Crystallographic texture of the magnetite-hematite transformation: Evidence for topotactic relationships in natural samples from Quadrilátero Ferrífero, Brazil

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ABSTRACT

The transformation of magnetite to hematite is described and analyzed in three natural samples of banded iron formation, from Quadrilátero Ferrífero, Brazil. In each sample, a particular microstructure related to the transformation process is described. In the first sample, magnetite crystals are large and euhedral, and they display the beginning of the transformation into hematite. In the second sample, a relict crystal of magnetite was found and the fabric of the transformed hematite was evaluated. In the last sample, the foliation was the main observed structure and the correlations of magnetite and hematite lattices were measured. All the microstructures were analyzed in a scanning electron microscope equipped with a detector for electron backscatter diffraction allowing the complete analysis of crystallographic orientations of hematite and magnetite on a local scale. The results show that the orientations of the basal planes of hematite coincide with the orientations of the octahedral planes of magnetite, indicating that the hematite crystals are a direct product from the magnetite transformation.

Keyword: Magnetite, hematite, mineral transformation, electron backscatter diffraction (EBSD), banded iron formation (BIF)

INTRODUCTION

Hematite and magnetite are the most common constituents of the iron formations (IF) of the Quadrilátero Ferrífero (QF) region in Brazil. In contrast to magnetite, the hematite crystals are stable under different $P_2O_5$ due to the presence of ferric iron (Otke et al. 2007), whereas magnetite possesses both oxidation states of iron, Fe$^{2+}$ and Fe$^{3+}$ (Fleet 1981). The difference between the stability of the two minerals, under different oxidation conditions, promotes the natural conversion of hematite to magnetite (Mücke 2003; Mücke and Cabral 2005). During the oxidation of magnetite, the trigonal and cubic lattices of the two oxides involved in the reaction are linked together by specific topotactic relationships (Heizmann et al. 1981). In QF and other iron formations around the world, the transformation of magnetite to hematite is very common (Floran and Papike 1978; Morris 1980; Mücke and Annor 1993; Rosière et al. 2001). Magnetite as the result of the hematite transformation, for example, is a very common iron oxide in many typical iron formations of the world. On the other hand, hematite is also abundant in secondary high-grade iron formations, originating from magnetite transformation (Otke et al. 2007). The three samples analyzed in this paper come from the metasedimentary sequence of iron formations of QF that was regionally deformed by folding and transposition of the original compositional banding (Alkmim and Marshak 1998). The deformation took place under regional metamorphism of greenschist to lower amphibolite facies (Herz 1978; Pires 1995), and the direct observation of the deformation in the iron formations is the transformation of magnetite to hematite with no evidence of maghemite metastable phases. The extensive presence of an aqueous fluid phase is indicated by the widespread presence of quartz veins associated with rich horizons of Fe oxides (Lageiro 1998) and phyllonitic rocks (Hippert 1998).

In the past, the geologic investigation of phase transformations and their related microstructures of Fe oxides have been conducted only in a qualitative aspect through the use of petrographic microscope. Techniques such as electron microscopy and X-ray diffraction have become useful in the quantitative analysis of these phase transformations. With these methods the description of phase differentiation can be based on the crystalline lattice of the mineral itself and not only exclusively on the optical properties, which in some cases have been shown to be subjective. Nowadays, although many methods of texture analysis are capable of evaluating the crystallographic orientation of single crystals (Leiss et al. 2000; Randle and Engler 2000), the electron backscatter diffraction technique (EBSD) has the advantage of measuring the complete crystallographic orientation on the scale of the electron beam–sample interaction volume.

In the context of the magnetite transformation to hematite, it is crucial to obtain the spatial position of the measured grain in relation to the bulk texture of the aggregate. Thus, the main objective of the paper is to describe the most frequent crystallographic textures developed during the progressive phase transition of magnetite to hematite, as well as to determine, when it is possible, a genetic relationship between both minerals, particularly when hematite aggregates have no direct link to magnetite grains. This is important in the sense that, if the transformation leaves a crystallographic memory on the new crystals, the study of crystallographic orientations in the site of transformation can be compared with those of hematite aggregates where no direct evidence of the transformation can be observed. This might be useful for evaluating the extent to which