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Serpentinization of mantle peridotites along an uplifted lithospheric section, Mid Atlantic Ridge at 11° N

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A B S T R A C T

Mantle peridotites from an exposed lithospheric section (Vema Lithospheric Section, VLS), generated during ~26 Ma at a ~80 km long Mid Atlantic Ridge segment (11° N), have been sampled and studied to understand the evolution of the serpentinization process. The VLS was uplifted due to a 10 Ma transtensional event along the Vema transform. Before the uplift residual mantle rocks were lying beneath a 0.8–1.3 km thick basaltic crustal layer. The major and trace element compositions of the serpentinites, as well as their H, O, Sr, Cl and B isotopic compositions were interpreted based on thermal models of lithospheric spreading from ridge axis. The results suggest that serpentinization occurred mostly near the ridge axis. Serpentinization temperatures, estimated from stable isotopes, are consistent with resetting of the closure temperatures during the tectonic uplift of the lithospheric sliver, reflected by decreasing $\delta^{18}O$ and increasing $\delta^{11}B$ values. Modeling shows that the thermal influence of the transtensional event affected mainly the region close to the RTI (ridge–transform intersection). Petrological, elemental and isotopic data suggest that, when the ultramafic basal unit of the VLS was uplifted and exposed on the ocean floor, serpentinization became superseded by low temperature water–rock reactions, with Fe–Mn crust formation, which is still progressing, as recorded by δD. Ultramafic mylonites, prevalent in a short stretch of the VLS, show only a partial serpentinization process, together with pervasive contamination by low-temperature Fe–Mn crust.

1. Introduction

Mantle-derived ultramafic rocks have been recovered frequently from the seafloor, indicating that they outcrop in vast areas of the ocean bottom. Exposure of mantle-derived rocks is particularly common along slow- and ultraslow-spreading mid ocean ridges where the thickness of the basaltic crust is strongly reduced, particularly in regions of sub-ridge mantle thermal minima (Bonatti et al., 1996, 2001; Christie et al., 1998; Michael et al., 2003). In addition, vertical tectonics may lead to mantle exhumation triggered by low-angle detachment faults and core complexes (Boschi et al., 2006; Dick et al., 2003; Escartìn et al., 2003; Karson et al., 2006; Olive et al., 2010; Smith et al., 2008), as well as by transtension/transpression along transform faults due to small changes in ridge/transform geometry (Bonatti et al., 1994, 2005).

Serpentinization of ultramafic rocks at or below the ocean floor is an important process; it decreases their density and seismic velocities (Escartín et al., 1997a,b), affecting vertical motions (Bonatti, 1976) and subduction zone dynamics (Hilairet and Reynard, 2009; Reynard, 2013–in this issue). Oceanic peridotites acquire H_2O during serpentinization (up to ~13%), together with significant amounts of B and Cl; their subduction may carry part of this boron-enriched water back into the mantle (Barnes and Sharp, 2006; Bonatti et al., 1984; Boschi et al., 2008; Iyer et al., 2012; Kodolányi et al., 2012; Rüpke et al., 2004; Scambelluri et al., 2004a,b; Ulmer and Trommsdorff, 1995; Vils et al., 2009). Low-T ultramafic rock–seawater reactions can release Mg to the ocean (Niu, 2004; Snow and Dick, 1995), deposit carbonates (Bonatti et al., 1980) and uptake organic carbon (Delacour et al., 2008; Früh-Green et al., 2003) that can also be recycled later through subduction (Kerrick and Connolly, 1998). Interaction between serpentinites and CO_2-rich hydrothermal fluids can form Mg-carbonates, and is considered as a natural analog of CO_2 mineral sequestration (Boschi et al., 2009). Thus, oceanic serpentinization is

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a major player in H_2O and C exchanges between the mantle and hydrosphere.

We report here results of a study of variably serpentinized mantle-derived peridotites, recovered from a section of oceanic lithosphere (Vema Lithospheric Section or VLS) exposed south of the Vema transform at 11° N along the Mid Atlantic Ridge (MAR). This 3–4 km thick section exposes lithosphere formed continuously for over ~26 Ma at the ~80 km-long eastern MAR segment (EMARS, Fig. 1), allowing detection of temporal variations in the generation of oceanic lithosphere at ridge axis, as well as its alteration with time. The basal unit (~1 km thick) of the VLS exposes variably deformed and serpentinized peridotites. We have carried out a systematic, close-spaced sampling of these ultramafic rocks in lithosphere ranging in age from ~2 to ~26 Ma (Fabretti et al., 1998). Elemental and isotopic chemical studies of mantle equilibrated mineral phases have documented temporal variations in the degree of partial mantle melting and/or source composition (Bonatti et al., 2003; Brunelli et al., 2006; Cipriani et al., 2004, 2009a,b).

The present study documents the serpentinization and low-temperature alteration history on these variably deformed (porphyroclastic to mylonitic) ultramafics along the VLS through: (a) the mineralogy of secondary phases produced by serpentinization and low-temperature alteration; (b) temperatures of dehydration; (c) whole rock major and trace element chemistry, and (d) hydrogen, oxygen, chlorine, strontium and boron isotope compositions.

2. Tectonic setting and geological overview

A prominent transverse ridge (Vema Transverse Ridge, VTR, Fig. 1) runs along the southern side of the Vema transform valley, starting from ~140 km west of the ridge axis, in crust dated at ~10 Ma (Bonatti et al., 2005). The 300 km-long VTR is interpreted as the edge of a slab of the South American plate flexured and uplifted along the transform, due to a transtensive tectonic event that occurred between ~10 and 12 Ma. The VTR exposes a basal mantle unit overlain by a gabbroic unit, a dyke complex and an upper basalt layer (Fig. 2). The VLS has been sampled both within the uplifted VTR and in the stretch between the ridge axis and the VTR during several expeditions recovering ultramafic rocks at 48 sites, with an average horizontal spacing of about 8 km (Bonatti et al., 2003; Brunelli et al., 2006; Cipriani et al., 2009a). The mantle basal unit is made of variably deformed granular to porphyroclastic peridotites and ultramafic mylonites. Their mineral chemistry demonstrated a steady increase in the degree of melting of the subridge mantle from 18.5 to 2 Ma, preceded by an interval from 26 to 18.5 Ma of decreasing extent of melting (Bonatti et al., 2003; Brunelli et al., 2006; Cipriani et al., 2009a,b). Superimposed on this long-range variation, the degree of melting of the upwelling mantle along the VLS has also undergone short-wavelength (a few Ma) fluctuations, paralleled by variations in crustal thickness, inferred from gravity data. The short term temporal variations have been ascribed to active components in mantle upwelling, while the long-term variations of the degree of melting have been related to variations in mantle temperature and/or composition beneath the EMARS (Bonatti et al., 2003; Cipriani et al., 2009a).

Strongly deformed ultramafic mylonites were found within a ~80 km-long stretch of VLS. Mylonites are abundant at several sites between 43°00′ W and 43°30′ W, within a time interval from 15 to 19 Ma crustal age (Fig. 3). The VLS mylonitic interval, located between two relatively undeformed peridotites suites, an “older suite” (>18.5 Ma) to the west and a “younger suite” (< 18.5 Ma) to the west and a “younger suite” (>18.5 Ma) to the east, represents a period of quasi-amagmatic, mostly tectonic emplacement of lithosphere at the ridge axis, involving possibly low-angle detachment faults. Other sampled lithologies include basalts, dolerites, gabbros and limestones from the overlying crustal layers. Dunites were sampled at a few sites, representing overall a rare lithology (<1%).

The ultramafic rocks studied in this work are from 17 sites along the VTR sampled during the R/V Strakhov cruise S19 in January–March 1998 (Fabretti et al., 1998), corresponding to 19 to 10 Ma crustal ages (Figs. 1 and 3; Table 1). We report the results of petrological, geochemical and isotopic analyses (H, O, Cl, Sr, B) of a number of porphyroclastic serpentinites, together with a set of mylonitic samples.

3. Analytical methods

49 ultramafic samples from 17 sites (Fig. 1) have been selected for petrographic studies. The thermal properties of 29 selected samples

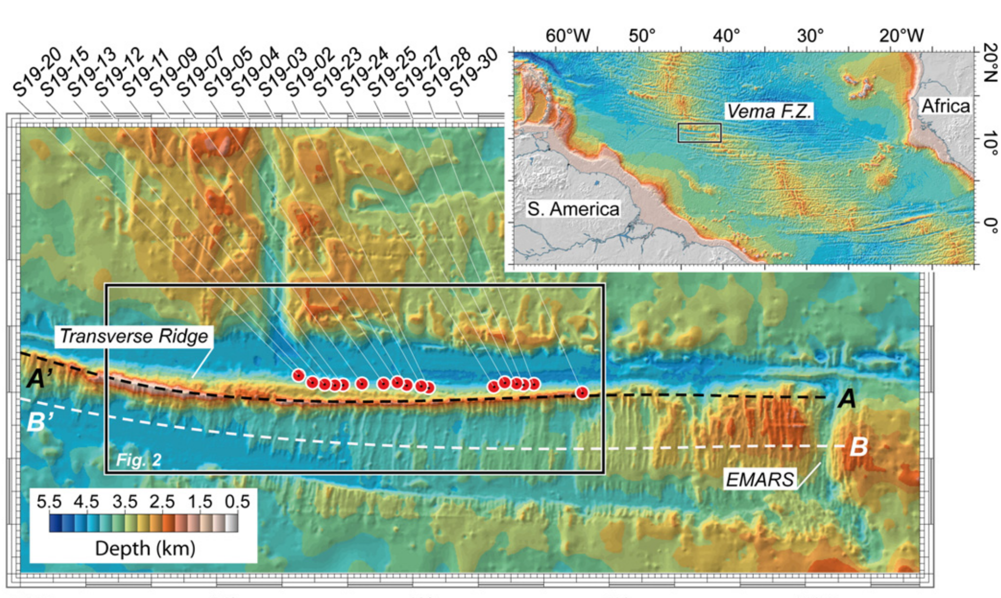

Fig. 1. Multibeam bathymetry of the Vema transform region. The Vema transform valley, the transverse ridge and the EMARS are clearly visible. Note on the southern side of the transform, the transverse ridge rises abruptly about 140 km from the eastern ridge–transform intersection, where oceanic fabric rotates sharply by 10° toward a N–S direction. Red circles indicate sample locations. The labeled box indicates the region depicted in Fig. 2. Dashed lines mark locations of the topographic profiles (A–A′ and B–B′) shown in Fig. 3. The inset shows predicted topography of the Central Atlantic (from Sandwell and Smith, 1997) with the Vema transform offset at 11° N.