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# Mantle–crust interactions in the oceanic lithosphere: Constraints from minor and trace elements in olivine

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## Abstract

Minor and trace element compositions of olivines are used as probes into the melt-rock reaction processes occurring at the mantle–crust transition in the oceanic lithosphere. We studied mantle and lower crustal sections from the Alpine Jurassic ophiolites, where lithospheric remnants of a fossil slow-spreading ocean are exposed. Olivines from plagioclase-harzburgites and replacive dunites (Fo = 91–89 mol%) and from olivine-rich troctolites and troctolites (Fo = 88–84 mol%) were considered. Positive correlations among the concentrations of Mn, Ni, Co, Sc and V characterize the olivines from the dunites. These chemical variations are reconciled with formation by melts produced by a mixed source consisting of a depleted peridotite and a pyroxene-rich, garnet-bearing component melted under different pressure conditions. We thereby infer that the melts extracted through these dunites channels were not fully aggregated after their formation into the asthenospheric mantle.

Olivines from the olivine-rich troctolites and the troctolites are distinct by those in the dunites by lower Ni and higher concentrations of Mn and incompatible trace elements (Ti, Zr, Y and HREE). Fractional crystallization cannot reproduce the chemical variations of the olivines from the olivine-rich troctolites and the troctolites. In these rock-types, the olivines commonly show heterogeneous Ti, Zr, Y and HREE compositions, which produce variable Ti/Y and Zr/Y values. We correlate these olivine characteristics with events of reactive melt migration occurred during the formation of the primitive lower oceanic crust. We propose that the migrating melts formed at the mantle–crust transition via interaction with mantle peridotites during periods of low melt supply.

## 1. INTRODUCTION

There is a general consensus that reactions between primitive MORB and peridotites extensively occur in the shallow mantle (Stolper, 1980; Elthon and Scarfe, 1984; Johnson et al., 1990; Kelemen et al., 1990). One example for this is the formation of replacive dunites, considered as products of melt-rock reactions between migrating primitive MORB and the host harzburgite/lherzolite through a process of pyroxene dissolution and precipitation of new olivine (Dick, 1977; Hopson et al., 1981; Quick, 1981). Once these replacive dunites are formed, they act as porous flow channels that transport melts extracted from the melting region preventing further interaction with the shallow mantle (see also Kelemen et al., 1995). Dunites are also expected to form the mantle–crust transition, where they may originate either by fractionation of primitive melts or by melt–peridotite interactions (e.g., Coleman, 1977; Nicolas and Prinzhofer, 1983; Kelemen et al., 1997; Dick

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et al., 2008, 2010). It has been recently proposed that the olivine-rich troctolites enclosed in the lower oceanic crust represent products of interaction between dunites at the mantle–crust transition and MORB-melts reactively migrating through the olivine-rich matrix (Drouin et al., 2009; Suhr et al., 2008; Renna and Tribuzio, 2011; Sanfilippo et al., 2013). Furthermore, evidence has been emerging that melt-rock reaction may also occur within the gabbros, when ascending magmas react chemically with a forming crystal mush, thereby modifying the compositions of the minerals and of the transient melts (Coogan et al., 2000; Dick et al., 2000; Gao et al., 2007; Lissenberg and Dick, 2008; Lissenberg et al., 2013). Taken as a whole, these melt-rock reaction processes questioned the idea that the lower oceanic crust exclusively represents the product of fractional crystallization of primitive melts (e.g., O'Hara, 1968) and that information about the mantle sources may be directly addressed from the composition of MORB after correction for fractional crystallization only (e.g. Klein and Langmuir, 1987).

Recent studies showed that the chemistry of olivine is a powerful tool to inspect mantle processes. For instance, the minor and trace element compositions of olivine were used to constrain the metasomatic and/or subsolidus history of lithospheric subcontinental mantle peridotites (Mallmann et al., 2009; De Hoog et al., 2010; Foley et al., 2013). Minor and trace element compositions of olivine phenocrysts in basalts were also used to obtain information about the compositions and/or the melting conditions of the mantle sources (Sobolev et al., 2005, 2007; Herzberg, 2011; Putirka et al., 2011). Olivine is the major constituent of the mantle peridotites and dunites and is the first phase to crystallize from a primitive MORB (Grove et al., 1992 and references therein). For these reasons, the olivine chemistry has great potential to investigate the melt-rock reaction processes occurring below an oceanic ridge (e.g. Drouin et al., 2009; Lissenberg et al., 2013). However, a thorough characterization of the minor and trace element compositions of olivines from the oceanic lithosphere has not been ascertained yet. This is partly due to the inability to recover abyssal sections in which olivine of the mantle peridotites and the lower crustal rocks are unaffected by the low temperature alteration.

In this study, we selected fresh mantle harzburgites, replacive dunites and primitive lower crustal rocks (olivine-rich troctolites to troctolites) from the Jurassic ophiolites exposed along the Alpine–Apennine belt. These ophiolites are considered to represent remnants of the oceanic lithosphere formed in an embryonic slow-spreading basin (Lagabrielle and Cannat, 1990; Tribuzio et al., 2004; Manatschal and Müntener, 2009; Sanfilippo and Tribuzio, 2011), which developed in the Middle to Upper Jurassic in conjunction with the opening of the Central Atlantic Ocean (Schettino and Turco, 2011; Vissers et al., 2013). We carried out *in situ* minor and trace elements analyses on olivines from these mantle and lower crustal rocks using Laser Ablation Inductively Coupled Plasma Mass Spectrometry. These data allow us to inspect the relationships between the melts extracted from the mantle and those crystallizing the primitive crust. Hence, we examine the early magmatic processes occurring under an oceanic ridge and the role of melt-rock reaction processes on the composition of the lower oceanic crust.

## 2. GEOLOGICAL FRAMEWORK AND SELECTED SAMPLES

The studied ophiolites include lower crustal sequences considered to be fossil analogues of oceanic core complexes from slow and ultraslow spreading ridges (Sanfilippo and Tribuzio, 2011, 2013a; Alt et al., 2012). These sequences are represented by the gabbroic sections from the Internal Ligurian and Pineto (Corsica) ophiolites (Fig. 1) and are associated with mantle sequences essentially consisting of depleted spinel-peridotites. These peridotites commonly record melt impregnation event and re-equilibration under plagioclase-facies conditions (Rampone et al., 1996, 1997). The mantle sequences from the Jurassic ophiolites of the Alpine–Apennine belt locally contain MOR-type replacive dunites (Piccardo et al., 2007; Sanfilippo and Tribuzio, 2011). The best examples for these replacive dunites are exposed in the Lanzo South massif (Fig. 1), where they are hosted by melt-impregnated plagioclase-peridotites (see also Kaczmarek and Müntener, 2009).

We selected three mantle harzburgites and three olivine-rich troctolites from the gabbro-peridotite sequences of the Internal Ligurian ophiolite. Two olivine-rich troctolites, four troctolites and two mantle harzburgites were considered for the Pineto gabbroic sequence and the associated mantle sequence from Serra Debbione. Five dunites and

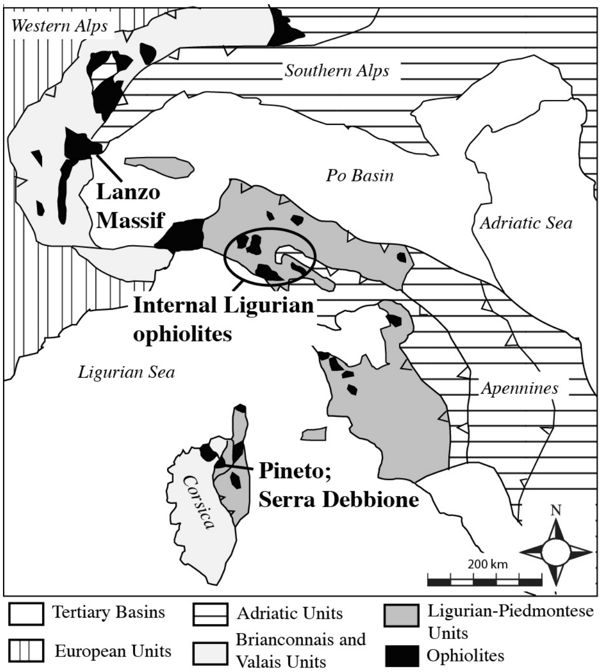

Fig. 1. Geological sketch map of the Alpine–Appenine system and location of the studied mantle and crustal sequences. Location and petrographic description of the samples are in the Supplementary material.