**JOINT NNLS, PCA, AND ELEVATION ANALYSIS OF CRISM DATA AND CARBONATES IN HUYGENS BASIN, MARS.** A. M. Zastrow[1] and T. D. Glotch[1], [1]Stony Brook University, Stony Brook, NY, USA (allison.zastrow@stonybrook.edu)

**Introduction:** Huygens basin is an ~450 km crater that is Noachian in age and located just north of Hellas basin (Figure 1). It is one of the few places on the planet where widespread carbonates have been identified [1]. Given the apparent absence of carbonate-rich rocks on Mars' surface, one of the prevailing theories is that any carbonate rocks on the planet may have been buried over time (or were always buried) [1, 2]. Thus, the presence of carbonate minerals around Huygens basin is of great interest as a potential view into the subsurface of Mars. [1] made an estimate of the amount of $CO_2$ that could have been sequestered if the carbonate layer exposed by Huygens were either global (~1 bar) or only local (a few millibars) at 40% carbonate abundance.

In this study, we used spectral unmixing to quantitatively estimate the amount of carbonate located in Huygens basin and make a more accurate estimate of the $CO_2$ potentially sequestered by the potential Huygens basin subsurface carbonate deposit.

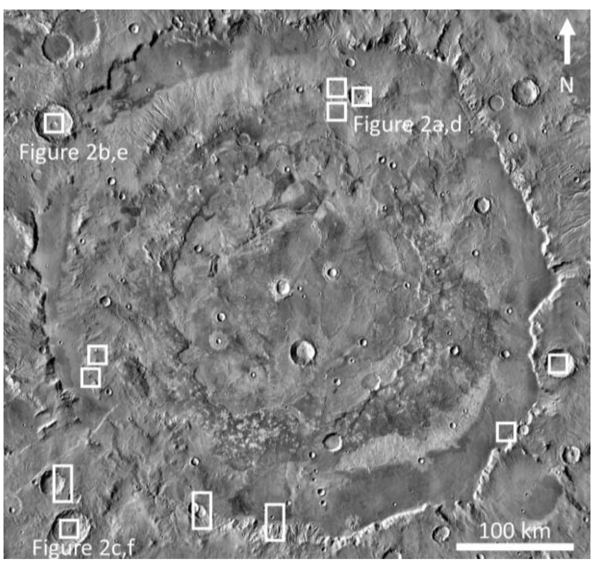


Figure 1. THEMIS image of Huygens Basin. CRISM stamps in white boxes.

**Remote Sensing Data:** We looked at 21 CRISM images, largely around the rim of Huygens basin (there are very few targeted CRISM stamps inside the basin). 11 of the images are located around Prao crater in the northeast corner floor of the basin. Most of the images are full-resolution (18 m/pixel) targeted (FRT) images, while a handful are half-resolution (36 m/pixel) targeted (HRL and HRS) images.

We start with uncorrected data (TRR3) and use a radiative transfer-based atmospheric correction (DISORT, as described in [3]) that allows for a more direct comparison between CRISM images regardless of differences in collection time, viewing geometry, and atmospheric conditions. With this atmospheric correction, the standard CRISM I/F spectra are converted to single scattering albedo (SSA).

We generated DEMs that cover many of our CRISM images using data from both the Context Camera (CTX) and the High Resolution Imaging Science Experiment (HiRISE) on MRO. The DEMs were processed using the MarsSI online interface. It was possible to generate CTX DEMs that cover most of the CRISM locations, but HiRISE DEMs were only available for three areas.

**Methods:** We have analyzed the CRISM data in multiple ways: using a non-negative linear least squares deconvolution algorithm (NNLS), using principal components analysis (PCA), and incorporating three-dimensional DEM data.

*Non-negative linear least squares.* Using the DISORT-corrected CRISM spectra, we can use a linear unmixing model for spectral mixture analysis. This model has a rich history in unmixing thermal infrared data (e.g. [4]) but, recently, has also been used with CRISM data [3, 5]. The spectral library has endmembers from all major mineral groups, as well as an endmember for Martian dust. SSA spectra for the minerals are generated using optical constants, *n* and *k*, and selected grain sizes between 15 and 1000 μm.

*Principal components analysis.* PCA is a method of dimensionality reduction that allows complex data to be represented by only a few of its "principal components" while still retaining most of the variation in the data. In our work we use the principal components to transform the CRISM data and identify pixels that share a similar spectral shape. We can then compare the PCA maps with our NNLS abundance maps. Including PCA in our analysis can provide a secondary "check" on results provided by the NNLS unmixing and may function as a mask to eliminate noise in the NNLS abundance maps.

*DEM elevation analysis.* To incorporate elevation into our analysis of modeling results, we overlaid CTX and HiRISE DEMs with the projected and geo-registered CRISM models and then compared abundances of different minerals and PCA eigenvectors to elevation.

**Results:** We have completed the NNLS modeling of all 21 CRISM images. Work on the PCA and DEM analysis has produced preliminary results for Lucaya crater on the northwestern rim of the basin, Prao crater, and an unnamed crater on the southwestern rim of Huygens and is ongoing for the other locations.

*NNLS modeling*. Our analysis shows that carbonates are present around Huygens in low abundances, mostly from 5 to 20%. The carbonate deposit along the rim of the central pit in Lucaya crater that was the basis for [1]'s $CO_2$ sequestration estimate has abundances up to ~15% (Figure 2a). Our model uses three different carbonate endmembers (Ca-, Mg-, and Fe-rich). The carbonates in Huygens are largely modeled with the Ca-rich endmember, except for a couple of small appearances of the Fe-rich endmember in Prao (Figure 2b) and the unnamed SW crater (Figure 2c).

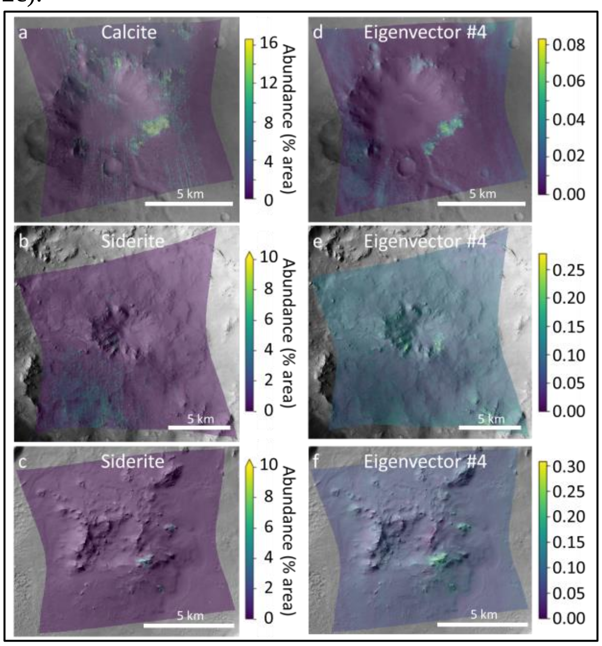


Figure 2. Left column: NNLS abundance maps, Right column: PCA eigenvector maps. Top row: FRT124B3, middle row: FRT0B5AF, bottom row: FRT1FD79.

*PCA analysis.* Here we present preliminary results based on PCA analysis of the CRISM image in Lucaya crater and applied to images in Lucaya (Figure 2d), Prao (Figure 2e), and the SW crater (Figure 2f). As expected, the abundance maps and the PCA eigenvector maps are not exact matches; however, a couple of the eigenvectors (2 and 4 in particular), do highlight areas of higher carbonate abundances. More analysis is needed to understand the full nature of these correlations.

*DEM analysis*. Lastly, we have used DEM topography in Lucaya crater combined with the abundance maps and PCA eigenvector maps to identify potential stratigraphic origins of carbonates. Comparing elevation with carbonate abundance results (Figure 3a) provides some potential, but fuzzy correlation; comparing elevation with PCA eigenvector #2, however, provides a clearer layer between ~1350-1650 m (Figure 3b). Our goal is to carry out a similar analysis for all the CRISM-DEM pairs and see if we can identify common layers throughout Huygens.

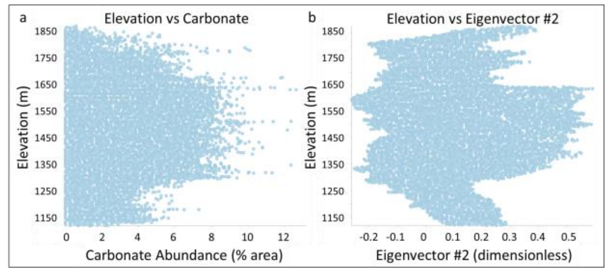


Figure 3. Y-axis: CTX DEM elevation, X-axis: a) FRT124B3 carbonate abundance, b) eigenvector #2 value.

**Conclusions and Future Work:** According to our NNLS modeling, the primary carbonate in Huygens Basin is largely Ca-rich. Using our modeled abundances of carbonate in Lucaya crater, which have their maximum around 15% per pixel, the $CO_2$ sequestration potential of a buried carbonate reservoir under Huygens is nearly one third smaller than previous estimates.

Future work involves completing all of the analyses for all possible locations, thus preparing a more complete and accurate inventory of carbonate deposits on the surface and potentially tying them to a larger deposit in the subsurface.

Also, in addition to (or in lieu of) the PCA analysis, we would also like to incorporate non-negative matrix factorization (NMF) into our analysis. NMF is similar to PCA, but with the restriction of non-negativity, which means the results will be more directly physically applicable.

**Acknowledgments:** This research was funding by NASA's Mars Data Analysis Program, Award #80NSSC18K1372. CRISM data were downloaded from the PDS Geosciences Node (https://pds-geosciences.wustl.edu/). CTX and HiRISE DEMs were processed using the MarsSI (marssi.univ-lyon1.fr) application founded by the European Union's Seventh Framework Program (FP7/2007-2013) (ERC Grant Agreement No 280168).

**References:** [1] Wray J. J. et al. (2016) *JGR-Planets, 121*(4), 652-677. [2] Michalski J. and Niles P. (2010) *Nature Geosci., 3*, 751-755. [3] Liu Y. et al. (2016) *JGR-Planets, 121*(10), 2004-2036. [4] Rogers A. D. and Aharonson O. (2008), *JGR-Planets, 113*, E06S14. [5] Zastrow A. M. and Glotch T. D. (2021), *GRL, 48*(9).