**CHARACTERIZATION OF OUTCROPS CONTAINING 'DOUBLET' SPECTRA AT MAWRTH VALLIS, MARS.**
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**Introduction:** Compact reconnaissance imaging spectrometer for Mars (CRISM) images are used to identify minerals using Visible/near-infrared (VNIR) spectroscopy. Mineralogy and stratigraphy of the Marwth Vallis region on Mars have been well documented [e.g. 1 - 3] and include a unique spectral "doublet" phase sitting above Fe/Mg-rich smectites and beneath Al-bearing phyllosilicates [4]. Mixtures of minerals including hydrated silica, phyllosilicates and sulfates (e.g. gypsum & jarosite) are thought to be responsible for the "doublet" type spectra with bands between 2.21 – 2.23 and 2.25 – 2.27 µm. Units composed of this "doublet" material may have resulted from acid-alteration of the underlying Fe-smectite rocks [5]. In this study, three CRISM images from Mawrth Vallis (FRT00003BFB, FRT0000A425, HRL000043EC; Figure 1) were analyzed and compared with laboratory mixtures in an attempt to identify distinct mineral phases resulting in the unique "doublet" spectra signatures.

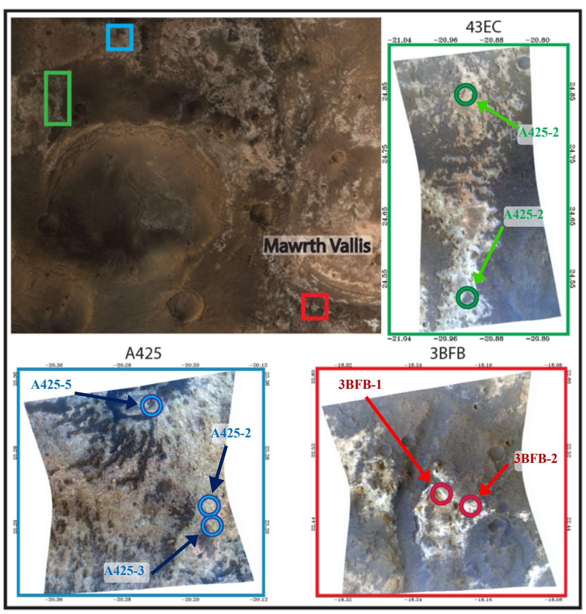


**Figure 1.** Map showing Mawrth Vallis region on Mars and corresponding locations of CRISM images: **HRL000043EC (green)**, **FRT0000A425 (blue)**, and **FRT00003BFB (red).** Outcrop locations of collected spectra presented in this study are marked by circles.

**Methods:** Two sets of spectral parameters were applied to the three MTRDR images to visually aid in identification of "doublet" units. R (MIN2250), G (BD2265), B (BD2210) was used to identify locations of "doublet" material, while R (BD2250), G (BD2265), B (BD2290) was used to differentiate Fe-rich smectites from "doublet" material. Spectra from areas containing the "doublet" material were collected using a spectral profile tool and averaged over a 3x3 pixel area from modified TRR3 images processed with a recently developed algorithm to minimize atmospheric effects and noise [6]. These new, cleaner spectra enabled much better resolution of the spectral features, which is especially important for investigating small outcrops such as these.

Mineral mixtures were prepared in the lab for nontronite/jarosite [7], opal/gypsum [8], and gypsum/jarosite [9] and VNIR spectra were measured to support analysis of the spectral "doublet" units. Minerals were ground and dry sieved to 45 – 125 µm and binary mixtures were created with 3 or more abundances by weight, typically including 25/75, 50/50, 75/25, and in some cases 10/90 and 5/95. VNIR reflectance spectra were measured under ambient conditions from 0.35 – 2.5 µm relative to Halon using an ASD spectrometer. Spectra of these mixtures and of additional pure mineral standards (e.g. montmorillonite, nontronite, opal, gypsum, jarosite) were compared to collected "doublet" spectra from CRISM images in order to evaluate trends and patterns in the band centers and relative band depths of the "doublet" features.

**Results:** All outcrops containing the spectral "doublet" also contain a water band near 1.9 µm and are likely mixed with basalt or other phases due to the low overall reflectance. Two general observations were made based on analysis of the lab spectra: (1) Mixtures of jarosite and Fe-smectites contain stronger bands near 2.27 – 2.29 µm, and (2) Mixtures of hydrated silica (opal), Al-rich phyllosilicates or gypsum with minor amounts of other components contain stronger bands near 2.21 µm and weaker bands near 2.27 µm.

Three distinct outcrops containing mixtures of jarosite and gypsum/nontronite are shown in Figure 2. Jarosite contains bands at 1.47, 1.86, and 2.26 µm [10]. The presence of the 1.86 µm band requires a high proportion of jarosite in mixtures [7, 9]. The 1.86 µm band in the ROI 3BFB-1 spectrum is more of a shoulder suggesting a small proportion of jarosite is present. Additional bands near 1.41 and 2.29 µm imply the presence of nontronite in all three outcrops. The bands near 1.75 and 2.21 µm in the spectrum of ROI 3BFB-2 are most consistent with gypsum [11] because there is no shoulder near 2.16 µm that could indicate alunite. The spectrum of ROI A425-5 contains jarosite based on the 1.48, 1.86 µm bands and is likely mixed with nontronite based on the 2.26 µm band being shifted to 2.28 µm. Additionally, the broader 1.41 and 1.91 µm bands in conjunction with a plateau near 1.75 µm may be indicative of gypsum. Each of these outcrops contains a stronger band near 2.27 µm and weaker band near 2.21 µm.

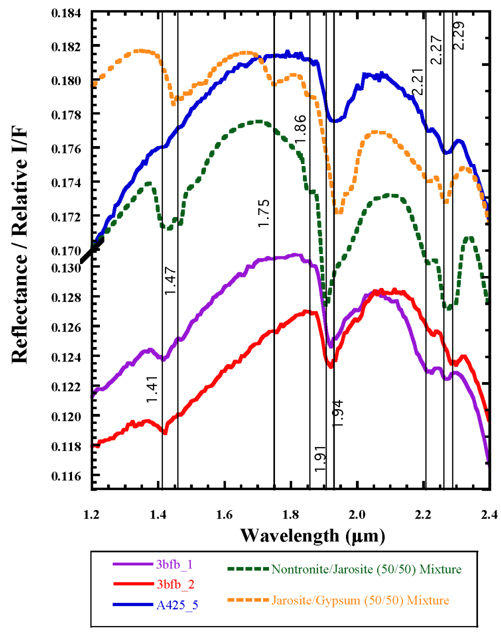


**Figure 2.** VNIR spectral profiles of laboratory mixtures (dashed lines) and CRISM spectra (solid spectra lines) with strong 2.27 – 2.29 bands, and weaker 2.21 bands. Characteristic features are marked by vertical lines.

Spectra in Al-rich "doublet" outcrops (Figure 3) are identifiable by stronger "doublet" bands near 2.21, and a weaker 2.27 band. The presence of a "doublet" near 1.39 – 1.41 µm implies mixtures of higher percentages of opal/montmorillonite as observed in the spectra of ROIs 43EC-2 and 43EC-4, while a single band near 1.41 has a higher proportion of montmorillonite. Opal has a broad band near 2.2 µm, while this is narrow for montmorillonite. The weak band near 1.85 µm in the spectrum of ROI 43EC-2 and the band near 2.26 µm are consistent with abundant jarosite, while the 2.27 µm band in the spectra of ROIs A425-2, A425-3, and 43EC-4 implies small mixtures of nontronite.

**Implication for Mars:** "Doublet" type spectra are observed in multiple locations across the Mawrth Vallis region on Mars and represent mixtures of various hydrated minerals. Three images were analyzed in an effort to identify individual mineral components and relative abundances based on mineral standards and laboratory mixtures. Two distinct differences were made in the "doublet" type spectra based on band location and strength. A stronger 2.21 µm band accompanied by a weaker 2.27 – 2.29 µm band is indicative of Al- or Ca-dominant mixtures consisting of montmorillonite, opal, or gypsum, and smaller percentages of nontronite and jarosite. A weaker 2.21 µm band in conjunction with a stronger 2.27 – 2.29 µm band implies mixtures of Fe-rich material (nontronite & jarosite) and smaller percentages of gypsum.

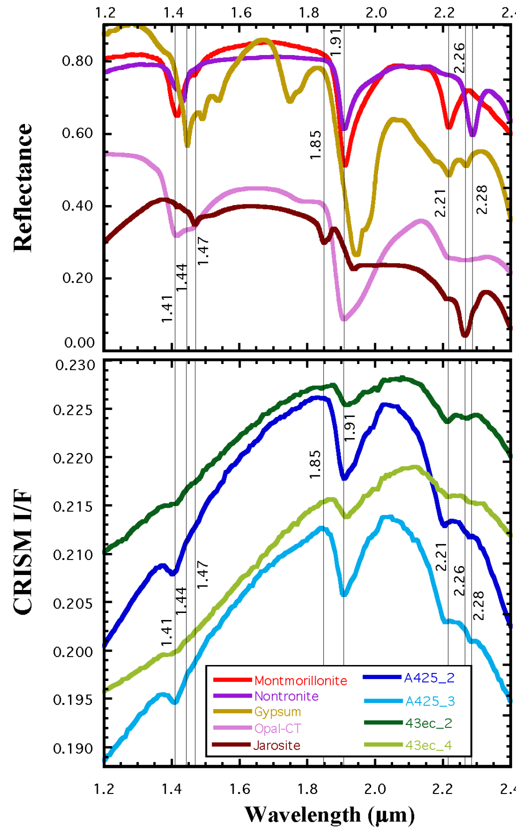


**Figure 3.** (Above) Spectra profiles of mineral standards. Vertical lines represent characteristic features. (Below) CRISM "doublet" spectra with strong 2.21 band and weaker 2.27-2.28 bands.

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