Temperature dependence of reflectance spectra and color values of hematite by in situ, high-temperature visible micro-spectroscopy

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ABSTRACT

We measured visible reflectance spectra and colors of hematite (α-Fe2O3) reagent powders and a natural feldspar grain containing dispersed hematite microcrystals from room temperature up to 800 °C using an in situ, high-temperature visible micro-spectrometer with dark field optics. The spectrum of room-temperature hematite powder is characterized by a nearly constant reflectivity in the range 400–550 nm, a shoulder near 620 nm, and a reflectivity maximum near 750 nm. The reflectance spectrum is similar to the diffuse reflectance spectra measured by a spectrophotometer and a conventional spectrometer with an integrating sphere. This result indicates that the dark field objective is suitable for measuring visible reflectance spectra of hematite powders with the visible micro-spectrometer. The reflectance of hematite powders in the longer wavelength region (>550 nm) decreases gradually with increasing temperature. The shoulder centered around 620 nm and the reflectance maximum near 750 nm also become indistinct at high temperatures. The calculated L* (dark-light), a* (red-green), and b* (blue-yellow) color values decrease with increasing temperature. This means that the red color of hematite becomes black with temperature increase. The calculated absorption intensities (Kubelka-Munk functions) suggest that this temperature dependence of the hematite powder-reflectance spectra can be mainly explained by a change in band gap absorption edges for a semiconductor ( Urbach rule). The visible spectra and colors of a natural feldspar grain containing dispersed hematite microcrystals show a similar change with temperature, indicating that the temperature dependence can be observed under natural conditions at high temperatures, such as in volcanic eruptions.

Keywords: Visible micro-spectroscopy, dark field optics, hematite, visible reflectance spectra, L*a*b* color values, temperature dependence, Kubelka-Munk function

INTRODUCTION

Colors and visible spectra of volcanic materials at high temperatures change with time because transition metal ions such as Fe2+ and Fe3+ are oxidized/reduced and some oxidized products like hematite (α-Fe2O3) are formed. Color changes in volcanic materials have been used as indicators for their high-temperature oxidation (Tait et al. 1998; Miyagi and Tomiya 2002; Yamanoi et al. 2004). Yamanoi and Nakashima (2005) developed in situ, high-temperature visible micro-spectroscopy for monitoring visible spectral changes with time of the high-temperature oxidation of olivine at 600–800 °C. However, the spectral changes, which were obtained at high temperatures, included temperature dependence of visible spectra for heated materials (e.g., Burns 1993), besides the oxidation processes. Therefore, to quantitatively evaluate the oxidation processes and kinetics of volcanic materials, the temperature dependences at 600–800 °C of visible reflectance spectra of volcanic materials without oxidation have to be investigated first.

We have selected hematite as a representative oxidation product of volcanic materials. It was reported to be one of the causes of red coloring of a basaltic scoria (Yamanoi et al. 2004).

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Hematite is stable at high temperatures [hematite does not change into maghemite (γ-Fe2O3) up to 1380 °C in air; Petras et al. 1998]. The temperature dependence of the visible spectrum of hematite has been reported in some previous studies (Marusak et al. 1980; Sherman et al. 1982; Morris et al. 1985, 1989, 1997; Mussella et al. 2002). Marusak et al. (1980) measured visible spectra of hematite at –173–7 °C. Sherman et al. (1982), Morris et al. (1985), and Morris et al. (1997) also measured visible spectra of hematite at 5 and 41 °C, –110 and 20 °C, and about –132, –63, and 27 °C, respectively. Morris et al. (1989) measured visible spectra of superparamagnetic (nanocrystalline) hematite at –100 and 20 °C. These data were taken at temperatures below 30 °C for simulating the martian surface. Mussella et al. (2002) measured spectral reflectivity of hematite from 510 to 860 nm up to about 900 °C. However, their spectra were affected by a notch filter artifact around 600 nm because a flash-lamp-pumped dry laser operating at 596 nm was used to heat samples.

In this study, we measured high-temperature visible reflectance spectra (400–800 nm) and colors of hematite reagent powders and those of mixtures of hematite and alumina powders at room temperature (about 27 °C) up to 800 °C by means of an in situ, high-temperature visible micro-spectrometer with dark field optics. In addition, a natural feldspar grain with dispersed hematite microcrystals was measured to confirm the temperature dependence under natural conditions. The focus of our work is