Factors in the preservation of coesite: The importance of fluid infiltration

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ABSTRACT

The survival of coesite in ultrahigh-pressure (UHP) rocks is most commonly attributed to rapid exhumation, continuous cooling during uplift, and inclusion in strong phases that can sustain a high internal over-pressure during decompression. Exceptions to all of these criteria exist. Perhaps less attention has been paid to the role of fluid infiltration in the preservation of coesite. We used infrared spectroscopy to measure water contents of coesite and coesite pseudomorphs in a variety of UHP rocks. In all cases, OH concentrations in coesite are below the detection limit of ~100 ppm H2O. The silica phases surrounding coesite, however, show varying amounts of H2O. This is most spectacularly observed in pyrope quartzites from the Dora-Maira massif that contain at least three phases of silica replacing coesite, also distinguished by varying color of cathodoluminescence (CL): palisade-textured quartz (<100 ppm H2O, red-violet CL); “mosaic” quartz, which is actually chalcedony (up to 0.4 wt% H2O, yellow/brown CL); and a rare, highly hydrated silica phase interpreted to be opal (~7 wt% H2O, dark blue CL). Very similar signatures are observed in a groszpydite xenolith from the Roberts Victor kimberlite. The quartz replacing coesite in other UHP samples studied contains on the order of 500 ppm H2O or less, and most measurements are under the detection limit of our technique. We infer that palisade quartz forms under dry or nearly dry conditions and at high temperatures during dilation of the host phase. The formation of hydrous silica phases such as chalcedony and opal, however, must take place at much lower temperatures, after cracking of the host phase, which allows external fluids to infiltrate. Delay of fluid infiltration to low temperatures, where kinetics are slow even in the presence of water, is the most critical factor in the preservation of coesite.

INTRODUCTION

Although coesite inclusions in eclogitic diamond were first reported by Sobolev et al. (1976), coesite and quartz pseudomorphs after coesite were first identified and fully described in an eclogitic rock by Smyth and Hatton (1977; see also Smyth 1977). The discovery of coesite in regionally metamorphosed rocks of the Dora-Maira massif (Western Alps) by Chopin (1984) proved for the first time that continental crust has been subducted to depths of 100 km or more and subsequently returned to the surface of the Earth. This remarkable finding galvanized the field of metamorphic petrology and spurred multi-disciplinary progress in our understanding of the tectonics of continental collision and mountain building. One enduring question for petrologists is how to explain the preservation of coesite, which is highly metastable at low pressures and should revert easily to quartz during exhumation of the host rocks from such great depths. Four major factors required for the survival of coesite were invoked by Chopin (1984), and they remain the most commonly cited criteria in more recent literature (e.g., Hacker and Peacock 1995; Ernst 1999, 2001). Perhaps the most critical factor is thought to be its inclusion in strong host phases, such as garnet and zircon, which can act as “pressure vessels” and sustain an overpressure on the inclusion, inhibiting the volume increase necessary to transform to quartz (Gillet et al. 1984; van der Molen and van Roermund 1986). Other factors considered to be important are rapid exhumation, continuous cooling during decompression, and prevention of fluid infiltration into the host mineral until fracturing at low temperatures.

In the last two decades following the initial discovery, coesite has been found in numerous other localities and some challenges to the above hypotheses have appeared. Discovery of coesite (and/or its well-preserved pseudomorphs) as inclusions in the volatile-bearing and relatively weak phases dolomite (Schertl and Okay 1994; Zhang and Liou 1996), tourmaline (Reinecke 1991), zoisite (Zhang et al. 1995a), epidote (Enami et al. 2004), apatite (Reinecke 1998), and wagnerite (Brunet et al. 1998) poses difficulties for the “pressure vessel hypothesis,” as does the extremely rare finding of intergranular coesite, sandwiched between two or more minerals (Liou and Zhang 1996; Wallis et al. 1997).

Rapid exhumation in most UHP terranes has now been confirmed with geochronological data (Gebauer et al. 1997; Amato et al. 1999; Rubatto and Hermann 2001; Carswell et al. 2003; Hacker et al. 2003; Treloar et al. 2003). However, uncertainties remain as to the residence time of some UHP rocks at elevated temperature within the middle or upper crust (e.g. Walsh and Hacker 2004), following an initial period of rapid exhumation.