IDENTIFICATION OF SPECTRAL ENDMEMBERS IN THE MARTIAN SOUTH POLAR RESIDUAL CAP. S. F. A. Cartwright[1], W. M. Calvin[1], K. D. Seelos[2], and F. P. Seelos[2], [1]Dept. of Geol. Sciences & Engineering, University of Nevada—Reno, (scartwright@nevada.unr.edu), [2]Johns Hopkins University Applied Physics Laboratory.

Introduction: The south polar residual cap (SPRC) of Mars is a 1–10 m-thick deposit of CO_2 ice that sits atop the ~4 km-high dome of dusty water ice layers known as the south polar layered deposits (SPLD) [1]. Through constant exchange with the atmosphere, the SPRC and SPLD contain variable ice and dust mixtures that reflect long-term climate variation [2]. In the SPRC, the effect of dynamic, shorter-term processes can be also be seen in the upper surface of the cap, which is riddled with erosional pits and troughs that form a variety of distinctive morphologies [3]. Additionally, water-ice-rich deposits have been observed in small windows through the SPRC, along its margins, and in an extensive outlying deposit [3, 4], though the exact nature of these exposures remains unclear [5, 6]. The relationship between variable ice and dust mixtures and their contributions to the creation and erosion of south polar ice deposits and the climate records they preserve is also an area of active research.

Understanding the formation and evolution of these deposits hinges on developing a more detailed picture of H_2O/CO_2 ice mixtures, grain sizes, and distributions across different south polar terrains. The Compact Reconnaissance Imaging Spectrometer for Mars (CRISM) [7] facilitates the investigation of compositional variation in the south polar region through the use of hundreds of observations that have been acquired at spatial resolutions up to 18 m/px. Here we present the results of a combination of automated and manual analyses used to identify a preliminary set of spectral endmembers present in the SPRC. Notable endmembers, their spectral characteristics, and spatial/topographic trends are discussed.

Methods: Fourteen CRISM targeted observations (Fig. 1) were selected to provide a wide spatial distribution across the SPRC while sampling 1) a variety of morphologic units mapped by [3], 2) examples of transitions from H_2O to CO_2 ice along SPRC margins, and 3) portions of the water ice outlier at the base of the SPLD. Each of the observations were acquired during late summer (L_S 315–350º) when seasonal CO_2 ice is not expected to obscure spectral signatures of residual ice surfaces.

To provide the best view of surface spectral variability, Targeted Empirical Records (TERs) [8] were generated from the selected observations. In south polar data, the standard TER workflow includes a geometric correction that is known to variably skew reflectances at higher wavelengths where H_2O and CO_2 ices display characteristic spectral shapes. Therefore, we modified the workflow to remove this step while retaining atmospheric, photometric, ratio shift, and smile corrections. The resulting products present spectral data in I/F, the ratio of observed spectral radiance to solar radiance at the time of observation.

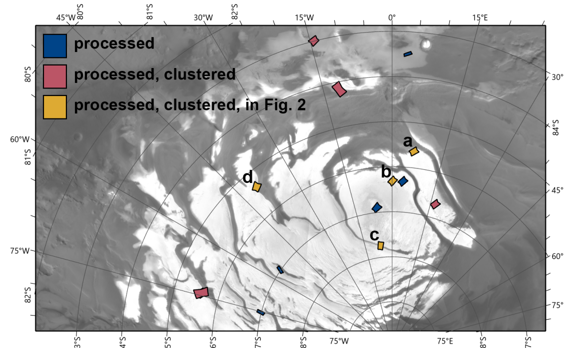

Figure 1. *Processed CRISM observations on the SPRC (high albedo) and water ice outlier (intermediate albedo). See Fig. 2 for results in lettered observations.*

Short-wave infrared TER data (~1.0–4.0 µm) were then passed through automated Python scripts to run K-means classification. Data reduction included normalizing spectra to the mean I/F between 1.8 and 1.9 µm. in each scene, a step meant to replace the TER geometric correction's mitigation of along-track albedo variation. Automated K-means clustering from the *scikit-learn* library [9] was used to map 10 clusters in each of the observations. Statistical envelopes for the cluster spectra in each observation were then evaluated by hand to combine classes whose spectral variation appeared to result from along- or across-track artifacts. Finally, spectral envelopes of the reclassified clusters were compared to compile a superset of both unique and shared spectral endmembers across the fourteen scenes.

Results & Discussion: Cluster reclassification of 8 observations show a variety of spectral endmembers that are linked to morphologic and textural differences on the surface (Fig. 2). The remaining 6 observations did not produce satisfactory classifications and were excluded from further analysis.

Water ice outlier. Spectral classes in two observations that cover the water ice outlier show clear gradation from nearly pure H_2O ice to CO_2 enrichment, though the markedly different spectral slope and feature depth between them indicate they do not share classes in common; this may reflect spatial variability in ice composition in the deposit or residual CO_2 ice cover in one of the observations.

SPRC margins. Four endmembers were identified in the transition from SPLD layering to the SPRC (W0–3), which includes the water ice-rich deposits described in [4, 5, 6]. Band depth of CO_2 ice features at 1.4, 2.29, and 2.35 µm remain constant through the transition from the SPLD to SPRC, which otherwise displays a gradation toward steeper spectral slope and a deepening of broad 1.5 and 2.0 µm features.

Anomalous water ice. One endmember (D0) is associated with "downwasted" erosional debris [1], walls and floors of erosional pits, and as a discrete step in the SPLD-SPRC transition. It is characterized by a steep negative slope between 2.2–2.6 µm and an unusually flat shape in the 2.8–3.3 µm feature, rather than being concave (H_2O ice) or convex (CO_2 ice). These trends may indicate an additional H_2O-CO_2 ice transition step or reflect a more complex interplay of grain size and composition in eroded material.

SPRC surface. Three CO_2 ice-rich endmembers were identified on the upper surface of the SPRC (C0–2) and display a gradation toward deeper 1.4, 2.29, and 2.35 µm CO_2 ice features and exaggeration of the 2.8–3.3 µm "hump". The strongest CO_2 spectra are found on smooth plains while weaker signatures are found in "reticulated" [1] erosional debris fields or nearer to the cap margin, possibly indicating sub-pixel mixing or layering of a CO_2 ice veneer over underlying H_2O ice-rich material.

Conclusion: These preliminary spectral endmembers provide a promising initial view of compositional variability in the SPRC. Future work will focus on improving CRISM data processing to remove image artifacts that mask endmembers in some observations. Incorporating additional data into our analyses and evaluating RMSE fits of these preliminary classes will allow us to expand to a universal set of SPRC spectral endmembers. Spectra in this library can be quantitatively modeled to characterize ice composition and grain size, providing an unprecedented view of some of the most dynamic terrains on Mars.

References: [1] Thomas et al. (2009) *Icarus, 203*, 352–375. [2] Byrne (2009) *Annu. Rev. Earth Planet. Sci., 37,* 535–560. [3] Thomas et al. (2016) *Icarus, 268,* 118–130. [4] Piqueux et al. (2008) *JGR, 113*(E8). [5] Douté et al. (2007) *Plan. & Space Sci., 55,* 113–133. [6] Montmessin et al. (2007) *JGR, 112,* E08S17. [7] Murchie et al. (2007) *JGR, 112,* E05S03. [8] Seelos F. P. et al (2016) LPSC XLVII, 1783. [9] https://scikit-learn.org/stable/modules/generated/sklearn.cluster.KMeans.html

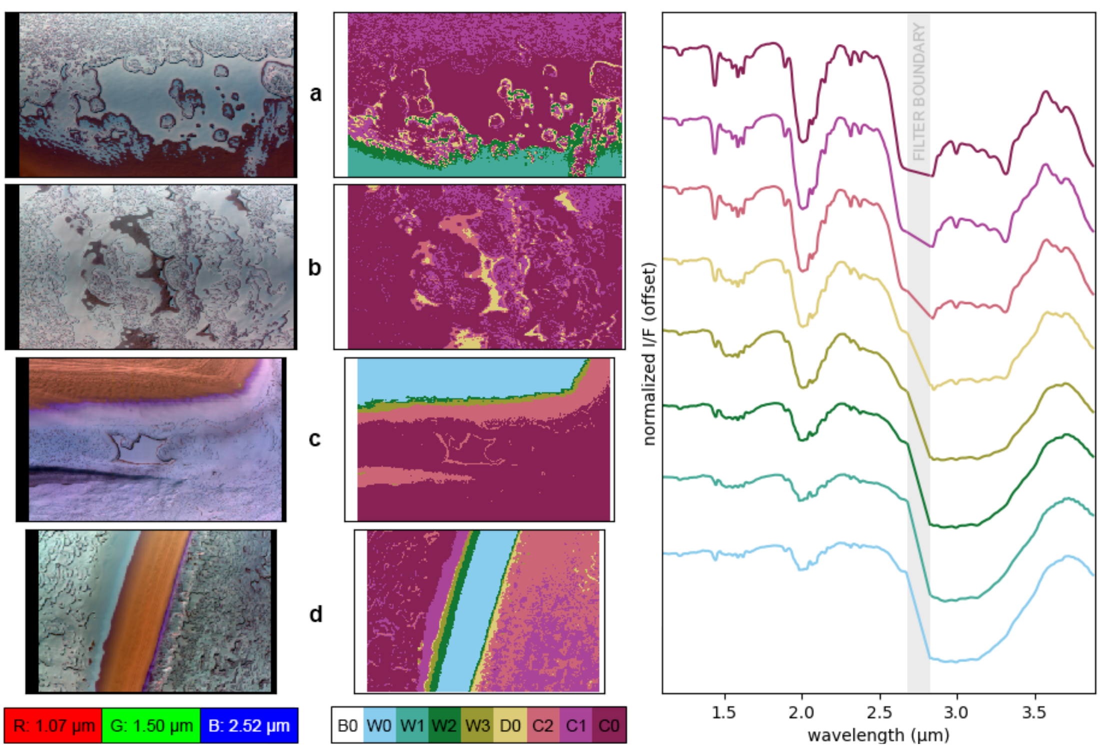

Figure 2. *Summary of spectral endmember results from four CRISM observations covering the SPRC. Leftmost column shows false-color RGB composites of IR data. Middle column shows endmember maps of background (B0), transitional H_2O ice from SPLD to SPRC (W0–3), downwasted and other H_2O ice-rich materials (D0), and CO_2 ice-rich material of the SPRC (C0–2). Rightmost column shows averaged spectra of each mapped endmember in an offset plot. Observation IDs: a) FRT00008354, b) FRT000083F2, c) FRT000144E9, d) HRS0000835D.*