Modified magnetite and hydrothermal apatite in banded iron-formations and implications for high-grade Fe mineralization during retrogressive metamorphism

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ABSTRACT

Modified magnetite and hydrothermal apatite in banded iron formations (BIFs) are ideal minerals for studying hydrothermal and metamorphic processes and are applied to linking with high-grade Fe mineralization and metamorphism in iron deposits hosted by BIFs. In this study, we have investigated the geochemical composition of modified magnetite and hydrothermal apatite and in situ U-Pb geochronology on apatite from the Huogezhuang BIF-hosted Fe deposit in northeastern China. The magnetite in metamorphosed BIF is modified, locally fragmented, and forms millimeter- to micrometer-scale bands. The apatite is present surrounding or intergrowing with magnetite, has corroded surfaces, and contains irregular impurities and fluid inclusions, indicating that it has been partly hydrothermally altered. Original element compositions (e.g., Fe, Al, Ti, K, Mg, and Mn) of magnetite in BIFs have been modified during high-grade Fe mineralization and retrogressive metamorphism with temperature reduction and addition of acids. The hydrothermally altered apatite has been relatively reduced in the contents of Ca, P, F, La, Ce, Nd, δCe, δEu, and total REEs compared to non-altered apatite. The magnetite and apatite in low-grade BIFs are poorer in FeO T than those from the high-grade Fe ores, indicating that Fe is remobilized during the transition from BIFs to high-grade Fe ores. The magnetite and apatite in high-grade Fe ores are overgrown by greenschist-facies minerals formed during retrograde metamorphism, suggesting that the high-grade Fe mineralization may be related to retrogressive metamorphism. In situ U-Pb geochronology of apatite intergrown with magnetite and zircon LA-ICP-MS U-Pb dating at Huogezhuang deposit reveals that the BIF-hosted magnetite was altered and remobilized at ca. 1950–1900 Ma, and deposition of the BIF began during the Late Neoarchean. The changes of elements in the modified magnetite and different geochemical compositions of the altered and unaltered apatite confirm that the modified magnetite and hydrothermal apatite can be effective in tracing high-grade Fe mineralization and retrogressive metamorphism in BIFs.

Keywords: Banded iron-formation, apatite, magnetite, high-grade iron ore, mineralization and metamorphism, Huogezhuang deposit

INTRODUCTION

The banded iron formations (BIFs) hosted iron deposits are an important iron resource, with the quantity of both exploitation and resource reserve ranking first in the world (Zhang et al. 2014a, 2014b, 2021; Li et al. 2015a). The high-grade Fe ores in China only account for <2%, which is significantly different from other countries where the high-grade ores are mainly BIFs-type iron ores (Zhang et al. 2014a, 2014b, 2021; Li et al. 2015a, 2016, 2019). Most of them are high-grade hematite deposits, with multistage fluids moved downward and leached the BIFs along deformation structures, including the Hamersley Province in Australia and the Quadrilátero Ferrífero region in Brazil (Hagemann et al. 2016; Sheppard et al. 2017a, 2017b; Rasmussen and Muhling 2018; Li et al. 2019). However, the high-grade Fe ores in China are related to magnetite deposits hosted by BIFs and have undergone retrograde metamorphism with fluid metasomatism (Li and Zhang 2013; Lan et al. 2019a, 2019b; Green et al. 2020). High-grade magnetite deposits hosted by BIFs have been mined mainly in the Anshan-Benxi area and eastern Hebei province-Miyun Terrane in northern China (Wan et al. 2018; Wang et al. 2018).

Magnetite and associated minerals (such as apatite, xenotime, and monazite intergrown with magnetite) are ideal provenance indicators for genetic studies of the Archaean to Early Paleoproterozoic BIFs (Lan et al. 2019a, 2019b). Compositions of these minerals have been successfully used for tracing the genesis of BIFs and the enrichment mechanism of the BIFs-related high-grade Fe ores (e.g., James 1954; Gross 1980, 1983; Clout and Simonson 2005; Dai et al. 2014, 2017; Li et al. 2019; Afrabi et al. 2021; Pirajno and Yu 2021). Most BIFs have undergone retrograde metamorphism at various grades after diagenesis (Klein 1978; Klein and Beukes 1993; Mücke et al. 1996; Konhauser et al. 2009; Li and Zhang 2013; Lan et al. 2019a, 2019b; Green et al. 2020). Magnetite (an abundant and widespread oxide mineral) and apatite (a common tracer mineral) in BIFs are ideal minerals to study the hydrothermal and metamorphic processes and the genesis of high-grade iron ores of BIFs (Cook et al. 2019b; Green et al. 2020).