Hydrothermal chloritization processes from biotite in the Toki granite, Central Japan: Temporal variations of the compositions of hydrothermal fluids associated with chloritization

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ABSTRACT

This paper describes the biotite chloritization process with a focus on mass transfer in the Toki granitic pluton, Central Japan, and also depicts the temporal variations in chemical characteristics of hydrothermal fluid associated with chloritization during the sub-solidus cooling of the pluton. Singular value decomposition (SVD) analysis results in chloritization reaction equations for eight mineral assemblages, leading to the quantitative assessment of mass transfer between the reactant and product minerals, and inflow and outflow of components through the hydrothermal fluid. The matrices for SVD analysis consist of arbitrary combinations of molar volume and closure component in the reactant and product minerals. The eight reactions represent the temporal variations of chemical characteristics of the hydrothermal fluid associated with chloritization: the progress of chloritization results in gradual increase of silicon, potassium, and chlorine and gradual decrease of calcium and sodium in the hydrothermal fluid with temperature decrease. The biotite chloritization involves two essential formation mechanisms: chloride formation (CF) mechanism 1, small volume decrease from biotite to chloride and large inflow of metallic ions such as Al³⁺, Fe²⁺, Mn²⁺, and Mg²⁺ from the hydrothermal fluid, and CF mechanism 2, large volume decrease and large outflow of the metallic ions into hydrothermal fluid. Chlorite produced with CF mechanism 1 dominates over that of CF mechanism 2, resulting in the gradual decrease of the metallic components in the hydrothermal fluid with chloritization progress. The chloritization reactions also give the temporal variations in physicochemical parameter of the hydrothermal fluid: a gradual decrease of pH and a gradual increase of redox potential in the hydrothermal fluid as chloritization proceeds. The combination of continuous reactions based on compositional variations in chloride together with corresponding continuous Al⁴⁺ variations gives an indication of the temporal variations in rates of decreasing and increasing concentration of chemical components in the hydrothermal fluid associated with chloritization. The biotite chloritization and resultant temporal variations of chemical and physicochemical characteristics in hydrothermal fluid act as a trigger for the successive dissolution–precipitation process of a granitic rock.

Keywords: Chloritization, fluorine-bearing biotite, hydrothermal fluid, tetrahedral aluminum in chlorite, singular value decomposition (SVD) analysis

INTRODUCTION

This study focuses on biotite chloritization in granite due to hydrothermal alteration. Hydrothermal alteration influences the geochemical features in a granitic rock (Ferry 1979). The degree and extent of the hydrothermal alteration in a granitic rock has a significant effect on weathering processes, which also influence the chemical characteristics of the groundwater due to water-rock interaction. Nishimoto and Yoshida (2010) described how the hydrothermal alteration in the granitic rock is constrained mainly by the dissolution–precipitation process during the infiltration of hydrothermal fluid along microcracks. The hydrothermal alteration of the granite progressed through three successive stages:

1. partial dissolution of plagioclase and partial chloritization of biotite,
2. biotite chloritization and precipitation of corrensite and smectite in the dissolution pores of plagioclase, and
3. dissolution of K-feldspar, the chlorite, corrensite, and smectite and precipitation of illite (i.e., sericitization). In such a hydrothermal alteration process, biotite chloritization occurs under a wide temperature range below about 400 °C (e.g., De Caritat et al. 1993; Yoneda and Maeda 2008) and occurs ubiquitously throughout the granitic rock body. Chlorites of hydrothermal origin in granitic rocks record the chemical characteristics of the hydrothermal fluid, which will therefore provide an important clue to the nature of alteration reactions and mass transfer due to hydrothermal fluid advection in the granitic pluton through a wide temperature range during sub-solidus cooling.

The biotite chloritization reaction in granitic rocks has