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Asthenospheric percolation of alkaline melts beneath the St. Paul region (Central Atlantic Ocean)

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ABSTRACT

Two peridotite suites collected by submersible in the equatorial Atlantic Ocean (Hekinian et al., 2000) were studied for textures, modes, and in situ major and trace element compositions in pyroxenes. Dive SP12 runs along the immersed flank of the St. Peter and Paul Rocks islets where amphibole-bearing, ultramafic mylonites enriched in alkalies and incompatible elements are exposed (Roden et al., 1984), whereas dive SP03 sampled a small intra-transform spreading centre situated about 370 km east of the St. Peter and Paul Rocks. Both suites are characterized by undeformed, coarse-grained granular textures typical of abyssal peridotites, derived from residual mantle after ~15% melting of a DMM source, starting in the garnet stability field. Trace element modelling, textures and lack of mineral zoning indicate that the residual peridotites were percolated, reacted and refertilized by ~2.6% partially aggregated melts in the uppermost level of the melting region. This relatively large amount of refertilization is in agreement with the cold and thick lithosphere inferred by previous studies. Freezing of trapped melts occurred as the peridotite entered the conductive layer, resulting in late-stage crystallization of olivine, clinopyroxene, spinel, ± plagioclase. Chondrite-normalized REE patterns in clinopyroxenes from SP03 indicate that they last equilibrated with (ultra-) depleted partial melts. In contrast, REE concentrations in clinopyroxenes from SP12 display U and S shaped LREE-enriched patterns and the calculated compositions of the impregnating melts span the compositional range of the regional basalts, which vary from normal MORB to alkali basalt sometimes modified by chromatographic fractionation with no, or very limited, mineral reaction. Thus the mylonitic band forming the St. Peter and St. Paul Rocks ridge is not a fragment of subcontinental lithospheric mantle left behind during the opening of the Central Atlantic, nor the source of the alkaline basalts as previously suggested. Rather, dive SP12 sampled residual peridotites of normal MORB mantle that were located close to channels transporting alkali basalts. Reacted melts escaping from these channels, infiltrated, and locally equilibrated with, the peridotite matrix by ion exchange reactions. Relicts of the source of the alkaline basalts were not sampled but our study suggests that it was a component of the MORB mantle underlying the St. Paul region.

1. Introduction

The Central Atlantic Ocean is characterized by a large concentration of closely spaced, anomalously long fracture zones, a high ratio of peridotites to volcanics exposed on the seafloor and the occurrence of alkaline basalts along with very fertile abyssal peridotites. These features were attributed to the presence of a lithospheric mantle colder and thicker with respect to other regions of the Atlantic Ocean (Bonatti et al., 1993; Schilling et al., 1995). A mid oceanic ridge "cold spot", similar to that known at the Australian-Antarctic Discordance may lie in the Equatorial Atlantic, in connection to downwelling of cold, dense upper mantle as suggested by Bonatti et al., 1993. Beside, global upper mantle tomography suggests the presence of a fossil detached subducted slab beneath the Equatorial Atlantic, in agreement with plate tectonic reconstructions showing that an old subduction zone remained active for the period between 460 and 300 Ma (Maia et al., 2001; Sichel et al., 2008).

Another aspect of this region is the petrology of the islets of St. Peter and St. Paul Rocks (SPPR) which have long been recognized as unusual to the oceanic environment (Darwin, 1891). They expose high temperature, strongly mylonitized, amphibole-rich mafic and ultramafic rocks which were, at first, identified as cumulates associated with alkaline basalts (Tilley, 1947; Frey, 1970; Melson et al., 1967a,b). A trace element and isotopic study led Roden et al. (1984) to suggest a 155 Ma old metasomatic event as the origin of

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these ultramafics. At this time residual mantle peridotites dynamically recrystallized while percolated by magmatic fluids. Based on this age and on mineral compositions, Bonatti (1990) interpreted these rocks as representative of a subcontinental lithospheric mantle left behind after the fragmentation and opening of the Central Atlantic. This very fertile, volatile-rich, upper mantle has long been thought to be a suitable source for Atlantic island basalts (Roden et al., 1984).

In December 1997–January 1998, the region was explored with the French submersible Nautile and its support ship R/V Nadir to investigate the mode of emplacement of the mantle peridotites and gain insight into the origin of the St. Peter and Paul massif (Hekinian et al., 2000). The data collected during this cruise show that the islets are the emerged summits of a sigmoidal ridge (Fig. 1) composed of oceanic mantle uplifted in a nearly amagmatic environment controlled by the tectonic activity of the transform (Hekinian et al., 2000; Sichel et al., 2008).

In this paper, we present a petrological–geochemical study including textural observations, reconstructed modal primary compositions and in situ mineral major and trace element compositions of two peridotite suites sampled by the submersible. Dive SP12 samples were recovered at the southern, immersed slope of the St. Peter and Paul massif (Dive SP12; Fig. 1B); they are nearly undeformed, coarse-grained peridotites, assumed to represent the protolith of the ultramafic mylonites. Dive SP03 samples were taken along the wall of a small intra-transform spreading ridge about 370 km East of the St. Peter and Paul Rocks and SP12 dive (Intra Transform Ridge A according to Hekinian et al., 2000; Fig. 1C). The aim of this study is to compare St. Paul peridotites with the global set of mid-oceanic ridge peridotites, to establish what SP03 and SP12 rocks are representative of, how they relate to each other and to St. Peter and Paul Rocks mylonites, and to have some insight into the sources of the regional basalts.

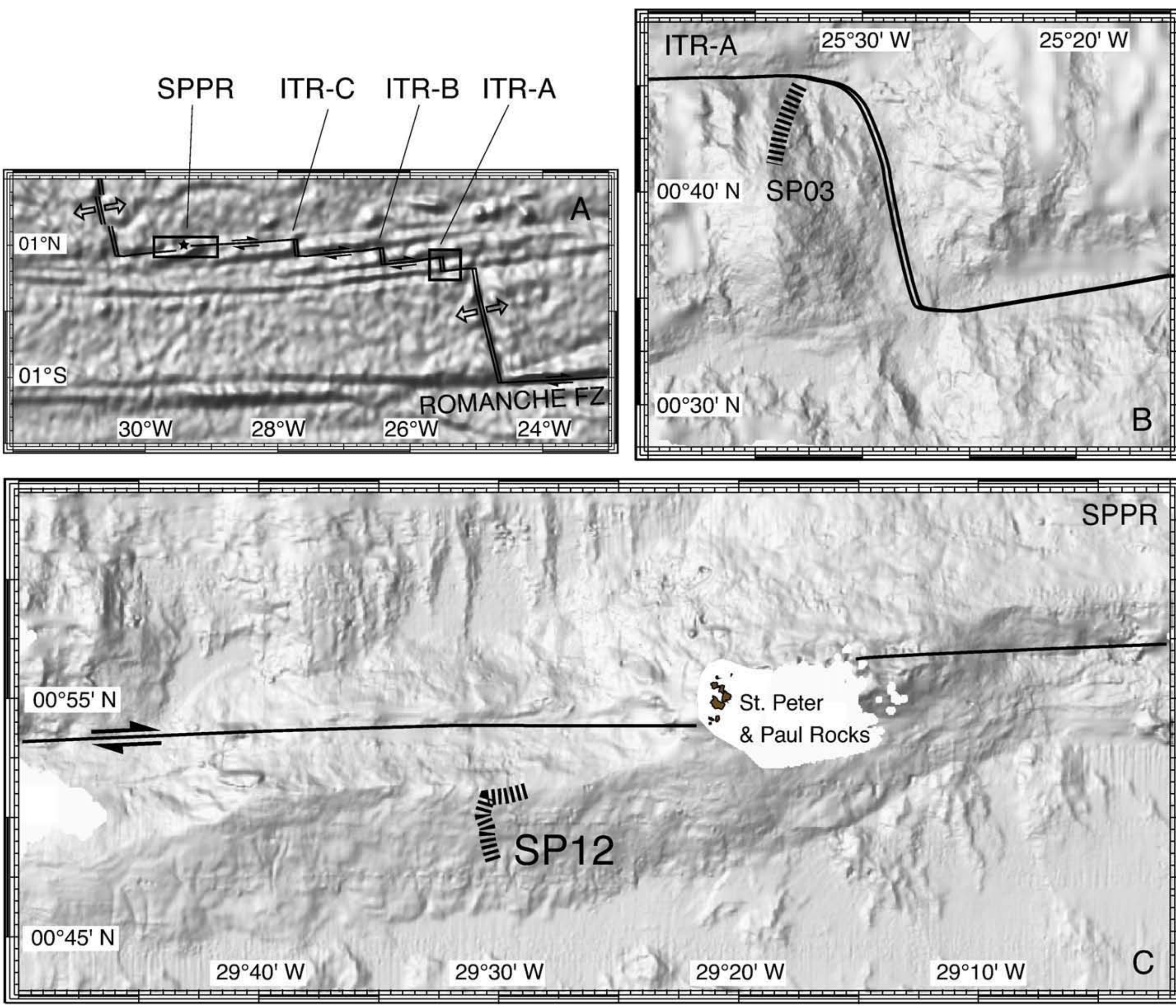

Fig. 1. Inset A: shaded relief rendering of the regional major tectonic structures based on predicted bathymetry after Sandwell and Smith (1997). The St. Peter and St. Paul fracture zone domain is composed of four transform faults separated by three short Intra-Transform Spreading Ridges (ITR) named according to Hekinian et al., 2000. The two studied areas reported in the insets B and C are shown as boxes. Inset B: Detailed bathymetry of the Intra Transform Ridge A at 25°30′ W. The trace of the Nautile SP03 dive is marked on the northern slope of the inner corner high. Inset C: Detailed bathymetry of the sigmoidal ridge where the St. Peter and St. Paul rocks lie (SPPR). The trace of the principal transform displacement zone is shifted northward west of the SPPR archipelago. The trace of the Nautile SP12 dive is reported on the southern flank of the ridge. Bathymetric data used in the insets B and C are from Gasperini et al., 1997 and Hekinian et al., 2000.