Laser Raman microspectrometry of metamorphic quartz: A simple method for comparison of metamorphic pressures

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ABSTRACT

A Laser Raman microspectrometry method was applied to metamorphic quartz in quartz-eclogite-, epidote-amphibolite-, and amphibolite-facies rocks to assess the quantitative correlation between the Raman frequency shift and metamorphic pressure. Quartz crystals sealed in garnet and other phases have a higher frequency shift than those in the matrix. Furthermore, the quartz inclusions show a frequency shift specific to the individual host crystals in eclogites (garnet ≈ kyanite > omphacite ≈ epidote). These observations imply that the residual pressures retained by quartz inclusions depend on elastic parameters of the host crystals, as discussed by previous researchers. The Raman frequency shift of quartz inclusions in garnet systematically increases with increasing peak metamorphic pressures from the amphibolite facies (0.30–0.55 GPa/470–570 °C), through the epidote-amphibolite facies (0.8–1.1 GPa/470–635 °C) to the quartz-eclogite facies (2.1–2.5 GPa/660–710 °C). Calibrations based on experimental work suggest that the measured Raman frequency shifts signify residual pressures of 0.1–0.2, 0.4–0.6, and 0.8–1.0 GPa for these three groups of metamorphic rocks, respectively. Normal stresses (internal pressures) of quartz inclusions in garnet, numerically simulated with an elastic model, and inferred pressure-temperature conditions at peak metamorphic stage are compatible with the residual pressures estimated from the frequency shifts. Laser Raman microspectroscopic analysis of quartz is a simple and effective method for (1) comparison of pressure conditions in metamorphic rocks formed under various pressure-temperature conditions, and (2) detection of a higher-pressure signature in metamorphic rocks extensively recrystallized during the subsequent exhumation and hydration stage.

Keywords: Raman shift, quartz, residual pressure, metamorphism, elastic model

INTRODUCTION

Laser Raman microspectroscopy is a useful tool for identification of minute crystals in terrestrial and extraterrestrial materials and inclusions in optically transmissive host phases (e.g., Wang et al. 1999; Gillet et al. 2002; Zedgenizov et al. 2004). The Raman spectral investigations of metamorphic rocks have (1) shown that garnet and zircon are useful pressure containers for the preservation of ultrahigh-pressure (UHP) phases (e.g., Sobolev and Shatsky 1990; Sobolev et al. 1995); and (2) revealed evidence for UHP metamorphism such as coesite and microdiamond inclusions in zircon and garnet from extensively retrograded gneissic rocks in several UHP metamorphic terranes (e.g., Tabata et al. 1998; Parkinson and Katayama 1999; Ye et al. 2000; Liu et al. 2001).

Coesite is identified by its diagnostic Raman spectrum with a strong band at about 521 cm⁻¹ at room temperature and atmospheric pressure (Sharma et al. 1981; Boyer et al. 1985; Hemley 1987). The main bands of α-quartz are located at about 464, 205, and 128 cm⁻¹. These Raman spectra often show shifts to higher frequency in various degrees depending on their mode of occurrence. Parkinson and Katayama (1999) and Parkinson (2000) reported that (1) the 521 cm⁻¹ band of monocristalline coesite inclusions in unfractured zircon and garnet of Kokchetav UHP metamorphic rocks shifts to 525–526 cm⁻¹; and (2) coesite inclusions occurring inside fractured host crystals show no significant Raman frequency shift. They deduced that the monocristalline coesite inclusions having the higher Raman frequency shift still retain ultrahigh overpressures (1.9–2.3 GPa).

Ye et al. (2001) classified the coesite/quartz inclusions in zircons from the Dabieshan-SuLu UHP metamorphic terrane into the following three types on the basis of textures: (1) single grains or aggregates of coesite with polycrystalline quartz totally enclosed in zircon without fractures; (2) single crystals or aggregates of coesite with quartz that was exposed on the surface of the section during polishing—these were also enclosed in zircon; and (3) aggregates of coesite and quartz enclosed in zircon with fractures. Ye et al. (2001) showed that the monocristalline coesite inclusions having the higher Raman frequency shift still retain ultrahigh overpressures (1.9–2.3 GPa).

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