Laboratory and field characterization of visible to near-infrared spectral reflectance of nitrate minerals from the Atacama Desert, Chile, and implications for Mars

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ABSTRACT

Large amounts of nitrate salts occur in very specific environments and somewhat rare hyper-arid conditions, which may provide clues to fundamentally different nitrogen cycling and life survival mechanisms. Remote detection of ancient and modern nitrates on Earth and on other planetary bodies where they may occur requires a detailed understanding of their visible to near infrared (VNIR) spectral signatures. This study explores the VNIR spectral characteristics of several synthetic nitrate salts, sulfate minerals, and nitrate-bearing field samples from the Atacama Desert, Chile, to identify diagnostic spectral features of nitrate and possible interferences from other coexisting minerals. Results indicated that most of the nitrate salts have characteristic absorptions around 1.81, 1.94, 2.06, 2.21, and 2.42 μm. A significant positive correlation exists between the continuum-removed band depths of the 2.42 μm absorption and nitrate contents for the Atacama regolith samples, especially for samples with >10 wt% nitrate. The five absorption features of nitrate in the field spectra collected from multiple nitrate-rich regions in the Atacama Desert were then evaluated to determine the variabilities in these features in natural settings, while the band depths of 2.42 μm absorption were further calculated on the continuum-removed field spectra to estimate the nitrate abundances at the study sites. This work will supplement spectral libraries where nitrate spectra are lacking and have implications for future comparisons to planetary spectra to search for potentially life-related nitrate on Mars.

Keywords: Nitrate, Atacama Desert, Mars, visible to near infrared reflectance; Earth Analogs for Martian Geological Materials and Processes

INTRODUCTION

The Atacama Desert in northern Chile has been proposed as an important Mars analog due to its hyper-arid climate (Navarro-González et al. 2003). The hyper-aridity in the core of the Atacama Desert is the combined result of the rain shadow effects created by the Coastal Range and the Andes, the cold upwelling Peru Current, and the south Pacific subtropical anticyclone (Houston and Hartley 2003; Houston 2006). The Atacama is known to have highly saline soils containing the largest nitrate deposits in the world (Ericksen 1981), which is unique and mainly due to that the hyper-arid climate minimizes leaching losses and preserves nitrate and other soluble salts, such as chloride, sulfate, and perchlorate. While the hyper-aridity stabilizes the saline soils in the Atacama, the origins of massive soluble salts were long disputed before recent isotopic studies definitely attributed these soluble salts to atmospheric origins (Bao and Gu 2004; Bao et al. 2004; Michalski et al. 2004; Wang et al. 2016). Oxides of nitrogen, sulfur, and chlorine in the atmosphere can be oxidized via photochemical pathways (i.e., chemical reactions caused by light) into their stable end products as nitrate, sulfate, and perchlorate, respectively, which can subsequently be deposited onto the ground surface (Seinfeld and Pandis 2006). As recent development of triple oxygen isotope analysis allowed the source apportionment of soluble salts in the soil based on distinctive oxygen isotope signatures in different sources, the Atacama salts were revealed to have similar oxygen isotope compositions to their atmospheric equivalents, suggesting their predominant origin from atmospheric deposition. Indeed, in hyper-arid environments such as the Atacama, where biological and hydrological activities should be extremely low, atmospheric deposition, especially dry deposition, may be one of the main processes that control surface geomorphology (Ewing et al. 2006). The successive detection of sulfate, chloride, and perchlorate on the surface of Mars (Squyres et al. 2004; Osterloo et al. 2008; Hecht et al. 2009), similar to the existence of chloride, perchlorate, and sulfate deposits in the Atacama, hints that analogous deposition processes may be occurring on Mars.

Whether there are also nitrate deposits occurring on Mars as in the Atacama is of great interests to the scientific community because nitrate is an important part of biogeochemical cycling on Earth and may be indicative of past life on Mars. Several studies have proposed mechanisms that could lead to photochemical production of nitrate in a martian atmosphere (Yung et al. 1977; Nair et al. 1994) and possible incorporation of nitrate into the martian regolith (Banin et al. 1997; Mancinelli 1996). Nevertheless, the

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