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Geochimica et Cosmochimica Acta 189 (2016) 236–250

Geochimica et Cosmochimica Acta

www.elsevier.com/locate/gca

High-precision lead isotopes and stripy plumes: Revisiting the Society chain in French Polynesia

Carole Cordier [a,*], Catherine Chauvel [a], Christophe Hémond [b]

[a] Univ. Grenoble Alpes, CNRS, ISTerre, F-38000 Grenoble, France

[b] UMR CNRS 6538 Domaines Océaniques, Université de Brest, UBO, Institut Universitaire Européen de la Mer, Place Copernic, 29280 Plouzané, France

Received 7 July 2015; accepted in revised form 4 June 2016; available online 16 June 2016

Abstract

An increasing number of geochemical studies looked for spatial organization of the isotopic variations along Pacific volcanic island chains (e.g., Hawaii, Marquesas, Samoa and Society Islands) in order to discuss the possible zoning of the plume conduits. Here, we reexamine the occurrence of isotopic stripes in the Society archipelago in French Polynesia, using new Sr–Nd–Hf–Pb isotope ratios of sixty-six lavas from six islands (Mehetia, Moorea, Maupiti, Huahine, Raiatea, Bora-Bora). We demonstrate that the Pb isotope variability observed using literature data is an analytical artifact related to the poor control of mass fractionation during Pb measurements by conventional TIMS technique. New MC-ICP-MS Pb data demonstrate that the isotopic stripes as previously defined disappear. They rather show that individual islands cover a significant part of the entire isotopic range of the chain. We suggest, therefore, that the dominant characteristic of the Society plume is small-scale heterogeneities, evenly distributed within the plume conduit. At a global scale, we show that some ocean island chains with similar geochemical and isotopic characteristics, such as Samoa and Society Islands, define different arrays when variations of Nd with high-precision Pb isotopes are considered. We proposed that this puzzling observation might record differences in recycling age of the basalt + sediment mixture subducted into the mantle and sampled by mantle plume.

Keywords: Mantle plume; Society Islands; Isotopic stripes; Mass fractionation correction

1. INTRODUCTION

Isotopic compositions of ocean island basalts (OIB) record the intrinsic heterogeneity of mantle plumes that contain oceanic and continental materials recycled deeply into the mantle. In some cases, isotopic compositions present a spatial organization with parallel and synchronous isotopic stripes, as suggested for Hawaii, Marquesas, Samoa, Society and Galápagos Islands in the Pacific or in Tristan-Gough Islands in the Atlantic Ocean (Abouchami et al., 2000; Hoernle et al., 2000; Workman et al., 2004; Abouchami et al., 2005; Huang et al., 2011; Weis et al., 2011; Chauvel et al., 2012; Payne et al., 2013; Rohde et al., 2013; Harpp et al., 2014).

These inferred bilateral trends imply that (at least) two mantle sources coexist and are spatially structured within the plume conduit (Farnetani and Hofmann, 2009; Farnetani et al., 2012). Several recent studies suggested that they could reflect the position of the deep-seated plume roots with respect to the boundary of the "Large Low Shear Velocity Province" (LLSVP), at the base of the mantle (Weis et al., 2011; Huang et al., 2011; Payne et al., 2013). According to such a model, Payne et al. (2013) suggested that isotopic stripes in Pacific hotspots delineate the

* Corresponding author at: Univ. Grenoble Alpes, ISTerre, F-38000 Grenoble, France.
E-mail address: carole.cordier@univ-grenoble-alpes.fr (C. Cordier).

http://dx.doi.org/10.1016/j.gca.2016.06.010
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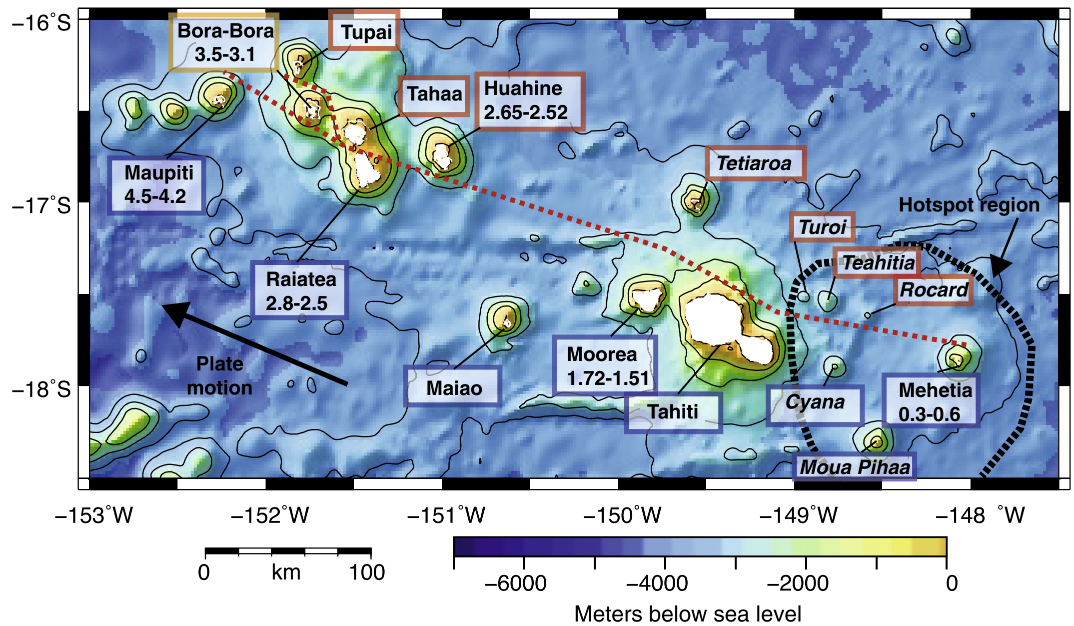

Fig. 1. Bathymetric map of the Society Islands built from the ETOPO1 Global Relief Model (Amante and Eakins, 2009; access date June 2014). The emerged islands and reefs are displayed in white and seamounts are labeled in italics. Timing of subaerial magmatism (Myr) is indicated for the studied islands and comes from Blais et al. (2002). The active hotspot region is delineated by the black dashed line. The Roca and Moua trends as defined by Payne et al. (2013) are shown by the colored boxes. Bora-Bora that was not assigned to a specific trend by Payne et al. (2013) is shown as an orange box. Direction of the Pacific plate is from Gripp and Gordon (2002). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

LLSVP, with the Hawaii and Marquesas chains located on the northern boundary and the Society Islands located on the southern boundary and showing mirrored isotopic stripes compared to the Marquesas Islands. Alternatively, the isotopic stripes could have a different origin and be related to small-scale structures in the rising plume (e.g. Chauvel et al., 2012). Such a geometry is also consistent with the physical model developed by Farnetani et al. (2012) but it locates the heterogeneities within the upper mantle plume source without extrapolating upper mantle compositions toward the lower mantle.

In this study, we reassess the bilateral zoning proposed for the Society Islands (Fig. 1). The Society chain is one of the French Polynesia chains together with the Marquesas, Tuamotu, Pitcairn-Gambier and Austral-Cook alignments. The archipelago includes 9 islands, 5 atolls and several seamounts (Fig. 1), built over the last 5 Myr. The plume is presently located over a broad region at the south-eastern end of the chain, around the island of Mehetia and 5 seamounts, Turoi, Teahitia, Cyana, Rocard and Moua Pihaa (Fig. 1). We use a new dataset of Sr, Nd, Hf and Pb isotopic compositions obtained on 6 out of the 9 islands of the Society chain. We demonstrate that the range of new MC-ICP-MS Pb isotopic compositions is significantly reduced compared to conventional TIMS data, due to better correction of the mass fractionation during measurement. The better precision and accuracy of these Pb isotope analyses warrant a re-examination of the spatial organization of the heterogeneities in the Society plume advocated by Payne et al. (2013) on the basis of literature data of lower precision. We also examine literature data on other global ocean island basalts, filtered to remove data with potential poor mass fractionation correction. On a worldwide scale, hotspot lavas define well-constrained trends in Nd–Pb isotope spaces that can be interpreted in terms of changing nature and age of the chemical heterogeneities carried by mantle plumes.

2. SAMPLES AND ANALYTICAL TECHNIQUES

2.1. Samples

Samples come from six islands of the Society chain: Mehetia ($n = 9$), Moorea ($n = 15$), Huahine ($n = 11$), Raiatea ($n = 17$), Bora-Bora ($n = 8$) and Maupiti ($n = 8$). The selected samples span the entire duration of magmatic activity of the Society plume (~5 Myr to present, Fig. 1) and they were recovered from subaerial formations in the nineties in the framework of systematic geological mapping of the French Polynesian Islands by the Bureau de Recherches Géologiques et Minières (BRGM, France) and during the course of two PhD projects (Binard, 1991; Le Dez, 1996).

Out of the 68 samples, 56 are shield stage basalts, with SiO_2 ranging from 42 to 50 wt.% (references for major and trace element data are given in Supplementary Table S1A). Our sample set also includes one Huahine pre-shield picrite (MgO = 15 wt.%) and 11 post-shield basaltic to trachytic lavas from Huahine, Maupiti, Raiatea and Moorea.