



Assessing the Sensitivity of the High Resolution Stereo Camera (HRSC) Colour Channels onboard Mars Express for Surface Material Discrimination

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Introduction:

The High-Resolution Stereo Camera (HRSC) onboard the Mars Express has been capturing multispectral images of Mars since 2004 [1]. In addition to its nadir and stereo-imaging capabilities, HRSC also acquires medium-resolution ($\sim 25\text{--}100$ m/pixel) multispectral data in four colour channels—Blue (444.0 nm), Green (538.0 nm), Red (748.0 nm), and Near-Infrared (955.5 nm)—though not consistently across all observations. Products and mosaics derived from these channels have been widely utilized for surface characterization, particularly in geological mapping, geomorphological analysis, and investigations of seasonal, polar, and atmospheric processes (e.g., [2–4]). Despite its extensive use for morphologic and contextual analysis, HRSC multispectral data have been underutilized for mineralogical discrimination. This is largely due to the availability of more spectrally resolved hyperspectral datasets from OMEGA (also aboard Mars Express) [5] and CRISM on the Mars Reconnaissance Orbiter [6]. However, with CRISM now non-operational and OMEGA currently limited to the VNIR, there is renewed relevance in evaluating the spectral utility of HRSC.

This study investigates the spectral sensitivity of HRSC's colour channels with a goal to determine the theoretical detectability and separability of various mineral types using HRSC, thereby enhancing its value as a bridging dataset between lower-resolution hyperspectral (i.e., OMEGA) and high-resolution instruments like HiRISE [7] and CaSSIS [8].

Methods:

For this analysis, we utilize the comprehensive database of CRISM-based Martian mineral detections [9]. Corresponding laboratory reference spectra for these minerals/mineral-groups were sourced from the USGS Spectral Library [10] and the RELAB spectral database [11]. The latest spectral response functions for HRSC were adopted from [1], and all laboratory spectra were resampled to match the four HRSC spectral bands. Each mineral-group was then examined individually to characterize its spectral behavior within the HRSC wavelength range. Based on these resampled spectra, we derive potential diagnostic band ratios/spectral parameters tailored to HRSC bands, based on similar sensitivity studies performed for CaSSIS [12–13] and HiRISE [14–15].

Results:

Figure 1 presents a series of plots illustrating laboratory reference spectra for all mineral groups identified on the Martian surface [9], resampled to HRSC wavelengths.

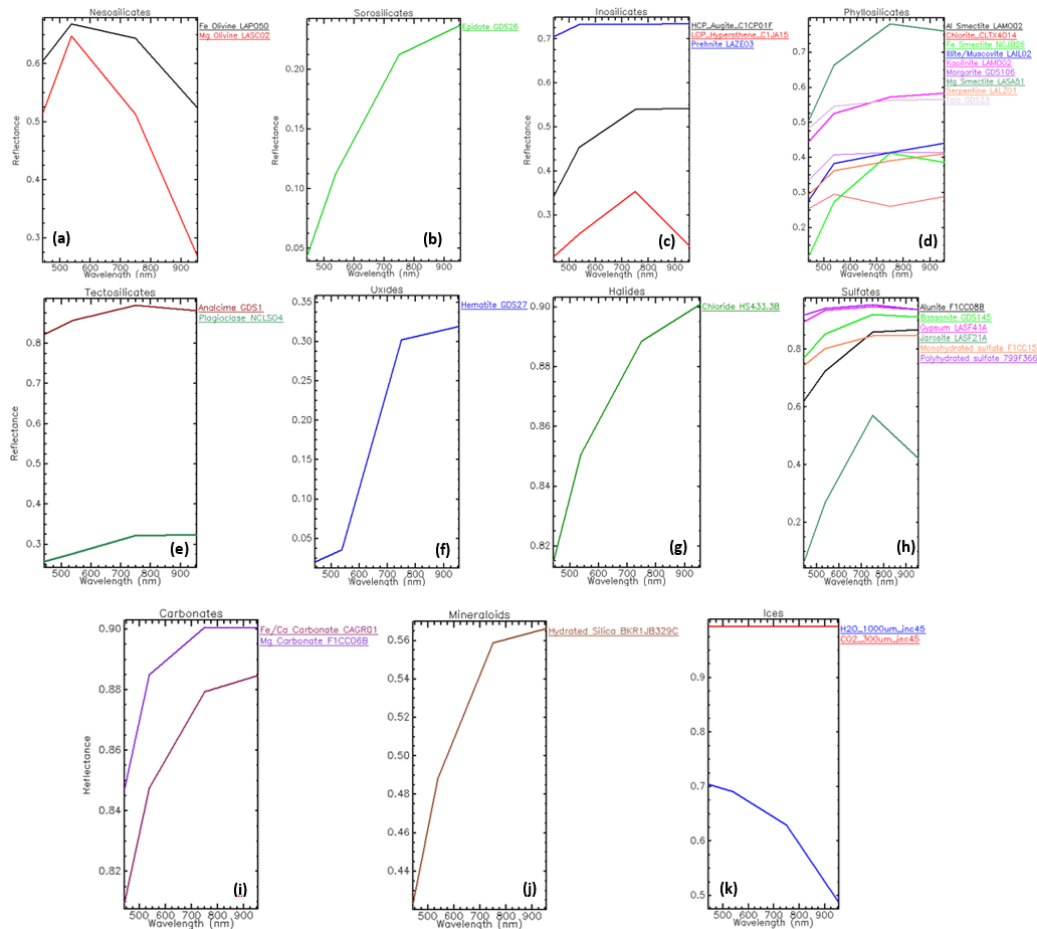


Figure 1. Plots showing laboratory spectra of all mineral groups identified on Mars [9] resampled to HRSC wavelengths. The laboratory spectra shown in panels (a) – (j) are obtained from multiple sources including USGS [10], RELAB [11]. The spectra shown in panel (k) are derived through Hapke radiative transfer modeling [18].

Mafic Minerals: Mafic minerals, including Fe-olivine, Mg-olivine, and low-Ca pyroxene-bearing materials, exhibit a sharp downward deflection towards the near-infrared (NIR), driven by an absorption feature near 1000 nm, attributed to Fe^{2+} crystal field transitions. Olivine, in particular, shows a broader absorption, leading to a noticeable decrease in reflectance starting from the green channel and continuing through the red and NIR channels (**Fig. 1a**). In contrast, low-Ca pyroxene (LCP) demonstrates a more confined drop-off, limited to the red and NIR channels, though its spectral behavior remains distinctive (**Fig. 1c**).

Hematite: Hematite reveals a unique spectral signature in the HRSC wavelength range (**Fig. 1f**), primarily due to its diagnostic absorption feature ~ 860 nm. Although HRSC cannot fully resolve this absorption like CaSSIS can [13,16], the combination of green, red, and NIR channels captures the leading limb of the absorption, suggesting that hematite could potentially be identified using HRSC.

Ices: Water-ice exhibits a characteristic spectral shape in the VNIR range, with a high reflectance in Blue followed by a gradual decrease towards the NIR, partially due to weak OH absorption near 1000 nm. CO_2 ice, however, remains spectrally featureless in the HRSC wavelength range (**Fig. 1k**). [14] note that this behaviour for water- and CO_2 ice is typically observed only in coarse-grained or pure ice. Hence, if the ice is sufficiently pure, HRSC should be able to distinguish between the two ices.

Halides: Chlorides are generally featureless in the VNIR range. However, the unique combination of them being relatively brighter (generally higher blue value than most other minerals, except perhaps for ices) and among the only few minerals with a significantly positive RED-IR slope may allow for their separation (**Fig. 1g**; [16]). Other minerals that show a positive RED-IR slope include hydrated silica (**Fig. 1j**), epidote (**Fig. 1b**), Fe/Ca carbonates (**Fig. 1i**), kaolinite (**Fig. 1d**) and alunite (**Fig. 1h**).

Other Minerals: A range of other minerals, including most phyllosilicates (**Fig. 1d**), sulfates (**Fig. 1h**), and tectosilicates (**Fig. 1e**), exhibit similar spectral behaviors at HRSC wavelengths, with subtle variations in their red-to-infrared slopes. While a definitive four-point spectral detection for these minerals may be challenging at the HRSC resolution, some of these minerals may be partially separable using specific colour-band-ratio-composites.

Table 1 presents a series of non-exhaustive spectral band ratios/parameters and their rationale. This list continues to be tested and updated.

Spectral Parameter	Formulation	Rationale
Blue/Red	Blue/Red	- Overall brightness and a reasonable alternative to using Blue I/F - May serve as a way to distinguish highly dusty surfaces from relatively dust-free ones
Red/Blue	Red/Blue	Targets absorption short of ~550 nm due to intervalence charge transfer of Fe³⁺
Red/NIR	Red/NIR	Broad absorption centered near ~1000-1100 nm due to crystal field transitions from the presence of Fe²⁺
NIR/Blue	NIR/Blue	Strong blue slope and absorption short of ~550 nm due to intervalence charge transfer of Fe³⁺
ICE-ATM	$\frac{\text{Mean (All bands)}}{\text{NIR/Blue}}$	Ices and some atmospheric phenomena (e.g., haze, fog, clouds, dust devils, avalanche clouds, etc.), compared to other surface materials, would have very high mean reflectance
WATER-ICE	$\frac{\text{Mean (All non NIR bands)}}{\text{NIR}}$	Particularly targets the Red to NIR spectral drop observed in water-ice. Higher values may also be observed in ferrous-bearing materials, that share an absorption close to ~1000 nm

Table 1. Possible HRSC band ratio and spectral parameter combinations (non-exhaustive) that may potentially help discriminate ferrous/ferric-bearing minerals and ices. These spectral parameters are adapted from similar efforts for CaSSIS [12-13] and HiRISE [14-15].

Conclusions and Future Work:

Preliminary results from the study of laboratory-based spectra show that HRSC colour may be able to confidently separate between most mafic vs ferric-bearing mineral phases, as well as ices. More particularly, the unique position of the four HRSC wavelengths should theoretically allow for identification of hematite-bearing minerals on the surface. [1] and [17] report of radiometric discrepancies (sometimes upto 10%) in the HRSC red and NIR channels, relative to OMEGA. Work is currently underway to better understand and constrain absolute calibration uncertainties of the instrument, following which, a detailed investigation into the true sensitivity of the colour filters for mineral differentiation based on HRSC images of the type locality sites is planned.

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