Initial Investigations of Endoevaporitic Gypsum Habitats of Salar de Pajonales, Chile

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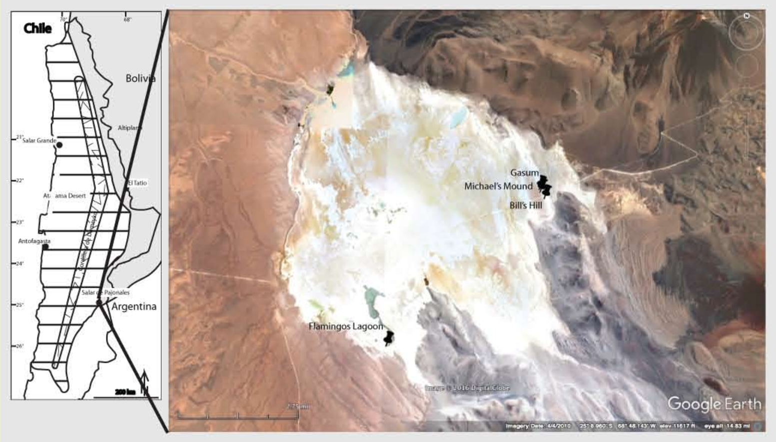
INTRODUCTION

Salar Pajonales is a dynamic, saline basin with evidence of present and former microbial communities comprising both aquatic and mineral habitats. The basin receives both groundwater and surface water recharge. Groundwater originates from the volcanic arc of the Andes to the east. Direct precipitation and surface runoff supplies water to the basin. The brines form from chemical weathering of volcanic rock in combination with evaporation.

Sands and fine gravels intercalated with evaporite deposits lie to the west of Salar de Pajonales. The evaporites formed at a time of generally greater precipitation, leading to a larger surface area of the salar. Periodic floods, intense evaporation, and continuous groundwater recharge determines the water level and thus the distribution of salt crusts.

Here we evaluate the potential of different microhabitats to harbor extant and extinct microbial colonies as endoliths and chasmoendoliths.

We compare potential biosignatures in different local geomorphological habitats to determine biosignature-preservation potential.



Location of sampling sites at Salar de Pajonales within Chile

RELEVANCE TO MARS EXPLORATION

High UV radiation, relatively thin atmosphere, broad diurnal and annual temperature variations, volcanic/hydrothermal activity, mineralogy, morphology, geomorphology, salt abundance, and aridity make Salar de Pajonales an excellent analog to evaporitic basins at the Noachian/Hesperian transition on Mars.

Gypsum likely associated with migrating waters in outcrops have been observed on Mars from the ground in vein exposures at the Meridiani by the Opportunity rover at "Homestake" [1]. Gypsum has also been detected from orbit, in sand dunes in the northern polar region [2]. Its formation of gypsum provides strong evidence of the presence of water on Mars, from evaporating standing bodies [3, 4], hydrothermal processes, circulation of water in aquifers [e.g., 5, 6, 2]. The highly concentrated calcium sulfate at Homestake could have been produced in conditions more neutral than the harshly acidic conditions indicated by the other sulfate deposits observed by Opportunity, one that could have been possibly more favorable for a larger diversity of microorganisms [7].

Prominent mineral veins at the "Garden City" site examined by NASA's Curiosity Mars rover vary in thickness and brightness, as seen in this image from Curiosity's Mast Camera (Mastcam). The image covers ~ 60 cm across. Types of vein material evident in the area include: 1) thin, dark-toned fracture filling material; 2) thick, dark-toned vein material in large fractures; 3) light-toned vein material, which was deposited last. Credit: NASA/JPL-Caltech. MSL mission.

HABITATS

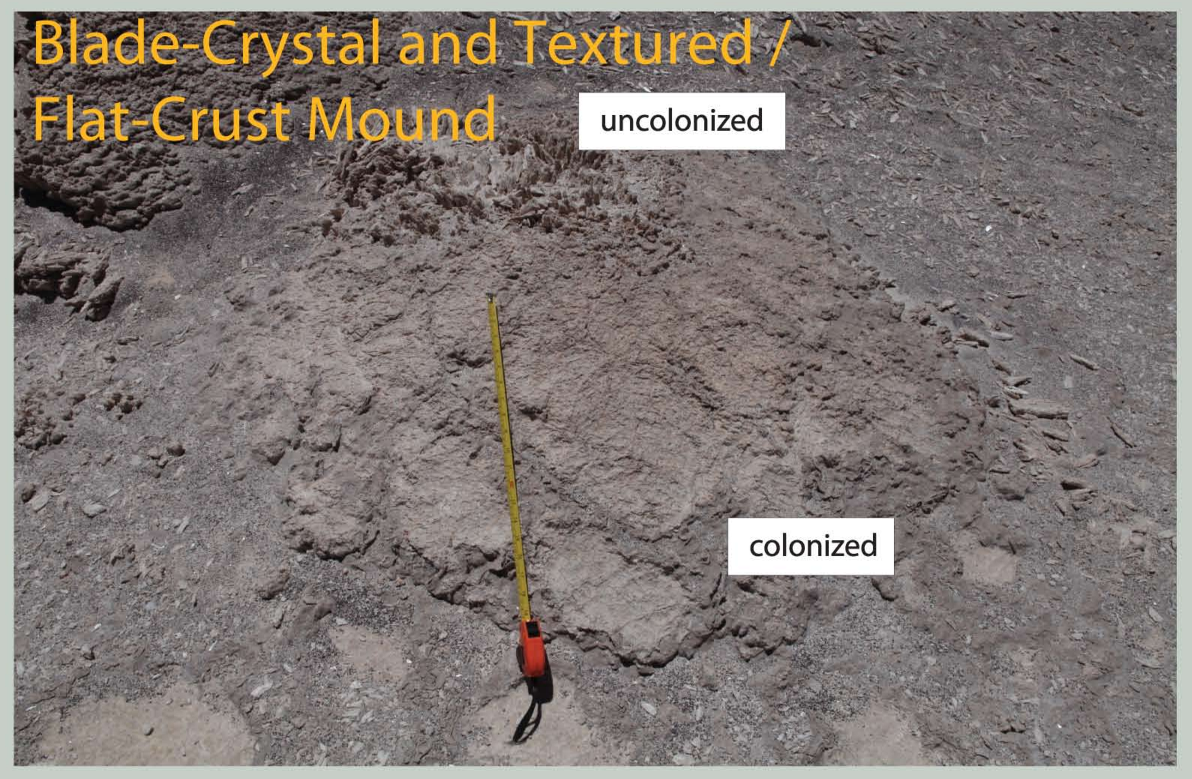
Low-altitude imaging documents several habitat with different mophologies that are detectable at varying spatial thresholds (see this session: Phillips et al. 2017, # 3373):

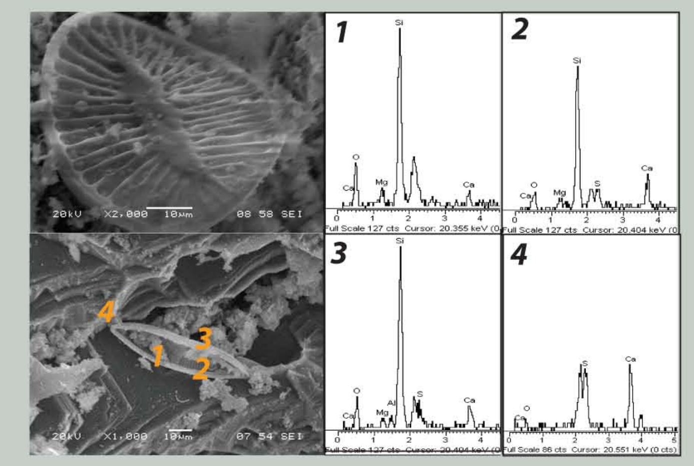
- Crusts are polygonally patterned, flat, low-relief areas covering several meters separated by low ridges of uplifted selenite crystals; the crusts themselves have smaller surface areas than the uplifted selenite crystals. In the example shown here, the polygonally patterned crust covers a couple-meter-high mound, although flat crust is more common.

- Mounds are centimeter- to meter-high structures of selenite crystals, overlying dry or water-bearing caverns. The surfaces of the mounds have different selenite crystal textures: i) bladed crystals are splayed, radially and randomly oriented selenite crystals, ii) capped crystals are similar to bladed crystals but are bridged at the terminus rather than splayed, iii) flat crusts are noted above, and iv) textured crusts are flat crusts with the surface texture of the capped crystals.

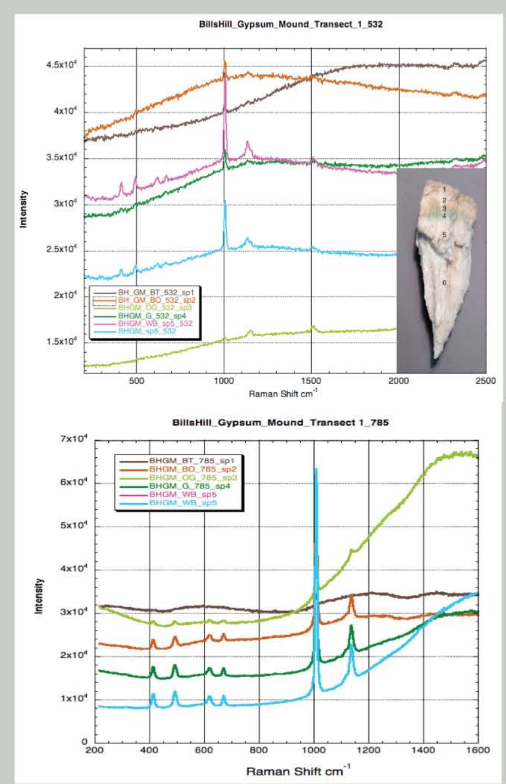
- Surface outwash channels comprise mainly colluvium, including blocks of selenite derived from the other morphological types listed above. Additionally, the deposits in the outwash channels contain selenite crystal fragments ranging from silt / sand sized grains to meter-sized blocks. It is these larger blocks that provide habitats.

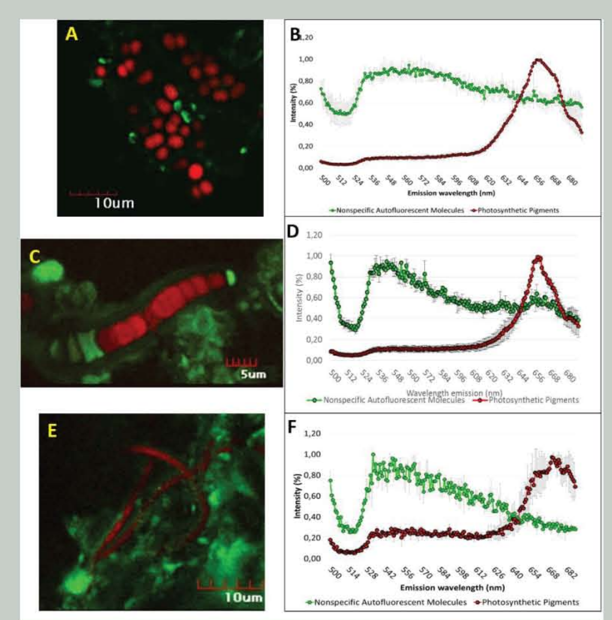
Within each morphological habitat type, some crusts, mounds or blocks are visibly colonized by pigmented microorganisms and others are not. We spectulate that the colonization likelihood / potential for the various habitats is controlled by the movement of water by capillary action from the subsurface during evaporation. Bladed crystals, for example, are rarely visibly colonized. This structure represents the evaporation pathway of least resistance, preventing the retention of water necessary for microbial habitats. Yet complete isolation does not guarantee colonization, as seen in the example of the A in which the flat crusts are not colonized but the randomly spaced capped crystal 'pimples' are colonized.



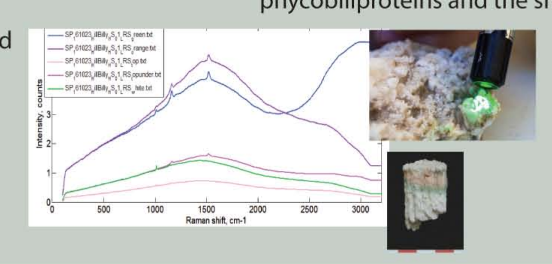


Scanning electron microscopy and wavelength dispersive spectrometry shows silicon, magnesium, aluminum, sulfur and calcium associated with diatoms and small spheres.

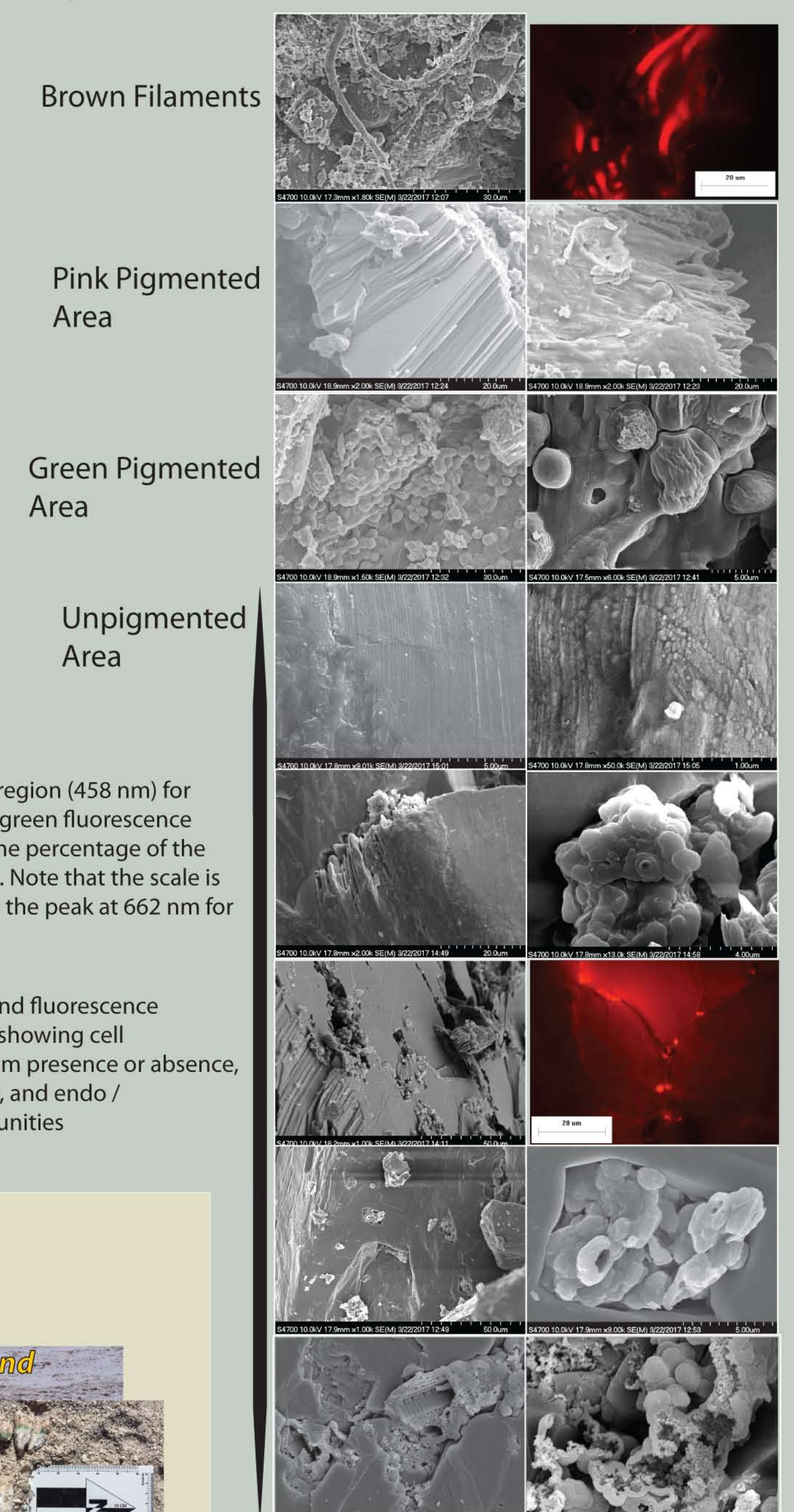




ACLSM λ-scan images and emission spectra in both green and red region (458 nm) for different cyanobacterial morphotypes. Cyanobacteria and red and green fluorescence associated were observed. The data from the spectrum represent the percentage of the mean fluorescent intensities (MFIs) (n= 3) ±standard deviation (SD). Note that the scale is in percentage for normalization. Note in the cell aggregate A and B the peak at 662 nm for phycobiliproteins and the shoulder at 685.2 nm for chlorophyll a.



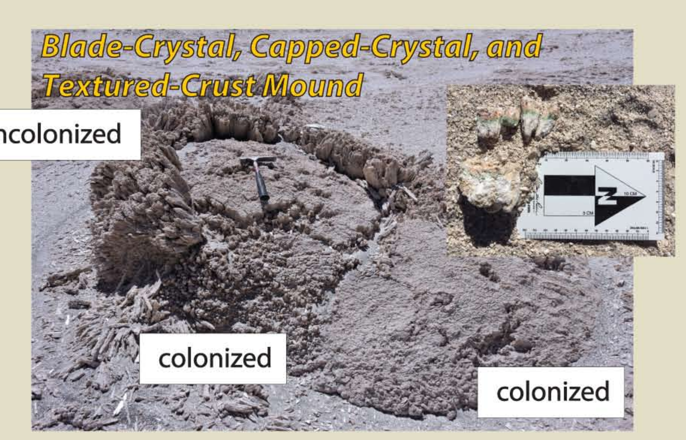
Laboratory (532 nm and 785 nm) and field (532 nm) laser Raman spectroscopy of pigmented selenite crystals

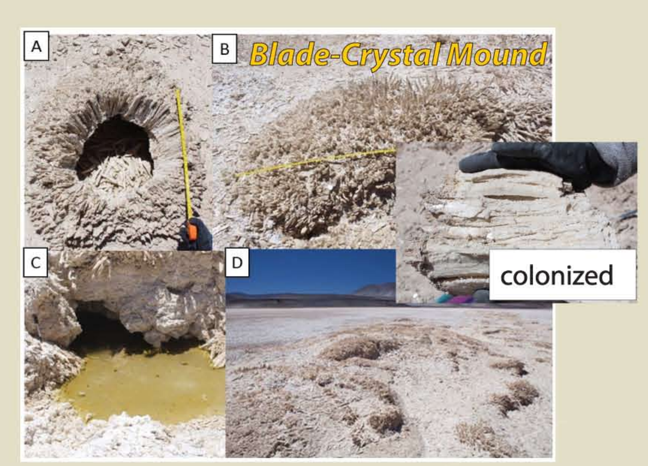


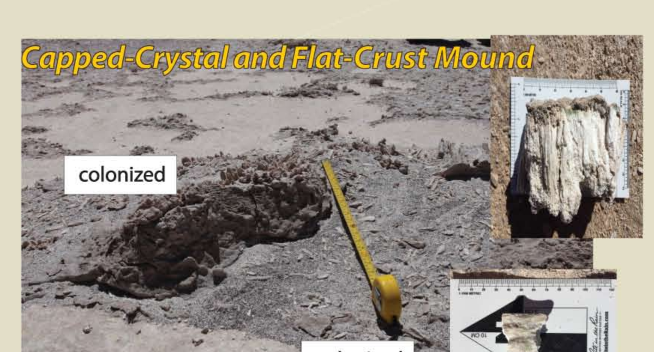
Scanning electron and fluorescence microscopy images showing cell morphologies, biofilm presence or absence, biofilm morphology, and endo / chasmolithic communities

Crusts

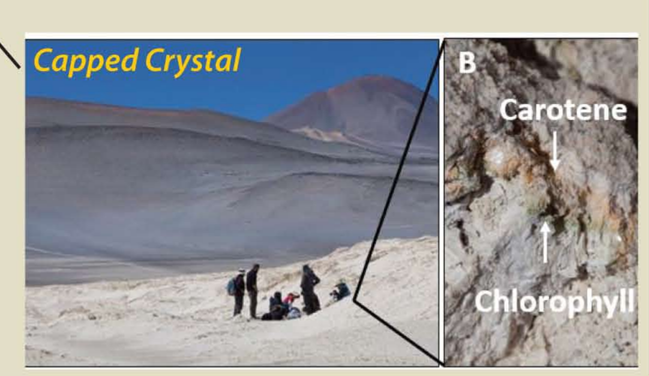
Mounds

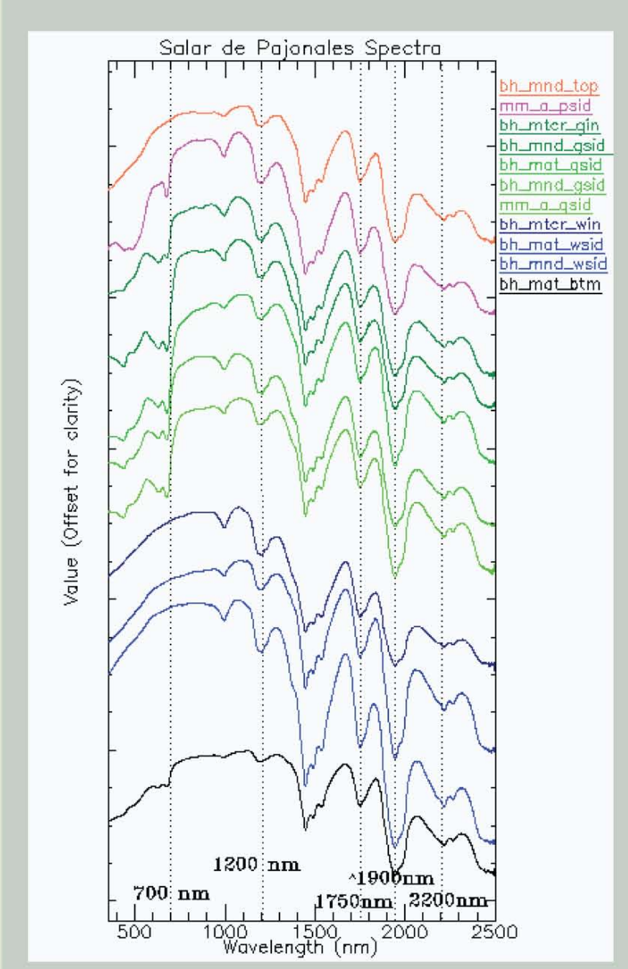






Outwash Channel





Detailed Study of One Morphology

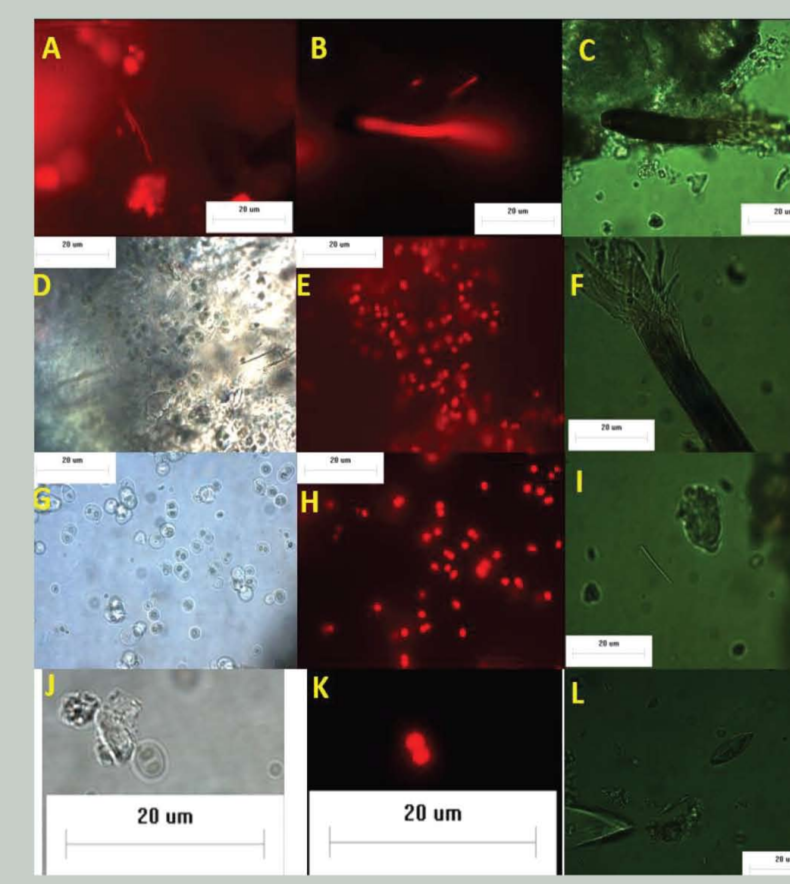
The blade-crystal and textured / flat crust mound morphology was investigated in detail for morphological, spectral, textural, and microbiological properties. We observed distinct and related characteristics across multiple scales relevant to identification of habitable environments and to location of habitats within such environments.

Thresholds of detectability are discussed by Phillips and others (this meeting, #3373). Their work demonstrates the necessary resolution to distinguish meter to submeter morphologies, such as the crust, mound, and outwash channels discussed here.

Detailed observations taken in the field demonstrate the ability to detect endolithic and chasmolithic communities from surface observations (see MM pimples) and from mechanically extracted materials (BHA, BHB) - see Sobron and others (#3640). VNIR and Raman spectroscopy taken in the field document the presence of clay minerals and gypsum along with the pigments, chlorophyll, carotenoids, and scytonemin. Laboratory spectra confirm these observations.

Microscopic textures within the selenite crystals demonstrate the presence and distribution of endolithic communities. Specifically, filamentous microorganisms

Zone	Color	XRD, VNIR, Raman Mineralogy	Crystal Morphology	Visual Microbiological Observations	Microscopic Microbiological Observations	Presense of Biofilms	Cell Morphology
Top	Brown	Gypsum, clay minerals	Solid, angular	Not visible	Not present		
Top	White	Gypsum, clay minerals	Solid, angular	Visible, brown filaments	Crystal-coated filaments	No	Filaments
Middle	Pink	Gypsum, clay minerals	Pitted, angular	Not visible, pink pigmentation	Spheres, coccoids	Yes, roll-up edges, dessication features	Shriveled spheres
Middle	Green	Gypsum, clay minerals	Pitted, angular	Not visible, green pigmentation	Spheres, coccoids	Yes, roll-up edges, dessication features	Shriveled spheres
Bottom	White	Gypsum, clay minerals	Pitted, hollow, angular	Not visible	Diatom fragments, spheres,	Yes, intact surfaces	Misshapen and punctured, hollow spheres



Light and fluorescence microscopic analysis of microorganisms present in the pigmented gypsum crystal. A, B, C, and F) Filamentous cyanobacterial morphotypes. D, E, G, H) Aggregates of coccoidal cyanobacterial morphotypes. J, K) Individual cells of coccoidal cyanobacteria. L) Diatoms.

Considerations for Detection

1) Are microbes everywhere that there are selenite crystals?
2) What spectral signatures might indicate the presence of colonies?
3) Which morphology provides the highest likelihood of success? Bladed crystals contain intact and active cells along with degraded and less active cells.
4) How can the morphological differences be determined and at what scale?

CONCLUSIONS

Gypsum salt deposits of Salar de Pajonales host extant and extinct microbial communities in microhabitats that can be identified by visual inspection and morphologically by remote sensing. Pink and green pigmented communities were observed visually; pigments were identified spectroscopically as carotenoids and chlorophyll, respectively. Scanning electron microscopic observations documented the presense of microorganisms with filamentous and coccoidal morphologies along with fossil diatoms. The filamentous microbes were found above the pink and green horizons. Their brown pigment is intepreted to be scytonemin, which is a UV-screening pigment. Coccoidal cells and are often associated with biofilms that appear dessicated in green horizons and more leathery in underlying, unpigmented horizons. Spheres were observed inside voids and fractures in gypsum crystals at depth below the surface. Some spheres were hollow, broken, and degraded.

Microbiological observations confirmed the presence of viable filamentous and coccoidal cells in intra-crystal microhabitats demonstrating the existence of extant [8] and extinct microbial colonies as endoliths and chasmoendoliths .

1. Squyres, S. W., R. E. Arvidson, J. F. Bell III, F. Calef III, B. C. Clark, B. A. Cohen (2012), DOI: 10.1126/science.1220476. 2. Fishbaugh, K. E., F. Poulet, V. Chevrier, Y. Langevin, and J.-P. Bibring (2007), DOI: 10.1029/2006JE002862. 3. Tosca, N. J., and S. M. McLennan (2005), Eos Trans. AGU, 86(52), Fall Meet. Suppl. Abs. P12A-07. 4. Tosca, N., S. McLennan, B. Clark, J. Grotzinger, J. Hurowitz, A. Knoll, C. Shroeder, and S. Squyres (2005), Earth Planet. Sci. Lett., 240, 122–148. 5. Langevin, Y., F. Poulet, J.-P. Bibring, and B. Gondet (2005), 307(5715), 1584–1586. 6. Tanaka, K. (2006), 4th Intl. Mars Polar Science and Exploration Conf., LPSI, Davos, Switzerland, Abstract 8024. 7. Counter Benison, K., and F. J. Karmanocky (2014), doi: 10.1130/G35542. [8] Roldán, Ascaso, and Wierzchos (2014), DOI: 10.1128/AEM.03428-13. This work funded by NASA Astrobiology Inst. Grant No. NNX15BB01A, N. Cabrol, PI.