Thermal infrared and Raman microspectroscopy of moganite-bearing rocks

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ABSTRACT

We present the first thermal infrared reflectance spectral characterization of moganite and mixtures of moganite with microcrystalline quartz. We find that for relatively high (>50%) abundances of moganite, the absolute reflectance for samples is significantly reduced. Using microscopic-Raman (~1 μm/pixel) measurements, we estimate the moganite content for various samples. We then compare Raman-derived moganite abundances with microscopic infrared reflectance (25 μm/pixel) spectra to determine the effects of increasing moganite abundance on thermal infrared spectra. We find that moganite is broadly spectrally similar to quartz with major reflectance maxima located between ~1030 and 1280 cm⁻¹ and ~400 and 600 cm⁻¹; but there are characteristic differences in the peak shapes, peak center positions, and especially the relative peak reflectance magnitudes. For regions with high (>50%) moganite content, the relative magnitudes of the reflectance maxima at 1157 and 1095 cm⁻¹ (R₁⁰⁹⁵/R₁₁⁵⁷ band ratio) can be used to estimate the moganite content. This work demonstrates the utility of thermal infrared microspectroscopy in isolating phases that are intimately mixed in a sample, and has applications in planetary science, where constituent phases of quartz-rich sedimentary rocks can be identified using remote or in situ thermal infrared spectroscopy.

Keywords: Moganite, chert, microcrystalline quartz, silica, Raman spectroscopy, infrared spectrosocopy, microspectroscopy, Mars

INTRODUCTION

Moganite, a silica polymorph, is a microcrystalline mineral first discovered in ignimbrite flows on the island of Gran Canaria (Flörke et al. 1976, 1984). Later, several comprehensive studies have identified moganite in various fibrous and granular microcrystalline quartz samples, suggesting moganite is present in many terrestrial microcrystalline quartz deposits (Heaney and Post 1992; Godovikov et al. 1991). On Earth, moganite is typically intergrown with quartz in chert and chaledony, which precipitates from silica-rich waters at temperatures characteristic of hydrothermal and diagenetic environments, and has been found as a weathering product on terrestrial volcanic rocks and in hydrothermally altered basalt veins (Flörke et al. 1982; Heaney and Post 1992; Parthasarathy and Kunwar 2001). Moganite also forms with microcrystalline quartz from diagenesis of opal (Knauth 1994). On Mars, thermal infrared (TIR) emissivity data have been extensively acquired of the surface, by both Mars Exploration Rovers Spirit and Opportunity, using the miniature-thermal emission spectrometer (Mini-TES) instruments (Christensen et al. 2003), as well as the orbiting Mars Global Surveyor Thermal Emission Spectrometer (TES) (Christensen et al. 2001). TIR spectra collected from the Spirit rover’s Mini-TES instrument were used to identify opaline silica, which is thought to have formed in a hydrothermal environment (Ruff et al. 2011). Quartz-bearing lithologies have been identified with TES data in craters found within Syrtis Major (Bandfield et al. 2004). As evidence for aqueous alteration and hydrothermal environments on Mars continues to grow (e.g., Bandfield 2008; Ehlmann et al. 2009, 2011), it is reasonable to determine whether moganite, which can be used as a diagenetic indicator, would be detectable using instruments on current Mars rovers or orbiters.

MOGANITE

A comprehensive discussion of the crystal structure of moganite, which is consistent with space group I2/a and described as stacked, alternating layers of left- and right-handed quartz, can be found in Graetsch (1994). Previous studies have shown that moganite is readily identifiable using X-ray diffraction (Miehe and Graetsch 1992), infrared absorption spectroscopy (Graetsch et al. 1994), and Raman spectroscopy (Kingma and Hemley 1994). Studies of terrestrial moganite abundances have revealed concentrations are higher in samples from arid environments, suggesting the relative amounts of quartz and moganite within a given sample can be used as an indicator of the environment subsequent to deposition (Heaney 1995). Experiments on moganite have determined that its rapid dissolution rate and high solubility could be used to explain these observations (Petrovic et al. 1996; Gislason et al. 1997). On the basis of these works, it was suggested that the absence of moganite within microcrystalline quartz deposits is indicative of high water to rock ratios in the post-depositional environment. In addition, variability in moganite content has been linked to macroscopic variations in color and texture within a sample, indicating that variable moganite content may be linked to changing environmental or depositional conditions (Kingma and Hemley 1994).

Microcrystalline silica and moganite can precipitate directly from a silica-rich solution or can form through the diagenesis of opal (Heaney 1993). A typical diagenetic sequence of opal is Opal A → Opal CT → microcrystalline (fibrous or granular) quartz