TIME-RESOLVED 3D X-RAY IMAGING OF HYDRATION REACTIONS

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Summary: The hydration of periclase and its transformation to brucite was used as analogue for retrogressive metamorphism processes occurring in the Earth's crust. The Hades rig at the beamline ID19 of the European Synchrotron Radiation Facility was used to monitor and image by in situ X-ray microtomography this mineral transformation at different temperature and pressure conditions. At low pressure conditions, chemical reaction induced fracturing phenomenon was observed, whereas at high pressure no fracture developed. Time-resolved 3D imaging of this reaction demonstrates that fracturing induced chemical reactions can speed up chemical rates by orders of magnitude.

1. INTRODUCTION

In the Earth's crust, hydration metamorphism is pervasive and may lead to the serpentinization of oceanic crust and the eclogitization of the lower continental crust [1]. Fracture generated by the hydration reactions may accelerate chemical reactions by producing more reactive surface area. However, the process cannot be directly accessed at depth. In the present study, we use a magnesium oxide ceramics – periclase - as a rock analogue to reproduce the hydration reactions under similar temperature and pressure conditions with those occurring at depth.

2. EXPERIMENTAL METHOD

The experiments were performed using high-resolution X-ray tomography at the beamline ID19 of the European Synchrotron Radiation Facility (ESRF) with the Hades rig (see a sketch of the rig on Fig. 1(a)), in Grenoble [2]. Core samples of magnesium oxide (periclase) were used as starting material. Under the presence of water, this mineral transforms into brucite according to the reaction: MgO(s) + H2O(l) = Mg(OH)2(s), with a large volume increase of 40%. The temperature condition was controlled at approximately 200 °C while three sets of pressure condition (1) Pa = 11 MPa, Pc =10 MPa; (2) Pa = 20 MPa, Pc = 10 MPa; and (3) Pa =81 MPa, Pc = 80 MPa, where Pa represents the axial pressure and Pc confining pressure. . These experimental conditions are shown on Fig. 1 (b). In the above three experiments, a fluid pressure in the range 4.5 MPa – 5 MPa were applied. X-ray microtomography experiments were performed every 3 minutes during several hours to follow the chemical reaction. The data processing was performed using the softwares (matlab, Avizo 9 and ImageJ) to extract porosity evolution, microfracture development, and the relative amount of periclase and brucite evolution through time.

3. RESULTS

The results show that at the lowest pressure conditions (Pa = 11 MPa, Pc =10 MPa; Pa = 20 MPa, Pc = 10 MPa), the reaction from periclase to brucite initiates along pre-existing heterogeneities such as elongated pores. Such initial porosity controls the rock-fluid reaction. Then, the volume change caused by the reaction accelerates the reaction by fracturing the whole sample and fragmenting it until a complete reaction. For a higher confining pressure (Pa = 81 MPa, Pc = 80 MPa), there are still fluid-rock interaction visible through the clogging of pre-existing pores with brucite. However, once these pores are closed, no fracturing could be observed and the reactions get inhibited. The experiments show that the hydration metamorphic reaction process preferentially at the sites where fluid get more interaction with rocks. So porosities and cracks are preferential reaction front and the volume changes induced by reaction might lead to more porosity and cracks.

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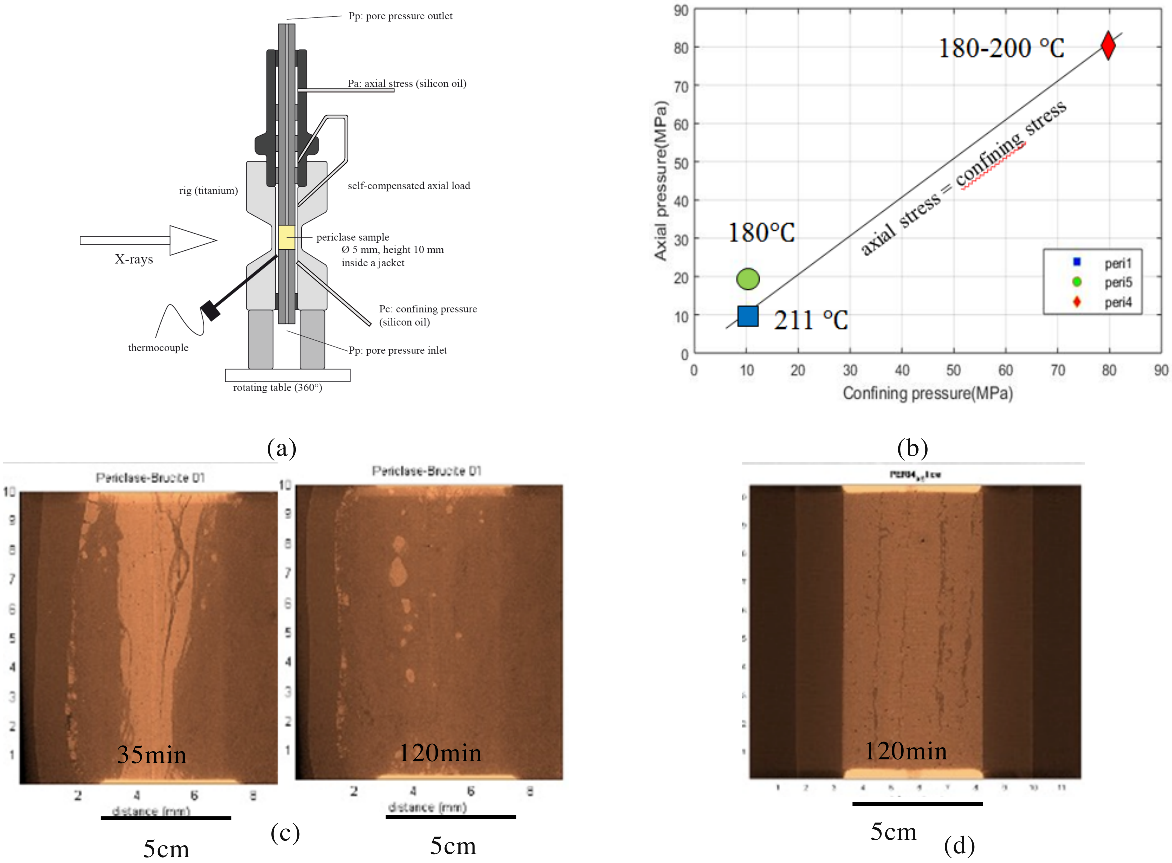

Figure 1: (a) Sketch of the triaxial rig Hades. (b) Experimental conditions. (c) Fracture accompanied hydration reactions during the transformation of periclase to brucite. Experiments were performed at 10 MPa confining pressure, 11 MPa axial pressure, 5 MPa pore fluid pressure, and a temperature of 210°C. (d) Inhibited reaction where no fracturing occurred. This experiments was performed at 80 MPa confining pressure, 81 MPa axial pressure, 5 MPa pore fluid pressure, and a temperature of 200°C. The elongated vertical pores correspond to initial heterogeneities in the periclase sample. In this experiment, no fractured could form due to the higher confining pressure.