The occurrence, origin, and fate of water in chromitites in ophiolites

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ABSTRACT

We present petrological investigations and mineral chemistry of several Tethyan ophiolites to reveal the occurrence, origin, and fate of water in podiform chromitites. The results show that clinopyroxene and olivine in chromitites have H2O contents of 801–366 and 53–17 ppm, respectively. The highest water contents of olivine occur in massive chromitite and the lowest always in the clinopyroxene-bearing ores because much of the available hydrous fluids was taken up by the clinopyroxene during crystallization. The major and trace elemental and Li isotopic compositions of clinopyroxene associated with chromite and olivine in podiform chromitites indicate formation from a mixture of surface hydrous fluids on chromite grains and evolved melts from which olivine crystallized. The hydrous fluids initially originated from dehydration of a subducting slab as revealed by Li isotopic compositions of clinopyroxene and olivine in the chromitites. High fluid/rock ratios facilitated concentration of chromite to form chromitite, suppressing crystallization of olivine. The hydrous fluids that were collected on the chromite grain surface during crystallization allowed chromite grains to rise via decreasing density in the form of bubbles, thus promoting their gathering and concentration. The fate of these hydrous fluids depends on ambient physical and chemical conditions. Mostly they hydrate adjacent olivine grains in the chromitite or penetrate the surrounding dunite envelope. In some cases, the fluids dissolve into silicate melts to produce water-bearing clinopyroxene and/or hydrous minerals, such as amphibole, or infiltrate silicate and chrome grains to form inclusions, which may exsolve later in the form of mineral lamellae. Our investigations provide direct natural evidence for the presence and importance of water in the formation and evolution of chromite deposits, as inferred by earlier experimental studies.

Keywords: Podiform chromitite, clinopyroxene, olivine, ophiolite, water

INTRODUCTION

The discovery of various exotic minerals (e.g., diamond, moissanite) in podiform chromitites of ophiolites (e.g., Robinson et al. 2004; Yang et al. 2007) has led to a renewed interest in these enigmatic bodies and challenged many existing assumptions on the nature of the upper mantle and the extent of large-scale recycling of sub-oceanic lithosphere (e.g., Arai 2013). The key to understanding the formation of podiform chromitites is to examine critically the nature and origin of their parental magmas. It is widely thought that high-Al and high-Cr chromitites are crystallized from mid-ocean ridge basalts (MORB) type and boninite-type melts, respectively (e.g., Zhou et al. 1996; Pagé and Barnes 2009). However, many details about podiform chromitite formation are still poorly understood in light of experimental and mineralogical data. For example, experiments show that chromite can form under dry conditions at temperatures of 1250 ± 100 °C and fO2 around ±1 log units relative to the FMQ buffer (Irvine 1977; Roeder and Reynolds 1991), precluding the need for water. On the other hand, the common presence of hydrous inclusions (e.g., amphibole, phlogopite, and fluids) in chromite (e.g., Melcher et al. 1997; Schiano et al. 1997; Borisova et al. 2012; González-Jiménez et al. 2014; Rollinson et al. 2018; Liu et al. 2018) is taken as evidence for the presence of hydrous fluids. Such hydrous inclusions may have been trapped contemporaneously with chromite crystallization or later during post-magmatic hydrothermal activity, e.g., during annealing and sintering processes that affect chromite in the presence of hydrous fluids (Lorand and Ceuleeneer 1989; Melcher et al. 1997; Johan et al. 2017; Kapsiotis et al. 2019). In addition, chromite in podiform chromitites typically undergoes sub-solidus re-equilibration with olivine, making it difficult to determine parental melt compositions (e.g., Rollinson and Adetunji 2015; Xiao et al. 2016; Zhang et al. 2019).

On the basis of experimental studies, Matveev and Ballhaus