Visible and short-wave infrared reflectance spectroscopy of selected REE-bearing silicate minerals

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ABSTRACT

Natural samples of the rare earth element (REE)-bearing silicate minerals cerite, mosandrite, kainosite, zircon, and eudialyte were studied using reflectance spectroscopy in the visible to short-wave infrared regions (500 to 2500 nm) and further characterized by scanning electron microscopy and electron microprobe analysis. Spectral features of these minerals are driven primarily by 4f-4f intra-configurational electronic transitions of trivalent lanthanides, as well as 5f-5f electronic transitions of uranium and vibrational overtones and combinations of H2O and OH-. Spectra of eudialyte are also impacted by relative amounts of 3+Fe and 2+Fe. Respective spectra of these REE-bearing silicate minerals are sufficiently distinct to enable spectral classification. Spectral variability (e.g., band depths and locations) of some specific REE-related absorptions, such as an Er3+- and Yb3+-related absorption near 978 nm and Nd3+-related absorptions near 746, 803, and 875 nm, are interpreted to be driven by cation site differences in the crystal structures. This work adds to the growing understanding of REE-bearing mineral reflectance spectroscopy, which facilitates detection, identification, and quantification of REE-bearing silicate minerals in remote sensing applications. This is especially relevant for hyperspectral imaging spectroscopy with high spatial resolutions where the spectral response of a pixel becomes increasingly dominated by mineralogy rather than lithology.

Keywords: Hyperspectral, reflectance, spectroscopy, rare earth elements, cerite, eudialyte, zircon, mosandrite

INTRODUCTION

Reflectance spectroscopy is being applied to a growing number of fields within the geosciences and at the same time there has been renewed interest in rare earth element (REE) deposits and minerals. Fundamental research at the intersection of these fields has been lacking, and here we provide detailed reflectance spectroscopy on several important REE-bearing silicate minerals. These minerals show a large diversity of overall crystal structures, chemical compositions, and host sites for the lanthanides. They can show strong enrichment in light rare earth elements (LREE, e.g., cerite), heavy rare earth elements (HREE, e.g., kainosite), or display relatively elevated values of all REE (e.g., mosandrite). The REE can form specific structural components (e.g., kainosite), be important constituents across multiple sites (e.g., eudialyte), or exist as trace to minor elements (e.g., zircon). The suite of minerals studied here (cerite, mosandrite, kainosite, zircon, and eudialyte) covers a wide breadth of variability but is by no means entirely comprehensive.

The REE-bearing silicate minerals can be locally abundant and contain high amounts of REE but have been traditionally viewed negatively with respect to their economic significance as compared to the REE phosphates and fluorocarbonates. Recent mineral exploration and metallurgical developments, however, are proving that some silicate phases are amenable to beneficiation (e.g., Mariano and Mariano 2012). Understanding differences in the spectral responses of REE-bearing silicates is important if reflectance spectroscopy is to be used in the exploration and exploitation of these commodities. The use of REE-bearing silicate minerals as geochronometers, especially zircon, provides an additional motivation for understanding the spectral responses of these minerals. Hancock et al. (2012) suggested that recognizing spectra of zircon in large spectral databases, such as hyperspectral core logs, could facilitate petrological studies by identifying areas with suitable (i.e., non-metamict) zircon.

This research builds on studies by Turner et al. (2014, 2016) that document the reflectance spectra of REE-bearing fluorocarbonate and phosphate minerals. Those publications documented that the strength of absorption features due to the lanthanides will primarily be a function of the concentration of the ion and the location of the absorption features will be primarily a function of the cation’s specific coordination and asymmetry in the host crystal structure. The presentation of the results of this study is similarly structured and intended to form a body of reference literature for the spectral characteristics of REE bearing minerals. The mineralogical and spectroscopic background of REE-bearing minerals is provided, followed by band registries and interpretations of spectral absorption features.

REVIEW OF REFLECTANCE SPECTROSCOPY STUDIES OF REE-BEARING SILICATE MINERALS

The widely used USGS spectral library (ver. 06, Clark et al. 2007) contains one spectrum for zircon from Brazil and one spectrum for metamict allanite from Ontario. Version 2 of the ASTER Library (Baldridge et al. 2009) contains one spectrum of zircon from Malawi. No chemical data are available for these