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Origin of enriched components in the South Atlantic: Evidence from 40 Ma geochemical zonation of the Discovery Seamounts

Antje Schwindrofska [a,*], Kaj Hoernle [a,b], Folkmar Hauff [a], Paul van den Bogaard [a], Reinhard Werner [a], Dieter Garbe-Schönberg [b]

[a] GEOMAR Helmholtz Centre for Ocean Research Kiel, Wischhofstraße 1-3, 24148 Kiel, Germany
[b] Christian-Albrechts-University of Kiel, Institute of Geosciences, Ludewig-Meyn-Strasse 10, Kiel, Germany

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ABSTRACT

Spatial geochemical zonation is being increasingly recognized in Pacific and Atlantic hotspot tracks and is believed to reflect zonation within plumes upwelling from the margins of the Large Low Shear Velocity Provinces (LLSVPs) at the base of Earth's mantle. We present new $^{40}Ar/^{39}Ar$ age data for the Discovery Rise (South Atlantic Ocean) that show an age progression in the direction of plate motion from 23 Ma in the southwest to 40 Ma in the northeast of the Rise, consistent with formation of the Rise above a mantle plume. The lavas have incompatible element and Sr–Nd–Pb–Hf radiogenic isotope characteristics similar to the enriched DUPAL anomaly occurring in the southern hemisphere. The northern chain of seamounts is compositionally similar to the adjacent Gough subtrack of the bilaterally-zoned Tristan–Gough hotspot track, whereas the southern chain has some of the most extreme DUPAL compositions found in South Atlantic intraplate lavas thus far. The nearby southern Mid-Atlantic Ridge, believed to interact with the Discovery hotspot, shows a similar spatial geochemical distribution, consistent with the Discovery hotspot being zoned over its entire 40 Ma history. Our study implies a deep origin for the DUPAL anomaly, suggesting recycling of subcontinental lithospheric mantle (± lower crust) and oceanic crust through the lower mantle. The presence of an additional (Southern Discovery) DUPAL-like component, in addition to the Tristan and Gough/Northern Discovery components, in long-term zoned South Atlantic hotspots, points to the presence of a third lower mantle reservoir and thus is not consistent with the simple model that bilaterally-zoned plumes sample a chemically distinct LLSVP and the ambient mantle outside of the LLSVP.

1. Introduction

Although numerous investigations of oceanic basalts showing DUPAL-like geochemical compositions have been carried out thus far, the ultimate origin of this signature is still uncertain. The so-called DUPAL anomaly, named after Dupré and Allègre (1983), is a large geochemical domain in the Southern Hemisphere between the Equator and 60°S characterized by enriched compositions found in South Atlantic and Indian Ocean mid-ocean-ridge basalts (MORB) and intraplate or ocean island basalts (OIB) (Hart, 1984). Enriched mantle components have elevated $^{87}Sr/^{86}Sr$, $^{207}Pb/^{204}Pb$ and $^{208}Pb/^{204}Pb$ isotope ratios for a given $^{206}Pb/^{204}Pb$ ratio, and low $^{143}Nd/^{144}Nd$ and $^{176}Hf/^{177}Hf$ ratios, e.g. as defined by Zindler and Hart (1986). The enriched mantle one (EMI) endmember is characterized by very unradiogenic $^{206}Pb/^{204}Pb$, Nd and Hf and intermediate Sr isotopic compositions. The enriched mantle two (EMII) endmember has very radiogenic Sr and Pb but intermediate Nd, Hf and $^{206}Pb/^{204}Pb$ isotope ratios. The low-μ (LOMU) component has high Sr and low Nd and Hf isotope ratios, similar to the EMI and EMII components, but the unradiogenic $^{206}Pb/^{204}Pb$ indicates closer affinities to EMI (e.g. Douglass et al., 1999). Both shallow (e.g. Douglass et al., 1999; Geldmacher et al., 2008; Hanan et al., 2004; Hoernle et al., 2011) and deep mantle origins (e.g. Castillo, 1988; Class and le Roex, 2011; Mahoney et al., 1992; Rohde et al., 2013a) of the DUPAL domain have been proposed. Most recently it has been suggested that the enriched "Gough"-type material in the Tristan–Gough hotspot track is derived from the African Large Low Shear Velocity Province (LLSVP) (Hoernle et al., 2015; Rohde et al., 2013a), a broad region at the base of the lower mantle characterized by low shear-wave velocities.

Geochemically-zoned plumes have been reported for several hotspots in the Pacific Ocean, e.g. the Galápagos, Hawaiian and Marquesas (e.g. Abouchami et al., 2005; Hoernle et al., 2000;

* Corresponding author. Tel.: +49 431 600 2141; fax: +49 431 600 2924.
E-mail address: aschwindrofska@geomar.de (A. Schwindrofska).

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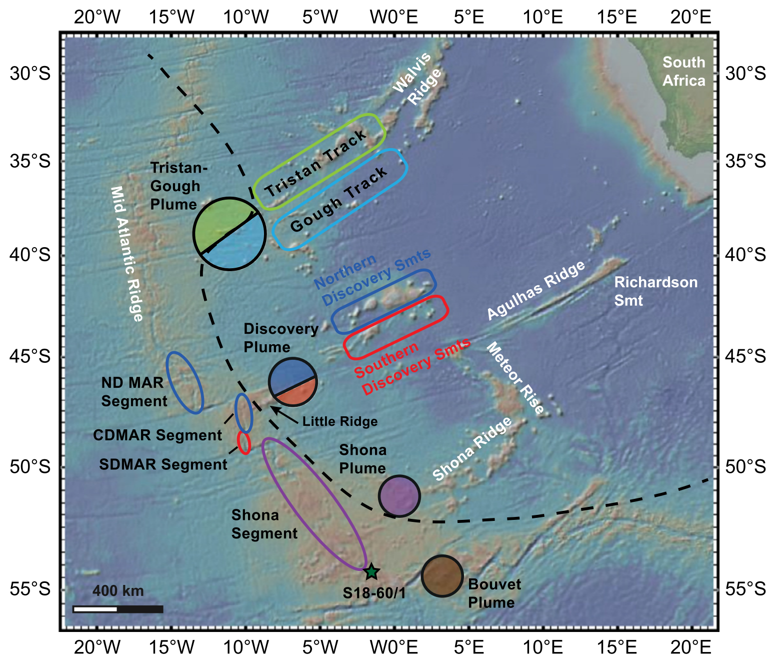

Fig. 1. Bathymetric map of the South Atlantic Ocean showing the main volcanic structures. Colored boxes highlight the different geochemical domains and ellipses the segments of the Mid-Atlantic Ridge exhibiting plume-ridge interaction corresponding to the Northern (Northern Discovery, NDMAR, and Central Discovery Segment, CDMAR, blue ellipses) and the Southern (Southern Discovery Segment, SDMAR, red ellipse) Discovery plume components, as well as the Shona Segment (purple ellipse). Filled circles mark assumed plume locations. The dashed line shows the approximate boundary of the African Large Low Shear Velocity Province (LLSVP), based on the −1.0% dln V_S contour from Davies et al. (2015). Placement of the LLSVP boundary between the Tristan and Gough zones of the plume is based on the model of Hoernle et al. (2015). Also shown is the location of the glass sample S18-60/1 near the Bouvet Triple Junction (Kamenetsky et al., 2001). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)
Source of the map: GeoMapApp (http://www.geomapapp.org).

Huang et al., 2011; Weis et al., 2011), but thus far only Tristan–Gough in the South Atlantic Ocean has been demonstrated to be geochemically zoned over at least 70 Ma of its history (Rohde et al., 2013a). The Discovery hotspot, similar to Tristan–Gough, is located close to the edge of the African LLSVP. Situated ∼500 km south of the Tristan–Gough hotspot track (Fig. 1), the Discovery Rise forms the older end of the Discovery hotspot track (Douglass et al., 1999; O'Connor et al., 2012) and consists of several seamounts, which form two (northern and southern) NE–SW trending sub-parallel chains (Figs. 1 and 2). The current Discovery hotspot must be located southwest of the seamounts, but its exact location is uncertain. Major and trace elements (Le Roex et al., 2010) and $^{40}Ar/^{39}Ar$ age data (O'Connor et al., 2012), ranging from 35–41 Ma, have been published from the NE end of the Rise covering both seamount chains. The only isotope data published from the Rise thus far is from a single basaltic sample from the Discovery Tablemount (Fig. 2) (Andres et al., 2002; Le Roux et al., 2002; Sun, 1980). Due to the similarity in composition between this sample and lavas from the adjacent southern Mid-Atlantic Ridge (SMAR) showing enriched geochemical compositions, this SMAR anomaly was attributed to the Discovery hotspot (Douglass et al., 1999).

In 2011 we conducted the first representative sampling of almost the entire Discovery Rise by dredging samples from 10 seamounts with the German R/V Maria S. Merian (cruise MSM19/3). Here we present major and trace element, as well as Sr, Nd, Hf and Pb double spike (DS) isotope, data from the Rise demonstrating that the Discovery hotspot track has been spatially zoned in geochemical composition over the last 40 Ma. Our study has important implications for the origin of zonation in mantle plumes and for evaluating a deep origin for the DUPAL anomaly in intraplate lavas and along mid-ocean-ridge segments adjacent to hotspots by recycling of subcontinental lithospheric mantle

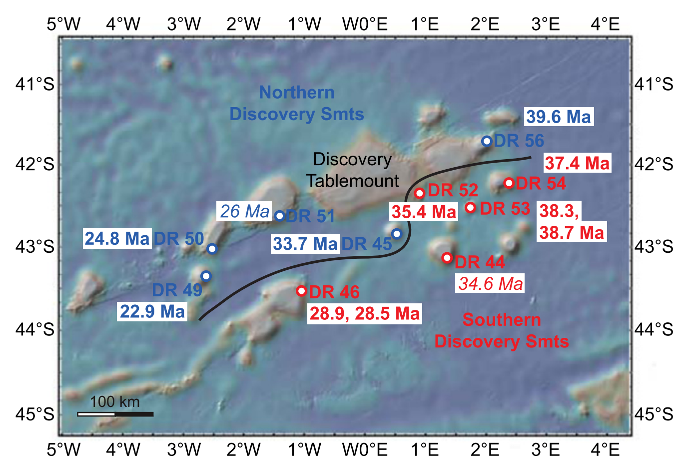

Fig. 2. Detailed map (http://www.geomapapp.org) of the Discovery Rise with dredge locations of the northern part (blue) and the southern part (red) and $^{40}Ar/^{39}Ar$ ages from this study. The ages in italics must be treated with caution (see explanation in the results). The black curved line represents the inferred boundary between the northern and southern geochemical domains. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

through the lower mantle. We further use our results to test the simple model for the origin of plume zonation by tapping material from inside and outside the LLSVP boundaries.

2. Analytical methods

Established methods were used for $^{40}Ar/^{39}Ar$ age dating and determination of major and trace element concentrations and radiogenic isotope ratios. Details about the methods are included in Appendix A.