Hematite and magnetite precipitates in olivine from the Sulu peridotite: A result of dehydrogenation-oxidation reaction of mantle olivine?

SHYH-LUNG HWANG, TZEN-FU YUI, HAO-TSU CHU, POUYAN SHEN, YOSHIYUKI IIZUKA, HOUNG-YI YANG, JINGSUI YANG, and ZHIQIN XU

1Department of Materials Science and Engineering, National Dong Hwa University, Hualien, Taiwan, ROC
2Central Geological Survey, P.O. Box 968, Taipei, Taiwan, ROC
3Institute of Earth Sciences, Academia Sinica, Taipei, Taiwan, ROC
4Department of Materials Science and Engineering, National Sun Yat-sen University, Kaohsiung, Taiwan, ROC
5Institute of Materials Science and Engineering, National Sun Yat-sen University, Kaohsiung, Taiwan, ROC
6Key Laboratory of Continental Dynamics, Ministry of Land and Resources. Institute of Geology, Chinese Academy of Geological Sciences, Beijing 100037, China

ABSTRACT

Analytical electron microscopic observations have been carried out on a garnet peridotite from the Maobei area, Sulu ultrahigh-pressure terrane. The results showed that olivine in this garnet peridotite (5.3–6.6 GPa; 853–957 °C), contains precipitates of chromian magnetite and chromian-titanian hematite at dislocations and (001) faults. Specific crystallographic relationships were determined between these precipitates and the olivine host, viz. [101] // [001]h, [110] // [011]t, and [011] // [001]t. These oriented oxides are not associated with silicate/silica phases and therefore cannot be accounted for by the mechanism of olivine oxidation. It is postulated that these magnetite and hematite precipitates most likely have resulted from dehydrogenation-oxidation of nominally anhydrous mantle olivine during rock exhumation. In view of the contrasting diffusion rates of H and Fe in the olivine lattice, it is suggested that the formation process might actually take place in steps. Hydrogen diffusion with concomitant quantitative oxidation of Fe$^{2+}$ to Fe$^{3+}$ in olivine occurred early during initial rock exhumation and was followed by slow Fe diffusion forming magnetite/hematite at stacking faults and dislocations within the olivine lattice. Two requirements are essential under such a scenario: an ample amount of H content of the olivine, and an appropriate exhumation rate, probably in the range of 6–11 mm/year, of the host rock. It is also noted that such dehydrogenation-oxidation processes may hamper a correct estimate of the actual P-T conditions and mantle oxidation state based on mineral chemistries present in mantle eclogite/peridotite. The present study demonstrates that oriented mineral inclusions may not necessarily form through exsolution processes sensu stricto, but may form through a series of more complicated reaction mechanisms.

Keywords: Magnetite, hematite, olivine, dehydrogenation-oxidation, UHP peridotite

INTRODUCTION

Lamellae or oriented needles/rods of a single oxide/silicate phase evenly distributed within host silicates have been generally regarded as precipitates formed upon unmixing of parental minerals. Albite lamellae in K-feldspar are a well-known classical example (e.g., Deer et al. 1966). Recently, numerous oriented needles/rods of oxides/silicates have been found within silicate minerals from ultrahigh-pressure (UHP) rocks and have been suggested to be of exsolution origin (Zhang and Liou 1999). Since exsolution, by definition, takes place in the solid state within a closed system (in terms of material transfer) as a result of changing physical conditions, the phenomena or the recalculated compositions of the presumed parental phase can theoretically be employed to yield quantitative estimates of the physical conditions at which the exsolution process occurred.

Some examples of such practices include pressure estimates based on the recalculated Ti content in olivine with oriented ilmenite rods from the Alpe Arami peridotite (Dobrzhinetskaya et al. 1996), and the recalculated Si content in titanite with oriented coesite needles from the Kokchetav UHP marble (Ogasawara et al. 2002). On the other hand, recent studies have also shown that oriented mica + quartz + talc in phengite from the Dora-Maira whiteschist (Ferraris et al. 2000) or oriented rutile needles in garnet from the Sulu UHP eclogite (Hwang et al. 2007) may not have necessarily formed in a closed system (in terms of material transfer). Such open-system reactions would not be ascribed to exsolution sensu stricto and would, in some cases, cast doubts on the quantitative estimation of the physical conditions mentioned above. Detailed studies of the formation mechanisms for such lamellae or oriented needles/rods are therefore required before any geological implications can be confidently proposed.

In the present study, two kinds of oriented Fe(-Cr-Ti) oxide precipitates have been identified within olivine crystals from a...