Role of silica for the progress of serpentinization reactions: Constraints from successive changes in mineralogical textures of serpentinites from Iwanaidake ultramafic body, Japan

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ABSTRACT

Serpentinization of peridotite in subduction zones and mid-ocean ridges is a key process that controls not only the geodynamic behavior of the mantle but also the activity of modern (and probably primordial) microbial systems on the seafloor. However, there is still controversy about what factors promote the mineralogical reactions of serpentinization in natural ultramafic rocks. Here we report textures, chemistry, and magnetic susceptibility of variably serpentinized harzburgite and dunite samples from Iwanaidake ultramafic body, Japan, which originated from the forearc mantle of the Northeast Japan arc. Successive changes in textures, mineral chemistry, and magnetic susceptibility during serpentinization of harzburgite involved two stages: replacement of olivine by serpentine and brucite, and subsequent formation of magnetite along with more-magnesian serpentine and brucite. The later reactions occurred concurrently with serpentinization of orthopyroxene, which supplied the silica component. In serpentinized dunite, which does not contain orthopyroxene, serpentinization involved replacement of olivine by serpentine and brucite, and the fraction of magnetite did not increase with the progress of serpentinization. These observations suggest that the silica supply from serpentinization of orthopyroxene is an essential factor for the formation of magnetite during serpentinization. Magnetite formation facilitated by addition of silica has often been reported for many serpentinite systems, suggesting that the magnetite formation triggered by silica addition is one of the key reactions for the progress of serpentinization in natural ultramafic rocks.

Keywords: Serpentine, magnetite, magnetic susceptibility, bulk H₂O content, mineralogical texture

INTRODUCTION

The transformation of mantle peridotite into serpentinite changes the physical properties of the mantle, such as seismic velocity, density, magnetic susceptibility, electric conductivity, and viscosity (e.g., Toft et al. 1990; Dyment et al. 1997; Escartin et al. 1997; Mèvel 2003; Katayama et al. 2009; Hirauchi et al. 2010). Serpentinization also produces hydrogen, which is essential for the establishment of microbial communities in serpentinite-hosted hydrothermal fields on the seafloor (e.g., Takai et al. 2004; Nealson et al. 2005). It is now generally thought that microbial activities associated with serpentinite-hosted hydrothermal systems played a key role in the genesis of life in the early oceans (e.g., Sleep et al. 2004; Martin et al. 2008).

Recent petrologic studies have proposed that serpentinization reactions proceed via a two-stage process involving the early formation of serpentine + brucite and subsequent magnetite formation (e.g., Toft et al. 1990; Bach et al. 2006; Beard et al. 2009). Magnetite, which is the key mineral controlling the magnetic properties, electrical conductivity, and density of peridotite, as well as the efficiency of hydrogen production, is thought to be formed by the second-stage reaction, but there remains considerable controversy regarding what factors promote the formation of magnetite (e.g., Oufi et al. 2002; Bach et al. 2006; Frost and Beard 2007; Beard et al. 2009; Plümper et al. 2012; Frost et al. 2013). Bach et al. (2006) and Beard et al. (2009) proposed that magnetite is formed by the breakdown of brucite promoted by the addition of aqueous silica:

\[ \text{brucite} + \text{silica} = \text{serpentine} + \text{magnetite} + \text{water} + \text{hydrogen} \]

Conversely, Katayama et al. (2010) suggested that magnetite is formed by the breakdown of ferroan serpentine, which results in the production of silica component:

\[ \text{serpentine} = \text{magnetite} + \text{silica} + \text{water} + \text{hydrogen} \]

In contrast, Evans (2008, 2010) suggested that the Fe-Mg exchange potential of olivine and the variability of Fe³⁺ in serpentine minerals are key factors to control the formation of magnetite.

One of the clues to solve this controversy is the successive change in mineralogical textures with the progress of serpentinite reactions, which will allow us to constrain the reactions responsible for the progression of serpentinization, because multistage serpentinization processes are expected to produce different textures in serpentinites at each stage of the reaction. Textural changes with the progress of serpentinization have been...