Lithos 224–225 (2015) 1–12

Contents lists available at ScienceDirect

Lithos

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

Resolving mantle and magmatic processes in basalts from the Cameroon volcanic line using the Re–Os isotope system

A. Gannoun [a,b,*], K.W. Burton [c], D.N. Barfod [d], P. Schiano [a], I. Vlastélic [a], A.N. Halliday [e]

[a] Laboratoire Magmas et Volcans, Université Blaise Pascal, CNRS-IRD, BP 10448, 63000 Clermont Ferrand, France
[b] Department of Earth Sciences, The Open University, Walton Hall, Milton Keynes MK7 6AA, United Kingdom
[c] Department of Earth Sciences, Durham University, Science Labs, Durham DH1 3LE, United Kingdom
[d] Argon Isotope Facility, NERC/SUERC, East Kilbride G75 1QF, United Kingdom
[e] Department of Earth Sciences, University of Oxford, South Parks Road, Oxford OX1 3AN, United Kingdom

ARTICLE INFO

Article history:
Received 9 September 2014
Accepted 15 February 2015
Available online 21 February 2015

Keywords:
Re–Os isotopes
Pb isotopes
Cameroon volcanic line
MORB
HIMU

ABSTRACT

This study presents major-, trace element and Re–Os isotope and elemental data for young alkaline basalts (<10 Ma) from oceanic (Annobon, S. Tomé, Principe), continental (Manengouba) and continent–oceanic boundary (COB, Mt. Cameroon) sectors of the Cameroon volcanic line (CVL). The CVL is a chain of Tertiary to recent, transitional to strongly alkaline intraplate volcanoes extending from the south Atlantic island of Annobon to the continental interior of West Africa (Biu Plateau).

The basalts from the oceanic sector display a range of initial $^{187}Os/^{188}Os$ ratios between 0.128 and 0.190 and those from the COB and continental sector range between 0.142 and 0.560. The samples with high $^{206}Pb/^{204}Pb$ (e.g. ratios >20) possess $^{187}Os/^{188}Os$ isotope compositions between 0.14 and 0.18 (e.g., basalts from Mt Cameroon and Sao Tomé) which reflect the chemical characteristics that are more likely to be primary features of CVL, and are close to the value of 0.153 attributed to the HIMU end-member (Tubuai–Mangaia). However, most of the lavas from the continental sector show highly radiogenic initial $^{187}Os/^{188}Os$ ratios (0.36 to 0.56) that are outside the range previously observed for ocean island basalts, with shifts to radiogenic Os isotope compositions accompanied by less radiogenic $^{206}Pb/^{204}Pb$ and increasing SiO_2 contents. The increase in $^{187}Os/^{188}Os$ is also associated with the decrease of Os, Ni, MgO and phenocryst abundances. These data can be explained by fractional crystallisation and assimilation of continental crust by the ascending magma.

The systematic shift to unradiogenic lead isotope compositions from the COB into the oceanic sector is positively correlated with variations in $^{187}Os/^{188}Os$ isotope composition (from 0.140 to 0.128). At first sight this covariation might be attributed to the mixing of HIMU material with the ambient upper mantle (DMM). However, there is a clear covariation of the Os isotope and elemental composition, best explained with contamination of the oceanic basalts by the physical entrainment of xenoliths and xenocrysts of mantle origin. Overall, these results indicate that Os in CVL basalts is highly susceptible to contamination from both oceanic and continental lithospheres, under these circumstances covariations with other isotopes and elements must be interpreted with caution.

1. Introduction

A fundamental objective of mantle geochemistry is to understand the scale and nature of the chemical heterogeneity of the mantle that is sampled by basaltic volcanism. Isotopic variations in oceanic basalts are generally ascribed to mixing and/or ageing relationships between different, variably 'depleted' and 'enriched', components in the Earth's mantle (Hart, 1988; Hofmann, 1997; White, 1985; Zindler and Hart, 1986). Of these, DMM ('depleted' mid-ocean ridge basalt (MORB) mantle) is generally considered to represent the Earth's upper mantle depleted in incompatible elements during the formation of the continental crust. Whereas, the various enriched components (HIMU, high $^{238}U/^{204}Pb$ mantle; EM1, 'enriched' mantle 1; and EM2, 'enriched' mantle 2) are thought to reflect recycling processes or intra-mantle differentiation. For example, the chemical characteristics of the HIMU source (radiogenic Pb and unradiogenic Sr) are generally attributed to ancient basaltic oceanic crust stored in the mantle for considerable periods of time (i.e. 1 Gyr or more; Chase, 1981; Chauvel et al., 1992; Hofmann and White, 1982).

The Re–Os isotope system is sensitive to the processes of mantle melting, and the generation and recycling of oceanic crust. This is because Os behaves as a strongly compatible element during melting and is preferentially retained in the mantle, whereas Re is moderately

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* Corresponding author at: Laboratoire Magmas et Volcans, Université Blaise Pascal, CNRS-IRD, BP 10448, 63000 Clermont Ferrand, France. Tel.: +33 4 73346706; fax: +44 4 73346739.
E-mail address: M.Gannoun@opgc.univ-bpclermont.fr (A. Gannoun).

http://dx.doi.org/10.1016/j.lithos.2015.02.017
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incompatible and enters the melt (e.g. Allègre and Luck, 1980; Hauri and Hart, 1993; Shirey and Walker, 1998). Consequently, oceanic (and continental) crust acquires very high Re/Os ratios, and develops radiogenic Os isotope compositions over relatively short periods of time (Dale et al., 2007; Gannoun et al., 2004, 2007; Hauri and Hart, 1993; Shirey and Walker, 1998). Pioneering studies of the Re–Os systematics in ocean island basalts (OIB) provided strong support for the role of oceanic crust in the HIMU mantle, and have demonstrated the utility of this system as a tracer of mantle sources (Class et al., 2009; Hauri and Hart, 1993; Marcantonio et al., 1995; Reisberg et al., 1993; Schiano et al., 2001; Skovgaard et al., 2001).

However, the Re–Os isotope system is also highly susceptible to a number of magmatic processes that may act to obscure the primary mantle signal. For example, it has been shown that some magmatic phases (e.g. olivine, clinopyroxene, …) possess extremely high Re/Os (parent/daughter) ratios (Burton et al., 2002; Gannoun et al., 2004). Consequently, within sample Os isotope heterogeneity in the constituant phases can develop in very short periods of time (several 100 kyr or less). This may well explain why aphyric basalts (i.e. those without phenocryst) tend to yield reproducible Os isotope data and display good correlations between Os and Sr–Nd–Pb, whereas phyric basalts (i.e. those with phenocrysts) are generally less well correlated with other isotope systems (e.g. Schiano et al., 2001). Assimilation of oceanic or continental crust, with a radiogenic Os isotope composition, with concomitant fractional crystallisation (producing magmas with decreasing Os concentrations) seems likely to also have an effect on magma compositions. Such process has been documented in several studies (e.g. Alves et al., 2002; Gleißner et al., 2012; Hart et al., 1997; Lassiter and Luhr, 2001). Finally, recent studies have shown that mantle minerals, not only sulphide but also silicates, generally possess Os concentrations some ~10^2 greater than magmatic phases (e.g. Burton et al., 1999, 2000; Gannoun et al., 2004) although some doubts remain if Os in silicate was indeed located in the lattice. Many OIB contain xenoliths and xenocrysts of mantle origin, and their assimilation, or physical entrainment within samples, could have a significant affect on the Os isotope chemistry of the basalt host.

The Cameroon Line is an alkaline volcanic province that straddles both oceanic and continental lithospheres. Combined Pb, Sr, Nd and Hf isotope studies have shown that in the vicinity of the continent–ocean boundary the lavas have many isotopic characteristics typical of a HIMU source, although the Pb is not as radiogenic as the classic oceanic HIMU localities. This study presents new Os isotope data for a suite of basalts and xenoliths from the Cameroon Line, for which major and trace elements and Pb and Nd isotope data have already been obtained. These results show that Cameroon volcanic line lavas possess Os isotope compositions with the typical HIMU signature. However, lavas from the continental sector show clear evidence of assimilation of material with radiogenic Os during fractional crystallisation, whereas, samples from the oceanic sector show Os isotope and elemental trends that strongly suggest that contamination by lithospheric mantle material has occurred.

2. Geological background and sample selection

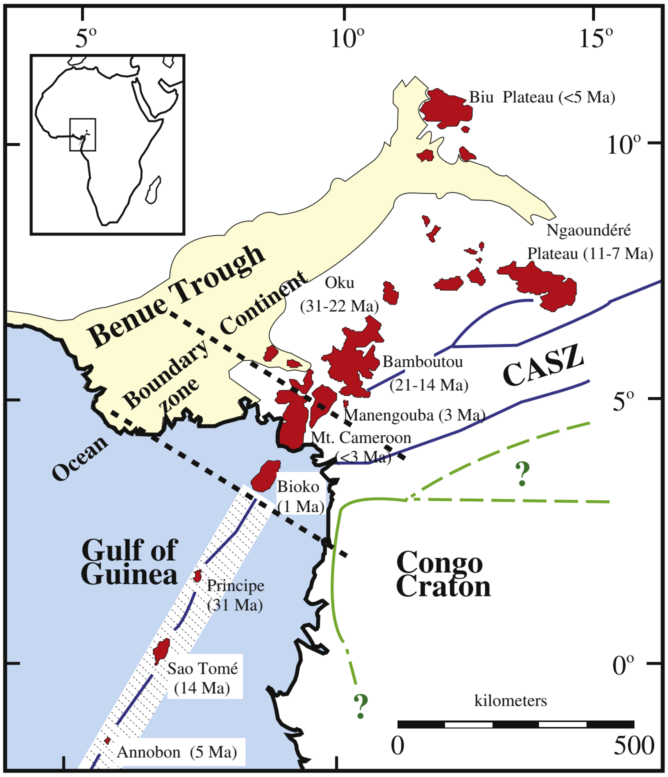

Fig. 1. Map of the main geological features of the area of the Cameroon Line and the Gulf of Guinea showing the distribution of the main Cenozoic volcanic centres (in red), the definition of the continent/ocean boundary region and the eruption ages of the major volcanic centres (adapted from Fitton and Dunlop, 1985). Ages are compiled from Fitton and Dunlop (1985), Halliday et al. (1990), and Lee et al. (1994). The thick blue lines trending east-northeast mark the Central African Shear Zone (CASZ). The stippled white box offshore is the inferred location of the Cameroon Fracture Zone (Sibuet and Mascle, 1978). The location of the Congo Craton is shown by the green line, however the exact location for the boundary to the northeast and west is not well known and possible locations of the boundary are shown with dashed green lines (after Schlüter, 2006; Reusch et al., 2010). The basement between the Congo Craton and the Benue Trough is comprised of the Oubanguides mobile belt.

The CVL is an alkaline volcanic province extending some 1600 km from the African continental interior into the Gulf of Guinea (Fig. 1). The petrology, geochemistry and geochronology of the Cameroon Line basalts have been extensively documented elsewhere (Aka et al., 2004; Fitton, 1987; Fitton and Dunlop, 1985; Halliday et al., 1988; 1990; Lee et al., 1994; Rankenburg et al., 2005; Yokoyama et al., 2007), and as such only the salient features are discussed here. Magmatic activity in the Cameroon Line extends over at least the past 65 Myr to the present but shows no systematic migration with time as might be expected for plume track migration (typified by the Hawaiian hot spot). Most of the volcanic centres along the entire length of the chain have recently been active. There are at least 17 plutonic complexes in the continental sector, ranging in age from 65 Ma to 30 Ma. Geochemical data indicate that these complexes are primarily of mantle origin but are contaminated by crustal components (Jacquemin et al., 1982; Parsons et al., 1986; Rankenburg et al., 2005). In addition there are 12 major volcanic centres extending into the oceanic sector ranging in age from 35 Ma to the present. The CVL can be divided into three zones: the oceanic sector (Annobon, Principe and São Tomé), the continent/ocean boundary (COB: Bioko and Mt. Cameroon) and the continental sector (Manengouba, Bamboutou, Oku, Ngaoundéré Plateau and Biu Plateau). The only currently active volcano is Mt. Cameroon (COB) which erupted last in 2000 (Suh et al., 2003). The volcanic centres in the CVL erupt mostly alkaline basalts, along with minor tholeiitic basalts and evolved rocks (phonolites and trachytes; Fitton and Dunlop, 1985).

Major and trace element patterns of the mafic rocks (≥4.0 wt.% MgO) are similar in both continental and oceanic sectors, suggesting that the lavas have not been significantly modified during ascent through the lithosphere. When compared with other representative mantle end-members the CVL basalts are close to those of a HIMU-type (Fig. 2), characterised by their enrichment in incompatible trace elements. As HIMU basalts, the CVL lavas share the same negative anomalies of K, and Pb which are complementary to the corresponding positive anomalies in average continental crust. Similarly, they show a decrease in the normalised abundances of the most incompatible elements (Rb, Ba), which indicates a depleted 'heritage' for HIMU OIB