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Hydrous melts weaken the mantle, crystallization of pargasite and phlogopite does not: Insights from a petrostructural study of the Finero peridotites, southern Alps

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ABSTRACT

This study reports petrostructural observations in the pargasite and phlogopite-bearing Finero peridotite massif (Italian Western Alps), which suggest that the pervasive foliation in this massif was formed by deformation concomitant with percolation of hydrous Si-rich melts: (1) diffuse contacts, but systematic parallelism between the pyroxenitic layers and the foliation of the peridotite (2) strong shape and crystal preferred orientations (SPO and CPO), but subhedral or interstitial shapes and weak intracrystalline deformation of the hydrous phases, (3) CPO, but interstitial shapes of the pyroxenes, (4) very coarse olivine grain sizes, which are correlated to the olivine abundance, and (5) elongated shapes, but weak intracrystalline deformation, and extremely weak and highly variable CPO of olivine. The pervasive deformation of the Finero peridotite occurred therefore under conditions that allowed coexistence of H_2O–CO_2-bearing melts, pargasite, and spinel, that is, temperatures of 980–1080 °C and pressures <2 GPa. The petrostructural observations suggest that the presence of hydrous melts results in accommodation of large amounts of deformation by stress-controlled dissolution–precipitation and advective transport of matter by the melts and in fast grain boundary migration in olivine. By consequence, it produces significant rheological weakening. Water contents in olivine are <4 ppm wt., implying limited contribution of hydration of olivine to weakening. In addition, the analysis of protomylonites composing the external domains of the shear zones that overprint the pervasive foliation indicates that the transition to melt-free conditions results in enhanced contribution of dislocation creep to the deformation. The associated increase of the peridotites' strength leads to onset of strain localization. The latter is not correlated to the local abundance in pargasite or phlogopite, implying that crystallization of amphiboles or phlogopite, even at concentrations of 25 vol.%, does not produce rheological weakening in the upper mantle.

1. Introduction

It is commonly accepted that hydration leads to significant weakening in the mantle. However, incorporation of water in the upper mantle results in different processes depending on the pressure and temperature conditions and on the water activity: (i) crystallization of hydrous minerals, (ii) incorporation of different hydrous point defects in the structure of olivine and pyroxenes, (iii) partial melting with partitioning of the water in the melt, or (iv) accumulation (and migration) of aqueous fluids in the peridotites.

Most of the existing experimental data accounting for the effect of water on the rheology has been obtained on the dry-end part of the water–peridotite system. The experiments focused on the rheological effect of hydrogen incorporation in the olivine structure, at conditions under which hydrous minerals are not stable. They corroborate that this hydration process, which occurs at the part per million level of equivalent H_2O, produces weakening, but the data differ on the estimation of its intensity. A first series of experiments suggested an almost linear increase in strain rate at constant stress with increasing hydrous point defect concentration in olivine (Mei and Kohlstedt, 2000a, 2000b). Subsequent diffusion and deformation experiments on single crystals suggested that this

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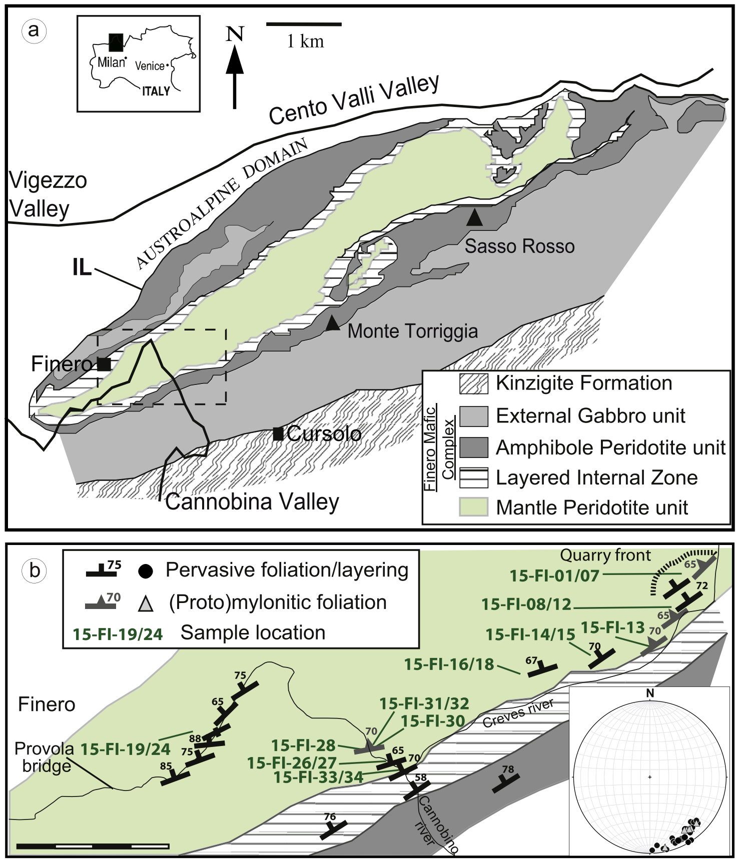

Fig. 1. (a) Sketch map of the northern sector of the Ivrea–Verbano Zone showing the main units of the Finero Complex, as well as the Insubric Line (IL) and the Kinzigite Formation, which bound it to the NW and SE, respectively. (b) Geological map of the area east/northeast of Finero village displaying samples' locations and foliation planes. Insert shows a stereonet (equal-area projection, lower hemisphere) of poles of the main pervasive foliation of the coarse-grained peridotites and of the foliation in the shear zones.

effect was likely overestimated for both diffusion (Fei et al., 2013) and dislocation creep regimes (Girard et al., 2013). The latter experiments show a modest weakening by a factor 1.3–1.6 for water contents of at least 290 H/10^6Si (18 ppm wt. of H_2O) and no significant effect on further incorporation of hydrogen. These results are consistent with torsion experiments on wet olivine polycrystals, which show a modest strength decrease by a factor of 2–3 relative to dry samples associated with hydrous defects in olivine and water-derived species in grain boundaries (Demouchy et al., 2012). Finally, recent data suggest that the weakening might depend on the type of hydrous defect in olivine, claiming for a higher rheological sensitivity to hydrogen when it is coupled to other trace elements, such as titanium (Faul et al., 2016).

There are few data on the mechanical behavior of peridotites in presence of hydrous melts. Comparison between experiments on olivine + basalt and olivine + basalt + water samples indicate that the presence of water in the system results in an increase in strain rate at constant stresses by ~2 orders of magnitude relative to dry systems in both the dislocation and diffusion creep regimes (Mei et al., 2002).

No experimental data constrain the rheological effects of the crystallization of hydrous minerals, such as amphiboles, chlorite, phlogopite, or of the presence of water-rich fluids in a peridotite. Yet, these processes are expected to be the dominant response to hydration in large domains of the mantle wedge and in the lithospheric mantle (e.g., Fumagalli and Klemme, 2015). Observations in natural systems deformed under such conditions are also rare. A recent study of a mantle shear zone in the Ronda peridotite points nevertheless to a major role of pressure-solution on the deformation of mantle rocks in presence of fluids at low temperature and pressure (Hidas et al., 2016).

In summary, the deformation processes and, by consequence, the rheology of the mantle in presence of hydrous melts, fluids, or hydrous minerals, like pargasite and phlogopite, are poorly known. This knowledge is essential for understanding how the base of the upper plate and the moderate temperature domains of the mantle wedge deform and for predicting the coupling between the plates (both subducting and overlying) and the convecting mantle wedge.

Petrostructural and chemical study of the pargasite-phlogopite peridotites of the Finero complex, in the Western Italian Alps, may provide answers to these questions by unraveling:

- Which are the deformation processes active in the mantle in the pargasite and phlogopite stability field, that is, at temperatures below 1080 °C?
- How does the presence of hydrous melts change the deformation processes and the mantle rheology?
- Does enrichment in hydrous phases by itself modify the rheology of a peridotite? May it promote strain localization?

2. Geological setting

The Finero complex is a unique example of a large orogenic mafic–ultramafic massif recording melt percolation leading to pervasive crystallization of large amounts (up to 25 vol.%) of pargasite and phlogopite in peridotites. It outcrops as a lens-shaped body in the northernmost part of the Ivrea–Verbano Zone (Fig. 1a). It is bounded to the N–NW by the Insubric line (IL, Fig. 1a), which places it in contact with an accretionary prism of the Alpine