

Scaling and nature of melting processes in the mantle wedge: a record from the Josephine Peridotite (Klamath Mountains, USA)

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The selected peridotite samples come from the Josephine ophiolite, emplaced 157 My ago and now part of the western Jurassic belt of the Klamath Mountains in Northern California and Southwest Oregon [1]. The ophiolite is partly dismembered but presents a complete ophiolitic section from mantle peridotites in the lower part (our samples) to pillow lavas at the top. The Josephine peridotite extends over >800km² and has most likely originated in a fore-arc or back-arc setting [1]. It is mostly composed of massive harzburgites, believed to be the residue of partial melting processes, crosscut by several generations of dykes and veins of variable lithologies [2]. Previous studies have mainly focused on the dunite bodies because of their importance as melt extraction channels in the upper mantle. They are believed to have formed through melt-rock reactions between depleted melts and the mantle wedge [3-6].

However, large areas of the Josephine peridotite have yet to be investigated. Here we propose to focus on the compositional variability of harzburgites and lherzolites, which likely represent the protolith of mantle wedge before the diking and veining events that later affected the massif. Our goal is to constrain the scale of melting processes in the upper mantle in subduction environments and better assess the role and distribution of subduction-derived fluids in the melting process. In order to achieve this, our study is based on the observation of geochemical gradients (major, minor and trace elements in minerals and whole-rocks) throughout the selected harzburgites and lherzolites. Based on major elements and most minor and trace element trends (e.g. HREE, Ti, Ni versus MgO wt%) we find that harzburgites and lherzolites are genetically related by a partial melting event, as suggested in previous studies [2]. However the concentrations of the most incompatible elements (e.g. LREE) and fluid-mobile elements (Ba, Rb, Sr) cannot result from a partial melting process but require the later addition of fluids and/or melts superimposed to the partial melting features recorded by the Josephine peridotites.

Mapping out the melting and melt percolation processes that took place in the Josephine Peridotite should shed a new light on the extent and nature (dry or hydrous) of melting in the upper mantle from subduction environments.

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The nanoSIMS as a tool to study zonation around/in melt inclusions

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Melt inclusions preserve geochemical records of magmatic processes and can provide windows into melt composition prior to near-surface fractionation processes such as degassing, crystal fractionation, and mixing that can influence the compositions of erupted magmas. The compositions of melt inclusions are usually measured near their centers using in-situ analytical techniques such as electron microprobe, ion probe, or LA-ICPMS. However, melt inclusions can experience post-entrapment modifications through crystallization or exchange with the host mineral or the outside melt via diffusion through the host mineral. For example, water loss (or gain) can occur by diffusion of H-bearing species through the host mineral toward (or from) the enclosing melt. Zonation in melt inclusions and their host minerals provide information on such post-entrapment modifications. We present a new approach to the study of such zonation using the nanoSIMS Cameca 50L high-resolution ion microprobe. Our data document mechanisms of chemical evolution of melt inclusion after entrapment and can constrain the nature and timescales of syn-eruptive processes.

The distinctive capabilities of the nanoSIMS are (1) small spot sizes – typically as small as ~0.2 μm for major elements, 1 μm for minor elements, and several microns for trace elements (including H in nominally anhydrous minerals); and (2) multicollection with large mass range, permitting simultaneous analysis of low- and high-mass elements.

We characterized H and F gradients in olivine around volatile-rich melt inclusions from two arc basalts. The H gradients are anisotropic and can be modeled by diffusion by the proton-polaron mechanism ($D_a=100D_b$). The length scales of these gradients (from < 20 μm to > 125 μm) indicate that diffusion from the melt inclusion to the olivine produced these gradients on timescales of a few hours.

We also discovered concentric major and volatile element concentration gradients inside melt inclusions (i.e., zonation within the glass) from various geological settings. Given the high rates of chemical diffusion in silicate melts, the preservation of these gradients implies that these gradients formed during or just prior to eruption on timescales on the order of 0,1-1 hour. For example, gradients in MgO and Al₂O₃ in inclusions from the Siqueiros fracture zone can be modeled as due to coupled olivine growth on inclusion walls and diffusion in the melt inclusion on timescales of ~10 min, presumably in the last stages of eruption. Gradients in H and F inside melt inclusions are more complex, likely reflecting the coupling of olivine crystallization with loss of H and F from the melt inclusion into the host olivine.