Strategies for detecting chlorine salts in visible/near-infrared spectra at Mars

Rebecca Carmack (rcarmack@purdue.edu)[1], Jennifer Hanley[2], Briony Horgan[1]

[1]Purdue University, [2]Lowell Observatory

Background

Perchlorate has been directly identified on Mars *in situ* by lander observations and inferred based on orbital spectra.

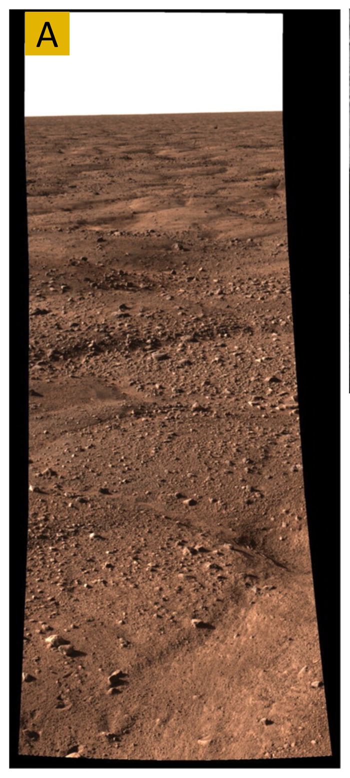


Figure 1. (A) Modified from Smith et al. (2009). Sol 0 image of ground shaped by subsurface ice.

Figure 2. (B) Modified from Smith et al. (2009). Image taken by the RA camera pointed under the lander. Landing thrusters revealed ice just below surface. Liquid brine droplets are present on the left lander strut.

Figure 3. (C) Modified from Smith et al. (2009). OM image (2 mm high) of a sparse sample on the strong magnet. The clumps are the size expected for (~50-mm diameter) for salted grains.

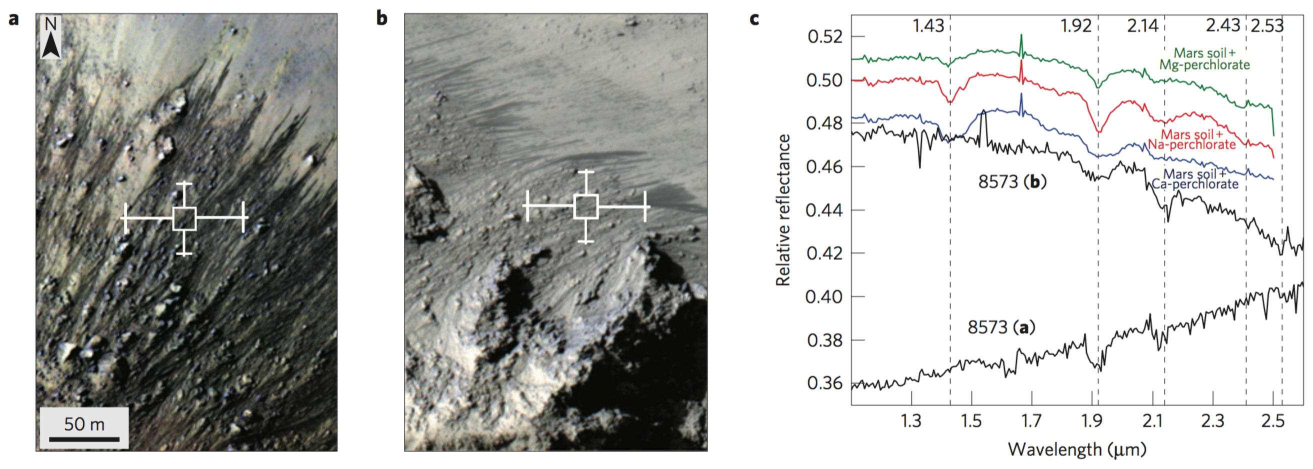


Figure 4. Modified from Ojha et al. (2015). (A) and (B) show recurring slope lineae on the central peak and another peak respectively in Horowitz Crater from image HiRISE image PSP_005787_1475. (C)Spectra from these slopes are compared with spectral mixing of Martian soil and different salts.

New NIR laboratory data for oxychlorine salts facilitate their identification.

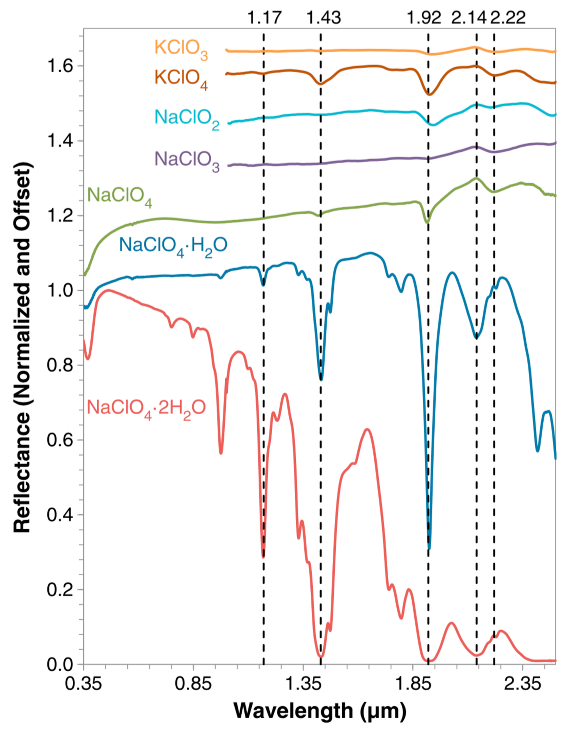


Figure 5. From Hanley et al. (2015). NIR reflectance spectra of KClO3, KClO4, NaClO2, NaClO3, and NaClO4 anhydrous, monohydrate, and dihydrate.

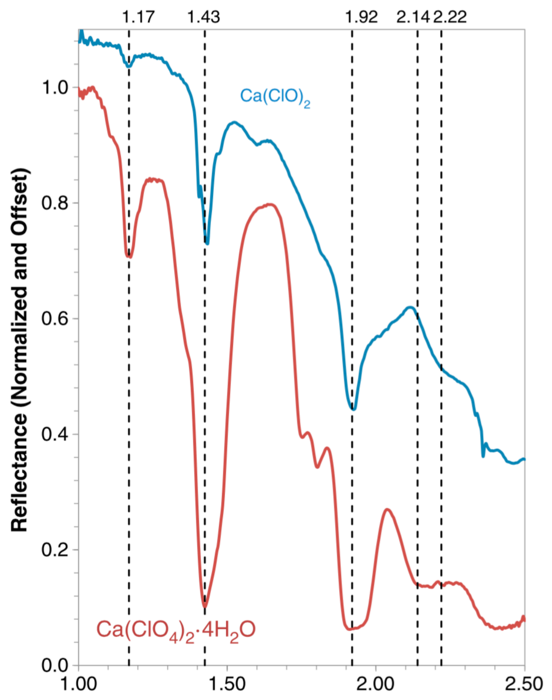


Figure 6. From Hanley et al. (2015). NIR reflectance spectra of Ca(ClO)2 and Ca(ClO4)2·4H2O.

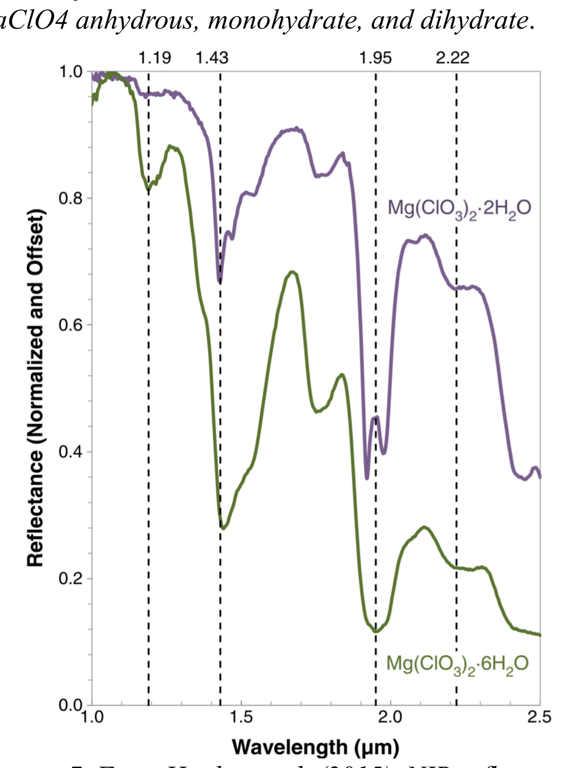


Figure 7. From Hanley et al. (2015). NIR reflectance spectra of magnesium chlorate dihydrate and hexahydrate.

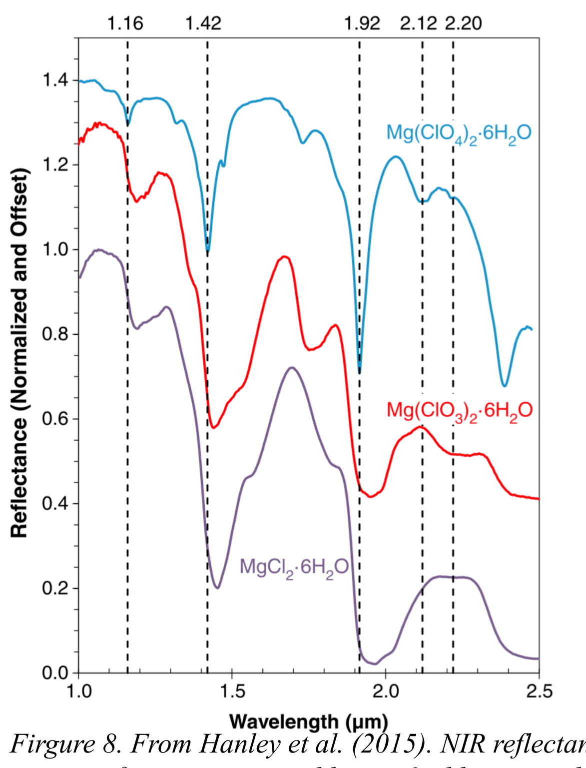


Figure 8. From Hanley et al. (2015). NIR reflectance spectra of magnesium perchlorate & chlorate, with MgCl2 shown for comparison.

Importance & Difficulty

The presence of oxychlorine salts on Mars could have major implications for the stability of water.

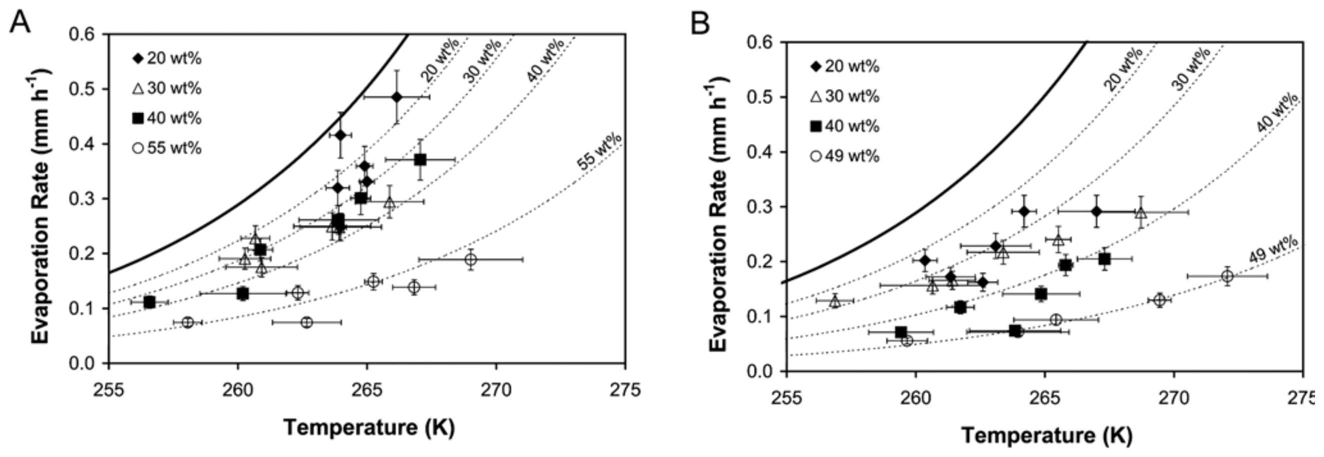


Figure 9. Modified from Chevrier et al. (2009). Evaporation rates of differing concentrations of (A) sodium and (B) magnesium perchlorates as a function of temperature. Dashed lines are theoretical evaporation rates with experimental concentrations.

Similar spectral features make oxychlorine salts hard to differentiate from other common Martian minerals.

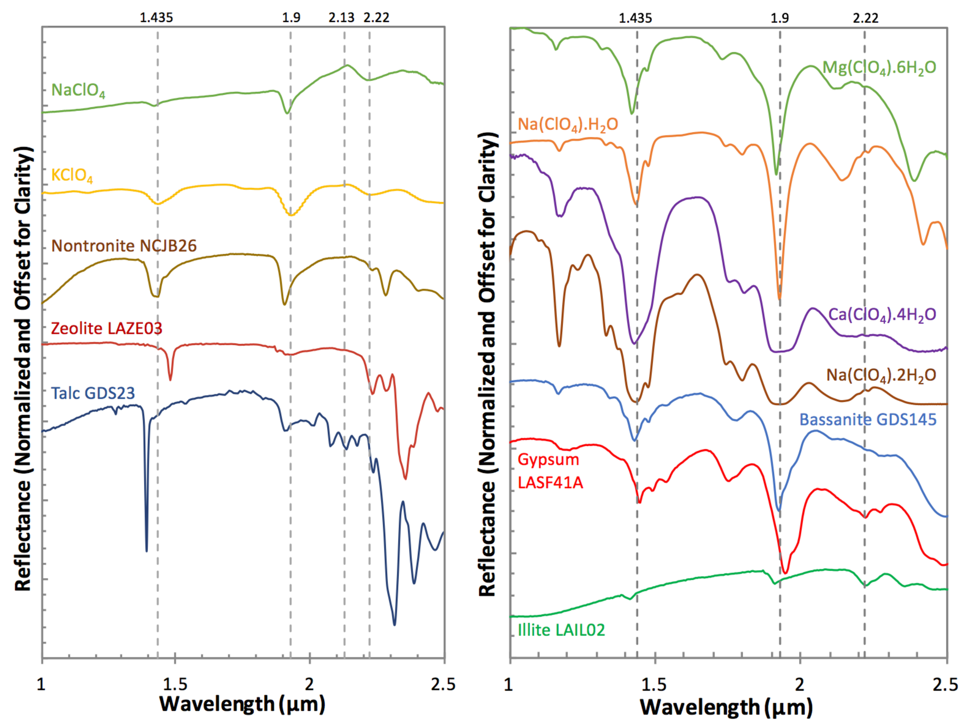


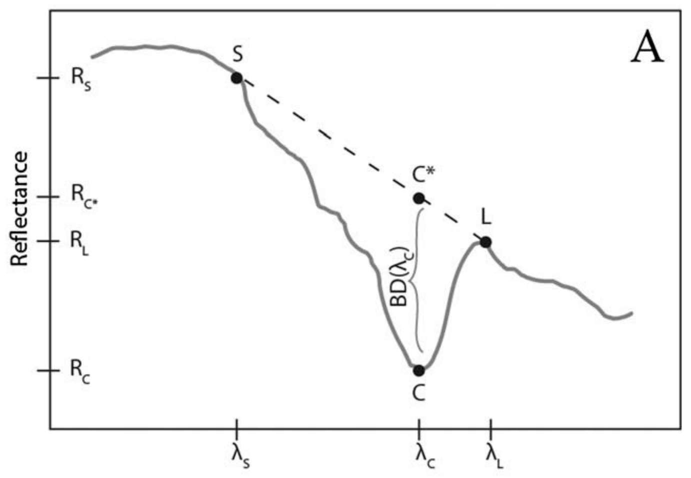
Figure 10. (left) Spectra of anhydrous perchlorates NaClO4 and KClO4 compared to Nontronite, Zeolite LAZE03 and Talc GDS23. Absorption bands related to relevant parameters are shown with grey dotted lines. (right) Spectra of hydrous perchlorates and Illite LAIL02, Gypsum LASF41A and Bassanite GDS145.

New Parameters Developed

Two new spectral parameters, BD2130 & BD2220, were created to identify spectral features specifically found in oxychlorine salts.

Name	Parameter	Formulation	Kernel Width	Rationale	Caveats
BD2130	2.14 μm ClO_4-H_2O 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

*Table 1. Newly created spectral parameters. Formulation is based off of Viviano-Beck et al. R#### is the reflectance at 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. *Information from Hanley et al. (2015)*



R_C reflectance at the center wavelength λ_C

R_S reflectance at shorter (λ_S) wavelength

R_L reflectance at longer (λ_L) wavelength

R_{C^*} reflectance value on continuum from λ_C

$$R_{C^*} = aR_S + bR_L$$

$$a = 1 - b \qquad b = \frac{\lambda_C - \lambda_S}{\lambda_L - \lambda_S}$$

$$BD(\lambda_C) = 1 - \frac{R_C}{R_{C^*}} = 1 - \frac{R_C}{aR_S + bR_L}$$

Figure 11. Image modified from Viviano-Beck et al. (2014) that shows how the band depth is calculated for a theoretical spectrum (solid line). The dashed line represents the continuum fit across the boundaries for the absorption feature.

Browse Products & Analysis

Combinations of parameters can aid in detecting different types of chlorine salts.

MINERAL GROUP	HYDRATION	HL	NHL	PROBLEM MINERALS
PERCHLORATES	Hydrous	BD1400 BD1435 BD2130		
	Anhydrous	BD2220	BD2130	Phyllosilicates (Nontronite, Talc); Zeolite
CHLORATES	Hydrous	BD1435 SINDEX2		Sulfates (Gypsum, Bassanite); Phyllosilicates (Illite)
	Anhydrous	BD2220	BD1400 SINDEX2	Phyllosilicates (Zeolite)
CHLORITES	Anhydrous	BD1900_2	BD1400 BD2130	Ice; Sulfates; Iron Oxides and Primary Mafic Silicates; Phyllosilicates; Carbonates; Halides (7 total)
HYPOCHLORITES	Anhydrous	BD1435 BD2220 SINDEX2		
CHLORIDES	Hydrous	BD1750_2	BD2130	Iron Oxides and Primary Mafic Silicates (Pyroxene); Sulfates (Kieserite, Bassanite)
	Anhydrous	BD2220 SINDEX2		

Table 2. Collection of parameters that need to be highlighted (HL), or pass a threshold value of >.01, or not highlighted (NHL) that would be indicative of different types of salts and their hydration state.

Browse products can be created to separate out possible oxychlorine salts.

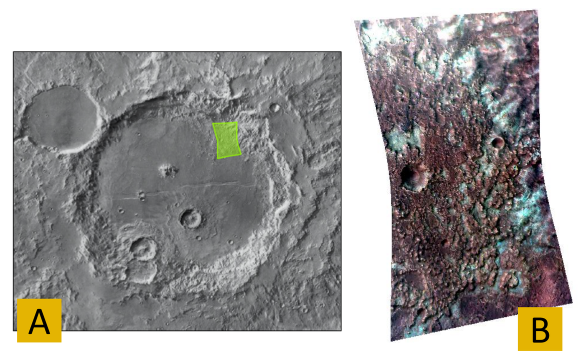
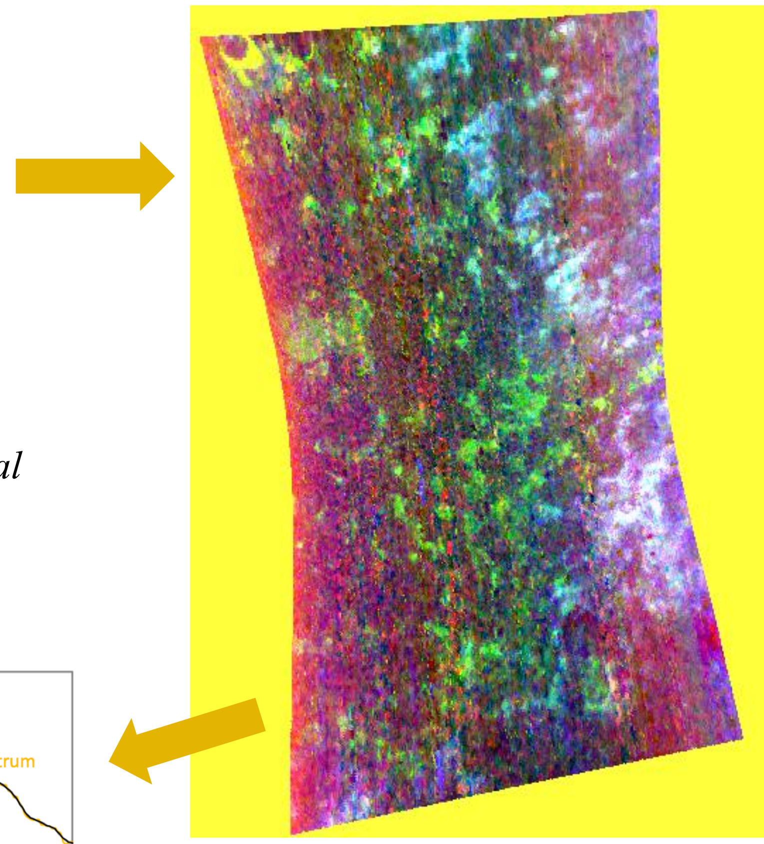
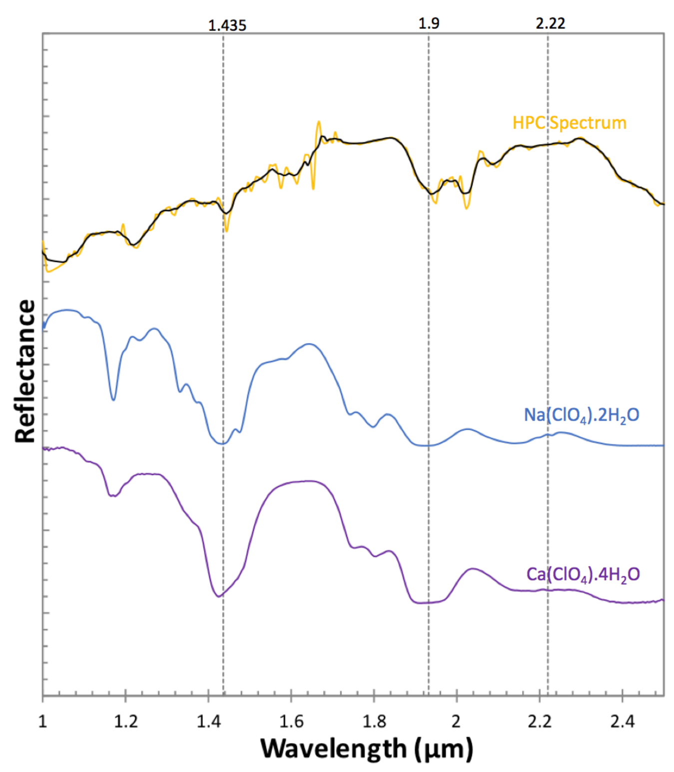


Figure 12. (A) Modified from Chaves (2017). Image of Columbus Crater. Green object is location of (B) spectral cube HRL000062B6_07_IF181J.





HPC: Hydrous Perchlorates { R: BD1435, G: SINDEX2, B: BD2220

Figure 13. Spectrum pulled from average of yellow regions in browse product compared to possible hydrous perchlorates.

Conclusion

- ☞Oxychlorine salts increase water stability on Mars
- ☞New spectral parameters were created to highlight oxychlorine salt spectral features
- ☞Parameters can be combined into browse products to facilitate both hydrous and anhydrous oxychlorine salt identification

References: [1] Smith, P. H., et al. (2009) *Science*, 325, 58-61. [2] Ojha L. et al (2015) *Nat Geosci*, *8*, 829–832. [3] Hanley J. et al. (2015) *JGR*, *120*, 1415-1426. [4] Chevrier, V. F., et al. (2009) *GRL*, 36. [5] Viviano- Beck C.E. et al (2014) *JGR*, 119, 2014JE004627. [6] Chaves, L. C. (2017) *LPSC*, #1744. [7] Hecht, M. H., et al. (2009) *Science*, *325*, 64–67. [8] Glavin D.P. et al (2013) JGR, *118*, 1955– 1973. [9] Hanley J. & Horgan B. (2017) *LPSC*, #2651. [10] Leask E.K. et al (2018) *GRL*, 45, 12180–12189.