Water transport by subduction: Clues from garnet of Erzgebirge UHP eclogite

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ABSTRACT

A key question concerning the water budget of Earth’s mantle is how much water is actually recycled into the mantle by the subduction of eclogitized oceanic crust. Hydrous phases are stable only in quartz eclogite not coesite eclogite so that water transport to greater depths is mainly governed by structural water in omphacite and garnet. Here we explore if garnet can be used as a proxy to assess the amount of this water. Available data on the water contents of garnet in coesite eclogite vary over orders of magnitude, from a few up to ca. 2000 ppm. By implication, the maximum bulk-rock water contents are unrealistically high (wt% level). New data from the Erzgebirge indicate moderate amounts of structural H2O stored in garnet (43–84 ppm), omphacite (400–820 ppm), and in the bulk coesite eclogite (ca. 280–460 ppm). Higher garnet water contents occur, but these are not primary features. They are related to molecular water in fluid inclusions that can be attributed to eclogite-facies fluid influx postdating the metamorphic peak. Fluid influx also caused the uptake of additional structural water in garnet domains close to fluid inclusions. Such secondary H2O incorporation is only possible in the case of primary water-deficiency indicating that garnet hosted less water than it was able to store. This is insofar astonishing as comparably high H2O amounts are liberated by the breakdown of prograde eclogite-facies hydrous minerals as a result of ultrahigh-pressure (UHP) metamorphism. Judging from Erzgebirge quartz eclogite, dehydration of 5–10% hydrous minerals (±equal portions of zoisite±calcic amphibole) produces 1500–3000 ppm water. We infer that the largest part of the liberated water escaped, probably due to kinetic reasons, and hydrated exhuming UHP slices in the hanging-wall. Depending on the physical conditions, water influx in eclogite during exhumation (1) produces fluid inclusions and simultaneously enhances the structural water content of nominally anhydrous minerals—as in the Erzgebirge—and/or (2) it may give rise to retrograde hydrous minerals. We conclude that eclogite transports moderate quantities of water (several hundred parts per million) to mantle depths beyond 100 km, an amount equivalent to that in ca. 1% calcic amphibole.

Keywords: Eclogite, garnet, infrared spectroscopy, nominally anhydrous minerals, omphacite, subduction, water

INTRODUCTION

It is known that water plays a key role in mantle dynamics, including convection and magma generation (e.g., Hirth and Kohlstedt 1996; Asimow and Langmuir 2003; Bercovici and Karato 2003). An important question in this context is: How much water is transported into the mantle via subduction? Quartz eclogite typically contains several percent of hydrous minerals, predominantly calcic amphibole and zoisite. However, these minerals are not stable in coesite eclogite and, therefore, cannot account for the transport of water into mantle regions beyond ca. 100 km. Conversely, water transport to greater depths is possible via nominally anhydrous minerals (NAMs) such as garnet and pyroxene. Both phases, together with olivine, are capable of incorporating considerable amounts of water in their structure (that is, structural hydroxyl or colloquially “water”; e.g., Bell and Rossman 1992a). Due to the fact that the capacity of these minerals to incorporate water increases with rising pressure (e.g., Kohlstedt et al. 1996; Lu and Keppler 1997), they are crucial for water storage in the mantle.

Garnet and omphacite are the dominant phases in eclogitized oceanic crust and the most important NAMs for subduction-related water transport into the mantle. Two questions arise in this context: (1) How much water is actually stored in coesite eclogite and transported to greater depth, and (2) are garnet and omphacite able to incorporate the entire water released by the breakdown of eclogite-facies hydrous phases? To seek answers to these questions, NAMs from natural samples of coesite eclogite have to be analyzed for water.

For four reasons, garnet is a very suitable proxy in this context. (1) Garnet is less affected by alteration compared to omphacite. (2) Omphacite may host nanometer-scale inclusions of various sheet silicates (Schmädicke and Müller 2000; Koch-Müller et al. 2004). (3) Unlike omphacite, garnet is stable in the transition zone (Ringwood 1991) and is very important for water transport to the deeper mantle. (4) Its optical isotropy simplifies sample preparation for infrared (IR) spectroscopy, the standard method for measuring water in NAMs (Rossman 2006), allowing for a larger database.

Several studies have been conducted on ultrahigh-pressure (UHP) eclogite to determine the water content of garnet, the