

**STRATEGIES FOR REMOTELY DETECTING CHLORINE SALTS ON MARS.** J. Hanley<sup>1,2</sup>, Z. Bandelier<sup>2</sup>, S. Mittal<sup>3,2</sup>, C. Murphy<sup>4,2</sup>, R. Carmack<sup>2</sup>, B. Horgan<sup>5</sup>. <sup>1</sup>Lowell Observatory, Flagstaff, AZ (jhanley@lowell.edu); <sup>2</sup>Northern Arizona University, Flagstaff, AZ; <sup>3</sup>Northeastern University, Boston, MA; <sup>4</sup>Amherst College, Amherst, MA; <sup>5</sup>Purdue University, West Lafayette, IN.

**Introduction:** The presence of chlorine salts on Mars is important for understanding the geological and chemical history of the planet, as the presence of chlorine salts can help us infer the chemistry and evaporation history of surface lakes and playas. Furthermore, the spectral similarity between perchlorates and sulfates raises the possibility that previous sulfate detections may actually be perchlorates (Fig. 1). This has major implications for habitability, as perchlorates indicate much lower water activity brines, which are less favorable for habitability than sulfates. This is because chloride, perchlorate, and chlorate salts can all suppress the freezing temperature of water significantly, in some cases with a eutectic temperature down to 204 K [1, 2]. They also slow down the evaporation rate, extending the lifetime of the liquid water solution.

Chlorine salts may also play a role in the mechanical properties of the regolith, as well as the stability of subsurface water. High soil cohesion was encountered at the Phoenix landing site making sample analysis challenging; such cohesion may result from hydrated salts and eutectic brines bonding grains together at their contacts by wetting, or from dehydrated salts crystallizing at grain contacts. Changes in hydration state with time (such as diurnally or seasonally) may then result in correlated changes in cohesive properties with time [3].

Although we know that chlorine salts exist on the surface at the Phoenix landing site, we do not know what their original hydration state or cation-anion pair was (e.g. Ca(ClO<sub>4</sub>)<sub>2</sub>·4H<sub>2</sub>O vs NaClO<sub>4</sub> anhydrous vs Mg(ClO<sub>3</sub>)<sub>2</sub>·6H<sub>2</sub>O vs NaCl, etc.). The biggest challenge to positively identifying and distinguishing these salts through remote sensing is that many hydrated salts look very similar in the near-infrared, even when comparing to sulfate salts [4, 5]. We have developed

new parameters specifically for identification and mapping of variations in the wavelength locations of absorption band minima in CRISM spectra [6]. Here we present strategies and discuss limitations for detecting chlorine salts through VNIR remote sensing spectroscopy.

**Methods:** The majority of CRISM analyses use spectral indices, however, these indices are not able to differentiate between spectrally similar minerals. For example, the SINDEXTM measures the convexity at 2.3 μm due to sulfate absorptions at 1.9/2.1 μm (poly/mono-hydrated sulfates) and 2.4 μm. This index, though, will also be positive for any hydrated mineral with a fall off toward 2.5 μm, like kaolinite. Likewise, hydrated minerals are often identified using the CRISM BD1900R parameter, which finds the average depth of absorption between 1.91-1.94 μm relative to ~1.86/2.12 μm; yet, this parameter is non-specific to a particular hydrated mineral.

New parameters indicative of hydrated perchlorates and oxychlorine salts (Table 1) [7], were created and utilized along with other common parameters [7]. Interesting features were then extracted and compared to known spectra to identify minerals present.

We have analyzed a variety of locations across Mars, including a likely paleolake in Columbus Crater, the north polar regions where Phoenix detected perchlorate, and Curiosity’s landing site at Gale Crater.

**Results:** High values displayed by these parameters allowed us to find the best spectra with absorptions unique to chlorine salts. These parameters often overlap with other spectral features of minerals commonly found on Mars, and care must be taken to look at the whole spectrum, rather than a single feature for identification, as well as mineralogical and geological context.

**Table 1.** Newly created spectral parameters. Formulation is based on Viviano-Beck et al. [7]. R#### is the reflectance at a given wavelength, kernel width is the number of channels over which the median of the reflectance was taken in order to reduce residual noise when applied to CRISM data. From [6].

Name	Parameter	Formulation	Kernel Width	Rationale	Caveats
BD2130	2.14 μm ClO <sub>4</sub> -H <sub>2</sub> O feature band depth*	$.5 * \left[ 1 - \frac{R2120}{a * R2030 + b * R2190} \right] + .5 * \left[ 1 - \frac{R2140}{a * R2030 + b * R2190} \right]$	R2030:5 R2120:3 R2140:3 R2190:5	Hydrous perchlorates	Orthopyroxene Alunite Gypsum Kaolinite Margarite
BD2220	2.2 μm Cl-O combination or overtone feature band depth*	$1 - \frac{R2220}{a * R2140 + b * R2320}$	R2140:5 R2220:3 R2320:5	Oxychlorine salts	Nontronite Talc Zeolite

In Columbus Crater, these parameters led to the identification of many spectra that have features suggestive of chlorine salts (Figure 1). However, pixels highlighted by BD2220 were sometimes false-positives caused by the similar wavelength features in phyllosilicates. The close wavelengths between the 2.22  $\mu\text{m}$  feature in several chlorine salts and absorptions in phyllosilicates prevented identification of chlorine salts within the lower phyllosilicate-bearing unit. Spectra from two CRISM images have features unique to chlorine salts. Salts from 13FF5 and 16CFE have an absorption centered near 2.12  $\mu\text{m}$ .  $\text{CaCl}_2 \cdot 2\text{H}_2\text{O}$  and  $\text{MgCl}_2 \cdot 4\text{H}_2\text{O}$  have similar absorptions at 2.12  $\mu\text{m}$ . The CRISM spectra have a hydration absorption feature centered near 1.43  $\mu\text{m}$  consistent with  $\text{MgCl}_2 \cdot 6\text{H}_2\text{O}$ ,  $\text{Mg}(\text{ClO}_3)_2 \cdot 2\text{H}_2\text{O}$ ,  $\text{Mg}(\text{ClO}_3)_2 \cdot 6\text{H}_2\text{O}$ , and  $\text{CaCl}_2 \cdot 6\text{H}_2\text{O}$ .

Within Gale Crater, A091 and 37DF showed strong absorptions at 1.9  $\mu\text{m}$ , and 37DF showed an additional broad absorption at 2.13  $\mu\text{m}$ . The parameter BD2130 used to look for the 2.13  $\mu\text{m}$  absorption was intended to identify hydrated perchlorates. High-calcium pyroxene (HCP) exhibits features that are also highlighted by the BD2130 parameter, having absorption features near 1.03  $\mu\text{m}$  and 2.3  $\mu\text{m}$  [7]. Figure 2 shows the comparison and not perfect overlap of the HCP and oxychlorine parameters.

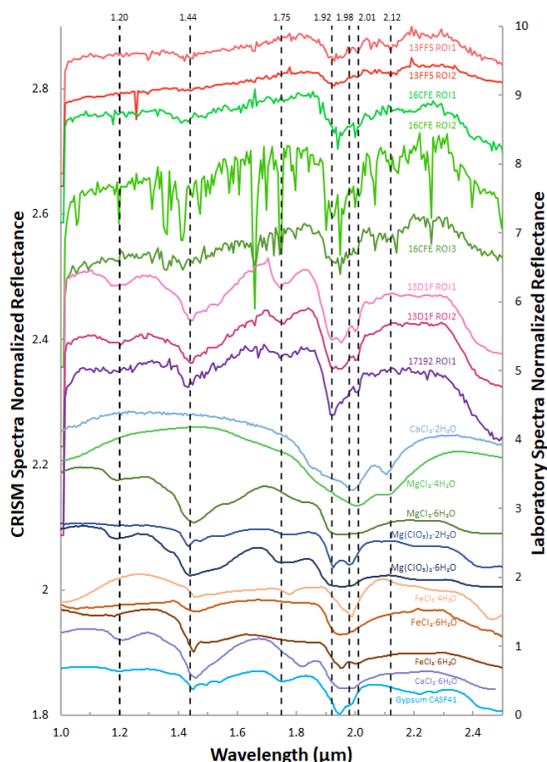


Figure 1. Comparison of CRISM spectra with lab spectra of Cl-salts [5, 6] and gypsum [CAT spectral library] All spectra are normalized and offset.

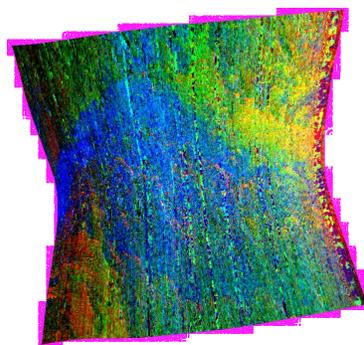


Figure 2. CRISM image 37DF in Gale Crater as a color composite with spectral parameters  $R = \text{HCPINDEX2}$ ,  $G = \text{BD2130}$ , and  $B = 1900_2$ . The yellow region in the top-quadrant of the image shows areas of overlap between the HCP and ClO parameters.

The 1.9  $\mu\text{m}$  absorption that was observed in 37DF and A091 is indicative of hydrated salts. After comparing the spectra from these sites to known lab spectra they were seen to most closely resembled  $\text{MgSO}_4 \cdot 7\text{H}_2\text{O}$  and hydrated  $\text{Ca}(\text{ClO})_2$ .

In the north polar regions near the Phoenix landing site, where perchlorates were discovered, our study identified a lot of water ice, even in the summer, presumably buried at shallow depths. We also observed some features that indicate chlorine salts (Figure 3).

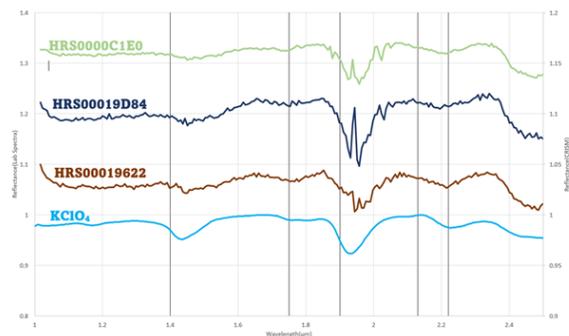


Figure 3. Interesting spectra from HRS0000C1E0, HRS00019D84, and HRS00019622 in the north polar regions plotted against  $\text{KClO}_4$ . The plots have been normalized and offset for easier comparison.

**Implications:** Our new parameters aim to improve our ability to identify chlorine salts and differentiate between hydrated and anhydrous phases. Proper identification of these salts would give insight to the history of brines on Mars.

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**References:** [1] Hanley J. et al (2012) *GRL* 39, L08201. [2] Chevrier V.F. et al (2009) *GRL* 36, L10202. [3] Hanley J. et al (2014). #2879. [4] Hanley J. et al (2015) *JGR* 120, 1415–1426. [5] Hanley J. et al (2014) *JGR* 119, 2370–2377. [6] Carmack R. et al (2019). *LPSC* Abstract #1701. [7] Viviano-Beck C.E. et al (2014) *JGR* 119, 2014JE004627. [8] Achilles C.N. et al (2017) *JGR* 122, 2344–2361.