Reflectance spectroscopy of chromium-bearing spinel with application to recent orbital data from the Moon

KELSEY B. WILLIAMS\textsuperscript{1,*}, COLIN R.M. JACKSON\textsuperscript{2}, LEAH C. CHEEK\textsuperscript{3}, KERRI L. DONALDSON-HANNA\textsuperscript{4}, STEPHEN W. PARMAN\textsuperscript{5}, CARLE M. PIETERS\textsuperscript{5}, M. DARBY DYAR\textsuperscript{6}, and TABB C. PRISSEL\textsuperscript{5}

\textsuperscript{1}Department of Earth and Planetary Sciences, Washington University in St. Louis, 1 Brookings Drive, St. Louis, Missouri 63130, U.S.A.\
\textsuperscript{2}Geophysical Laboratory, Carnegie Institution of Washington, 5251 Broad Branch Road NW, Washington, D.C. 20005, U.S.A.\
\textsuperscript{3}Department of Earth and Environment, Boston University, 685 Commonwealth Avenue, Boston, Massachusetts 02215, U.S.A.\
\textsuperscript{4}Atmospheric, Oceanic and Planetary Physics, Oxford University, Clarendon Laboratory, Parks Road, Oxford, Oxfordshire OX1 3PU, U.K.\
\textsuperscript{5}Department of Earth, Environmental, and Planetary Sciences, Brown University, 324 Brook Street, Providence, Rhode Island 02912, U.S.A.\
\textsuperscript{6}Department of Astronomy, Mount Holyoke College, 217 Kendade Hall, 50 College Street, South Hadley, Massachusetts 01002, U.S.A.

ABSTRACT

Visible to near-infrared (V-NIR) remote sensing observations have identified spinel in various locations and lithologies on the Moon. Experimental studies have quantified the FeO content of these spinels (Jackson et al. 2014), however the chromite component is not well constrained. Here we present compositional and spectral analyses of spinel synthesized with varying chromium contents at lunar-like oxygen fugacity ($f_{O2}$). Reflectance spectra of the chromium-bearing synthetic spinels (Cr# 1–29) have a narrow (~130 nm wide) absorption feature centered at ~550 nm. The 550 nm feature, attributed to octahedral Cr\textsuperscript{3+}, is present over a wide range in iron content (Fe# 8–30) and its strength positively correlates with spinel chromium content $[\ln(\text{reflectance}_{550}) = -0.0295 \times \text{Cr#} – 0.3708]$. Our results provide laboratory characterization for the V-NIR and mid-infrared (mid-IR) spectral properties of spinel synthesized at lunar-like $f_{O2}$. The experimentally determined calibration constrains the Cr# of spinels in the lunar pink spinel anorthosites to low values, potentially Cr# < 1. Furthermore, the results suggest the absence of a 550 nm feature in remote spectra of the Dark Mantle Deposits at Sinus Aestuum precludes the presence of a significant chromite component. Combined, the observation of low chromium spinels across the lunar surface argues for large contributions of anorthositic materials in both plutonic and volcanic rocks on the Moon.

Keywords: IR spectroscopy, Cr in spinel, lunar and planetary studies, lunar remote sensing, experimental petrology, synthetic spinel, visible to mid-infrared, lunar highlands, dark mantle deposits

INTRODUCTION

Recent analyses of Chandrayaan-1 Moon Mineralogy Mapper (M3) and SELENE Kaguya Spectral Profiler (SP) orbital data have identified spinel-bearing lithologies across the lunar surface (e.g., Sunshine et al. 2010, 2014; Pieters et al. 2011, 2014; Dhingra et al. 2011a, 2011b; Yamamoto et al. 2013). Detections of these previously unresolved surface components provide new insight into the petrogenesis and evolution of the lunar crust.

Most remotely detected spinels are Mg- and Al-rich ("Mg-spinel") and are thought to be mixed with high proportions of plagioclase based on their prominent 2000 nm absorption feature and relatively high albedos. This new rock type has been termed "pink spinel anorthosite" (PSA, e.g., Taylor and Pieters 2013; Pieters et al. 2014) and has been found globally (Pieters et al. 2010, 2011, 2013, 2014; Sunshine et al. 2010; Dhingra et al. 2011a, 2011b; Lal et al. 2011, 2012; Dhingra and Pieters 2011; Kaur et al. 2012, 2013a, 2013b; Bhattacharya et al. 2012, 2013; Donaldson Hanna 2013; Yamamoto et al. 2013; Sun et al. 2013; Kaur and Chauhan 2014). Additionally, unique low-albedo regions identified within the Sinus Aestuum pyroclastic deposits are suggested to be rich in Fe- or Cr-rich spinel due to their spectral signature near 1000 nm (Sunshine et al. 2010, 2014; Yamamoto et al. 2013). The specific nature of each spinel-bearing lithology remains uncertain and several petrogenetic models have been proposed, including melt-rock reaction and impact melting (Gross and Treiman 2011; Yamamoto et al. 2013; Prissel et al. 2014; Gross et al. 2014). Constraining the composition of the remotely sensed lunar spinels is fundamental in identifying plausible formation mechanisms.

Previous laboratory investigations have typically focused on characterizing terrestrial spinels (e.g., Cloutis et al. 2004). Spectral comparison with terrestrial spinels suggests PSA lithologies contain Mg-spinel similar to those found in pink spinel troctolites. However, terrestrial spinels form under more oxidizing conditions than lunar spinels, leading to relatively high ferric iron contents. Ferric iron in terrestrial spinels is expressed across the spectral range of M3 and SP, obscuring the connection to lunar spinels (Fig. 1). In this context, we conducted the current study to explore the spectral effects of chromium on well-characterized lunar analog spinel.