DIVERSE SURFACE MINERALOGY OF MARS FROM HYPERSPECTRAL SENSING

James J. Wray

School of Earth and Atmospheric Sciences, Georgia Institute of Technology, 311 Ferst Drive, Atlanta, Georgia, USA 30332-0340 (jwray@gatech.edu)

ABSTRACT

Hyperspectral imaging of Mars from space-based platforms has transformed our perception of it from a single "red planet" to a rich world with environments—both modern and ancient—as varied as those found on Earth. Here we provide a summary and update of minerals and mineral assemblages detected using the Compact Reconnaissance Imaging Spectrometer for Mars (CRISM) on board NASA's Mars Reconnaissance Orbiter. These minerals and their mapped spatial distributions allow formulation and testing of hypotheses on how Martian environments varied across space and time. We will provide an overview of the data processing and analysis techniques used most widely to date and an outlook on how innovative approaches could yield further insights.

Index Terms— Mars, planets, geology, minerals, hyperspectral imaging

1. INTRODUCTION

Mars, although smaller than Earth, contains approximately the same terrestrial land area. Like Earth, its surface morphology provides evidence for impact, volcanic, tectonic, and gradational processes, the latter including erosion and deposition driven by gravity, wind, and water. Unlike Earth, Mars lacks compelling evidence for plate tectonics, and in the absence of this process has been able to retain rocks from the first billion years of solar system history at or near its modern surface. It should therefore come as no surprise that the Martian surface documents a great diversity of physical and geochemical processes and environments.

Since dry river valleys were first identified on Mars nearly 50 years ago, supporting evidence for water-rock interactions has been sought from the surface mineralogy. Orbital searches for such aqueous minerals initially utilized mid-infrared wavelengths [e.g., 1,2,3], and reached full fruition with the arrival of visible and shortwave-IR hyperspectral instruments in 2003 [4] and 2006 [5]. Here we will focus on the science enabled by the latter of these two instruments, CRISM.

2. DATASET AND METHODS

Observing a ~10 km-wide ground swath, CRISM samples the ~0.4–3.9 μm spectral range at 6.55 nm/channel, operating in two general modes: mapping or targeted imaging. CRISM mapping data (now covering >75% of Mars) are acquired in long strips having resolutions of ~100–200 m/pixel, typically with only a subset of spectral channels being downlinked to Earth. Targeted images, by contrast, achieve spatial sampling of ~18 or ~36 m/pixel over smaller areas (each a few to ~20 km long) and typically include full spectral sampling, although aging of the infrared detector coolers has rendered the >1 μm spectral region increasingly noisy and less informative in recent years.

Our work uses CRISM data calibrated to I/F (the ratio of measured radiance to the incoming solar flux) as described by [6]. These I/F data are then divided by the cosine of the solar incidence angle to minimize photometric effects on scene brightness. Atmospheric removal is approximated via division by a scaled transmission spectrum derived from observations over the summit vs. flank of volcano Olympus Mons; this "volcano-scan" algorithm does not account for atmospheric aerosols or variable CO and H_2O mixing ratios, but is an effective and widely used approach to remove CO_2 gas absorptions from Mars orbital spectra [e.g., 7]. Wherever possible, we average spectra from many pixels to improve the signal-to-noise ratio, and the resulting average spectra are divided by a spectral average from a dusty or otherwise spectrally "neutral" region in the same CRISM scene. This spectral ratio method suppresses residual artifacts of instrument calibration and atmospheric removal while accentuating spectral signatures in the numerator spectrum that are unique relative to the denominator, thereby facilitating comparisons to laboratory spectra of single minerals or simple mixtures (e.g., Figure 1).

CRISM pixels having spectral absorptions characteristic of particular minerals can be mapped using spectral summary (i.e., mineral indicator) parameters [8,9]. The intensity of each parameter at a given pixel corresponds to an absorption band depth (or, in some cases, the steepness of a spectral slope), which reflects a combination of mineral abundance within the pixel as well as textural effects such as grain size. These parameter maps can be overlain on high-resolution imaging (e.g., Figure 2) or topographic data to provide insights into compositional stratigraphy on Mars.

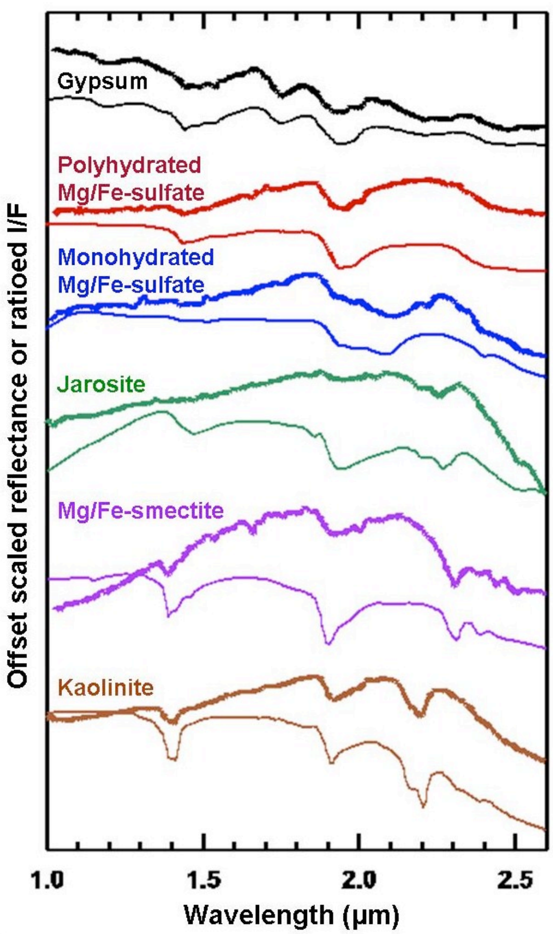

Figure 1: CRISM ratio spectra (bold upper line in each pair) and laboratory reflectance spectra, scaled and offset for comparison. CRISM spectra are from Columbus crater; lab spectra are from CRISM and USGS spectral libraries.

3. MINERALOGICAL DISCOVERIES

Hydrated salt and clay minerals were detected on Mars even prior to CRISM [e.g., 4], but CRISM analyses continue to reveal their remarkable diversity. Highlights include hydrous silicates ranging from aluminous to ferromagnesian clays, chlorite, mica, opaline silica, and even metamorphic prehnite and epidote [e.g., 10,11,12]. In a single mid-sized impact crater [13], clay minerals are interbedded with sulfate salts that exhibit a range of chemistries and hydration states, including the acid sulfates jarosite (Figure 1) and alunite, precipitated from extreme solutions on early Mars.

Our own recent work has found layered (perhaps sedimentary) carbonates in some of the oldest martian rocks [14]; evidence for evolved magmatic processes yielding a wider range of volcanic rock types (e.g., Figure 2) than expected [15]; and possible ongoing deposition of perchlorate salts from seasonal brine flows [16]. Recent challenges to the latter of these claims [17] illustrate the dynamic nature of this scientific area, the degree to which recent efforts have pushed the limits of the available methodologies, and the potential value of more automated, objective approaches.

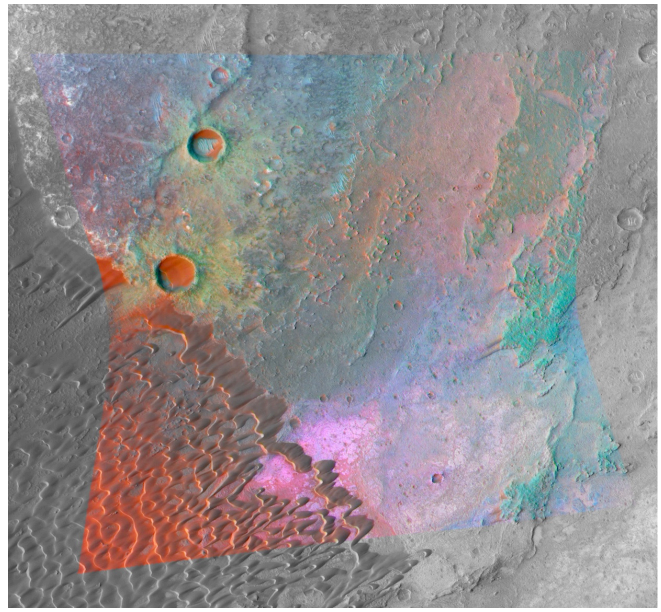

Figure 2: CRISM three-band composite image overlain on (colorizing) grayscale image from the Context camera (CTX) on NASA's Mars Reconnaissance Orbiter. Area shown is ~15 km wide, covering part of a volcanic caldera (Nili Patera) on Syrtis Major. Color differences correspond to differences in the igneous mineralogy of the caldera floor and superposed wind-blown or crater-excavated materials.

4. FUTURE WORK

The steps described in paragraphs 2-3 of section 2 above are currently performed manually on each individual CRISM observation. With the shortwave IR portion of CRISM's spectral dataset unlikely to further expand in the coming years, now is an opportune time to develop and test more sophisticated—and ideally automated—approaches to analyzing the existing data. We have begun to experiment with such approaches [18], and hope that this conference presentation may inspire additional efforts by an ever-growing community of users.

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