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Supporting Online Material for

Orbital Identification of Carbonate-Bearing Rocks on Mars

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Orbital Identification of Carbonate-Bearing Rocks on Mars – B.L. Ehlmann et al.

Co-occurrences and spatial correlations of the 2.3, 2.5, 3.4, and 3.9 bands

In over 20 images from Nili Fossae, the material we identify as carbonate is characterized by strong 2.30 and 2.51 μm absorption bands observed in conjunction with a 1.9 μm hydration band and a broad 1.0 μm Fe^{2+} feature. Due to its continuum shape, the material we identify as carbonate appears characteristically bright green in false color infrared images generated with 2.38 μm as red, 1.80 μm as green, and 1.15 μm as blue (Figure S1a). In Nili Fossae, the carbonate can also be mapped uniquely relative to other mineral-bearing units using three parameters for absorption bands: the OLINDEX parameter which is sensitive to the 1.0 μm ferrous iron band, the D2300 parameter which is sensitive to narrow vibrational absorptions near 2.3 μm , and the BD2500 parameter which maps narrow vibrational absorptions near 2.5 μm (Table 1). The rationale and formulation of the first two are described in greater detail in Pelkey et al. (2007) while the latter was formulated in order to map in hyperspectral data the occurrence of the 2.5 μm absorption observed first in the Nili Fossae region (Table 1; 19). The putative carbonate bearing phase has all three absorption bands and maps white in images composed of these three parameters (Figure S1a-c; circled regions). In this parameter mapping, while a 2.3 μm absorption is frequently observed alone and serves as an indicator for regional iron/magnesium smectite-bearing rock units, a 2.5 μm absorption is never observed alone in the Eastern Nili Fossae region. It is always paired with the 2.3 μm absorption. An example from CRISM targeted image FRT00003E12 is shown in Figure S1a-b.

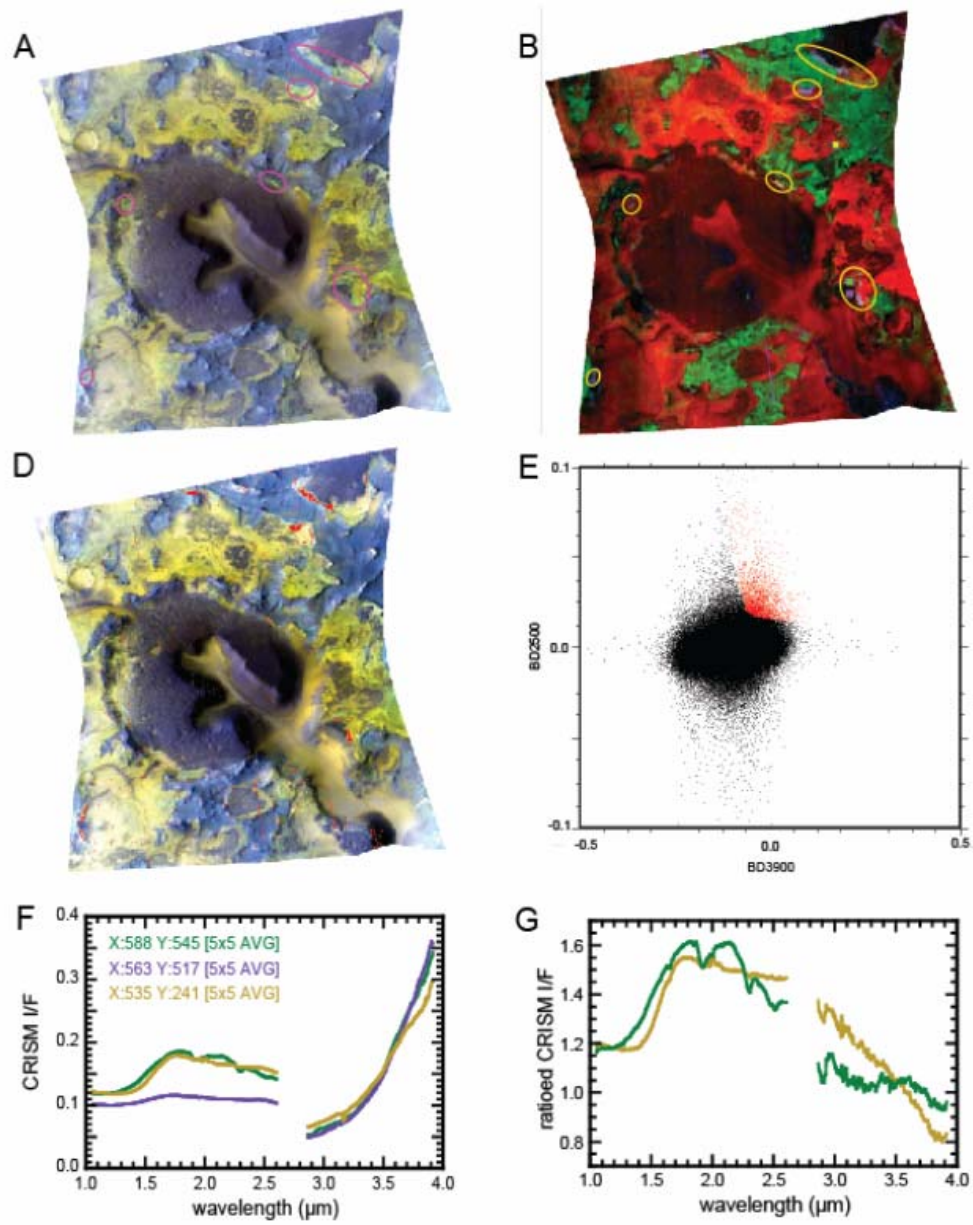


Figure S1. Nili Fossae CRISM image FRT00003E12 (also discussed in 18) (A) false color composite with R: 2.38, G: 1.80, B: 1.15 um (B) parameter map with R: OLINDEX, G: D2300, B: BD2500 (C) BD3900 parameter map. Spots of putative carbonate are circled. (D) same as (A) with regions of high BD2500 and BD3900 from pixels selected in (E) overlain. (E) scatterplot of BD3900 vs. BD2500. Pixels with high values in both are selected in red (F) atmospherically corrected spectra obtained from 5x5 pixel regions with locations indicated by the boxes in (B), (G) ratios of the yellow and green spectra in (F) to the purple.

Table 1. Wavelengths and formulae used in CRISM parameter maps.

Parameter	Formula	Range
OLINDEX	$R_{1695} / [0.1(R_{1080})+0.1(R_{1210})+0.4(R_{1330})+0.4(R_{1470})] - 1.0$	0 to 0.5
D2300	$1.0 - ((CR_{2290}+CR_{2320_CR_{2330}})/(CR_{2120}+CR_{2170}+CR_{2210}))$ where CR are essentially R values, continuum removed from a local slope over 1.82 to 2.53 μm	0 to 0.07
BD2500	$1.0 - (R_{2500}+R_{2510})/(R_{2540}+R_{2380})$	0 to 0.05
BD3900	$1.0 - \text{AVG}(R_{3837}:R_{3897})/(2.0(\text{AVG}(R_{3597}:R_{3663}) - \text{AVG}(R_{3364}:R_{3430}))$	-0.1 to 0.05*

* BD3900 strength reflects the difference of a multi-channel average reflectance at 3.86 μm from that of the projection of a straight line through multi-channel average reflectance at 3.4 and 3.63 μm . Because of the steep upward rise of the Planck function due to surface temperature (Figure S1f), values should be very negative for no band and may be slightly negative to positive when a band is present.

The 3-5 μm spectral range is not yet commonly employed on Mars for identification of minerals due to the complexity of interpreting this region where reflectance and thermal emission both contribute; however, carbonate has overtones and combinations of fundamental bands at these wavelengths that can be diagnostic. Bands from 3-4 μm are typically strong in anhydrous carbonate and weak to absent in hydrous carbonate (Calvin et al., 1994; Cloutis et al., 2003; Jouglet et al., 2007). In addition to the apparently unique match between the shape and position of the 2.3 and 2.5 μm bands in the spectral phase we observe on Mars with those of magnesite (Fig. 2 and 3), a key factor in the identification of the phase we observe on Mars as carbonate is that it also has absorptions in the 3-4 μm region near 3.4 and 3.9 μm . The 3.4 μm band in the putative carbonate bearing phase is weak in CRISM data (its appearance at a level above the noise requires 100s of pixel averages), and it is not obviously present in OMEGA data which is acquired at ten to thirty times coarser spatial resolution. However, a parameter was constructed to map the stronger absorption at 3.9 μm in CRISM data (Table 1; Figure S1c). (OMEGA has a strong, 10-20% non-linearity in the detector at this wavelength and cannot be employed). The BD3900 parameter appears strongest in bright-toned rock units which we infer to be olivine and carbonate bearing.

The CRISM L detector data calibration in this wavelength range is not yet fully understood, and there are some complications to mapping the 3.9 μm band, including a left to right gradient across the scene and thermal effects (and an intermittent artifact at 3.18 μm which not present in this scene). However, a true 3.9 μm band can be easily distinguished from a high BD3900 value resulting from a spectral slope by examining individual spectra. In ratioed data the putative carbonate bearing phase has absorptions at 1.0, 1.9, 2.3, 2.5, 3.4, and 3.9 while locations of other high BD3900 values do not display the 2.5 μm feature and have simply strong slopes from 3 to 4 μm (Figure S1g). The 3.9 μm band is stronger in the putative carbonate bearing phase, i.e. that with the 2.3 and 2.5 μm absorptions than in other locations in the scene and is distinctly a band. In Figure S1d-e, we use a scatterplot of all scene values for BD2500 and BD3900 to highlight regions with the highest values in both. These correspond to the putative carbonate-bearing terrains predicted from examination of the false color image and the OLINDEX/D2300/BD2500 parameter maps (Figure S1a-b). A suite of 100's of pixel ROIs from putative carbonate bearing units from multiple images are shown over the full L detector range in Figure S2. All show bands at 1.0, 1.9, 2.3, 2.5, 3.4, and 3.9 μm , diagnostic of carbonate.

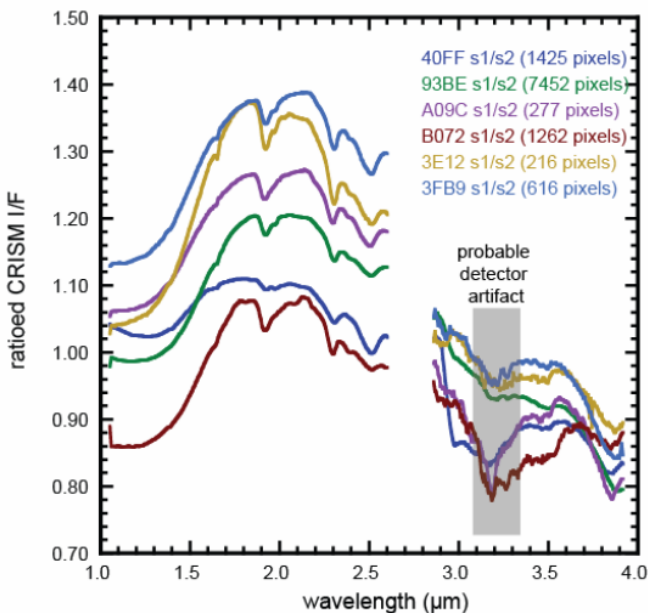


Figure S2. CRISM ratio spectra from 6 images in Nili Fossae (same as those in Figure 2b) shown over the full wavelength range of the L detector. In parentheses is the number of pixels from the putative carbonate phase used in the numerator spectrum. The number of pixels used in the denominator spectrum was always greater, and all denominator spectra had shape similar to the purple in Figure S1f above.

Additional References

S.M. Pelkey, *et al.*, *J. Geophys. Res.*, **112**, E08S14, doi:10.1029/2006JE002831 (2007)