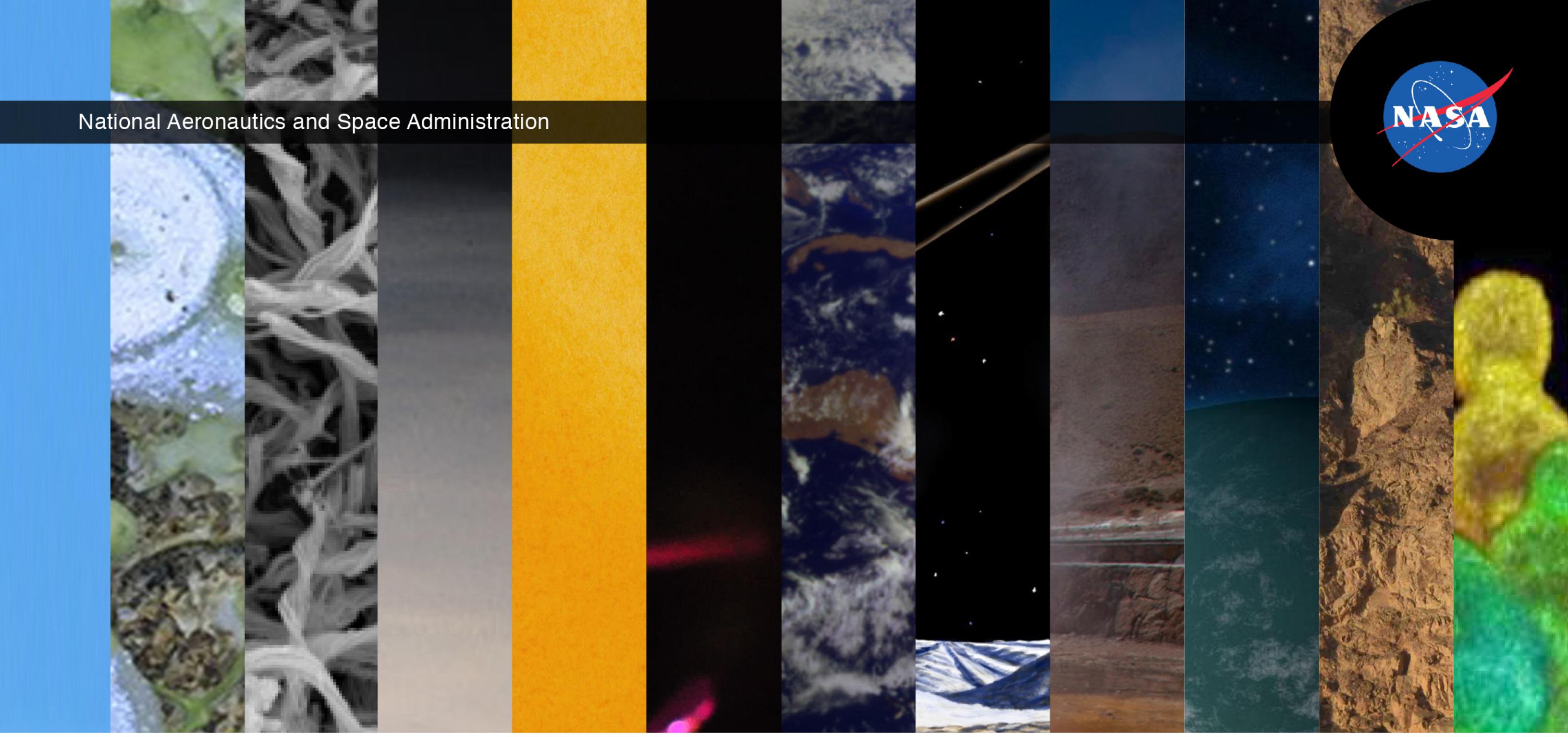
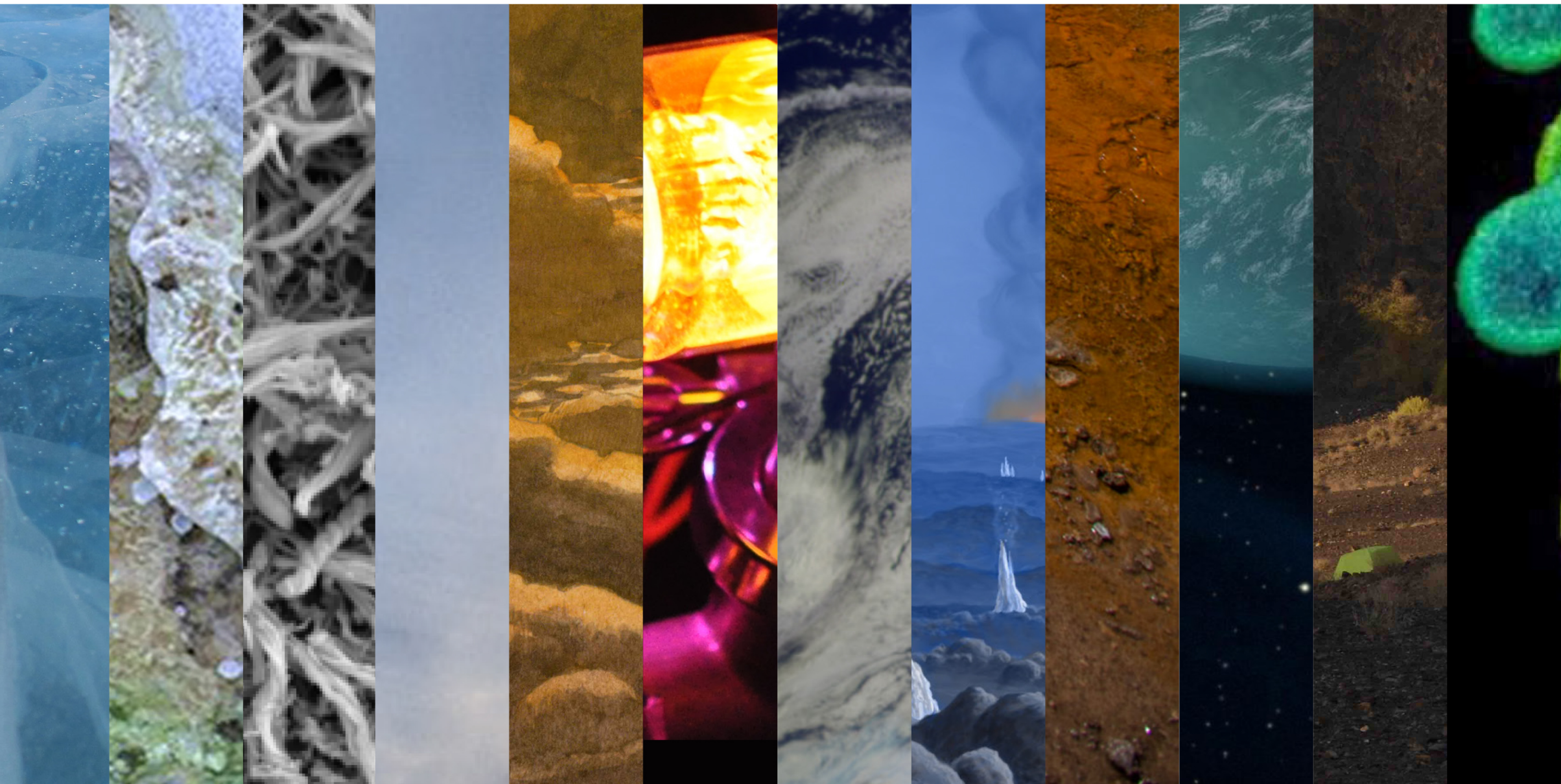


NASA Astrobiology Institute

2017 Annual Science Report

Changing Planetary Environments and the Fingerprints of Life

SETI Institute



Changing Planetary Environments and the Fingerprints of Life

Lead Institution:
SETI Institute

Team Overview

Principal Investigator:
Nathalie A. Cabrol

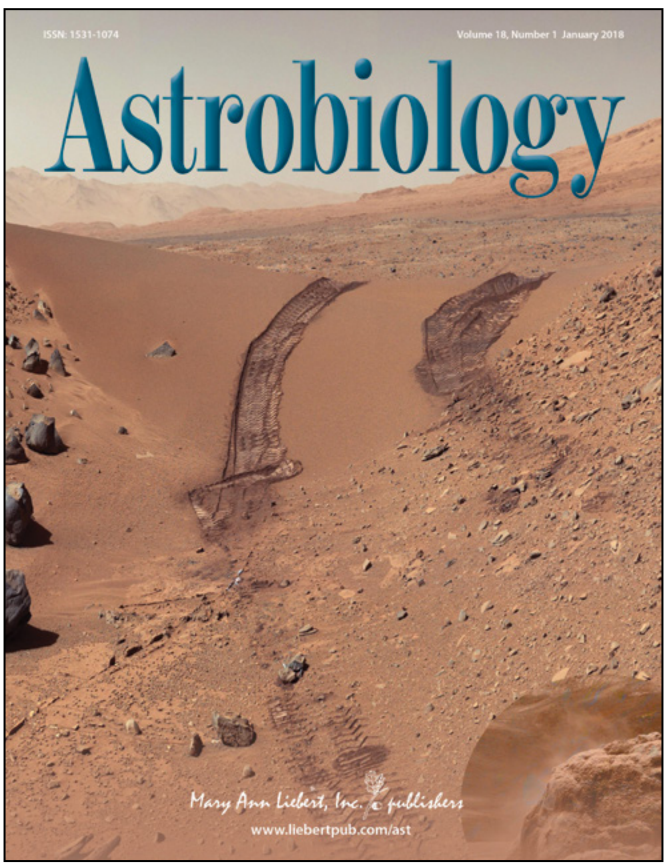
The SETI Institute Changing Planetary Environments and the Fingerprints of Life Team is developing a roadmap to biosignature exploration in support of NASA's decadal plan for the search for life on Mars – with the Mars 2020 mission providing the first opportunity to investigate the question of past life on Mars. In an ancient martian environment that may have once either supported life as we know it, or sustained pre-biological processes leading to an origin of life, the Mars 2020 is expected to be a Curiosity-class rover that will cache samples for return to Earth at a later date. Our Team addresses the overall question "How do we identify and cache the most valuable samples?"

Understanding how a biogeological record was transformed through the loss of atmosphere, increased biologically-damaging ultraviolet radiation, cosmic rays, and chaotically-driven climate changes, we focus on these three themes:

- Where to search on Mars?
- What to search for?
- How to search?

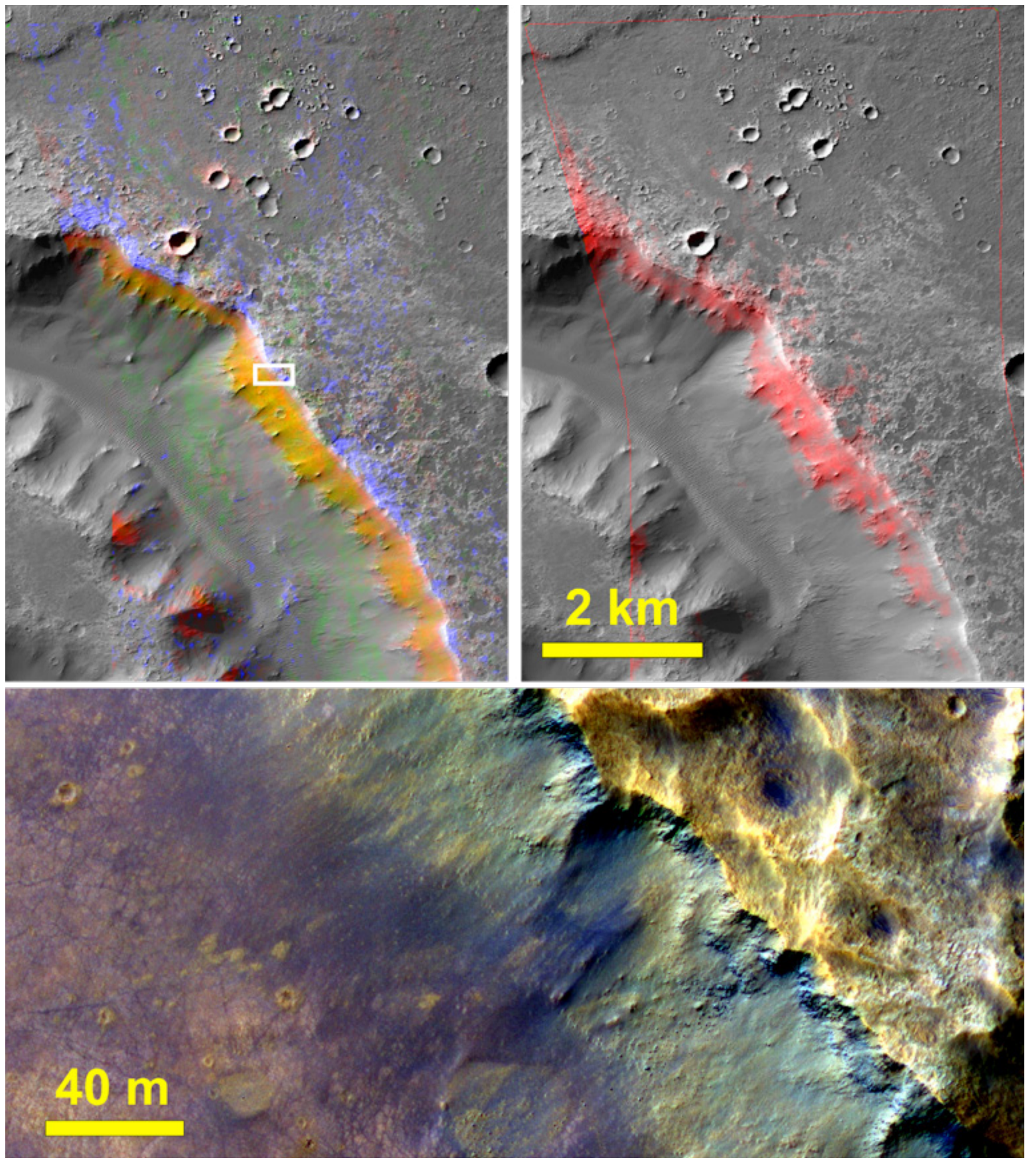
2017 Executive Summary

During 2017, the SETI Institute NAI team continued to address the challenges of biosignature detection through investigations performed under the research areas Signatures of Habitability, Taphonomic Windows and Biosignature Preservation, and Environmental Controls on Biosignature Preservation. Our focus has been centered on bringing together existing knowledge (e.g., mission orbital and landed data, fieldwork in terrestrial extreme environments, and robotic field experiments) into a framework of coevolution of life and the environment for Mars. This effort aims at injecting key astrobiological concepts that are currently lacking into the design and operations of planned missions to search for life on Mars. Despite major advances in our understanding of the red planet, the current framework underpinning missions like Mars 2020 and ExoMars remains fundamentally the same as the one that guided the characterization of Mars habitability. Meanwhile, knowledge gaps related to the sustainability of habitable conditions on Mars severely constrain our ability to evaluate the past and present



In "The Coevolution of Life and Environment on Mars" (2018), N.A. Cabrol explores how early environmental change could have affected a Martian biosphere, microbial ecotones, and biological pathways to dispersal, and examines the implications for the exploration strategies of upcoming missions (scale, resolution, detection thresholds). image credit: NASA/JPL-Caltech/MSSS. Credit: The SETI Institute NAI Team/Campoalto/Victor Robles.

Yungay site in the hyperarid core of the Atacama. Microorganisms in these soils must survive more extreme conditions than at the biological control site, however we failed to detect a signal of stress lipids, which suggests that the microorganisms are not metabolically active and likely reflect exogenous sources of biomass (atmospheric).Credit: SETI NAI



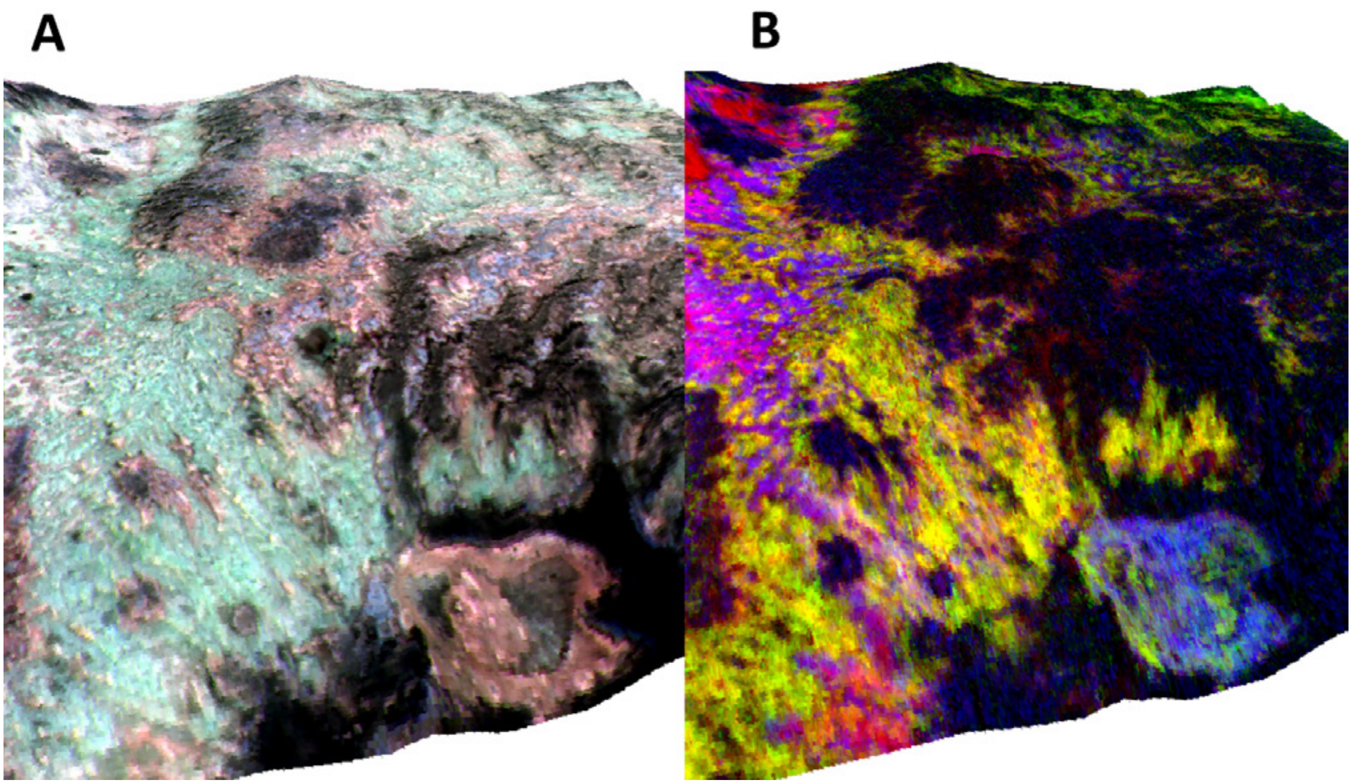
Aqueous minerals exposed in Her Desher Vallis on Mars. A layer in the shallow subsurface contains ubiquitous phyllosilicates (red at upper left), variably mixed with carbonate (yellow). These are overlain by a different hydrous mineral, possibly sulfate (blue). At upper right, carbonates are independently confirmed using a different spectral feature (red). The area boxed at upper left is shown at bottom in enhanced color, where the hydrous (sulfate?) layer appears bright blue to yellow, while underlying clay- and carbonate-bearing layers are darker maroon. Credit: SETI NAI

ecological potential of Mars, and possible interactions between the environment and life. These gaps can generate lack of precision in discussions on the search for life on Mars (e.g., habitability vs. habitats), and alter our perspective on key questions, such as where biomass repositories might be located, what types of landing sites should missions target, what type of biosignatures we should be searching for, and what are the detection thresholds and limit of sensitivity required to identify biosignatures in situ and remotely. Coevolution and coevolutionary models allow the introduction of a biosphere approach to the search for evidence of life on Mars, including consideration of ecosystems, habitats, microbial ecotones, pathways to biological dispersal, biomass repositories, and their meaning for exploration. A first perspective of this Mars exploration approach, The Coevolution of Life and Environment on Mars: An Ecosystem Perspective on the Robotic Exploration of Biosignatures, has recently been published in Astrobiology (Cabrol 2018).

Project Reports

Signatures of Habitability - What and Where to Search?

Knowledge gaps about the sustainability of habitable conditions constrain our ability to evaluate Mars' past prebiotic and biological potential. Understanding the origin and formation of clays on Mars is central to this debate. Clays may have played a critical role in the emergence of life on Earth, and can form in a wide range of conditions. We have explored formation conditions with a focus on linking specific types of phyllosilicate assemblages observed by MSL and Curiosity to early Mars climate (Bishop, lead). Major results include the identification of three groups of clays defined by different climate regimes: 1) surface smectites formed temperatures above 0-10°C, suggesting short-term warm and wet environments during a generally cold early Mars; 2) Bursts of short-lived weathering events caused by impacts or geothermal sources at 25-50°C for thousands to hundreds-of-thousands of years could have supported the formation of other clays, including the 200 m thick surface smectite deposits at Mawrth Vallis and across Arabia Terra. Studies of fluvio-lacustrine systems in other regions, such as the Hellas Basin, suggest that clay formation through hydrothermal processes was widespread over long periods on Mars. Using MRO CTX and HiRISE images, analysis of Navua Valles, a series of disconnected drainages ranging in ages from Noachian to Amazonian, show hydrological activity included several episodes of surface ponding, runoff, infiltration, subsurface flow and subsequent outflow (Gulick, lead). The formation of the older lakes is consistent with Hadriaca Patera formation and associated hydrothermal activity; 3) Poorly crystalline or nanophase aluminosilicates at Gale Crater, Mawrth Vallis, and elsewhere formed from volcanic tephra in cold or low water/rock environments as observed in terrestrial glacial environments. All three clay groups may have been able to support life, although Group 2 is associated with moderate climates that are most consistent with microbial life on Earth.



3D views of CRISM image FRT0000A425 from the Mawrth Vallis region A) with light-toned clay-bearing deposits in white and cyan and a sulfate-bearing knob in orange-gold , and B) with Fe/Mg-smectite in red, sulfates and Al-phyllosilicates in pink-yellow, jarosite in green, and jarosite/phyllosilicate mixtures in light blue. 5X vertical enhancement. Credit: SETI NAI

Taphonimic Windows and Biosignature Preservation - What, Where, and How to Search?

The goal of our Taphonimic Windows and Biosignature Preservation research is to explore analog Mars environments from mesoscale to textural microscale. Field investigations in terrestrial analogs and laboratory analyses form the backbone of the SETI team's development and validation of approaches to biosignature exploration. New sites explored in 2017 provided additional examples of habitable environments, and new elements in our "space-for-time" substitution experiment for Mars. Sample analysis brought major findings: lipid biomarkers in the hyperarid Atacama show that surface soils might represent the dry limit of adaptability and survivability on Earth, and could be also the best-case biological scenario for Mars (Davila). The investigation of microbial colonization and biosignature preservation at multiple scales in the evaporitic basin of Salar de Pajonales (Altiplano Puna, Chile) provides critical clues about the spatial relationships between microbial communities, organic content and composition, and mineral formation. Microbial biosignature suites preserved in El Tatio's hot spring sinters (Chile) under high-UV, dry, cold conditions (Hinman) show: a) lack of cellular fossil preservation; b) preservation of the once-gelatinous microbial extracellular polymeric substances; c) preservation of organic compounds indicative of the primary and secondary microbial communities disperses in silica sinter matrices; d) evidence of microbial input to sinter formation preserved in the microstructures of laminated fabrics, and d) the enhancement of stromatolite-like macro-structures in the sinters due to the predominance of evaporative-driven deposition of opaline silica. New NIR reflectance, Raman, and LIBS instruments were used in acid sulfate environments at Rio Rinto, talc-carbonate deposits in Timmins (Canada), and lava tubes in Lava Beds NM (California), with analysis focusing on secondary on secondary mineral precipitates and organic mats. Results show that the combined use of these three techniques may allow unique mineral identification in samples from Mars surface and subsurface (Sobron).

Fields of forming and collapsed gypsum (selenite) tumuli in Salar de Pajonales (Chilean Altiplano) are host to pigmented microbial communities (box). No microbes were detected on the surface. Underlying layers contain morphologically distinct microbial communities, both with and without associated biofilms. In situ spectroscopy identified beta-carotene and chlorophyll. Where present, biofilms entombed cells. Credit: SETI NAI

Environmental Controls on Biosignature Preservation - What, Where, and How to Search?

Sinter samples collected from active and inactive hot springs at the El Tatio, Chile, hydrothermal field. These primary opaline sinter materials are hypothesized to be the closest analogs for possible silica sinter deposits encountered near Home Plate on Mars.

Here, our team experimentally examined at molecular scales synthetic and natural samples returned from Mars analog environments. In 2017, our labs were hives of activity around the analysis of samples collected during the November 2016 expedition in the Chilean Atacama desert, Altiplano, and Andes. Efforts focused on coordinating, cataloguing, describing, distributing, tracking and analyzing samples from the NAI 2016 field season in order to ensure integrated analysis and interpretation, e.g., for mineralogy, microscopy, and genetics (Warren-Rhodes, lead). Protocols were established for laboratory-based analysis of organics in field samples; selection/study of first set of El Tatio silica sinter samples and the launch of our team's correlative analysis of these samples. Round robin experiments were initiated to establish limits of detection/limits of quantitation for mission-relevant instruments within our NAI team and with external collaborators. At microscale, this effort was led by Co-I Cady. In situ experiments linking orbital to surface data in terrestrial analogs provided the first quantification of the requirements for the integrated detection/identification of habitats (cm-scale). This effort started in 2017 will be continued in 2018, and is spearheaded by Co-Is Moersch and Wettergreen Coordinated lab investigations are being used to characterize the individual and combined role played by water, minerals and soil matrices, UV, and cosmic rays on organic preservation potential. The synthesis of Fe-Si oxide solids in support of team efforts to characterize short-range-order solids and experiments on the degradation products of organic compounds exposed to radiation in the presence of these materials is underway. Photochemistry experiments in Yellowstone hot springs combined with laboratory studies are unraveling the relationship between mineral precipitates and microbial cells in the context of UV exposure and reactive oxygen production rates (Hinman lead).

Field Work

Yungay Region, Atacama Desert, Chile
We found lipids with an excellent degree of preservation in soils up to 2 million years old. The exceptional preservation of lipids is likely due to the extreme dryness, which has minimized microbial and enzymatic degradation. Contrary to biological control sites where a stress response was measured, no evidence of stress lipids was found in the hyperarid soils. These results suggest that while organisms are present in the soils, they are never, or very rarely, metabolically active. Surface soils in the driest parts of the Atacama Desert might represent the dry limit of adaptability and survivability on Earth, but they are also a best-case biologic scenar-io for Mars.

Salar de Pajonales, Altiplano Puna, Chile
Microbial colonization within morphologically distinct areas in this evaporitic basin varied significantly at multiple scales. All environments investigated contained proximate colonized / layered and uncolonized habitats. Morphologically distinct microbial communities, both with and without associated biofilms, were identified with depth in the playa deposits. The investi-gation of microbial colonization and biosignature preservation at multiple scales in the evapo-ritic basin of provides critical clues about the spatial relationships between microbial commu-nities, organic content and composition, and mineral formation.

Hot spring sinters, El Tatio, Chile
Microbial biosignatures preserved under high-UV, dry, cold conditions show: a) lack of cellular fossil preservation; b) preservation of the once-gelatinous microbial extracellular polymeric substances; c) preservation of organic compounds indicative of the primary and secondary microbial communities disperses in silica sinter matrices; d) evidence of microbial input to sinter formation preserved in the microstructures of laminated fabrics, and d) the enhancement of stromatolite-like macro-structures in the sinters due to the predominance of evaporative-driven deposition of opaline silica.

Elk Geyser, Yellowstone National Park
A photochemical field study of Elk Geyser documented high and near-sterilizing concentrations of ROS produced during peak natural UV flux followed by lower values during diminished UV flux. Microbes were observed in but not on precipitated opal deposits. This suggests that the microbes may use the precipitates as protection from both UV and harsh chemical conditions. The UV radiation promotes iron oxidation, which possibly leads to formation of recognizable microfossils.

Timmins, Canada; Lava Beds NM, California; Rio Tinto, Spain
NIR reflectance, Raman, and LIBS instruments were used to explore these sites. This work ad-dresses Mars astrobiology exploration objectives by performing field work and instrumental analyses in acid sulfate environment (Rio Tinto), talc-carbonate deposits in (Timmins) Lava Tubes National Monument (California) as high fidelity analog environments to putative habitable environments on Mars.

Changing Planetary Environments and the Fingerprints of Life: 2017 Publications

Cabrol, N. A. (2018). The co-evolution of life & environment on Mars: An ecosystem perspective to the robotic search of biosignatures. *Astrobiology* 18(1). DOI: 10.1089/ast.2017.176 (open access, v1. 2018).

Cavalazzi, B., Glamoclija, M. Westall, F., Brack, A. Orosei, and R., Cady, S. (2017). Astrobiology, the Emergency of Life, and Planetary Exploration. In *Planetary Geology*, A.P. Rossi, and S. van Gasselt (Eds.). Springer International Publishing, eBook. ISBN: 978-3-319-65179-8, 441 pgs.

Flahaut, J., Martinet, M., Bishop, J. L., Davies, G. R. and Potts, N. J. (2017). Remote sensing and in situ mineralogic survey of the Chilean salars: An analog to Mars evaporate deposits? *Icarus* 282: 152-173. DOI: 10.1016/j.icarus.2016.09.041.

Hargitai, H. I., Gulick, V. C., and Glines, N. H. (2017). Discontinuous drainage systems formed by highland precipitation and ground-water outflow in the Navua Valles and southwest Hadriacus Mons regions, Mars. *Icarus* 294: 172-200. DOI: 10.1016/j.icarus.2017.03.005.

Wilhelm, M. B., Davila, A., Eigenbrode, J., Parenteau, N., Jahnke, L., et al. (2017). Xeropreservation of functionalized lipid biomarkers in hyperarid soils in the Atacama Desert, Chile. Organic Chemistry. *Organic Geochemistry* 103: 97-104. DOI: 10.1016/j.orggeochem.2016.10.015.

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