Synthetic fluid inclusions as recorders of microfracture healing and overgrowth formation rates

STÉPHANE TEINTURIER* AND JACQUES PIRONON

UMR G2R-7566, Université Henri Poincaré BP239, F-54506 Vandoeuvre-lès-Nancy Cedex, France

ABSTRACT

Aqueous fluid inclusions have been synthesized within fluorite microfractures \( (T = 200 \, ^\circ\text{C}, P = P_{\text{sat}}, t < 30 \, \text{days}) \), quartz microfractures, and quartz overgrowths \( (T = 400 \text{ to } 300 \, ^\circ\text{C}, P = 400 \, \text{bars}, t < 20 \, \text{days}) \). The experiments were designed to determine the time necessary to form the inclusions, within a minute in a fluorite host, and within a day in a quartz host. The results permit estimation of the time needed to heal microfractures or create overgrowths, which is accomplished by measuring the melting temperature \( (T_{m}) \) of the inclusions in fluorite and the homogenization temperature \( (T_{h}) \) of the inclusions in quartz.

For the fluorite experiments, the results show that fluorite/\( \text{NH}_{4}\text{Cl} \) solution equilibrium took 82 hours. Moreover, the healing process appears to be an irregular process along the microfracture. Fluorite experiments mimic boiling processes occurring in natural hydrothermal or epithermal systems and show how a boiling fluid may be progressively salted during vaporization and trapped as fluid inclusions.

For the experiments involving quartz, the quartz/\( \text{H}_{2}\text{O}-\text{NaCl} \) solution equilibrium was reached on the first day for synthetic quartz and on the sixth day for natural quartz. This difference is linked to the hydration state of the two types of quartz. The decrease in \( T_{h} \) of synthetic fluid inclusions from the core-overgrowth boundary to the external part of the quartz overgrowth shows that the growth of quartz is a progressive and protracted process, which involves a silica oversaturated solution.

INTRODUCTION

Fluid inclusions are often used to delineate diagenetic events (i.e., mineral growth, the healing of microfractures) in time and space. Nevertheless, natural case studies often show poor control on timing of inclusion formation, especially if the inclusions have been reequilibrated, re-filled, or necked-down (Teinturier et al. 2002). The amount of time needed to form fluid inclusions is mainly related to the pressure and temperature of the system, but is also controlled by the fluid chemistry, the dimensions of the crack, and the cementation rates of the host mineral (Brantley 1992). Previously, crack sealing in fluorite crystals was documented in the \( \text{H}_{2}\text{O}-\text{NaCl}-\text{CH}_{4} \) system over four weeks at a constant temperature of 200 \( ^\circ\text{C} \) (Dubessy et al. 2000). For quartz, crack-healing experiments have been documented at 200–600 \( ^\circ\text{C} \) and at vapor pressures up to 2 kbar (Smith and Evans 1984; Brantley 1992; Sawaki et al. 1997; Guillaume et al. 2003). Sawaki et al. (1997) showed that it took several hours to synthesize a small number of inclusions with a pH 13 solution at 300 \( ^\circ\text{C} \) and four days at 200 \( ^\circ\text{C} \) under saturated vapor pressures. With pure water and neutral pH conditions, it takes two weeks to synthesize smaller inclusions in quartz around 300 \( ^\circ\text{C} \) and saturated vapor pressures (Sawaki et al. 1997).

In this paper we aim to study fluid inclusion formation under laboratory conditions, both in fluorite microfractures \( (T = 200 \, ^\circ\text{C}, P = P_{\text{sat}}, t < 30 \, \text{days}) \) in the \( \text{NH}_{4}\text{Cl}-\text{H}_{2}\text{O} \) system, and in quartz microfractures and quartz overgrowths \( (T = 400 \text{ to } 300 \, ^\circ\text{C}, P = 400 \, \text{bars}, t < 20 \, \text{days}) \) in the \( \text{NaCl}-\text{H}_{2}\text{O} \) system. The fluorite experiments were conducted under constant \( P-T \) conditions and during a progressive decrease in salinity accomplished by induced leakage, whereas the quartz experiments were carried out at constant pressure by decreasing the temperature by 10 \( ^\circ\text{C} \) per day. Petrographic observations coupled to microthermometric data allowed us to acquire temporal and spatial information about inclusion sealing within the fluorite microfractures and within quartz microfractures and quartz overgrowths. The experimental and analytical procedures described here should allow dating of fluid inclusion formation, which can aid in determining mineral growth kinetics.

EXPERIMENTAL PROCEDURE

Fluorite crystals (SOREM) were thermally fractured by immersing heated crystals in cold water. The quartz experiments were conducted using natural Brazilian quartz fragments (<1cm) and synthetic quartz (1 cm in length with a square section of 0.3 mm), which were cut perpendicular to the c axis. Prior to synthesis, samples were heated to 700 \( ^\circ\text{C} \) to eliminate pre-existing inclusions. Quartz was then thermally fractured as above and dried for six hours at 80 \( ^\circ\text{C} \).

Fluorite experiments were carried out in a 150 cm\(^3\) gas-pressure autoclave (‘Autoclave Engineer), while maintaining equilibrium between liquid and vapor at experimental conditions (Fig. 1). Under these conditions, the homogenization temperatures \( (T_{h}) \) of resulting inclusions are equal to the trapping temperature of the fluid inside the inclusion.