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# Refertilization of Jurassic oceanic peridotites from the Tethys Ocean — Implications for the Re–Os systematics of the upper mantle

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**Abstract**

The influence of melt migration and solid state mixing of pyroxenites on Re–Os isotopic and major element systematics of oceanic mantle rocks have been studied in serpentinized spinel lherzolites and associated spinel and spinel–garnet pyroxenite layers from the Totalp ultramafic massif near Davos (eastern Swiss Alps). The ultramafic body originally was emplaced and serpentinized on the Jurassic Liguria–Piedmont ocean floor and was little modified during the Alpine orogeny. Field and petrographic observations indicate that refertilization of the peridotites occurred by migration of melt between abundant websterite layers and the peridotites, as well as by mechanical stretching and thinning of websterite layers down to the subcentimeter scale, thus producing fertile lherzolite compositions.

Osmium concentrations in the peridotites are in the range observed for normal upper mantle peridotites, whereas Re concentrations in some peridotites are substantially higher than typical mantle values (up to 0.76 ppb). Initial Os isotopic compositions and Re/Os ratios in the peridotites range from subchondritic to suprachondritic ($\gamma_{Os}$ (160 Ma) between −5.5 and +7.2). Re/Os, $\gamma_{Os}$ (160 Ma) and Re concentrations correlate with fertility indicators such as $Al_2O_3$ and $Na_2O$, suggesting limited influence of serpentinization on Re–Os systematics of the peridotites. These correlations extend beyond estimates for primitive upper mantle (PUM) compositions suggesting that depletion by partial melting cannot have been the only process producing the variations.

The pyroxenites generally have higher Re (up to 3.2 ppb Re), but lower Os concentrations than lherzolites, and suprachondritic initial $\gamma_{Os}$ (+9.0 to +497). Websterites with suprachondritic $\gamma_{Os}$ (160 Ma) alternate with peridotites with chondritic or even subchondritic $^{187}Os/^{188}Os$, indicating substantial small-scale Os isotopic heterogeneity. The combined petrographic observations and contrasting compositions of peridotites and pyroxenites indicate that the correlations of $\gamma_{Os}$ (160 Ma) with fertility indicators reflect mixing of peridotites with a long-term depletion history and Re-enriched melts. The pyroxenites may represent residues of eclogites that melted during asthenospheric upwelling or could be cumulates which precipitated from asthenospheric melts.

These data provide new evidence that the lower section of the suboceanic lithospheric mantle contains fertile components that are enriched in Re and radiogenic Os. Melt migration evidently does not completely homogenize small-scale Os isotopic heterogeneities in the lower lithosphere, thus accounting for the presence of old depleted peridotites in young oceanic lithospheric mantle.


*Keywords:* Re/Os; mantle; peridotites; pyroxenites; ultramafic massif; refertilization

## 1. Introduction

The $^{187}Re$–$^{187}Os$ decay system ($\lambda_{187Re}=1.666\times10^{-11}$ a$^{-1}$, Smoliar et al., 1996) applied to mantle-derived rocks represents a versatile tracer to constrain processes ranging from late accretion to ancient melt extraction and recycling events in the

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Earth's mantle (Shirey and Walker 1998, and references therein). In mantle peridotites, Re and Os are mostly concentrated in trace sulfides and platinum group element (PGE) alloys (Morgan and Baedecker, 1983; Hart and Ravizza, 1996; Luguet et al., 2007). During mantle melting, Re behaves as a moderately incompatible element, whereas Os is normally highly compatible (Morgan, 1986; Hauri and Hart, 1993; Shirey and Walker, 1998; Burton et al., 2000). Residual peridotites depleted in Re by partial melting will, thus, evolve to subchondritic $^{187}Os/^{188}Os$. In contrast, crustal rocks with high Re/Os quickly develop highly suprachondritic $^{187}Os/^{188}Os$ (e.g., Roy-Barman and Allègre, 1994; Schiano et al., 1997; Shirey and Walker, 1998).

Early studies of the Re–Os systematics of mantle rocks led to the conclusion that melt extraction is the main control on Re and Os abundances and, consequently, the $^{187}Os/^{188}Os$ of mantle peridotites (Walker et al., 1989; Reisberg and Lorand, 1995; Shirey and Walker, 1998, and references therein). Effects of secondary melt or fluid migration on Re–Os systematics of peridotites were presumed to be minor (e.g., Handler et al., 1997). A number of studies over the last 10 years, however, have changed this picture. Detailed Re–Os work, in combination with other radiogenic isotopes and trace elements has shown that Re and Os abundances and $^{187}Os/^{188}Os$ of mantle peridotites can be significantly affected by at least two different styles of melt or fluid migration in the mantle. Melt percolation by porous flow at high melt/rock ratios leads to the formation of replacive dunites and harzburgites (Kelemen et al., 1997). This open-system process may produce lower than normal abundances of the compatible Ir group PGE (Os, Ir, Ru), low-Re abundances, and often chondritic to suprachondritic $^{187}Os/^{188}Os$ in the modified peridotites. These variations have been most clearly noted in spatially-controlled Re–Os studies of peridotite massifs, and may reflect dissolution of sulfides, along with pyroxenes, in percolating basic melt, and addition of radiogenic Os from such melts (Becker et al., 2001; Büchl et al., 2002; 2004). Similar compositional features, although less clearly documented, occur in peridotite xenoliths (e.g. Handler et al., 1997; Brandon et al., 1999; Schmidt and Snow, 2002; Pearson et al., 2003; 2004; Reisberg et al., 2005; Handler et al., 2005) and possibly in abyssal peridotites (Standish et al., 2002; Harvey et al., 2006).

Melt addition at low melt/rock ratios leads to a very different manifestation of mantle metasomatism. These conditions likely prevail in the lithospheric mantle where cooling magma may precipitate pyroxenes and sulfides, leading to addition of basaltic components to previously depleted peridotites ('refertilization') (see reviews of Bodinier and Godard, 2003; Pearson et al., 2003). Considerable uncertainties remain regarding the behavior of Re, Os and other highly siderophile elements (HSE) during these secondary mantle processes. Since for a number of elements (including the HSE), fertile lherzolites represent the most reliable material to constrain the composition of Earth's primitive upper mantle (PUM; a hypothetical primitive upper mantle reservoir), the influence of melt migration and refertilization on Os isotopes and HSE abundances in lherzolites needs to be better understood.

The purpose of the present work is to investigate the importance of melt migration processes on Re–Os systematics of the deeper suboceanic mantle in a detailed study of fertile spinel lherzolites emplaced on the Jurassic Liguria-Piedmont ocean floor, and now exposed in the Totalp ultramafic massif in the Eastern Swiss Alps. The Totalp massif provides a rare opportunity to study the deeper section of suboceanic lithosphere in a very slow-spreading environment not unlike modern occurrences from the Arctic Ocean (Michael et al., 2003). Field and petrographic observations as well as major element compositions of the ultramafic rocks show evidence for melt migration and related refertilization that may have occurred near the transition from asthenosphere to lithosphere. We also discuss the role of pyroxenite layers as sources of Re and radiogenic Os in the generation of Os isotopic heterogeneities in the convecting mantle.

## 2. Geological setting and petrology

The Totalp ultramafic massif is comprised of a fragment of former ocean floor exposed in the Eastern Swiss Alps over an area of about 10 $km^2$ between approximately 46°47′ and 46°51′ northern latitude and 9°47′ and 9°50′ eastern longitude. The ultramafic massif is now in an overturned position, but still in primary stratigraphic contact with pelagic sediments (Weissert and Bernoulli, 1985). The age of emplacement on the ocean floor has been constrained to ~160 Ma by biostratigraphic correlation and $^{39}Ar/^{40}Ar$ dating (Weissert and Bernoulli, 1985; Peters and Stettler, 1987). The rock association has been interpreted as a remnant of a fracture zone (Weissert and Bernoulli, 1985) of the slow-spreading Piedmont–Liguria ocean basin, the Southern branch of the Jurassic Alpine Tethys Ocean (Schmid et al., 2004). The period of spreading was between 210 and 170 Ma (Stampfli and Borel, 2004, Schmid et al., 2004). Fragments of ocean floor were obducted during the Alpine orogeny (Schmid et al., 2004, Müntener et al., 2004). The ultramafic rocks are now part of the Arosa imbricate zone, which separates the Penninic and Austroalpine units (e.g. Schmid et al., 2004). For a detailed geological overview and a geological map, see e.g. Peters and Stettler (1987) and Schmid et al. (2004).

The massif consists of moderately to strongly serpentinized spinel lherzolites, spinel and rare garnet–spinel pyroxenite layers. The pyroxenites are sometimes folded and concordant or oblique to a high-temperature foliation (Peters, 1963). The peridotites within the massif experienced a very low grade metamorphic overprint during serpentinization on the seafloor, and possibly during the Alpine orogeny (Früh-Green et al., 1990). The presence of spinel in the lherzolites and spinel and spinel–garnet assemblages in the pyroxenites indicates that the last equilibration occurred in the deeper lithospheric mantle (>50 km depth, Peters and Stettler, 1987). Temperatures between 830 and 975 °C and a pressure of 10±3 kbar were estimated for a last equilibration under spinel-lherzolite facies conditions (Peters and Stettler, 1987). The Totalp ultramafic rocks are conspicuously free of plagioclase indicating rapid uplift and cooling.