Hydrothermal troctolite alteration at 300 and 400 °C: Insights from flexible Au-reaction cell batch experimental investigations

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ABSTRACT

Troctolites are increasingly recognized as a common rock found in association with oceanic core complexes. They are similar to komatite in composition, and hence troctolite alteration may provide insight into H₂ production on Early Earth. We investigated the hydrothermal alteration of olivine-rich troctolites in two batch experiments (300 °C, and 400 °C – 40 MPa) by reacting forsteritic olivine and anorthite-rich plagioclase with salt solutions. The alteration process was evaluated based on concomitant fluid samples and solids retrieved upon the termination of the experiments. In both experiments, the initial rock powder was turned into a hard, compact mass through cementation by secondary phases. The heterogeneity of this mass was documented using µ-computed tomography and electron microscopy. Thermodynamic computations were conducted to determine the equilibrium phase assemblages and fluid compositions with increasing reaction turnover.

Mineral zonation developed between the fast-reacting, fluid-dominated top portion of the solids and the more isolated portions at the bottom of the reaction cell. At 300 °C, the total reaction turnover after 1800 h was 77.5%. Serpentinitization of olivine controlled the fluid composition after plagioclase had reacted away in the top layers. In contrast, a Ca- and Al-enriched assemblage of xonotlite and chlorite developed alongside unreacted plagioclase at the bottom. The porosity is very low in the top layers but high (around 15%) in the bottom part of the cemented mass. At 400 °C, the reaction turnover was only 51% as olivine was stable after plagioclase had reacted away. Clinopyroxene and andradite ± chlorite had formed in the top layers, whereas xonotlite, grossular, and chlorite had formed at the bottom. The permeability is more uniform and the mineral zonation less pronounced at 400 °C. These mineral zonations developed as a consequence of increased mobility of Ca, Al, Mg, and to a lesser extent of Fe in the experiment, which may be facilitated in the highly permeable granular materials when compared to a compact rock. Steady-state hydrogen concentrations were at least 20 mmol L⁻¹ at 300 °C and <1 mmol L⁻¹ at 400 °C. A lack of magnetite formation at the higher temperature is responsible for the low-H₂ yields.

KEYWORDS: Troctolite alteration, experimental petrology/geochemistry, hydrogen, fluid-rock interaction

INTRODUCTION

Oceanic core complexes (OCCs) are the result of extensive detachment faulting and exhumation along slow and ultraslow spreading ridges and provide a unique opportunity to study fluid-rock interactions between seawater and ultramafic lithologies (Blackman et al. 1998; Smith et al. 2008, 2012). These unique settings have attracted increasing interest, especially since hydrothermal systems hosted in OCCs produce some of the most fascinating geochemical environments on earth (Charlou et al. 2002; Schmidt et al. 2007; German et al. 2010). The hydrothermal fluids originating from alteration of ultramafic rocks are often extremely enriched in H₂ and CH₄, which support chemolitho-autotrophic microorganisms in core complex-hosted hydrothermal vent systems (Takai et al. 2004; Kelley et al. 2005). The production of H₂ and CH₄ in these systems is commonly related to serpentinitization of mantle peridotite (Charlou et al. 2002; Sleep et al. 2004; Takai et al. 2004; Proskurowski et al. 2006; Konn et al. 2015), and hence most studies investigating the underlying reactions focused on ultramafic rocks (Seyfried et al. 2007; Klein et al. 2009, 2013; McCollom and Bach 2009; Cannat et al. 2010). However, other lithologies associated with OCCs reveal a high geochemical diversity of rocks in the crust-mantle transition zone facilitated by varied water-rock reactions during OCC exhumation such as rodiginitization (Bach and Klein 2009; Frost et al. 2008) or melt impregnation of mantle peridotite (Jöns et al. 2010; Albers et al. 2019). These metasomatic reactions are driven by strong contrasts in chemical potential between major rock components, such as silica (Frost and Beard 2007; Klein et al. 2009, 2014). In this respect, troctolites provide