Early Archean alteration minerals in mafic-ultramafic rocks of the Barberton greenstone belt as petrological analogs for clay mineralogy on Mars

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ABSTRACT

Characterization of terrestrial analog sites is critical for detection and determination of clay mineralogy in remote sensing studies of Mars aimed at geological, hydrological, and potentially biological investigations. In this study, we investigate a suite of hydrothermally altered early Archean rocks from the Barberton greenstone belt (BGB) of South Africa as potential petrological, mineralogical, and spectral analogs to hydrothermally altered metabasalts and mafic-ultramafic intrusions in the martian subsurface and impact craters. We present the first spectral imaging measurements on exceptionally well-preserved early Archean mafic-ultramafic rocks from the BGB, with the aim of studying their clay mineralogy and spectral signatures. Multiple spectral analyses were conducted on different sample textures (rock powders, crushed rocks, and rock slabs) appropriate for Mars rover and remote sensing exploration. Visible/near-infrared (VNIR) and mid-IR reflectance spectra were acquired on particulate samples, while VNIR spectral imaging data were collected on rock slabs. Mid-IR emission spectra were measured for the rock slabs and grains. Spectral features are compared from these different spectral techniques to identify the minerals present in the samples and compare macroscale vs. microscale detections. The measured spectra reveal absorption bands that correspond to clay mineralogy of the serpentine and chlorite mineral groups, consistent with petrographic observations, as well as magnetite, olivine, quartz, feldspar, and Al-phyllosilicate. The spectral data acquired in this study expand the reference spectra data set for remote sensing studies. The implications of this study are that rocks from early Archean greenstone belts, such as those of the BGB, serve as potential clay-bearing petrological analogs for hydrothermal environments on Mars.

Keywords: Barberton greenstone belt, early Earth, Archean metabasalts, Mars petrological analogs; Earth Analogs for Martian Geological Materials and Processes

INTRODUCTION

In the search for life on Mars, “follow the water” has been a validated and useful approach. The main indicator of surface and subsurface groundwater on Mars is the presence of low-temperature alteration minerals such as phyllosilicates, opal, zeolite, and sulfate (e.g., Murchie et al. 2019; Carter et al. 2013; Ehlnmann and Edwards 2014). Orbital remote sensing missions and Mars rover observations have found evidence for alteration and clay formation in multiple surface and subsurface environments, including various hydrothermal conditions (e.g., Ehlnmann et al. 2009, 2010, 2011a, 2013; Marzo et al. 2010; Squyres et al. 2012; Bishop et al. 2013; Michalski et al. 2013, 2017; Bridges et al. 2015; Bristow et al. 2015). These studies report in situ and hyperspectral data in support of the relatively common occurrence of (Fe,Mg)-rich phyllosilicates (e.g., smectite, chlorite, and serpentine) and Al-rich phyllosilicates (kaolinite, montmorillonite) on the exposed surface of Mars. Lab spectra of clay-bearing rocks from various hydrothermal settings on Earth (e.g., Bishop et al. 2002, 2004, 2007; Michalski et al. 2006; Schiffman et al. 2006; Hamilton et al. 2008; Ehlnmann et al. 2011b, 2012; Cuadros et al. 2013; Yant et al. 2018) provide important constraints on geochemical conditions, temperature, type of salts, and nature of water activity on Mars. Furthermore, sub-surface mafic-ultramafic hydrothermal environments on early Earth and Mars may have been very similar (e.g., Cockell 2006; Izawa et al. 2019; Grosch and Hazen 2015). Investigation of Fe/Mg-rich clays from seafloor sites (Cuadros et al. 2013) has led to characterization of distinct types of clays on Mars (Michalski et al. 2015; Bishop et al. 2018). Consequently, clay-bearing early Archean terrestrial rocks may be useful as analog materials to extend the visible/near-infrared (VNIR) and mid-infrared (mid-IR) spectral databases for remote sensing studies on orbital and rover missions at Mars. It is important to point out that clay mineral formation processes on early Earth and Mars may not necessarily have been the same in all geological environments, and we propose that the Barberton rocks are possible petrological analogs, not necessarily direct alteration process analogs. However, the early sub-surface hydrothermal environments may have been similar in some parts of early Earth and Mars. Bioalteration of basaltic volcanic glass is a model that has

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