Evolution of the North Polar Gypsum Dunes: Mineralogical Variations Across the Dunes and Interdune Regions

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Unique Gypsum-bearing Dunes at Olympia Undae (Below North Polar Ice Cap)

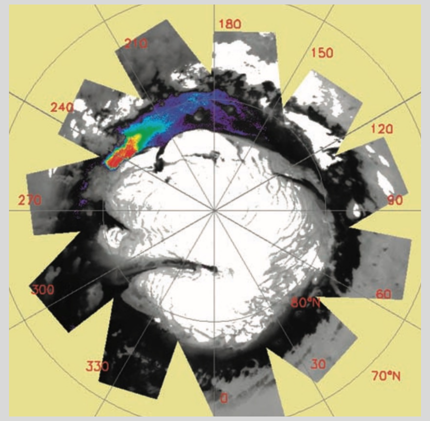


Fig. 1 Gypsum-bearing dunes detected by Langevin et al. [1] in Olympia Undae region of Mars near north polar ice cap using OMEGA data (surface resolution 300 m to 3 km).

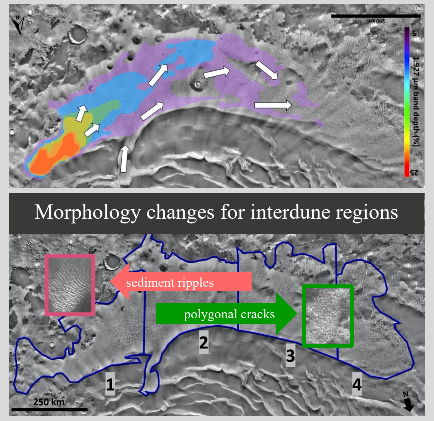


Fig. 2 Olympia Undae region
(a) Top view from Fishbaugh et al. [2] demonstrates high gypsum concentration in east and wind direction towards the west.
(b) The region was subdivided into 4 study sites by Yanez et al. [3] to evaluate changes in morphology of the interdune regions and by Yanez et al. [4] to document changes in mineralogy across the region.

Mapping Minerals at Mars using CRISM

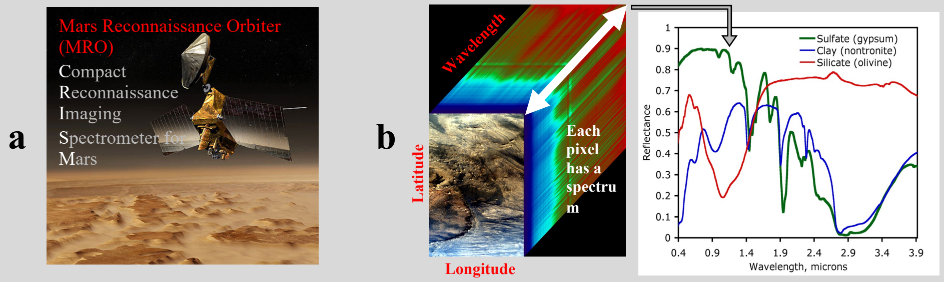


Fig. 3 Mineralogy determined at Mars from orbit.
(a) CRISM spectrometer [5] collected hyperspectral images across planet at 18 m spatial resolution (best targeted images, ~10x10 km region).
(b) Each pixel contains 544 channels from 0.4 to 3.9 µm to fingerprint minerals by their unique spectral bands and shapes.

Recent Advances in Image Processing Enabled Improved Mineral Characterization

- iterative process including testing and recalibration
- use climate data to improve atmospheric model for separation

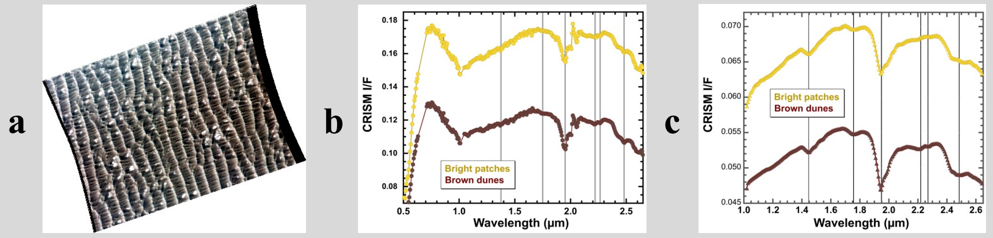


Fig. 4 Recent improvements to spectral processing of CRISM images allows for better characterization of mineralogy.
(a) CRISM image HRS0000302A from Olympia Undae.
(b) Spectra from MTRDR calibration developed by Seelos et al. [6] with improved spectral quality and reduced noise across full spectral range (0.4-3.9 µm).
(c) Spectra from subconv calibration by Itoh & Parente [7] that greatly improve spectra of smaller surface outcrops through new atmospheric separation and denoising processes, but only works for 1-2.65 µm range.

Recent Advances in Mapping Algorithms Enabled Improved Mineral Mapping

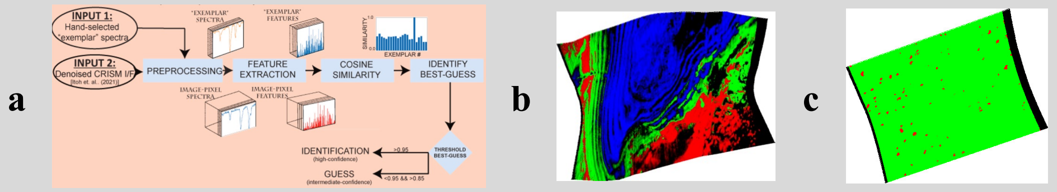


Fig. 5 Recent applications of Generative Adversarial Networks (GANs) successful in discriminating spectral components in CRISM images.
(a) Diagram of feature extraction and mapping algorithm developed by Saranathan & Parente [8].
(b) Example mineral map from CRISM image FRT00009C0A containing 3 types of sulfate minerals at Juventae Chasma.
(c) Mineral map for HRS0000302A from Olympia Undae with bright patches in red (Figure 4).

Summary

The Olympia Undae Sand Sea of the North Polar region contains unique gypsum-rich dunes that provide insights into modern polar processes. Detailed characterization of gypsum and associated minerals is now feasible due to advances in CRISM image processing.

We collected spectra of dunes and interdune regions (bright patches) using multiple 3x3 and 10x10 18m-pixel clusters as well as polygons and points using ENVI's ROI tool. Our analyses reveal changes from the dunes to the interdune regions.

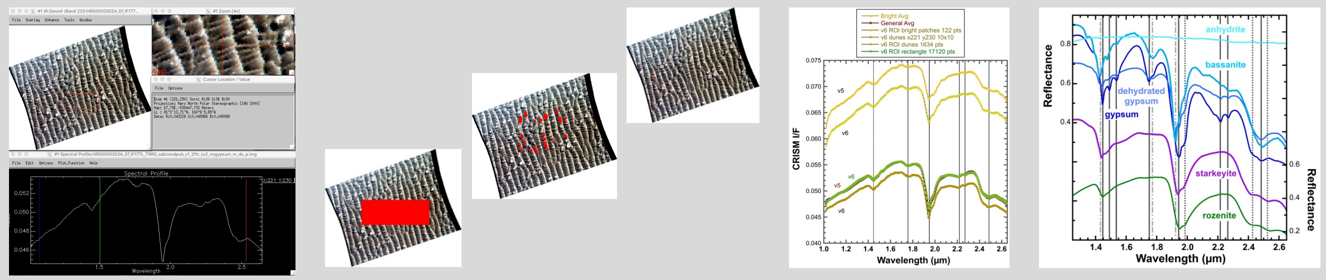
Dunes with the strongest gypsum signatures are present in the east and contain features at 1.75, 1.94-1.95, 2.22, 2.27 and 2.49 µm as well as a triplet at 1.45, 1.49, and 1.54 µm. The bright regions in the east also have spectra consistent with gypsum but are brighter, indicating another bright material is present (likely salt). HiRISE views reveal bright ripples at these bright patches.

Traveling west, the dunes have similar gypsum-like spectral bands that are shifted slightly and are attributed to dehydrated gypsum. The spectra of the interdune regions here instead contain weak gypsum features and also spectral signatures due to polyhydrated sulfates (starkeyite or rozenite). HiRISE views of the interdune materials reveal polygonal cracks consistent with an evaporite deposit.

We are investigating potential causes for these changes in the Ca sulfates present in the Olympia Undae Sand Sea. Winds in past environments likely formed the gypsum-bearing dunes from the evaporite-like interdune materials formed by brine alteration of basalt. Winds in current environments traveling from the east to the west appear to be altering the gypsum in the dunes.

Testing Procedures for Collecting Spectral Data

- Collected spectra from multiple 5x5 or 10x10 spots from dunes, shadows, and bright patches.
- Collected spectra from Regions of Interest (ROIs) using polygons, points or rectangles.
- Compared CRISM data to lab spectra of sulfates [9].



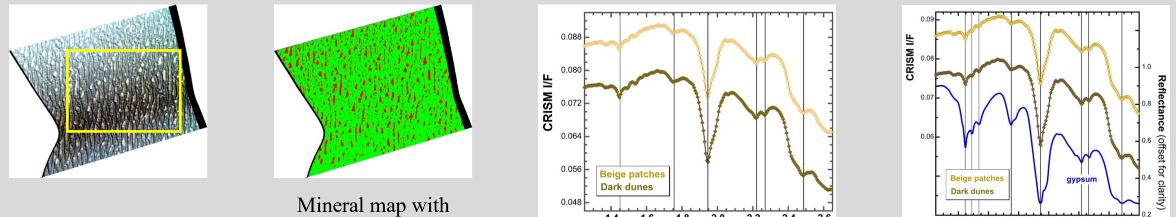
Ca sulfates
gypsum $CaSO_4 \cdot 2H_2O$
bassanite $CaSO_4 \cdot 0.5H_2O$
anhydrite $CaSO_4$
Mg sulfate
starkeyite $MgSO_4 \cdot 4H_2O$
Fe sulfate
rozenite $FeSO_4 \cdot 4H_2O$

References:

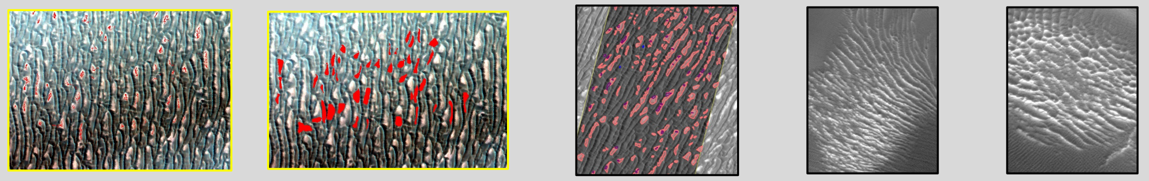
[1] Langevin Y. et al. (2005) Sulfates in the north polar region of Mars detected by OMEGA/Mars Express. *Science*, **307**, 1584-1586.
[2] Fishbaugh K. E. et al. (2007) On the origin of gypsum in the Mars north polar region. *Journal of Geophysical Research*, **112**, E07002, 1-17.
[3] Yanez K. L. et al. (2022) Evolution of the north polar gypsum dunes: Variations in the morphology and composition of the Olympia Undae sand sea. *Geological Society of America Connects, October 9-12, 2022*, Abstract #156-13.
[4] Yanez K. L. et al. (2022) The intriguing mineralogy of the dunes at Olympia Undae and implications for dynamic modern polar processes on Mars. *American Geophyscal Union Fall Meeting, December 12-16, 2022*, Abstract #1138024.
[5] Murchie S. L. et al. (2009) The Compact Reconnaissance Imaging Spectrometer for Mars investigation and data set from the Mars Reconnaissance Orbiter's primary science phase. *Journal of Geophysical Research*, **114**, E00D07, doi:10.1029/2009JE003344.
[6] Seelos F. P. et al. (2016) CRISM hyperspectral targeted observation PDS product sets - TERs and MTRDRs. *47th Lunar Planet. Sci. Conf.*, Abstract #1783.
[7] Itoh Y. & Parente M. (2021) A new method for atmospheric correction and de-noising of CRISM hyperspectral data. *Icarus*, **354**, 114024.
[8] Saranathan A. M. & Parente M. (2021) Adversarial feature learning for improved mineral mapping of CRISM data. *Icarus*, **355**, 114107.
[9] Bishop J. L. et al. (2014) Spectral properties of Ca-sulfates: Gypsum, bassanite and anhydrite. *American Mineralogist*, **99**, 2105-2115.

Results – CRISM image FRT000285F from eastern Olympia Undae

- dunes containing strongest gypsum signatures
- interdune regions covered by bright ripples



Mineral map with bright patches in red



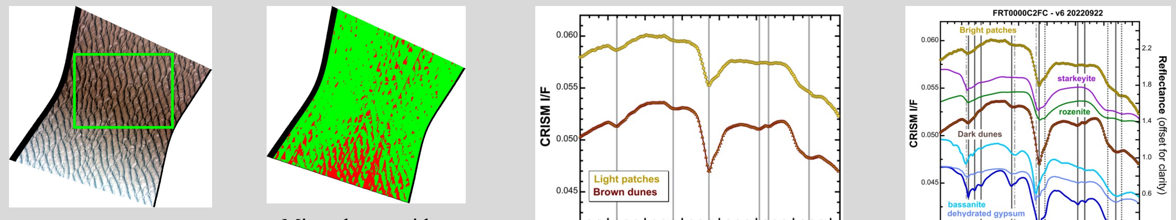
ROIs for spectrum of bright patches

ROIs for spectrum of dark dunes

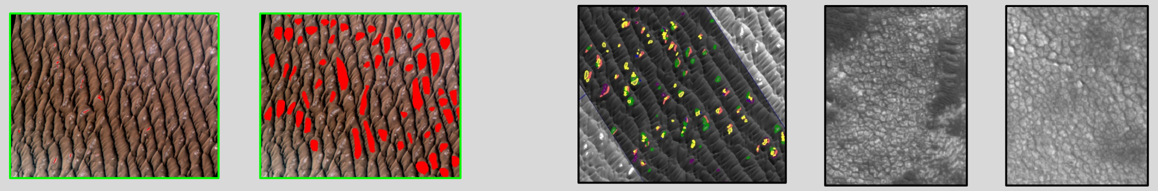
Views of bright patches containing gypsum-bearing ripples in HiRISE image ESP_036730_2600_RED (from [3])

Results – CRISM image FRT000C2FC from central Olympia Undae

- dunes contain some gypsum
- bright interdune regions mostly cracked evaporite surfaces



Mineral map with bright patches in red



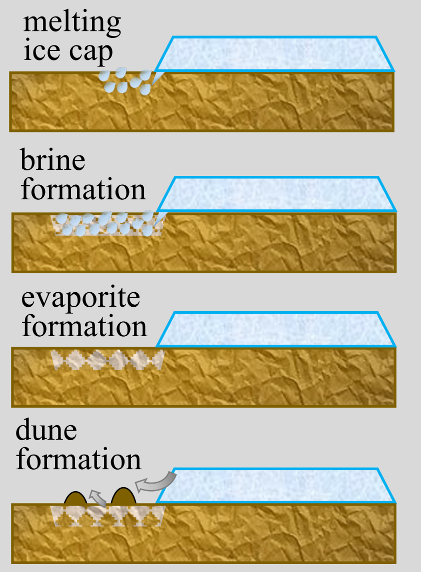
ROIs for spectrum of bright patches

ROIs for spectrum of dark dunes

Views of bright patches containing polygonal cracks in HiRISE image ESP_027343_2610_RED (from [3])

Likely Geologic Processes at Olympia Undae

- Dunes and Interdune Regions
  - Bright interdune patches appear to be part of wider evaporite deposit, likely formed from brine alteration of basaltic basement rocks.
  - Dunes likely formed through wind action, similar to White Sands, NM.
- Strong winds from east towards west
  - Could be spreading gypsum from primary source in east towards west.
  - Could be dehydrating gypsum in west.



Wind blowing across dunes from east to west