FLUIDS IN THE CRUST

A new experimental approach to study fluid–rock equilibria at the slab-mantle interface based on the synthetic fluid inclusion technique

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ABSTRACT

The role of high-pressure aqueous fluids in mass transfer processes during slab dehydration has been recognized for a long time. However, the quantitative assessment of their material transport capacity in complex natural systems remains poorly understood, mainly as a consequence of their unquenchable nature and current experimental limitations. A new experimental approach has been developed to investigate complex fluid–rock equilibria at high-pressure and -temperature conditions relevant for slab dehydration processes. Aqueous fluids pre-equilibrated with high-pressure mineral assemblages were sampled at run conditions in the form of synthetic fluid inclusions (SFI) in quartz and subsequently analyzed by laser-ablation ICPMS (LA-ICP-MS). The main innovation introduced in the experiments is that the quartz crystal was fractured in situ during the run only after chemical equilibrium between phases has been achieved, thus allowing the entrapment of fluid inclusions that sample true equilibrium compositions. An efficient fracturing of quartz at high-pressure and temperature conditions was achieved by crossing the α-quartz–coesite reaction boundary, which occurs at pressures of the sub-arc slab-mantle interface. An experimental methodology has been developed to implement this strategy and experiments in the eclogite–water system were conducted to demonstrate the feasibility and advantage of the method. The results demonstrate that secondary fluid inclusions formed early in pre-fractured quartz are systematically diluted compared to secondary inclusions formed after in situ fracturing of quartz, particularly for elements such as Sr, Zr, Nb, Ti, and Mg. These observations demonstrate that early entrapment of fluids in pre-fractured quartz do not represent equilibrium fluids at high-pressure-temperature conditions.

Keywords: Subduction zone, magma, slab dehydration, high-pressure fluids, synthetic fluid inclusions

INTRODUCTION

Aqueous fluids along with hydrous melts and supercritical liquids are considered as the transport agents responsible for large-scale mass transfer from the subducting slab to the mantle wedge (e.g., Manning 2004; Poli and Schmidt 2002; Scambelluri and Philippot 2001; Ulmer 2001). However, it remains unclear which of these mobile phases is responsible for the transfer of slab-derived components that metasomatize the mantle wedge, ultimately leading to the characteristic trace-element signature of arc magmas. Hydrous silicate melts have received the most attention in terms of mineral solubility and trace-element partitioning studies because they can be sampled by quenching them to glasses and subsequently analyzed by several techniques. Numerous experimental studies have reported the composition of hydrous silicate melts in equilibrium with relevant mineral assemblages (e.g., Brenan et al. 1995a; Klemme et al. 2002, 2005; Prowatke and Klemme 2006; Hermann and Rubatto 2003; Hermann and Spandler 2008; Klimm et al. 2008; Skora and Blundy 2012; Spandler and Pirard 2013), and many authors consider melts as the main transport agent. The available information on the composition of aqueous fluids is much scarcer as they cannot be quenched and experiments suited to determine their composition at high pressure (P) and temperature (T) remain challenging.

One of the first experimental approaches established to determine the solubility of minerals in high P-T aqueous fluids is the weight-loss technique. This technique has been well proven on systems that dissolve congruently, such as calcite/quartz/rutile and H2O (e.g., Caciagli and Manning 2003; Manning 1994; Troppe and Manning 2005). However, its application is limited in multi-component systems, which involve incongruent dissolution of the mineral phases, as well as in mineral solubility studies at trace concentration levels or in fluid/mineral partitioning studies. The unquenchable nature of aqueous phases has thus required the development of original experimental approaches to characterize in situ the chemical composition and/or structure of aqueous fluids and hydrous melts at conditions relevant for subduction zones. For instance, approaches employing diamond-anvil cells (DAC) in conjunction with synchrotron X-rays have provided