basalt (OIB) remains an ongoing question in igneous geochemistry. To constrain the magmatic sources for OIB related to the Kerguelen plume activity, we performed detailed microanalytical investigation of the 21.4 Ma picritic basalt (MD109-D6-87) dredged during the "Marion Dufresne" cruise on a seamount between Kerguelen Archipelago and Heard Island. Lead isotope compositions of olivine-hosted melt inclusions and matrix glasses were measured by Laser Ablation Multiple Collector Inductively Coupled Plasma Mass Spectrometry (LA-MC-ICP-MS) and Secondary Ion Mass Spectrometry (SIMS). We also performed major and trace element microanalyses and mapping of the inclusions and the host olivine phenocrysts by electron microprobe (wavelength-dispersive X-ray spectroscopy, WDS). The observed significant major element (K_2O/P_2O_5, Al_2O_3/TiO_2) and Pb isotope ($^{207}Pb/^{206}Pb$ and $^{208}Pb/^{206}Pb$) heterogeneities of parental melts (MgO = 7–10 wt.%) during early high pressure crystallisation stage (200–300 MPa, Fo_{82-86} mol%), and relative homogeneity at later lower-pressure crystallisation stage (<100 MPa, Fo_{75-80} mol%) are interpreted by mixing between "Plume" and "Assimilant" melts during magma residence and transport. Lead isotope composition of the parental basaltic melts was inherited from both heterogeneous mantle and the Kerguelen Plateau crust. High K_2O/P_2O_5 (>4), Al_2O_3/TiO_2 (>4) ratios are attributed to assimilation of the plateau basaltic crust (≥50 wt.%) by the melts in the magma chamber at palaeodepths from 6 to 9 km. The crustal assimilation may have happened through plagioclase dissolution. The large chemical and isotopic heterogeneity of the parental OIB melts found by *in situ* microanalyses in this study suggests that the bulk rock chemistry alone cannot provide enough information to constrain the nature of the magmatic sources.

1. Introduction

The origin of ocean island basalt (OIB) is believed to be due to partial melting of a deep plume mantle containing subducted material recycled through the mantle (*e.g.*, Hoffman and White, 1982; Sobolev et al., 2011). Trace element and isotopic compositions of the OIB are interpreted in terms of chemical and isotopic equilibrium with their deep mantle source. The assumption that isotopic compositions of OIBs reflect those of their mantle source has allowed Zindler and Hart (1986) to develop Chemical Geodynamics. However, it is likely that in the presence of a chemically anomalous lithosphere (where the magma transport and differentiation happens), the isotopic signatures of deep mantle-derived melts may be strongly affected (*e.g.*, Borisova et al., 2001, 2002; Edwards and Russell, 1998; Kamenetsky et al., 2001). The anomalous Pb isotope composition (high $^{207}Pb/^{204}Pb$ and $^{208}Pb/^{204}Pb$) of OIB located in the Southern hemisphere (so-called DUPAL anomaly, Dupré and Allegre, 1983; Hart, 1984) is attributed either to the anomalous upper mantle contaminated by Precambrian material during Gondwana break-up (*e.g.*, Frey et al., 2002a) or to shallow-level assimilation of fragmented "micro-continent" from Gondwana (*e.g.*, Borisova et al., 1996, 1997, 2001). Moreover, several bulk rock and grain-scale studies have demonstrated significant isotope (Sr–Nd–Pb–He–O) variations (*e.g.*, depletion in $\delta^{18}O$ and increase in $^{207}Pb/^{204}Pb$, $^{208}Pb/^{204}Pb$) resulting from oceanic and fragmental subcontinental lithosphere (in particular, mafic crust) assimilation by OIB magmas (Bindeman et al., 2006, 2008; Hilton et al., 1995; Kamenetsky et al., 2001).

* Corresponding author at: Géosciences Environnement Toulouse, UMR 5563, Observatoire Midi Pyrénées, 14 Avenue E. Belin, 31400 Toulouse, France. Tel.: +33 5 61 54 26 31; fax: +33 5 61 33 25 60.
E-mail addresses: anastassia.borisova@get.obs-mip.fr (A.Y. Borisova), ffaure@crpg.cnrs-nancy.fr (F. Faure), deloule@crpg.cnrs-nancy.fr (E. Deloule), michel.gregoire@get.obs-mip.fr (M. Grégoire), fbejina@irap.omp.eu (F. Béjina), J.L.Devidal@opgc.univ-bpclermont.fr (J.-L. Devidal).

http://dx.doi.org/10.1016/j.lithos.2014.03.022
0024-4937/

To constrain the isotopic composition of the parental basaltic melts, *in situ* isotopic microanalyses of basaltic melt inclusions have been recently performed. Pioneering works by Saal et al. (1998, 2005) suggested that huge Pb isotope heterogeneity of OIB melts entrapped by olivine phenocrysts may record reactions between deep plume mantle-derived melts and lithospheric rocks during the basaltic magma percolation through the oceanic lithosphere. However, the reaction mechanisms were not constrained. Jackson and Hart (2006), MacLennan (2008), Paul et al. (2011), and Sobolev et al. (2011) infer that Sr–Pb isotope heterogeneities in OIB melt inclusions are more likely related to mixing of different mantle source-derived melts and possibly due to local reaction of the melt with the mush column.

Experimental and theoretical studies demonstrate that crustal assimilation by basaltic magma through mineral, in particular plagioclase, dissolution and wall-rock partial melting is fast and efficient (Edwards and Russell, 1998; Kvassnes and Grove, 2008; Tsuchiyama, 1986). Crustal assimilation and magma mixing happen over short timescales (*e.g.*, Bindeman et al., 2008; Turner and Costa, 2007 and references therein) and therefore may affect the isotopic composition of OIB during its transport and residence in the lithosphere. Several investigations (Borisova et al., 1996, 2001, 2002) demonstrated that Pb isotopes are sensitive to lithosphere assimilation. *In situ* measurements of major elements and Pb isotopes in olivine-hosted melt inclusions are an efficient approach to constrain the origin of the parental melts. However, such combined approach has never been applied to OIBs related to the Kerguelen plume activity.

The on-going Kerguelen plume activity represents a continuous process beginning with the break-up of Gondwana (~120 Ma), to the formation of the Cretaceous Kerguelen Plateau (118–85 Ma) and construction of the Ninetyeast Ridge (83–38 Ma) (*e.g.*, Frey et al., 2002a), to the recent magmatism of the Kerguelen Archipelago and Heard Island (39–0.1 Ma, *e.g.*, Barling and Goldstein, 1990; Barling et al., 1994; Scoates et al., 2008; Weis et al., 2002). The 29–24 Ma flood basalts and gabbros of the Kerguelen Archipelago are believed to be derived from the Kerguelen plume mantle (*e.g.*, Frey et al., 2002b; Scoates et al., 2008; Weis et al., 2002). Sr–Nd–Pb isotope composition of the Kerguelen Plume is suggested to be represented by the composition of the 25–22 Ma Kerguelen Archipelago alkaline basalts (Weis and Frey, 2002). However, the youngest and most alkaline magmatism of the Kerguelen might be strongly affected by the diminishing flux of plume mantle-derived melts and increasing influence of the Kerguelen Plateau lithosphere (Frey et al., 2002b; Nicolaysen et al., 2000). For example, Kerguelen mafic volcanic products, such as the 21–19 Ma picritic basalts discovered during the "Marion Dufresne" MD 109 cruise (Dredge 6, Fig. 1), have Pb isotope signatures distinct from 25 to 22 Ma Kerguelen plume mantle-derived basalts (Frey et al., 2002b; Weis et al., 2002), a feature that was attributed to the Cretaceous Kerguelen Plateau lithosphere assimilation (Table 1, Borisova et al., 2002). This model of lithosphere assimilation is based on the *in situ* major and trace element analyses of olivine phenocryst-hosted melt inclusions in one sample of the 21.4 Ma picritic pillow basalt (MD109-D6-87) related to the Kerguelen plume activity. In this work we applied precise Pb isotope analysis of the olivine-hosted melt inclusions and glassy matrix by two microanalytical techniques: Laser Ablation Multiple Collector Inductively Coupled Plasma Mass Spectrometry (LA-MC-ICP-MS) and Secondary Ion Mass Spectrometry (SIMS). We also performed new *in situ* wavelength-dispersive X-ray spectroscopy (WDS) microanalysis and mapping of major and trace elements in the host olivine phenocrysts and the olivine-hosted melt inclusions. These new *in situ* microanalytical data provide further constraints on the nature of magmatic sources and mechanisms of the OIB formation situated in DUPAL isotope anomaly zone.

2. Materials, experimental and microanalytical techniques

2.1. Dredged host and associated basaltic samples

In this work we investigate picritic pillow basalt sample MD109-D6-87 (D6) from MD109-D6 series (D6 refers to the 21.4 Ma dredged basalt sample MD109-D6-87 and D6 host basalts refer to the 21–19 Ma MD-109-D6 basaltic series: 51°01′S–07°′04′E, here and elsewhere in the text) collected during the "Kerimis" survey cruise of "Marion Dufresne"

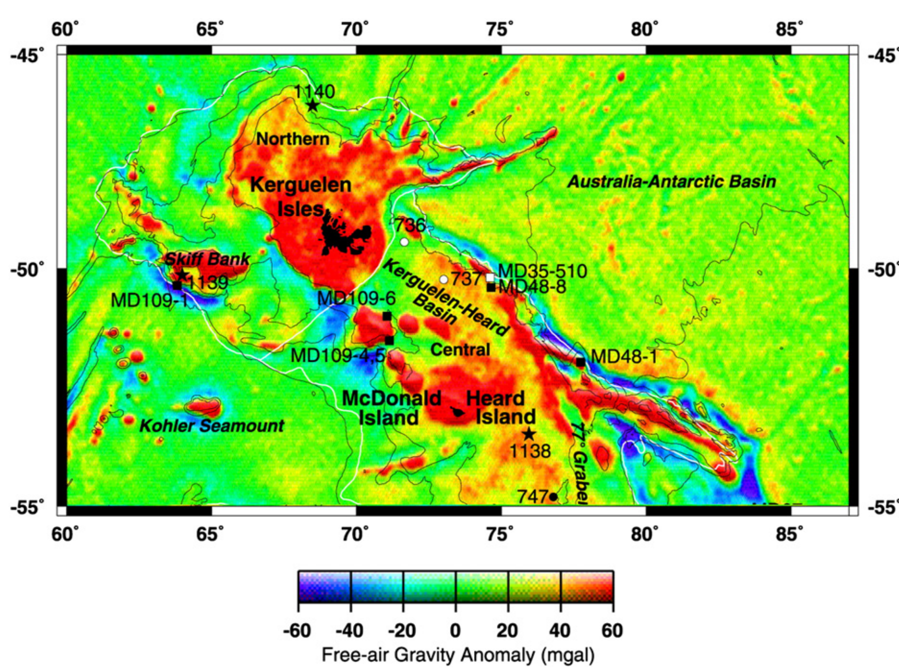

Fig. 1. Map of the southeastern Indian Ocean showing major physiographic features related to the activity of the Kerguelen plume, as well as the drill sites of ODP Legs 119, 120 (circles) and 183 (black stars) and the "Marion Dufresne" dredge sites (MD109-4, -5, -6, black squares) sampled basaltic material (from dredges 4, 5, 6 corresponding to MD-109-D4 (=D4), MD-109-D5 (=D5), MD-109-D6 (=D6), basaltic series, respectively) during the "Kerimis" research cruise on the northern and central Kerguelen Plateau. The MD109-D5 (20–19 Ma) and MD-109-D6 (21–19 Ma) basalts were dredged from the same seamount. Note that the dredged MD-109-D4-33 basalt sample is the only one as young as 1.6 Ma (Weis et al., 2002). The map is adopted from Weis et al. (2002).