Biosignature Preservation and Detection in Mars Analog Environments

May 16–19, 2016
Lake Tahoe, Nevada

Program

Biosignature Preservation and Detection in Mars Analog Environments

May 16–18, 2016 • Lake Tahoe, Nevada

Sponsor

Lunar and Planetary Institute
Universities Space Research Association
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Conveners

Lindsay Hays
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David Beaty
Jet Propulsion Laboratory
Mary Voytek
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Michael Meyer
NASA Headquarters

Lunar and Planetary Institute   3600 Bay Area Boulevard   Houston TX 77058-1113

Scientific Organizing Committee

Abstracts for this conference are available via the conference website at

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Monday, May 16, 2016
SEARCHING FOR PAST LIFE FROM ORBIT AND ON THE GROUND: TOOLS, STRATEGIES AND EVOLVING IDEAS
8:30 a.m.   Regency AB

Times include a 5 minute discussion at the conclusion of each presentation.

Chairs: **Lindsay Hays**
David Beaty

8:30 a.m. Hays L. E. *
Introduction and Welcome to the Workshop

8:45 a.m. Meyer M. A. *
Mars Exploration Strategy

9:10 a.m. Des Marais D. J. *
The Importance of Terrestrial Analog Environments in Guiding Mars Exploration Strategy

9:35 a.m. McEwen A. S. *
Martian Geologic Settings of Interest to the Search for Biosignatures, as Seen from Orbit **[#2057]**
This presentation will summarize high-resolution orbital datasets and introduce key terrain types of interest for biosignature preservation.

10:00 a.m. Break

10:30 a.m. Cabrol N. *
Introduction to Comparison of Environmental Habitability: Evolution and Preservation in Time

10:55 a.m. Allwood A. C. *
Introduction to Signatures of Past Life as We Know it: Where the Microbes Were **[#2054]**
Signatures of ancient microbial life on Earth occur in a range of geologic settings, but a much smaller subset of environments host the vast majority of early microbial biosignatures.

11:20 a.m. McCollom T. M. *
Introduction to Paleobiological Prospects of Different Environments

Monday, May 16, 2016

FUNDAMENTAL COMPARISON OF EARTH VS. MARS FROM A PALEOBIOLOGY PERSPECTIVE

1:30 p.m. Regency AB

Times include a 5 minute discussion at the conclusion of each presentation.

Chairs: **Nathalie Cabrol**
Elizabeth Hausrath
Richard Leveille

1:30 p.m. Ehlmann B. L. *
Mars Time and Martian Environments: Changing Habitability Through Time and Prospects for Ancient Mars Biosignatures **[#2080]**
A summary of martian chronology and processes contributing to habitability (magnetic field, atmospheric pressure, solar luminosity, impact cratering, and volcanism) versus the age of rocks accessible at each landing site.

1:50 p.m. Boston P. J. * Alexander C.
Preservation of Microbial-Mineral Biosignatures in Caves **[#2074]**
Earth caves are wonderful preservation environments for distinctive in situ biopatterns and biominerals. Several thousand volcanic caves have been detected on Mars and may contain biosignatures or extant life and are valuable future mission targets.

2:10 p.m. Horgan B. *
Strategies for Searching for Biosignatures in Ancient Martian Sub-Aerial Surface Environments **[#2032]**
Organics can be preserved in sub-aerial soil environments if the soils have high clay contents and were formed under reducing (saturated) conditions. Possible ancient soils with these characteristics are present on Mars.

2:30 p.m. Break

3:00 p.m. Gupta S. * Grotzinger J. P. Sumner D. Y. Rubin D. M. Banham S. G. Stack K. M. Watkins J. A. Stein N. Edgett K. S. Hurowitz J. Lewis K. X. Yingst R. A. Minitti M. E. Schieber J. Vasavada A. R.
Ancient Lacustrine Mudstones and Associated Fluvio-Deltaic Strata at Gale Crater: Martian Sedimentary Contexts in the Search for Ancient Biosignatures **[#2053]**
We characterize the sedimentology of ancient lacustrine mudstones in Gale crater, Mars, and consider the implications of their physical and chemical characteristics in the search for ancient biosignatures.

3:20 p.m. Clarke J. D. A. Stoker C. R. *
Searching for Life on Early Mars: Lessons from the Pilbarra **[#2020]**
We mapped, imaged and sampled a field of 3.4 Ga stromatolites in Pilbarra Western Australia. Results from that work provide insight into requirements for finding early life on Mars.

3:40 p.m. Ruff S. W. * Farmer J. D.
Opaline Silica Occurrences in the Columbia Hills of Mars: A Case Study in the Hunt for Biosignatures **[#2024]**
Microbially mediated silica sinter deposits of El Tatio in the Atacama Desert of Chile have remarkably similar morphologic and spectral characteristics as those of silica deposits adjacent to Home Plate in the Columbia Hills of Mars.

4:00 p.m. SESSION DISCUSSION

5:00 p.m. Session Adjourns

Monday, May 16, 2016
POSTER SESSION: FUNDAMENTAL COMPARISON OF EARTH VS. MARS FROM A PALEOBIOLOGY PERSPECTIVE
5:30 p.m. Regency C

Thomas N. K. Hamilton J. C. Veillet A. Muir C. ***POSTER LOCATION #1***
Biologic Analog Science Associated with Lava Terrains **[#2016]**
The goal of BASALT is to use Hawaiian volcanic terrain to constrain the upper limits of biomass that could have been supported on Mars and how those upper bounds inform future detection requirements for manned missions.

Osterhout J. T. Czaja A. D. Fralick P. W. ***POSTER LOCATION #2***
Organic Geochemistry of a 1.4-Billion-Year-Old Evaporitic Lake: Insights for the Mars 2020 SHERLOC Instrument **[#2068]**
Evaporitic lakes on Mars have been considered interesting target sites for astrobiological investigations on Mars. Findings from this study provide a useful geochemical context for interpreting future detections of sedimentary organics by Mars 2020.

Thomas R. J. Hynek B. M. ***POSTER LOCATION #3***
Crater Floor Fractures: Probes Into Habitable Martian Environments **[#2007]**
Geologic and spectral analysis of martian impact craters reveals the potential for floor-fractures with a aqueous/volcanic genesis to probe into both ancient surface and Hesperian-aged deep habitable environments.

Bower D. M. Conrad P. G. Steele A. Fries M. D. ***POSTER LOCATION #4***
Characterizing the Biological and Geochemical Architecture of Hydrothermally Derived Sedimentary Deposits: Coupling Micro Raman Spectroscopy with Noble Gas Spectrometry **[#2013]**
The chemical species in cherts and glass fragments were analyzed using micro Raman spectroscopy in conjunction with measurements of heavy noble gas isotopes to characterize hydrothermally derived sedimentary environments.

Faucher B. F. Lacelle D. L. Davila A. D. Pollard W. P. McKay C. P. M. ***POSTER LOCATION #5***
Abundance, Distribution and Cycling of Organic Carbon and Nitrogen in University Valley (McMurdo Dry Valleys of Antarctica) Permafrost Soils with Differing Ground Thermal and Moisture Conditions: Analogue to C-N Cycle on Mars **[#2046]**
High elevation McMurdo Dry Valleys of Antarctica are key Mars analogue sites. Our investigation focuses on the link between ground ice origin, distribution and cycling of organic carbon and nitrogen in University Valley, and its soil habitability.

Gibson E. K. Thomas-Keprta K. L. Clemett S. J. McKay D. S. ***POSTER LOCATION #6***
Martian Biosignatures: Tantalizing Evidence Within Martian Meteorites **[#2052]**
Several of the martian meteorites offer a unique opportunity to study possible biosignatures over the history of Mars. Reduced carbon components have been found within the pre-terrestrial aqueous alteration phases (iddingsite) of martian meteorites.

Miura Y. Tanosaki T. ***POSTER LOCATION #7***
Different Topography and Composition of Earth- and Mars-Type Surfaces **[#2077]**
Mars shows different location and shape of higher lands compared with global water planet Earth, together with possible carbon concentration process of global surface on Earth and Mars with more detailed exploration on Mars.

Vidmachenko A. P. ***POSTER LOCATION #8***
Where is Necessary to Search Traces of Life on Mars? **[#2002]**
To identify possible relict life on Mars needs to carefully examine areas, which are located in areas of soil emission in Hellas valley at latitudes near –(40–50)°, where there are evidence of modern water outputs from under the planet’s surface.

Fairen A. G.   Uceda E. R.   Essefi E.   Rodriguez J. A. P.   ***POSTER LOCATION #9***
Spring Mounds in Eastern Tunisia as Analogs to Open Pingos on Argyre **[#2040]**
The MCSH system in Eastern Tunisia is an exceptional terrestrial analog which continuing analysis will help to make informed decisions regarding where to search for biosignatures on Mars.

Westall F.   Campbell K. A.   Gautret P.   Bréhéret J.   Foucher F.   ***POSTER LOCATION #10***
Vago J.   Kminek G.   Hubert A.   Hickman-Lewis K.   Cockell C. S.
Hydrothermal Chemotrophic Biosignatures on Mars **[#2028]**
Hydrothermal chemotrophic biosignatures (morphological and geo-organochemical) were common in shallow water on the anaerobic early Earth, preserved by silicification. They are representative also of shallow crustal biosignatures.

Monday, May 16, 2016
POSTER SESSION: INSTRUMENTS, SIMULATED MISSIONS AND LIFE DETECTION STRATEGIES
5:30 p.m. Regency C

Osinski G. R. Sapers H. M. Francis R. Pontefract A. **_POSTER LOCATION #11_**
Tornabene L. L. Haltigin T.
Defining Analytical Strategies for Mars Sample Return with Analogue Missions **[#2062]**
The characterization of biosignatures in MSR samples will require integrated, cross-platform laboratory analyses carefully correlated and calibrated with Rover-based technologies. Analogue missions provide context for implementation and assessment.

Kelly H. S. Boston P. J. Parness A. J. **_POSTER LOCATION #12_**
Distinctive Biopatterns for Detection and Characterization from a Robotic Platform **[#2069]**
Mars-analog environment biosignature detection via a novel robot design.

Glass B. Davila A. Parro V. Quinn R. Willis P. Brinckerhoff W. **_POSTER LOCATION #13_**
DiRuggiero J. Williams M. Bergman D. Stoker C.
Atacama Rover Astrobiology Drilling Studies: Roving to Find Subsurface Preserved Biomarkers **[#2061]**
The ARADS project is a NASA PSTAR that will drill into a Mars analog site in search of biomarkers. Leading to a field test of an integrated rover-drill system with four prototype in-situ instruments for biomarker detection and analysis.

García-Descalzo L. Gómez F. MASE Team **_POSTER LOCATION #14_**
Biomarkers Detection In Mars Analogue Sites Within Mase Project **[#2027]**
In MASE project (Mars Analogues for Space Exploration) we work to improve approaches and methods for biomarker detection in samples with low biomass from Mars analogue sites.

Dartnell L. R. **_POSTER LOCATION #15_**
Martian Analogue Samples, Their Spectroscopic Biosignatures, and Degradation by the Cosmic Radiation Environment **[#2008]**
Here we discuss the use of Raman and FTIR spectroscopy for the detection and characterisation of biosignatures in martian analogue samples, and their degradation by the cosmic ray environment in the martian near-subsurface.

Szopa C. Coll P. Stalport F. Poch O. Jaber M. Lambert J. F. **_POSTER LOCATION #16_**
Rouquette L. Lasne J.
Fate of Organic Molecules in the Mars Regolith Under UV Radiation Deduced from the MOMIE Laboratory Experiment **[#2018]**
From laboratory experiments simulating the Mars surface conditions including pressure, temperature, and UV radiation, the fate of organic molecules alone or mixed with minerals is studied.

Steele A. **_POSTER LOCATION #17_**
Life Detection with Minimal Assumptions — Setting an Abiotic Background for Mars **[#2038]**
I set out a strategy for life detection on Mars with minimal assumptions and review the state of knowledge of martian organic carbon in Martian meteorites. Analyses of martian meteorites represents an invaluable “analogue” suite of samples for study.

Gaboyer F. Bohmeier M. Foucher F. Le Milbeau C. Gautret P. **_POSTER LOCATION #18_**
Richard A. Sauldubois A. Guegan R. Westall F.
Mineralization and Potential for Fossilization of an Extremotolerant Bacterium Isolated from a Past Mars Analog Environment **[#2039]**
To better characterize the preservation of biomarkers during microbial fossilization, we mineralized a bacterial strain isolated from a cold-acidic-oligotrophic lake in SiO_2 and $CaSO_4$ and studied it using SEM, TEM, FT-IR, Raman, GC-MS or Rock-Eval.

Sobron P.   Andersen D. T.   Pollard W. H.   ***POSTER LOCATION #19***

In-Situ Exploration of Habitable Environments and Biosignatures in Arctic Cold Springs and Antarctic Paleolakes **[#2064]**

We have characterized Artic cold springs and Antarctic paleolakes as high-fidelity analogs to putative inhabited/habitable environments on Mars, using in-situ techniques relevant to the ExoMars 2018 and Mars 2020 missions.

DasSarma S.   DasSarma P.   Laye V.   Harvey J.   Reid C.   Shultz J.   ***POSTER LOCATION #20***
Yarborough A.   Lamb A.   Koske-Phillips A.   Herbst A.
Molina F.   Grah O.   Phillips T.

Survival of Halophilic Archaea in the Stratosphere as a Mars Analog: A Transcriptomic Approach **[#2044]**

On Earth, halophilic Archaea tolerate multiple extreme conditions similar to those on Mars. In order to study their survival, we launched live cultures into Earth's stratosphere on helium balloons. The effects on survival and transcriptomes were interrogated in the lab.

Monaghan E. P.   Ehrenfreund P.   Cockell C. S.   Schwendner P.   ***POSTER LOCATION #21***
Rettberg P.   Belbo-Vranesevic K.   Bohmeier M.   Rabbow E.   Westall F.
Gaboyer F.   Walter N.   Moissil-Eichinger M.   Perras A.   Gomez F.
Amils R.   Garcia L.   Marteinsson V.   Vannier P.

MASE Mars Analogue Sites: Physicochemical Context Synthesis and Organic Inventory **[#2058]**

A discussion of the MASE (Mars Analogues for Space Exploration) project fieldwork, the process of organics extraction from field samples, their quantification, and an initial habitability assessment.

Stevens A. H.   Amador E. S.   Cable M. L.   Cantrell T.   Chaudry N.   ***POSTER LOCATION #22***
Cullen T.   Duca Z.   Gentry D. M.   Jacobsen M. B.   McCraig H.
Murukesan G.   Rennie V.   Schwieterman E. W.   Tan G.   Yin C.
Stockton A. M.   Cullen D. C.   Geppert W.

Spatial Variability and Correlation of Multiple Biomarkers in Icelandic Mars Analogue Environments and the Implications for Life Detection Missions **[#2010]**

We describe fieldwork to Icelandic Mars analogues that investigated the spatial variation and correlation of three separate candidate biomarkers.

Gómez F.   Garcia-Descalzo L.   Cockell C. S.   Schwendner P.   Rettberg P.   ***POSTER LOCATION #23***
Beblo-Vranesevic K.   Bohmeier M.   Rabbow E.   Westall F.   Gaboyer F.
Walter N.   Moissl-Eichinger M.   Perras A.   Amils R.   Malki M.
Ehrenfreund P.   Monaghan E.   Marteinsson V.   Vannier P.

Life Detection System DTIVA for Monitoring Parameter in Fossilization Process **[#2033]**

Using Life Detection System LDS we followed the physicochemical parameter in a growth culture under fossilization/mineralization-induced process with the objectives of biomarkers detection. Biomarkers study is crucial for the search for life on Mars.

Bywaters K. F.   McKay C. P.   Davila A. F.   Quinn R. C.   ***POSTER LOCATION #24***

In Situ Life and Biosignature Detection at Mars Analog Sites Using the Oxford Nanopore Minion Sequencer **[#2014]**

A proof-of-concept study is being performed to conduct in situ field analysis of biopolymers contained in samples from Mars analog sites using the Oxford Nanopore MinION.

Beegle L. W.   Bhartia R.   DeFlores L.   Abbey W.   Carrier B.   Asher S.   ***POSTER LOCATION #25***
Burton A.   Conrad P.   Clegg S.   Edgett K. S.   Ehlmann B.   Fries M.   Hug W.
Reid R.   Kah L.   Nealson K.   Minitti M.   Popp J.   Langenhorst F.   Orphan V.
Sorbon P.   Steele A.   Tarcea N.   Wanger G.   Wiens R.   Williford K.   Yingst R. A.

SHERLOC: An Investigation for Mars 2020 **[#2022]**

The Scanning Habitable Environments with Raman and Luminescence for Organics and Chemicals (SHERLOC) investigation consists of a Deep UV (DUV) native fluorescence and resonance Raman spectrometer with MAHLI like imaging capabilities.

Carrier B. L.   Beegle L. W.   Bhartia R.   Abbey W. J.   ***POSTER LOCATION #26***

Measurement of UV Fluorescence and Raman Signatures of Subsurface Organics in Mars Relevant Minerals to Constrain Detection Depth for the SHERLOC Mars 2020 Instrument **[#2043]**

Using UV fluorescence and Raman spectroscopy to detect subsurface organics in various minerals to determine detection depths for the SHERLOC Mars 2020 instrument.

Duca Z.   Tan G.   Cantrell T.   Van Enige M.   Dorn M.   Cato M.   Foreman S.   Putman P.   Kim J.   Mathies R.   Stockton A.   ***POSTER LOCATION #27***

Development of an Extraterrestrial Organic Analyzer (EOA) for Highly Sensitive Organic Detection on a Kinetic Penetrator **[#2067]**

Development of an Extraterrestrial Organic Analyzer (EOA) for Highly Sensitive Organic Detection on a Kinetic Penetrator.

Riedo A.   Tulej M.   Neuland M. B.   Wurz P.   ***POSTER LOCATION #28***

Miniature LIMS System for In Situ Detection of Biosignatures **[#2030]**

The current measurement capabilities of our miniature Laser Ablation Ionization Mass Spectrometer for sensitive and quantitative in situ chemical analyses (element, isotope and molecular) of solids on planetary surfaces will be presented.

Monday, May 16, 2016
POSTER SESSION: SPECIAL SUPPLEMENTAL SESSION
5:30 p.m. Regency C

Hays L. E. Voytek M. A. New M. H. ***POSTER LOCATION #29***
2015 NASA Astrobiology Strategy Document and the Exploration of Mars **[#2065]**
A discussion of the new 2015 NASA Astrobiology Strategy and how the research directions apply to the exploration of Mars.

Williford K. H. Farley K. A. ***POSTER LOCATION #30***
Astrobiology Strategy for Mars 2020 **[#2070]**
An astrobiology strategy for Mars 2020 that draws from previous Mars rover surface operations as well as the search for evidence of ancient life on Earth is presented.
31
Bruner R. B. ***POSTER LOCATION #***
Special Exhibit on Meteorites and Minerals Associated with the Origin of Life on Earth or Mars **[#2001]**
This is an exhibit that contains minerals and meteorites associated with the origin of life on Earth or Mars. It was shown at the 8th International Mars Conference in 2014 and the Gordon Origin of Life conferences in 2014/2016.

Calvin W. C. Farmer J. D. ***POSTER LOCATION #32***
Steamboat Spring Field Trip Overview **[#2085]**

Tuesday, May 17, 2016
BIOSIGNATURES AND ENVIRONMENTS I: LOW-TEMPERATURE SURFACE AND SUBSURFACE
8:30 a.m. Regency AB

Times include a 5 minute discussion at the conclusion of each presentation.

Chairs: **Abigail Allwood**
Wendy Calvin
Briony Horgan

8:30 a.m. Eigenbrode, J. L. *
Deltas on Earth and Mars: An Environment for Deposition and Preservation of Organic Matter and Biosignatures

8:50 a.m. Juarez Rivera M. * Sumner D. Y.
Recreating Microbial Ecosystems of the Late Archean **[#2056]**
Microbialites are important deposits for studying early microbial life. Cuspate and plumose microbialites of the Gamohaan Formation provide evidence for multiple microbial communities that grew contemporaneously with different growth rates.

9:10 a.m. Graham H. V. * Stern J. C. Baldridge A. M. Thomsen B. J.
Australian Acid Brine Lake as a Mars Analog: An Analysis of Preserved Lipids in Shore and Lake Sediments **[#2063]**
This study investigates organic molecules preserved in sediment cores from an acid brine lake. We explore the distribution and stable isotopic composition of lipids in order to understand preservation potential in similar martian environments.

9:30 a.m. Break

10:00 a.m. Johnson S. S. * Soni M. L. Collins D. J. Benison K. C. Mormile M. R. Chevrette M. G. Ehlmann B. L.
Biosignatures in Mars Analog Acid Salt Lakes **[#2072]**
Paleolake sites on Mars serve as intriguing targets for the search for life. Acid salt lake sediments in Western Australia can offer insights into biosignature preservation in these environments.

10:20 a.m. Hausrath E. M. * Harrold Z. Murray A. E. Tschauner O. Garcia A. H. Bartlett C. L. Raymond J.
Interactions of Snow Algae, Microorganisms and Minerals in Snowy Mars-Analog Environments Provide Potential Elemental and Mineralogical Biosignatures **[#2050]**
Interactions between snow algae, microorganisms, and minerals in laboratory and field environments result in Fe-rich phases that may be important biosignatures on Mars.

10:40 a.m. Nealson K. *
History of Searching for Biosignatures in the Subsurface

11:00 a.m. SESSION DISCUSSION

12:00 p.m. Session Adjourns

Tuesday, May 17, 2016
BIOSIGNATURES AND ENVIRONMENTS II: HOT SPRINGS AND IRON-RICH DEPOSITS
1:30 p.m. Regency AB

Times include a 5 minute discussion at the conclusion of each presentation.

Chairs: **David Des Marais**
Jack Farmer
Anna-Louise Reysenbach

1:30 p.m. Campbell K. A. * Guido D. M. Farmer J. D. Van Kranendonk M. J. Ruff S. W. Westall F.
Tracing Hot-Spring Facies and thier Geothermally Silicified Microbial Textures into the Geologic Record: Relevance for Mars Biosignature Recognition **[#2023]**
Siliceous hot-spring deposits (sinters) in terrestrial volcanic terrains preserve robust microbial textures, owing to early mineralization, in the geologic record as far back as 3.48 billion years ago. Some resemble features at Columbia Hills.

1:50 p.m. Van Kranendonk M. J. * Djokic T. Campbell K. A. Walter M. R. Oto T. Nakamura E.
Earliest Life on Earth Preserved in Hotspring Deposits: Evidence from the 3.5 Ga Dresser Formation, Pilbara Craton, Australia, and Implications for the Search for Life on Mars **[#2011]**
A variety of biosignatures preserved in hotspring facies from the c. 3.5 Ga Dresser Formation, Australia, lends support to an origin of life in terrestrial hotsprings, and have profound implications for the search for life on Mars.

2:10 p.m. Jahnke L. L. * Parenteau M. N. Farmer J. D.
Organic Biomarker Preservation in Silica-Rich Hydrothermal Systems with Implications to Mars **[#2083]**
Microbial community structure and preservation of organic matter in siliceous hydrothermal environments is a critical issue given the discovery of hydrothermal vents and silica on Mars. Here we discuss preservation of cyanobacterial biomarker lipid.

2:30 p.m. Break

3:00 p.m. Potter-McIntyre S. L. * Williams J. Phillips-Landers C. O’Connell L.
Progressive Diagenetic Alteration of Macro- and Micro-Scopic Biosignatures in Ancient Springs and Spring-Fed Lacustrine Environments **[#2005]**
Microscopic and macroscopic biosignatures in modern spring deposits are compared with the Quaternary and Jurassic examples to show how these features are progressively altered and preserved on geologic time scales.

3:20 p.m. Parenteau M. N. * Jahnke L. L. Bristow T. F. Som S. M. Des Marais D. J. Farmer J. D.
Preservation of Organic Compounds in Circumneutral Iron Deposits **[#2076]**
We are investigating the capture and retention of microbial biosignatures in modern circumneutral Fe springs. The aim is to characterize the taphonomy of the lipid biomarkers in this Fe-rich system.

3:40 p.m. Williams A. J. * Sumner D. Y. Eigenbrode J. L. Wilhelm M. B. Cook C. L. Mahaffy P. R.
Physical and Molecular Biosignature Preservation in Hydrous Ferric Oxides: Implications for Detection wtih MSL and Future Missions **[#2015]**
Physical and molecular biosignature preservation in modern to 1000s-of-years-old iron-bearing environments and their potential for detection by instruments onboard the Curiosity rover and future surface missions.

4:00 p.m. SESSION DISCUSSION

5:00 p.m. Session Adjourns

Tuesday, May 17, 2016
POSTER SESSION: SIGNATURES OF PAST LIFE AS WE KNOW IT
5:30 p.m. Regency C

Kolb V. M. ***POSTER LOCATION #33***

On the Use of Biomarkers of Poly(Extremophiles) in the Search for Life on Mars **[#2009]**

We present a compilation of selected chemical structures of biochemical compounds that are involved in metabolism of (poly)extremophiles, and their infrared frequencies. The latter could be useful for identification of related compounds on Mars.

Pavlov A. A. Glavin D. McLain H. Dworkin J. ***POSTER LOCATION #34***
Elsila-Cook J. Eigenbrode J.

Preservation of Organic Molecules Under Cosmic Rays in Martian Surface Rocks **[#2066]**

Organic molecules are destroyed in the surface rocks of Mars by cosmic rays at faster rates than was assumed in previous studies. Only surface rocks, with an exposure age of less than 50 million years, might contain unaltered amino acids.

Quinn R. C. ***POSTER LOCATION #35***

Radiolytic Alteration of Biosignatures on Mars **[#2073]**

When exposed to ionizing radiation, a complex distribution of redox states and reactive intermediates form in both perchlorate and nitrate salts. These reactive species then act to alter the forms of organic biosignatures preserved on Mars.

Lorber K. N. Czaja A. D. Lee P. ***POSTER LOCATION #36***

Variations in Biosignature Preservation: Geochemical Analysis of Kerogen Comparing Two Mars Analog Environments **[#2078]**

This work investigates kerogen from early Earth and impact crater environments, both of which can be viewed as an analog for those on Mars. The biosignatures presented here are geochemically preserved as microfossils or as amorphous kerogen.

Freissinet C. Glavin D. P. Buch A. Szopa C. Archer P. D. Jr ***POSTER LOCATION #37***
Brinckerhoff W. B. Brunner A. E. Eigenbrode J. L. Franz H. B.
Kashyap S. Malespin C. A. Millan M. Miller K. E. Navarro-Gonzalez R.
Prats B. D. Summons R. E. Teinturier S. Mahaffy P. R.

Preservation of Organic Molecules at Mars' Near-Surface **[#2049]**

Detection of organics at Mars' surface is challenged by its degradation. Curiosity rover was able to detect some organics in a martian mudstone, providing a context for a habitable environment and raising the possibility for detecting biosignatures.

Noe Dobrea E. Z. McAdam A. C. Freissinet C. Franz H. Belmahdi I. ***POSTER LOCATION #38***
Hamersley M. R. Stoker C. R. Parker W. G. Glavin D. P.
Calef F. Aubrey A. D.

Preservation of Organics at the Painted Desert: Lessons for MSL and Beyond **[#2031]**

We explore the preservation of organic molecules in a variety of lithologies represented at the Painted Desert to better understand the mechanisms for the preservation of organics in ancient fluivo-lacustrine and deltaic sediments.

Kamakolanu U. G. Freund F. T. ***POSTER LOCATION #39***

Matrix Embedded Organic Synthesis **[#2082]**

In the matrix of minerals such as olivine, a redox reaction of the low-z elements occurs. Oxygen is oxidized to the peroxy state while the low-Z-elements become chemically reduced. We assign them a formula $[C_xH_yO_zN_iS_j]^{n-}$ and call them proto-organics.

Szynkiewicz A. Mikucki J. ***POSTER LOCATION #40***
Sulfur Biosignatures in Continental Hot Spring, Stream and Crater Lake Sediments Affected by Hydrothermal H_2S Gas Emission **[#2034]**
In this study, we focused on identifying two types of biosignatures in a continental volcanic complex of Valles Caldera, New Mexico: 1) metabolic sulfur isotope biosignatures; 2) molecular (genomic) signatures.

Conrad P. G. Arevalo R. D. Fa K. A. Rice M. S. Gupta S. ***POSTER LOCATION #41***
Brinckerhoff W. B. Getty S. A.
Interrogation of Temporal Planetary Analogs for Biosignature Detection **[#2071]**
We present an approach and an instrument for identifying promising temporal horizons for preservation of organic materials in the martian rock record. Time After Time uses radiometric and exposure age dates to optimize candidate sample location.

Mickol R. L. Craig P. I. Kral T. A. ***POSTER LOCATION #42***
Nontronite and Montmorillonite as Nutrient Sources for Life on Mars **[#2035]**
Methanogens were grown in media containing bicarbonate buffer, nontronite or montmorillonite clay, and hydrogen gas. No other nutrients were added. These results suggest that martian clays may provide adequate nutrients to support organism growth.

Archer R. Ralat A. ***POSTER LOCATION #43***
Biosignature Preservation Vulnerability Associated with Stress Response Metabolic Redox Mode Switching in a Mars Analogue Coupled Microbial Mat Transiting Near-Space **[#2036]**
Examination of a coupled microbial mat recovered from Death Valley failed to detect rosickyte, both before and after exposure to near-space conditions; associated redox proxies suggest diagenesis caused by rapid adaptive microbial stress response.

Plescia J. B. Johnson J. R. ***POSTER LOCATION #44***
Visible Near-Infrared Reflectance Spectra of Hydrothermal Silica Sinter Deposits and Extremophiles **[#2045]**
VNIR spectra of silica sinter show absorptions due to OH, H_2O and various alteration products. Spectra of extremophile organisms demonstrate that species can be differentiated.

Sklute E. C. Kashyap S. Holden J. F. Dyar M. D. ***POSTER LOCATION #45***
Spectral Evolution of Bioreduced Ferrihydrite by Hyperthermophiles **[#2048]**
The hyperthermophile Pyrodictium sp. Su06 reduces ferrihydrite to a black, magnetic, Fe(II)-bearing mineral. Mossbauer spectra for that mineral freeze dried vs. frozen in the original liquid suspension differ. Both represent potential biosignatures.

Perl S. M. Vaishampayan P. A. Corsetti F. A. Piazza O. Ahmed M. ***POSTER LOCATION #46***
Willis P. Creamer J. S. Williford K. W. Flannery D. T. Tuite M. L.
Ehlmann B. L. Bhartia R. Baxter B. K. Butler J. Hodyss R.
Berelson W. M. Nealson K. H.
Identification and Validation of Biogenic Preservation: Defining Constraints Within Martian Mineralogy **[#2026]**
This investigation seeks to confine the limits of preservation potential within evaporate minerals by performing analyses to determine the extent of biological retention, in-situ validation of biogenic matter, and volumetric examination of clays.

Munoz-Saez C. Gutierrez J. I. Manga M. ***POSTER LOCATION #47***
Textural Bio-Signatures of Geyserites Imaged by ?XRT **[#2025]**
Discharge of water from hot springs form sinter deposits, inhabited by micro-organisms. By analyzing textures of sinter rocks from El Tatio (Atacama), using XRT, we found bio-signatures and related to environmental conditions of deposition.

Gnanaprakasa T. J. Domanik K. DiRuggiero J. Zega T. J. ***POSTER LOCATION #48***

Sensing Biosignatures Within Rocks of the Atacama Desert — An Analog for Mars Environments **[#2079]**

We have been investigating potential biosignatures and mineral microstructure alteration of rocks from the Atacama desert in Chile. These materials represent martian analogs and are known to contain colonizing bacteria, to establish biosignatures.

Bonaccorsi R. Fairen A. G. Baker L. McKay C. P. Willson D. ***POSTER LOCATION #49***

Pizza or Pancake? Formation Models of Gas Escape Biosignatures in Terrestrial and Martian Sediments **[#2084]**

Fine-grained sedimentary hollowed structures were imaged in Gale Crater, but no biomarkers identified to support biology. Our observation-based (gas escape) terrestrial model could inform on possible martian paleoenvironments at time of formation.

Zaloumis J. Farmer J. D. ***POSTER LOCATION #50***

Diagenetic Changes in Microstromatolites from a Modern Cool-Water Travertine Spring **[#2055]**

Microstromatolites from Crystal Geyser travertine deposits show rapid diagenetic degradation. Morphological textures quickly degrade with burial, though organic signatures are still preserved as kerogen and may be detected with Raman spectroscopy.

Hickman-Lewis K. Garwood R. J. Brasier M. D. Goral T. ***POSTER LOCATION #51***
Jiang H. McLoughlin N. Wacey D.

Carbonaceous Microstructures of the 3.46 Ga Stratiform 'Apex Chert', Pilbra, Western Australia: Presenting a New Suite of Early Archaean Microbially Induced Sedimentary Structures **[#2029]**

We present morphological and geochemical evidence for a new suite of MISS from the stratiform Apex chert. Four potential biosignatures are identified in this marine unit: laminated clasts, roll-ups, flaky grains and persistent filamentous laminae.

Tuesday, May 17, 2016
POSTER SESSION: SURFACE ENVIRONMENTS, SHALLOW, AND DEEP SUBSURFACE ENVIRONMENTS — PALEOBIOLOGICAL PROSPECTS
5:30 p.m. Regency C

Glamoclija M. Steele A. Starke V. Zeidan M. Potochniak S. Sirisena K. Widanagamage I. H. ***POSTER LOCATION #52***
Microbial Signatures In Sulfate-Rich Playas **[#2051]**
Microbes that live in playas represent organisms able to cope with transient environments, ranging from fresh to hyper-saline water settings and from wet to dry. We will try to identify mineral and chemical signatures of their presence.

Shkolyar S. Farmer J. D. ***POSTER LOCATION #53***
Impact of Diagenesis on Biosignature Preservation Potential in Playa Lake Evaporites of the Verde Formation, Arizona: Implications for Mars Exploration **[#2003]**
We studied evaporite subfacies in the Verde Fmn., AZ. We identified diagenetic pathways and assessed how diagenesis affected biosignature preservation potential (BPP) in each. Results revealed eight pathways, each with diverse impacts on BPP.

Mitchell J. L. Christensen P. R. ***POSTER LOCATION #54***
Bristol Dry Lake, California: An Analog for Ancient Lacustrine Environments on Mars **[#2081]**
This study investigates Bristol Dry Lake, CA, as an analog site for ancient lakes on Mars. Water chemistry and spectra were used to explore the geology and chemistry of chlorides at Bristol and their impact on possible habitable environments on Mars.

Lynch K. L. Biddle J. F. Schneider R. J. Rey K. A. Wray J. J. Rosenzweig R. F. ***POSTER LOCATION #55***
The Pilot Valley Basin, Utah: A Modern Habitability and Preservation Model for Groundwater-Fed Martian Paleolake Basins **[#2075]**
The Pilot Valley basin in northwestern Utah serves as an excellent modern environment for habitability and biosignature preservation analog studies of groundwater-fed martian paleolake basins.

Smith H. D. Duncan A. G. Davilla A. F. McKay C. P. ***POSTER LOCATION #56***
Biosignatures of Hypersaline Environments (Salt Crusts) an Analog for Mars **[#2060]**
Halophilic ecosystems are models for life in extreme environments including planetary surfaces such as Mars. Our research focuses on biosignatures in a salt crusts and the detection of these biomarkers by ground and orbital assests.

Uceda E. R. Fairen A. G. Rodriguez J. A. P. Woodworth-Lynas C. ***POSTER LOCATION #57***
Ocean Fertilization from Giant Icebergs on Earth and Early Mars **[#2042]**
Assuming that life existed on Mars coeval to glacial activity, enhanced concentrations of organic carbon could be anticipated near iceberg trails, analogous to what is observed in polar oceans on Earth.

Bishop J. L. Englert P. ***POSTER LOCATION #58***
Antarctic Dry Valley Sediments as Analogs for Microbial Systems in a Cold Mars-Like Environment **[#2017]**
Investigations of surface and lake bottom sediments in the Antarctic Dry Valleys have revealed microbial life nearly everywhere and some evidence for clays, carbonates, sulfates and other minerals associated with microbes in the sediments.

Wilhelm M. B.   Davila A. F.   Eigenbrode J. L.   Parenteau M. N.   ***POSTER LOCATION #59***
Jahnke L. L.   Liu X.   Summons R. E.   Stamos B. N.
Wray J. J.   O'Reilly S. S.   Williams A. J.
Xeropreservation of Functionalized Lipid Biomarkers in Hyperarid Soils in the Atacama Desert, Chile **[#2019]**
The preservation of lipid biomarkers was investigated in hyperarid soils with depth in the Atacama Desert. Clays sealed from rainwater for 2 Ma contained functionalized lipids, indicating that minimal degradation has occurred since their deposition.

Sapers H. M.   Pontefract A.   Osinski G. R.   Cannon K. M.   Mustard J. F.   ***POSTER LOCATION #60***
Habitability and Biosignature Preservation in Impact-Derived Materials **[#2059]**
Meteorite impacts create environments conducive to microbial colonization. Biosignatures in impact-derived materials have been characterized on Earth. Impact environments comprise candidates for biosignature detection and preservation on Mars.

McCollom T. M.   Hynek B. M.   Rogers K. L.   ***POSTER LOCATION #61***
Potential for Preservation of Biosignatures from Endolithic Photosynthetic Communities in a Mars Analog Fumarole Environment **[#2006]**
Thermophilic photosynthetic communities inhabit the moist interiors of mineral deposits in volcanic fumaroles. Contemporaneous mineral precipitation provides a high potential for preservation of morphological and chemical biosignatures.

Skok J. R.   Farmer J. D.   Jerman G.   Gaskin J.   Lindsey N.   ***POSTER LOCATION #62***
Munoz-Saez C.   Kaasalainen H.   Tobler D.   Parente M.   Craft K. L.
Seeking Signs of Life in Ancient Martian Hot Springs with Icelandic Analogs **[#2021]**
Using Icelandic analogs to develop a mission profile for biosignature detection in ancient siliceous hydrothermal systems on Mars.

Hinman N. W.   Kendall T. A.   MacKenzie L. A.   Cady S. D.   ***POSTER LOCATION #63***
Diagenetic Changes in Common Hot Spring Microfacies **[#2047]**
The friable nature of silica hot spring deposits makes them susceptible to mechanical weathering. Rapid diagenesis must take place for these rocks to persist in the geologic record. The properties of two microfacies at two deposits were compared.

Mustard J. F.   Sapers H. M.   ***POSTER LOCATION #64***
Biosignatures from a Deep Biosphere: The Largest and Longest-Lived Habitable Environments on Mars **[#2086]**

Wednesday, May 18, 2016
WORKSHOP WRAP-UP AND DISCUSSION
8:30 a.m. Regency AB

Chairs: **Lindsay Hays**
David Beaty

8:30 a.m.	*Wrap-up of Fundamental Comparison of Earth vs. Mars from a Paleobiology Perspective*
8:45 a.m.	*Discussion of Comparison Themes*
9:05 a.m.	*Wrap-up of Biosignatures and Environments I: Low-Temperature Surface and Subsurface*
9:20 a.m.	*Discussion of Biosignatures and Environments I Themes*
9:40 a.m.	*Wrap-up of Biosignatures and Environments II: Hot Springs and Iron-Rich Deposits*
9:55 a.m.	*Discussion of Biosignatures and Environments II Themes*
10:15 a.m.	Break
10:45 a.m.	*Workshop Themes Discussion*

PRINT ONLY: PRINT

Eigenbrode J. L. Steele A. Summons R. E. McAdam A. C. Sutter B. Franz H. B. Freissinet C. Millan M. Glavin D. Ming D. W. Navarro-Gonzalez R. Pavlov A. Hurowitz J. A. Grotzinger J. Conrad P. G. Mahaffy P. R.
In Situ Observations of Refractory Organic Matter in Lacustrine Mudstones of Gale Crater and Their Implications for the Search for Organic Biosignatures **[#2012]**
Evidence of refractory organic matter has been discovered in the ancient lacustrine sediments of Gale Crater by the Sample Analysis at Mars (SAM) instrument suite onboard the Curiosity rover.

Onstott T. C. Harris R. L. Sherwood Lollar B. Pedersen K. A. Colwell F. S. Pfiffner S. M. Phelps T. J. Kieft T. L. Bakermans C.
Biomarker Preservation Potential of Subsurface Ecosystems **[#2041]**
If surface life emerged on Mars it may have succumbed to a Gaian bottleneck, whereas subsurface life would have continued to grow and evolve sheltered in rocks with sub-freezing saline pore water and their remains preserved in excavated rock.

WHERE THE MICROBES WERE.

A. C. Allwood[1] [1]Jet Propulsion Laboratory, California Institute of Technology. 4800 Oak Grove Dr, Pasadena, CA 91109.

Introduction: An effective way to narrow the search for past life on Mars is to look for the kinds of geologic settings that are similar to environments on Earth that best preserve evidence of primitive microbial life. Signatures of ancient microbial life on Earth occur in a range of geologic settings, but a much smaller subset of environments host the vast majority of early microbial biosignatures. These taphonomic hotspots are rock successions that formed in highly habitable environments, where conditions through time were favorable for preserving signatures of life. Understanding what defines these hotspots is key to narrowing the search for life on Mars.

Being habitable is not enough. A growing body of evidence suggests that "habitable environments" on Mars have been plentiful in the past. Microbial life inhabits an enormous variety of environments on Earth, from high altitude to the deep ocean and deep crust, and virtually everywhere in between. Given life's ability to inhabit such diverse and extreme environments, it's no great leap of imagination to conclude that Mars through time must have offered an enormous array of potential places that could be habitable for life as we know it. However, degrees of habitability can vary enormously. An environment that allows life not just to survive, but to flourish, will favor dense biomass accumulations, community formation, persistence through time and environmental interactions that can leave an obvious and lasting impression in the rock record.

Preservation and recognition. Biosgnatures are more likely to occur in rocks formed in an environment where processes and conditions favored preservation of chemical, morphological, isotopic, organic or mineralogical traces of microbial activity. While preservation of these types of clues may be possible in a variety of settings, some geological environments are naturally dominated by processes that are inherently more likely to preserve a variety of biosignatures.

In addition, when trying to interpret the origin of any potential biosignatures that may be found, the geologic context is critical for testing alternate hypotheses. If the context is ambiguous or overly complex, the interpretation of biosignatures will be hampered. A robust, detailed understanding of the ancient environment provides a framework for interpretation of potential biosignatures.

Thus, evaluating the relative *degree* of habitability, potential for preservation of biosignatures, and intepretability of the geologic setting makes for a well-informed, targeted search strategy.

Where the microbes were on the early Earth. While life today inhabits almost every known environment on Earth, relicts of ancient microbial life on Earth occur in a much narrower range of environments. An even narrower subset of those environments hosts the vast majority of microbial biosignatures – especially from the early Earth. Most Archean and Proterozoic are associated with subaqueous sedimentary settings. Shallow oceans, lakes, hydrothermal vents and springs offered a highly habitable environment as well as a means of entombing and preserving fossil remnants of the inhabitants. The sediment-water interface in all of these environments would have offered chemical gradients for energy and a substrate where microbes could congregate, adhere, form biofilms, exhibit community behaviours, persist through time, and affect the sediments that were being deposited around them. The ongoing accumulation of sediment – especially if that included certain kinds of chemical (precipitated) sediments – inherently would have tended to favor burial and encapsulation of biosignatures.

Lakes and shallow marine environments were also sites for deposition of transported organics from habitable environments in the catchment area. Today, the sedimentary rocks of ancient lakes, oceans, hydrothermal vents and springs host a spectacular array of biosignatures from early Earth.

BIOSIGNATURE PRESERVATION VULNERABILITY ASSOCIATED WITH REDOX MODE SWITCHING IN A MARS ANALOGUE COUPLED MICROBIAL MAT FROM DEATH VALLEY.

R. Archer[1] and Ralat, A.[2]ARRA Environmental[1,2] (Denver, Colorado, 80128)

Introduction:A coupled microbial mat from Death Valley was launched into the stratosphere at an altitude of 32817m for 74 minutes, in order to examine the response of an extremophilic microbial community exposed to Mars-like environmental conditions and to determine the spatial and temporal robustness of biosignatures to both internal and external forcing of boundary conditions; results are presented herein.

Coupled Microbial Mat Environment Approximating Mars Surface Conditions: UV irradiation (UV-A, UV-B, UV-C) dosing of the microbial mat at 24.25 ± 0.01KJ*m^{-2} was integrated over column flight (200nm-400nm, mean 270nm), atmospheric minimum pressure of 7.3mmHg, < DL ppm humidity, 230K, 3 G acceleration and Mach 1.2 acceleration.

Visible Microscopy and Viability of the Badwater Microbial Community: In contrast to Douglas *et al.*, 2002, XRD of sample from the same sight did *not* reveal any rosickyte presence. However, *Oscillatoria* sp. and cocci cyanobacteria were abundant and associated with gypsum and calcite at 0.9 cm. Recovery analysis showed canopy pH values of 9.9 in conjunction with 10% post-flight viability (BacLite). The sample postflight-preflight δwater*cm$^{-3}{}_{\text{(Bulk Sediment)}}$ = +32% after passing through a saturated tropopause.

Stable Isotope Results as a Reflection of Biosignature/Diagenesis Conditions: Modeled diffusion rates for $\delta\,^{13}C_{org}$, $\delta\,^{13}C_{dic}$, $\delta^{34}S$, $\delta^{15}N_{org}$, δD, $\delta^{18}O_{PDB}$ and $\delta^{18}O_{V\text{-}SMOW}$ are calculated in order to present a snapshot view of preflight diagenetic mechanism for this reduced microbial mat. Isotopic results, together with modeled reaction exchange values are consistent with protracted preflight microbially mediated sulfate reduction to H_2S by organic carbon. Temperature dependent $\delta^{34}S$ artifact contribution was insignificant. Results from 2015 results contrast sharply to positive rosickyte biosignatures [1] and supporting $\delta\,^{13}C_{org}$, and $\delta^{15}N_{org}$ isotopic results [2] from the same location in from 2002. Canopy [OH] production following exposure to near-space conditions was sufficient to shift stable $\delta pH_{(\text{preflight-postflight})}$ = +5.9 pH units (4.0pH-9.9pH), or a ~1.5×10^3-fold increase in [OH], inside of 20 minutes despite 10% total microbe population viability.

XRD and EPMA Fails to Demonstrate a Robust Rosickite Biosignature, SEM Hints Otherwise: As of March, 2015, both XRD and EPMA failed to detect rosickyte while positively detecting salts consistent with evaporative succession within a hypersaline playa environment (pore water salinity of 110ppμ). In contrast to both XRD and EPMA, SEM imagery revealed filament morphologies consistent with S^0(rosickyte) with a mean length of 4.54μM, (n=43, σ=0.37 and length/width ratio α = 0.01). Such morphologies appear embedded within possible extracellular matrix [1] and associate with dissolution pits with a mean major axis length of 1.19 μM (n=432, σ =1.41).

Viral-Bacterial Coupling as Evolved Microbial Adaptive Mechanism to Extreme Environments: Rapid redox mode-switching may be exacerbated by viral lysing of labile organic elements (CHNOPS) outside of Redfield ratios. viral:bacterial dominance in 2002 [2] was limited to thin, discreet horizons between layers. In contrast, in 2015, viral:bacterial dominance from the same site reveals more diffuse and active lytic activity under reducing conditions.

Conclusion and Implication for Mars Exploration: This study suggest that coupled microbial mats from Death Valley rapidly recover from environmental stressors such as UV irradiation and dessication through unique symbiotic adaptations conducive to cryptoendolithic survival. Perhaps, interplanetary inoculation of of genetic information may be possible for such a microbial community. Regarding exploration, negative biosignature results based upon XRD and EPMA may result from a weighted combination of factors affecting microbial endolithic niche conditions such as sustained drought of source watersheds. [3]. Microbial stress adaptive responses could hinder biosignature detection, causing high spatial and temporal variability. Biosignatures such as rosickyte are more labile than previously proposed [1]. It is inferred that Martian samples may also be vulnerable to rapid post-depositional diagenesis or during transit. Perhaps instruments should include lightweight portable minaturized apparatus; including red and green Raman spectrometers, trace-metal ICP-MS, laser ablation micro-mass MS, and, finally, SEM with microprobe elemental analyzer capability.

References:

[1] Douglas, S. *et al.* (2002) *Geol.*, *30*, 1151–1154.
[2] Archer R. *et al. AGU EOS Proc.*(2002)
[3] Aiger, E. *et. al.,* Circle of Blue, 11, (2014), 1344-1345.

SHERLOC: AN INVESTIGATION FOR MARS 2020.

L. W. Beegle[1], R. Bhartia[1], L. DeFlores[1], W. Abbey[1], B. Carrier[1], S. Asher[2], A. Burton[3], P. Conrad[4], S. Clegg[5], K. S. Edgett[6], B. Ehlmann[7], M. Fries[3], W. Hug[8], R. Reid[8], L. Kah[9], K. Nealson[10], M. Minitti[11], J. Popp[12], F. Langenhorst[12], V. Orphan[7], P. Sobron[13], A. Steele[14], N. Tarcea[12], G. Wanger[10], R. Wiens[5], K. Williford [1], R. A. Yingst[11]. [1]Jet Propulsion Laboratory, California Institute of Technology, Pasadena Ca, 91109 (Luther.Beegle@jpl.nasa.gov, Rohit.Bhartia@jpl.nasa.gov,),[2]University of Pittsburgh, [3]Johnson Space Center, [4]Goddard Space Flight Center, [5]Los Alamos National Laboratory, [6]Malin Space Sciences, [7]California Institute of Technology, [8]Photon Systems Inc., [9]University of Tennessee, [10]University of Southern California, [11]Planetary Science Institute, [12]University Of Jena, [13]SETI Institute, [14]Carnegie Institute Washington

Introduction: The next rover to explore Mars has been proposed to launch in 2020. The primary goal of the mission is to better understanding the geologic and climate history of Mars including the identification of potential signs of past life on Mars. Once identified, these samples will be collected and stored by the rover for return to the earth so they can be analyzed by state-of-the art instruments in terrestrial laboratories.

As part of the payload, NASA selected the Scanning Habitable Environments with Raman & Luminescence for Organics and Chemicals (SHERLOC) investigation. SHERLOC consists of a Deep UV (DUV) native fluorescence and resonance Raman spectrometer that includes a built-to-print version of the Mars Hand Lens Imager (MAHLI) instrument on the Mars Science Laboratory (MSL). It is a robotic arm mounted instrument that utilizes a DUV laser to generate characteristic Raman and fluorescence photons from a targeted spot. The DUV laser is co-boresighted to a context imager and integrated into an autofocusing/scanning optical system that allows us to correlate spectral signatures to surface textures, morphology and visible features. An internal scanning mirror enables the generation of maps that allow for the identification of spatially resolved organic structure.

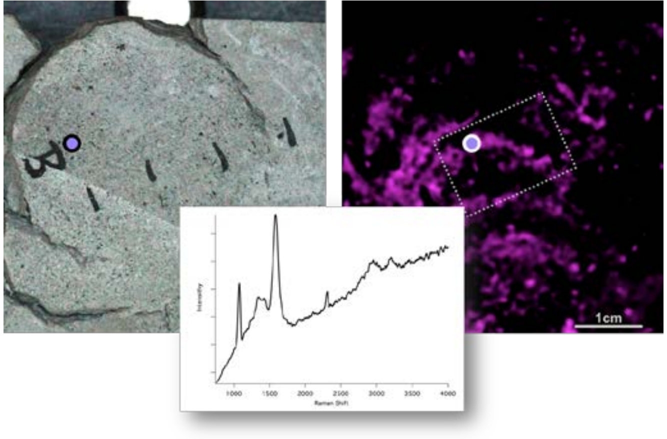
The SHERLOC investigation combines two spectral phenomena, fluorescence and pre-resonance/resonance DUV Raman scattering. These spectral features are resolvable when a high-radiance, narrow line-width, laser source illuminates a sample. In fluorescence, the incident photons are absorbed and re-emitted at a longer wavelength. Typical fluorescence cross-sections are 10^4 greater than traditional Raman, enabling the detection of sub-picograms levels of aromatic organic compounds. Fluorescence emission of organics extends from ~270 nm into visible wavelengths.

The deep UV resonance Raman enables classification of bonds such as C-H, CN, C=O, C=C, NHx, NOx, SOx, POx, ClOx, and OH. It should be noted that Raman shifts (cm-1) (i.e., peak position as energy loss from the excitation energy) are invariant to excitation wavelength. Thus peak positions in Raman databases (at 229, 248, 488, 532 and 785 nm) can be compared (c.f. http://rruff.info/).

SHERLOC's science goals include the detection and classification organics and astrobiologically relevant minerals on the surface and near subsurface of Mars. It is capable of organic sensitivity of 10^{-5} to 10^{-6} w/w over the entire observation region of 7 mm x 7 mm. It is capable of organic sensitivity of 10^{-2} to 10^{-4} w/w spatially resolved at 100µm and can detect astrobiologically relevant aqueously formed mineral grains with sizes <100µm.

The figure below demonstrates the power that mapping of organic molecules over a surface and the ability of SHERLOC to identify potential biosignatures. The image on the left is of a carbonate collected on the sea floor (courtesy of V. Orphan Caltech). The mineral matrix is primarily dolomite $CaMg(CO_3)_2$. A map of the fluorescence features identifies organic structure that was not visible in the color image (purple image on right). Raman spectra (see insert) obtained in these fluorescence regions shows spectral features of aromatics, aliphatics, hydroxyls, nitrogen & sulfur bearing organics. These features would possibly a result of ancient microbial processes This sample would be a high priority sample to be collected and returned in a future mission.

Acknowledgement: This work was carried out at the Jet Propulsion Laboratory, The California Institute of Technology under a contract from NASA



ANTARCTIC DRY VALLEY SEDIMENTS AS ANALOGS FOR MICROBIAL SYSTEMS IN A COLD MARS-LIKE ENVIRONMENT.

J. L. Bishop[1] and P. A. J. Englert[2], [1]SETI Institute (189 Bernardo Ave., Mountain View, CA; jbishop@seti.org), [2]Quest University (3200 University Blvd., Squamish BC V8B 0N8, Canada).

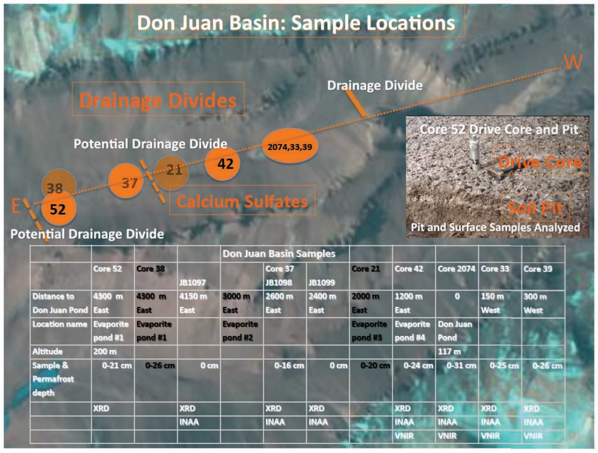
Introduction: The Antarctic Dry Valleys (ADV) were valued very early as microbiological proxies for Mars exploration [e.g. 1], and the geological significance of cold and arid deserts as Mars analogs concerning past and present water action and salt formation was suggested by Gibson et al. [2]. Since that time numerous studies have investigated the chemical, physical and biologic properties of sediments, both from the bottom of ice-covered lakes and from surface regions [e.g. 3-8]. These studies observed microbial life nearly everywhere and some evidence for clays, carbonates, sulfates and other minerals associated with microbes in the sediments.

Lake bottom sediments: Studies of the mineralogy, geochemistry, spectroscopy, and isotope patterns have been performed on igneous sediments from Lake Hoare, a nearly isolated ADV ecosystem [e.g. 6]. The mineralogy and chemistry of these sediments were studied in order to gain insights into the biogeochemical processes occurring in a permanently ice-covered lake and to assist in characterizing potential habitats for life in paleolakes on Mars. Obtaining VNIR, mid-IR, and Raman spectra of such sediments provides the ground truth needed for remote exploration of geology, and perhaps biology, on Mars.

These sediments are dominated by quartz, pyroxene, plagioclase, and K-feldspar, but also contain calcite, organics, clays, sulfides, and iron oxides/hydroxides that resulted from chemical and biological alteration processes [6]. Chlorophyll-like bands are observed in the spectra of the sediment-mat layers on the surface of the lake bottom, especially in the deep anoxic region. Layers of high calcite concentration in the oxic sediments and layers of high pyrite concentration in the anoxic sediments are indicators of periods of active biogeochemical processing in the lake. Micro-Raman spectra revealed the presence of ~5 µm-sized pyrite deposits on the surface of quartz grains in the anoxic sediments. C, N, and S isotope trends were compared with the chemistry and spectral properties. The $\delta^{13}C$ and $\delta^{15}N$ highlight differences in the balance of microbial processes in the anoxic sediments versus the oxic sediments. Biogenic pyrite found in the anoxic zone sediments is associated with depleted $\delta^{34}S$ values, high organic C levels, and chlorophyll spectral bands, and could be used as a potential biomarker mineral for paleolakes on Mars.

Surface Sediments: ADV surface sediments surrounding Lakes Fryxell, Vanda and Brownworth were investigated as analogs for the cold, dry environment on Mars [8]. Sediments were sampled from regions surrounding the lakes and from the ice cover on the lakes. The ADV sediments were studied using Raman spectra of individual grains and reflectance spectra of bulk samples. Elemental abundances were coordinated with the spectral data in order to assess trends in sediment alteration. The surface sediments in this study were compared with lakebottom sediments [6] and samples from soil pits [7]. Feldspar, quartz and pyroxene are common minerals found in all the sediments. Minor abundances of carbonate, chlorite, actinolite and allophane are also found in the surface sediments, and are similar to minerals found in greater abundance in the lakebottom sediments. Surface sediment formation is dominated by physical processes in contrast to biomineralization taking place in lakebottom sediments. Characterizing the mineralogic variations in these samples provides insights into the alteration processes occurring in the ADV and supports understanding alteration in the cold and dry environment on Mars.

High Saline Ponds: Don Juan Pond (DJP) in Wright Valley has a high salinity of 40 wt.% or more salt content. Salt accumulation and its history is complex and is still waiting to be unraveled. The focus of the current study is on characterizing the mineralogy and salt chemistry at the DJP region through analyses of multiple sediment cores (Figure 1). We are applying XRD, VNIR and mid-IR reflectance spectroscopy, Raman spectroscopy and chemical analyses toward understanding the geochemistry of the DJP basin. This will enable documentation of potential elemental and mineralogic biomarkers.



				Don Juan Basin Samples							
	Core 52	Core 38	JB1097		Core 37 JB1098	JB1099	Core 21	Core 42	Core 2074	Core 33	Core 39
Distance to Don Juan Pond	4300 m East	4300 m East	4150 m East	3000 m East	2600 m East	2400 m East	2000 m East	1200 m East	0	150 m West	300 m West
Location name	Evaporite pond #1	Evaporite pond #1		Evaporite pond #2			Evaporite pond #3	Evaporite pond #4	Don Juan Pond		
Altitude	200 m								117 m		
Sample & Permafrost depth	0-21 cm	0-26 cm	0 cm		0-16 cm	0 cm	0-20 cm	0-24 cm	0-31 cm	0-25 cm	0-26 cm
	XRD		XRD		XRD	XRD		XRD	XRD	XRD	XRD
			INAA		INAA	INAA		INAA	INAA	INAA	INAA
								VNIR	VNIR	VNIR	VNIR

Figure 1. Selected sample locations at Don Juan Pond.

References: [1] Cameron R.E. et al. (1971) *Antarct. J. US*, **6**, 211-213. [2] Gibson E.K. et al. (1983) JGR, 88, A912-A928. [3] Wharton R.A. et al. (1989) Adv.SpaceRes., 9, 147-153. [4] McKay C.P. et al. (1992) Adv.SpaceRes., 12, 231-238. [5] Doran et al. (1998) JGR, 103, 28-48. [6] Bishop et al. (2003) IJA, 2, 273-287. [7] Englert et al. (2014) 77thMet.Soc., abstract #1800. [8] Bishop et al. (2014) *Phil. Trans. R. Soc. A*, **372**, 20140198.

Acknowledgements: Support from the SETI Institute team of the NAI on this project is greatly appreciated.

PIZZA OR PANCAKE? FORMATION MODELS OF GAS ESCAPE BIOSIGNATURES IN TERRESTRIAL AND MARTIAN SEDIMENTS.

R. Bonaccorsi[1,2] A.G. Fairen[3,4], L. Baker[5]; C. P. McKay[2]; and D. Willson[2]. [1]SETI Institute – Carl Sagan Center (rosalba.bonaccorsi-1@nasa.gov); [2]NASA Ames Research Center (M.S. 245-3, Moffett Field CA 94035); [3]Department of Planetology and Habitability, Centro de Astrobiologia, Spain; [4]Department of Astronomy, Cornell University; [5]Dept. of Geological Sciences, University of Idaho (PO Box 442339, Moscow, ID).

Introduction: Fine-grained surface sedimentary structures referred as to "Hollow nodules" (HNs) were discovered at *Yellowknife Bay Site* by the Curiosity rover (Fig. 1A). Plausible abiotic [1,2] and biological formation mechanisms have been proposed, but no biomarkers have been detected to support their biogenic origin in Gale Crater [3].

In an ephemeral pond in Ubehebe Crater (UC), Death Valley, Calif., we found sedimentary structures (Fig. 1B) strikingly similar to those imaged by the MSL rover (Fig. 1A). Potential biogenic and abiogenic processes of HN formation on Mars could not be discerned based on a morphological approach. Yet, studies of their terrestrial analogues could inform about potential biogenic activities that might be responsible for intriguing sedimentary structures on Mars.

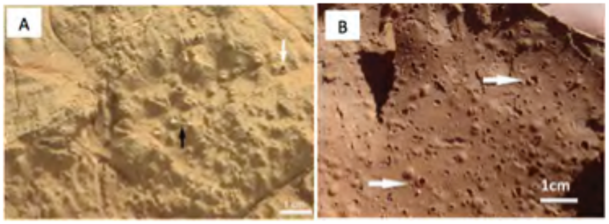


Figure 1*. HNs in mudstone (white arrows) imaged by Mastcam-100, sol 159, Yellowknife Bay Site (A). Mini hollows in the terrestrial mud gas escape structures (B)*

Methods: As part of long-term monitoring of the surface water cycle, and microclimate conditions at UC [e.g., 4,5], H_2O content/ground moisture, temperature and relative humidity (*rH*) were acquired with miniature sensor/data loggers.

Observations: During the pond's 11-day life (August 5th to 16th, 2014), from accumulation thru total evaporation of shallow standing water (5-20 cm-depth) we witnessed the active formation of HNs-like gas escape features (Fig. 1B) under conditions of extreme evaporation (~2 cm/day) and preceded by an unusual cyanobacterial bloom and decay during the first 2 days of pond's life (Fig. 2). The intra-crater mud's surface is otherwise extremely dry for most of the year (Air_*rH* ~2-5%; moisture 1-2 wt.%; Summer air/ground T: 45-48ºC/ 67-70ºC).

Formation Model of Ubehebe's HNs. Based on terrestrial observations/measurements and literature data a plausible model could involve H_2S/CO_2 gas bubbles released by fermenters and/or Sulfur Reducing Bacteria (SRB) using decaying cyanobacterial biomass (Fig. 2A). In this model, the HN-forming clay-rich mud is the most habitable layer with bacteria plausibly supported by redox reactions involving sulfides (FeS_2, FeS) from HS^- and Fe^{2+} in reduced sediments, sulfates, iron-bearing minerals and biological S.

Pizza or Pancake? Are HNs from biological fermenting processes (very much like bubbles rising from our fermenting pizza dough)? Or, are they from abiological processes, just like CO_2 bubbles forming in fluffy pancakes by baking soda? If the former is the case, gas-escape strictures on Mars might offer an intriguing evidence of cryptic, yet metabolically active and ephemeral life leaving gas-escape strictures in lacustrine deposit.

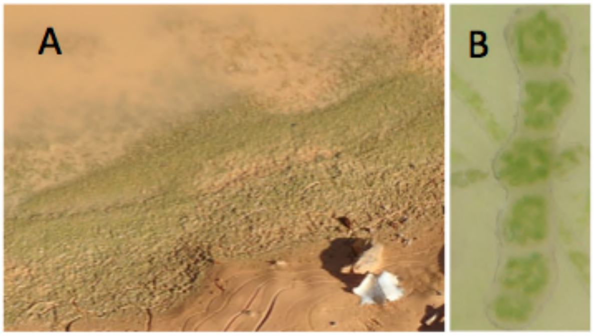


Figure 2. *Pond's cyanobacterial biomass (B) and underwater bubbles forming gas escape structures (A).*

Conclusions: UC surface HNs represent a novel type of microbially-induced sedimentary structures (MISS) [e.g., 6-8] and offer an unequivocal evidence that short-lived and cryptic terrestrial microbial mats are fundamental for their formation.

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PRESERVATION OF MICROBIAL-MINERAL BIOSIGNATURES IN CAVES AND PALEO SPRINGS.

P. J. Boston[1,2] & E. C. Alexander, Jr.[3], [1]Earth & Environm. Sci. Dept., New Mexico Tech, 801 Leroy Place, Socorro, NM 87801, pboston@nmt.edu, [2]National Cave & Karst Research Inst., Carlsbad, NM 88222, [3]Earth Sciences Dept., Univ. of Minn., 310 Pillsbury Dr. SE, Minneapolis, MN 55455, alexa001@umn.edu

Introduction: Cave environments on Earth possess unique combinations of features that give rise to exquisite preservation of biosignatures, both biomolecular and structural, at micro and macro scales [1]. Caves are famous as places where elaborate and often unique minerals form [2] including the production of highly distinctive biominerals [3, 4]. Caves also house some of the most remarkable preservation of microbial mats and other biopatterns [5,6]. Cave microbial communities often engage in extensive mineral precipitation while they are living, in a sort of "autofossilization" that provides many of the well-preserved life traces that we see in these environments [5].

Caves as Habitats on Earth: As habitats, caves provide many advantages including absence of ordinary surface weather, protection from ultraviolet radiation, protection from dessication and seasonal temperature and humidity extremes, and some protection from predation by other organisms. The price paid is a very oligophilic environment where sources of energy can be scarce, and organic matter is surface derived rendering many cave organisms detrivores. However, many caves also gain energy from geological sources like chemically reduced gases coming from deep crustal or even mantle sources, or accessible oxidizable minerals (e.g. iron, manganese, sulfur compounds and others).

Cave Habitats on Mars: Caves from volcanic processes have been detected on Mars by Cushing et al in 2007. Such subsurface cavities could potentially represent a unique bridge between the risks to life on the Mars surface (harsh oxidizers, large temperature extremes, extreme aridity, radiation, dust storms, etc.) over the course of its diminishing surface habitability [x] and the difficulty in accessing potential Martian life forms yet extant or extinct but preserved in the subsurface (drilling or otherwise trying to sample the interior of Mars). The potential for long term stable ices in Mars caves has been modeled and is of timescales not inconsistent with obliquity super seasons on Mars. Further, such cavities may contain somewhat higher vapor pressures of gases than the aboveground atmosphere. Such subsurface habitats should be interrogated by future missions for biosignatures or even the prospect of extant lifeforms which may be dormant in the current era of Mars' obliquity cycle.

Spring and Paleo Spring Habitats on Mars. In addition to caves, springs can function as refugia for life forms as enviornments degrade either cyclically or monotonically. Springs are direct conduits that bring subsurface life and its characteristic metabolic products to the surface. On Mars large geochemical and physical gradients are possible between the surface and subsurface environments. Springs often generate biologically precipitated, characteristic deposits on the surface such as tufas and silica sinters.

Concentrated brines are ubiquitous in terrestrial Archean shield rocks [1,2]. The ongoing research of the present day transient presence of liquid water on the Martian surface initiated by Malin and Edgett's [3] discovery of active gullies is increasingly focused on concentrated brines and hydrated salts [13]. The biologically rich anoxic brines of the Soudan Mine [4] provide evidence that such brines can host microbes and produce iron oxyhydroxide precipitate "siderothems" analogous to features visible on the Martian surface.

Mars Caves as Mission Targets: Caves allow more ready access to the shallow interior of Mars than any other mode of sampling. Lavatube caves tend to be relatively close to the surface and the task of drilling through a few meters of rock to access cavities is a far less daunting prospect than an open-ended very deep drilling approach to a lake bed or other sedimentary feature, and will yield some of the same types of data, possibly including a history of organic material, climate proxies, and other types of data that have likely been actively destroyed by the highly chemically active and radiation influenced surface.Springs or seeps in caves combine the life advantages of both environments.

Conclusions: Earth caves house an enormous variety of microbial communities, many of whom produce spectacular, distinctive morphological biosignatures that are visible to the naked eye and possess qualities not found in abiotic mineral precipitates. Such biosignatures are tremendously well preserved in the protected environments of caves which escape the ravages of weather and other disturbance. These may be a model for detecting and characterizing unequivocal biopatterns. The Martian subsurface is represented so far by the detection of several thousand volcanic caves in many parts of Mars which could be highly valuable targets for future landed missions.

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Characterizing the biological and geochemical architecture of hydrothermally derived sedimentary deposits: coupling micro Raman spectroscopy with noble gas spectrometry.

D.M. Bower[1], P.G. Conrad[1], A. Steele[2] and M.D. Fries[3], [1]Planetary Environments Laboratory, NASA Goddard Space Flight Center, Greenbelt, MD 20771, dina.m.bower@nasa.gov, [2]Geophysical Laboratory, Carnegie Institution of Washington, 5251 Broad Branch Rd, NW, Washington, D.C., 20015, [3]Astromaterials Research and Exploration Science (ARES), NASA Johnson Space Center, Houston, TX 77058.

Introduction: The chemical components of sedimentary strata on the surface of Mars contain clues to its planetary evolution and possibly signatures indicative of life. The most efficient way to interrogate these clues is to use non-destructive in situ analytical techniques, but often it is necessary to use methods that are destructive to collected samples. A good strategy to combat the loss of potential biosignatures and paleoenvironmental indicators is to utilize non-destructive techniques prior to destructive ones.

A wide variety of microbes flourish in modern hydrothermal environments on Earth, and their ancient ancestors are preserved in siliceous deposits that formed in hydrothermal settings [1]. Hydrothermally derived silicate materials are also of particular relevance to Mars analog studies, and these studies may be very informative in determining possible landing sites for upcoming missions [2]. With these ideas in mind, chemical species in cherts and glass fragments representative of hydrothermally derived sedimentary samples were analyzed using micro Raman spectroscopy. We tested a novel Raman spectroscopic mapping technique that utilizes quartz Raman peak ratios to investigate features of interest in the context of silicate fabrics [3]. In particular, we established the provenance of quartz in cherts that contain multiple quartz generations and determined that much of the macromolecular carbon in our chert samples is not syngenetic.

To expand upon our understanding of the origins of the sedimentary deposits that contain possible biosignatures, we will also analyze the same sample fragments for heavy noble gas isotopes. The chemical inertness of noble gases (Ne, Ar, Kr, Xe) results in the retention of their isotopic signatures, and some of these signatures are useful in indicating the origins of hydrothermal deposits [4]. The noble gas xenon is especially useful as a geochemical tracer and can be trapped in amorphous siliceous materials as part of the silicate structure or as components of fluid inclusions [5]. Our goal is to combine micro Raman spectroscopy and noble gas spectrometry to robustly characterize the biological and geochemical architecture of ancient hydrothermal sedimentary deposits.

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SPECIAL EXHIBIT ON METEORITES AND MINERALS ASSOCIATED WITH THE ORIGIN OF LIFE ON EARTH OR MARS.

R.B. Bruner[1], [1]Denver Museum of Nature and Science, 930 S Euclid Way, Denver, CO 80209; bobbruner40@hotmail.com.

Black Smoker-type Hydrothermal Vent Theories

- Pyrite to represent Wachtershauser's Iron-Sulfur world
- Saphalerite to represent Mulkidjanian's Zinc world

Clay Theories

- Montmorillonite to represent Ferris et al
- Kaolinite to represent Hashizume et al
- Muscovite to represent Hansma et al

Lost City-type Serpentization Theories

- Olivine, Pyroxene, Serpentine, Magnetite, Brucite, Molybdenum to represent Russell et al
- Serpentine proven by Nakhla meteorite - Bridges et al

Conditions on Mars

- Boron and molybdenum indicated by Wulfenite, Tourmaline, and Colemanite - Benner et al

Conditions on Earth and Mars

- Organic molecules proven by Murchison meteorite- Kvenvolden et al
- Organic molecules and CAI's proven by Allende meteorite- Clarke et al
- Organic molecules proven by Tissint meteorite- Steele et al
- Organic molecules proven by Orgueil meteorite(cometary fragment)- Gardinier et al
- Other clay minerals (nontronite, saponite, halloysite, illite, chlorite) proving water-Ehlmann et al
- Water contribution from asteroids like Vesta (Camel Donga meteorite) - Alexander et al

Phosphorus proven by

- apatite and Tambo Quemado meteorite- Pasek et al

Life Materials Going from Mars to Earth - Dated by Zircon (CHNOPS)

- Black Beauty Mars Meteorite NWA 7034 (and its cousins)

IN SITU LIFE AND BIOSIGNATURE DETECTION AT MARS ANALOG SITES USING THE OXFORD NANOPORE MINION SEQUENCER.

K. F. Bywaters*[1], C. P. McKay[1], A. F. Davila[2] and R. C. Quinn[3], [1]NASA Ames Research Center, Moffett Field, Mountain View, CA 94035 (*correspondence: kathryn.f.bywaters@nasa.gov, chris.mckay@nasa.gov), [2]Carl Sagan Center, SETI Institute, Mountain View, CA 94043 (adavila@seti.org), [3]Carl Sagan Center, SETI Institute/NASA Ames Research Center, Moffett Field, Mountain View, CA 94035 (richard.c.quinn@nasa.gov).

Introduction: Biomolecules are the most unambiguous and information-rich of all known biosignatures. The identification of biopolymers akin to DNA, RNA or proteins, would be difficult to refute as a successful life detection experiment. In the case of Mars, the search for biomolecules is inescapable, but few technological solutions exist for *in situ* identification.

The Oxford Nanopore MinION is a novel, miniature, off-the-shelf instrument capable of detecting biological polymers (DNA, RNA and proteins) without the need for amplification (i.e. the use of primers) and/or bulky sequencing equipment.

The MinION determines the structure of a biopolymer (such as the A, T, G, C sequence of DNA) by measuring changes in current across a membrane as the biopolymer passes through a protein nanopore. In contrast to traditional sequencing methods, prior knowledge of molecular structure or composition is not required.

Due to the versatility and portability of the MinION it has the potential to be used to conduct *in situ* field analysis of samples. These attributes make the MinION a prime candidate as an astrobiological life or biosignature detection instrument for planetary missions, such as Mars landers and icy world flybys.

The MinION Experiment: A proof-of-concept study is being performed to conduct *in situ* field analysis and to determine the detection limit of biopolymers, including DNA and RNA, contained in samples from the hyperarid Atacama Desert, the Mojave Desert and the Dry Valleys of Antarctica. These samples contain one of the lowest biomass levels on Earth and represent excellent Mars analogs for ground truthing instrument performance.

The results of this study will be used to establish measurement and instrument requirements needed for implementation of MinION technology on future NASA missions. By identifying the structure and possible survival strategies of the microbial communities in these extreme ecosystems, which may provide an analog of conditions on other worlds, a better understanding will be obtained about the conceivable adaptations and evolution of life beyond Earth. By testing of the MinION in analog settings this work will also assist in the development of tools for monitoring the adaptation of organisms in other planetary or space environments.

The MinION has been tested in the hyperarid core of the Atacama Desert at a field site located in the Yungay region. Preliminary results show that the MinION can detect DNA in halite samples from the hyper arid Atacama Desert. Endolithic communities containing cyanobacteria (*Halothece*) and associated heterotrophic bacteria in the halite deposits have already been characterized [1, 2]. The results obtained by processing the Atacama halite deposit will be discussed in the context of comparison to the previously described results obtained by traditions methods (PCR amplification of 16S rRNA genes) [2].

Figure 1. MinION in a halite field at the Yungay site in the Atacama Desert, Chile.

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TRACING HOT-SPRING FACIES AND THEIR GEOTHERMALLY SILICIFIED MICROBIAL TEXTURES INTO THE TERRESTRIAL GEOLOGIC RECORD: RELEVANCE FOR MARS BIOSIGNATURE RECOGNITION.

K. A. Campbell[1], D. M. Guido[2], J. D. Farmer[3], M. J. Van Kranendonk[4], S. W. Ruff[3], and F. Westall[5]. [1]School of Environment, Univ. Auckland, Private Bag 92106, Auckland 1142, New Zealand (ka.campbell@auckland.ac.nz), [2]Instituto de Recursos Minerales, Facultad de Ciencias Naturales y Museo (UNLP), Calle 64 #3, La Plata 1900, Argentina, [3]School of Earth and Space Exploration, Arizona State Univ., PO Box 871404, Tempe, AZ 85287, U.S.A., [4]Australian Centre for Astrobiology, Univ. New South Wales, Kensington, NSW 2052, [5]Centre de Biophysique Moléculaire, CNRS, Rue Charles Sadron, Orléans, cedex 02, France.

Introduction: More than 125 years of study of siliceous hot-spring sedimentary facies since Weed's insightful observations on "algous vegetation" in sinter at Yellowstone National Park [1] has illuminated a variety of deposit geometries and macro- and micro-textures, most microbial in origin [2-5]. The microbial fabrics entombed in sinter are controlled by temperature, pH and physico-chemical parameters operating along environmental gradients in any given geothermal system [2,3]. Many of these textures can be recognized in the geologic record [5-8], in some cases as far back as 3.48 billion years to the earliest signs of life on Earth [9]. Early silicification is paramount for preserving high-quality biosignatures in ancient hydrothermal settings [10]. One recurring sinter facies resembles siliceous nodules at Columbia Hills on Mars [11], and thus warrants more detailed comparative study.

Sinter Preservation and Facies on Earth and Mars(?): Alkali chloride thermal waters of nearly neutral pH tend to precipitate the thickest stratiform deposits (dm's to 10's of m's). This geometry implies high fluid volumes and/or systems that were active over long durations [12]. Acid-sulfate-chloride springs precipitate thin sinters (few cm's to dm thick) [13] with distinctive fabric types [14]. Aridity may strongly dictate the amount and distribution of precipitated silica. Sinters are rare in rocks older than Cenozoic age, being best represented in subsiding basins during the waning stages of regional volcanism [5]. On Earth, all old and some young sinters have diagenetically transformed from amorphous opal to micro- or mesocrystalline quartz. In contrast, the inferred sinters at Columbia Hills remain opaline, indicating a lack of diagenesis [11]. Because of this history, Mars may be the best place in the Solar System to preserve ancient biosignatures, if ever they were present [15,16].

In New Zealand, sheet channel-flow areas bathed by warm (~40-60°C) discharge from acidic or neutral pH springs commonly form digitate knobby to spicular textures that are broadly similar in morphology at the macro-scale, and which may be compared to features in the Columbia Hills siliceous nodular deposits [11,19]. The terrestrial examples invariably develop by evaporative wicking and silicification of microbial communities situated at the air-water interface, growing thin (<3 cm) microstromatolites on pumiceous clasts or sediments that are slightly elevated above the steaming, sluggish (≤0.5m/sec), thin (mm's to 1-2 cm) water layer [14]. More detailed analysis of these features is needed to differentiate environmental controls on the range in style of their micro-digitate morphologies.

Sinter Biosignatures: Following the paragenesis and diagenesis of recurring microbial fabrics in sinters of different ages enables an understanding of the fate of biosignatures through time. Over >3 billion years of geologic history of geothermal settings suggests that the most robust biosignatures are preserved as silicified macro- and micro-textures, with laser micro-Raman analysis providing additional important characterization of carbonaceous material, its mineralogic replacement by iron or titanium oxide minerals, and fingerprinting of the enclosing hydrothermal minerals [10]. Lipid biomarkers, while preserved in some Quaternary sinters [17], thus far do not extend meaningfully into the deeper time record we have studied [18].

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MEASUREMENT OF UV FLUORESCENCE AND RAMAN SIGNATURES OF SUBSURFACE ORGANICS IN MARS RELEVANT MINERALS TO CONSTRAIN DETECTION DEPTH FOR THE SHERLOC MARS 2020 INSTRUMENT.

B. L. Carrier*, L. W. Beegle, R. Bhartia, W. J. Abbey, Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA (*bcarrier@jpl.nasa.gov).

Introduction: SHERLOC is an instrument that is part of the Mars 2020 payload. It utilizes a deep UV laser (248.6 nm) to induce Raman and fluorescence in organics and minerals [1]. Samples of interest are spatially scanned with the laser to stimulate fluorescence emissions and Raman scattering from the sample. Specifically, fluorescence is generated from electronic transitions in aromatic organics and Raman scatter is generated from vibrational bonds in both organics and minerals [2]. SHERLOC will be used on Mars to identify, in situ, interesting samples for sample caching and potential subsequent return to Earth.

The mineral transparency at the wavelengths of interest (250-400 nm) for both the incident laser light and the sample specific photons from fluorescence emission or Raman scattering will affect the interrogation volume of analysis and thus constrain the limits of detection. To date the depth of penetration of UV photons into natural minerals has not been well characterized. Here we report on preliminary results using a SHERLOC-like laser to detect organics under thin layers of MMS basalt (Mojave Mars Simulant) [3], kaolinite and gypsum.

Methods:

Pellets consisted of three layers. The bottom layer consisted of the target mineral dust mixed with 10 wt.% cellulose (as a binder). A second layer consisted of the powdered organic to be analyzed. The top layer was a thin layer (~100-200 μm) of organic free mineral. The thickness of the top layer was measured using a Mitutoyo digital thickness indicator before being applied on top of the organic layer. Each pellet was analyzed at 58 micron spot size over 300 discrete points. Fluorescence spectra were obtained with 25 pulses and Raman spectra with 1200 pulses.

Results and Discussion: Preliminary results have been obtained for phenanthrene, phenylalanine and alanine under MMS, gypsum, and kaolinite. The aromatic compounds have been analyzed using fluorescence and Raman spectroscopy while the aliphatic alanine was analyzed using Raman only. In each case there was substantial variability from point to point, ranging from 0 to near 100% transmission. This is likely due to natural heterogeneity in the mineral matrices. Natural martian rocks will also show significant variability in their compositions, but these results indicate that the SHERLOC instrument should be able to detect aromatic and aliphatic organics with Raman and fluorescence spectroscopy to a depth of >100 μm in the minerals examined.

Preliminary results.

Figure 1 shows the averaged Raman spectrum for alanine, an aliphatic amino acid. Peak locations and relative intensities correlate well to the spectrum of pure alanine. The relative intensity between subsurface and surface samples of alanine was on the order of ~1.5%.

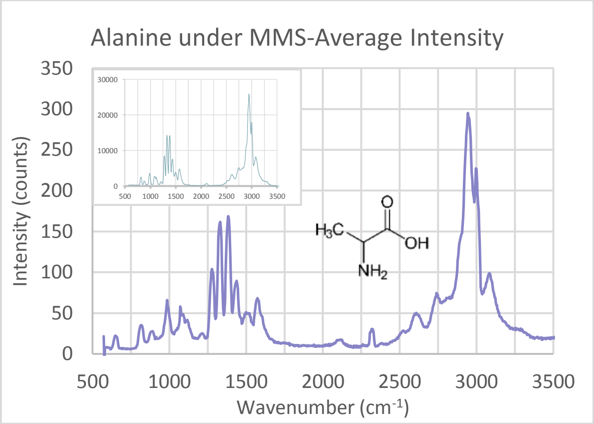

Figure 1. Averaged Raman spectrum of alanine under 99 ± 10 μm MMS. Inset-Raman spectrum of alanine on a surface.

Conclusions: Preliminary results show that organic molecules can be detected by the SHERLOC instrument at depths in excess of 100 μm in basaltic minerals. Aromatic compounds such as phenanthrene and phenylalanine can be detected via fluorescence spectroscopy to a depth of >160 μm. Aliphatic compounds such as alanine can be detected to a depth of >100 μm using Raman. The spectra of the subsurface organics investigated herein have been found to correlate well with the spectra of the pure organic. Further experiments will be performed to constrain the maximum depth and minimum concentrations at which organics can be detected using this method. The detection depth of these and other organics in various other Mars relevant minerals such as kaolinite and gypsum will also be investigated.

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SEARCHING FOR LIFE ON EARLY MARS: LESSONS FROM THE PILBARA. J.D.A. Clarke[1] and C. R. Stoker[2], [1]Mars Society Australia jon.clarke@bigpond.com, [2]NASA Ames Research Center, Moffett Field, CA 94035, carol.stoker@nasa.gov

Stromatolites in the Pilbara region of Western Australia constitute the earliest outcrop-scale evidence of life on Earth (Figure 1). The stromatolites in the 3.4 Ga Strelley Pool Formation (SPF) provide an important analog for searching for fossil evidence of early life on Mars, as Noachian aged sediments on Mars were formed under similar environmental conditions. Stromatolites represent possibly the best evidence that could be collected by a rover because they form recognizable macroscopic structures and are often associated with chemical and microscopic evidence.


Figure 1: 3.4 Ga stromalites of the Strelley Pool Formation.

Analog Site Work: Field and basic laboratory investigations of SPF stromatolites near Nullagene Australia (Clarke and Stoker, 2013) helps illustrate issues important for searching for past evidence of life on Mars. We mapped 38 different stromatolite locations within 18 outcrops or clusters of outcrops. Morphologies were domes (45 imaged) low relief domes (26 imaged) and cones (25 imaged). There was abundant evidence for hydrothermal activity including hydrothermal breccias, cavity filling quartz, and nail hole columns of bladed barite, consistent with the suggestion that stromatolite grew in areas of hydrothermal activity (Van Kranendonk 2006). Because of the sensitive nature of the site, no rock hammering was performed to acquire samples but some small float samples were obtained. Field spectra were acquired using an Integrated Spectronics SWIR (1300-2500 nm) PIMA field portable spectrometer. Typical minerals identified in stromatolitic lithologies were dolomite, calcite, talc, and hornblende. Primary phyllosilicates were talc and phengite (Table 1).

One outcrop selected for laboratory study consisted of partially silicified limestone with undulating laminations. This sample was examined in thin section via petrographic microscope. The stromatilites were originally calcite, variably replaced by dolomite and silica. No evidence of cellular structure or microfossils was found in the thin sections, nor would be expected given the crystallized nature of the carbonates and the late silicification. However the stromatolites appear strongly biogenic in form. SWIR spectra were obtained with the PIMA (Table 1) and XRD data with a Terra X-Ray diffractometer (Sarrazin et al., 2008), a commercial version of the CHEMIN on MSL (Table 2). Mineralogy within the sample consists of quartz, calcite and talc.

Discussion: Findings from the analog site provide some lessons for Mars sample return to search for evidence of life. Stromatolites are rare, possibly outcropping in only one millionth of the area of the Pilbara. Even where the stromatolites are found, they make up ~1% of the host unit and considerable traversing to look at every outcrop is needed to study the area and select the best samples. The stromatolite morphology in our field sample is the only evidence of biogenic activity, organic carbon or microfossils are not preserved. The stromatolitic outcrops in the Pilbarra are steeply dipping whereas on Mars they are likely to be flat lying so exposures may only be on steep walls of craters or valleys, making them difficult to access. Brown et al. (2005) showed that high resolution (5 m or better) hyperspectral imagery was needed to identify alteration zones where stromatolites are found; CRISM resolution at 15m/pixel was unable to allow this mapping. Even if the right outcrops are found and sampled, considering that it has taken many decades of careful work by teams of researchers studying hundreds of kg of samples to prove the likely biogenicity of the Archean Pilbara stromatolites, proof of early life on Mars with sample return is unlikely.

Table 1: PIMA hyperspectral analyses (those marked * also analysed with XRD)

Sample location	Lithology	Minerals
Interior	Marble	Calcite
Exterior	Silicified limestone	Talc, hornblende, dolomite
Interior	Silicified limestone	Talc, hornblende
Interior	Silicified limestone	Talc, hornblende, dolomite
Exterior *	Silicified limestone	Talc, tremolite, dolomite
Interior*	Silicified limestone	Talc, hornblende, dolomite
Interior*	Silicified limestone	Talc, hornblende, dolomite

Table 2: Terra XRD analyses

Sample location	Lithology	Minerals	%
Exterior	Silicified limestone	Quartz Calcite Talc	61.7 8.9 29.4
Interior	Silicified limestone	Calcite Talc Dolomite Quartz	53.7 25.0 15.2 6.2
Interior	Silicified limestone	Quartz	100

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INTERROGATION OF TEMPORAL PLANETARY ANALOGS FOR BIOSIGNATURE DETECTION.

P. G. Conrad[1], R. D. Arevalo[1], K. A. Farley[2], M. S. Rice[3], S. Gupta[4], W. B. Brinckerhoff[1], S. A. Getty[1] and P. R. Mahaffy[1], [1]NASA Goddard Space Flight Center, Greenbelt MD 20771, Pamela.G.Conrad@nasa.gov, [2]California Institute of Technology, Pasadena, CA 91125, [3]Western Washington University, Bellingham, WA 98225, [4]Imperial College, London UK.

Introduction: The radiation environment at the surface of Mars poses a significant challenge to survival for many chemical compounds over time, including potential chemical biosignatures.

Therefore, it is important to determine whether materials have been exposed to the environment recently or for a long time in order to evaluate the probability of alteration for putative biosignatures or other chemical indicators of habitable environments in the rock record.

Farley et al. have advocated that the best environments for which to search for organic materials in the rock record on Mars could be on rapidly retreating scarp faces where we can exploit the exposure due to Aeolian abrasion [1]. We have developed an instrument and an approach for the evaluation of both the exposure age [1] and the radiometric age, the latter based upon a double-spiked technique demonstrated by Farley et al. [2]: Isotope Dilution K-Ar Dating (IDKArD).

Approach and Instrumentation: The instrumentation for measuring the radiometric age of the materials includes a quadrupole mass spectrometer (2-250 AMU) a thermal ionization source, and a pyrolysis oven, that is capable of achieving 1200°C. The instrument surveys the geochemistry of a sample unknown by standard pyrolysis evolved gas analysis (EGA). A second sample split is then characterized with respect to its radiometric and exposure ages.

The IDKArD approach to dating makes use of a lithium borate flux and a terrestrial calibrant, artificially spiked in both ^{39}Ar and ^{41}K. The thermal ionization source allows for collection and release of ^{39}K from the sample unknown as well as ^{41}K from a spiked glass calibrant, as per the IDKArD method. The advantages of using this dating approach include no requirement for either measurement of sample mass or for high temperature to achieve complete Ar release from the sample.

Exposure Age: On Mars, exposure age is determined by concordant isotope measurements of cosmogenic ^{36}Ar, ^{21}Ne and ^{3}He. On Earth, however, these isotopes are mostly atmospheric and nucleogenic. So for Earth analog studies, we are measuring ^{10}Be.

Field Site: We are assessing the viability of a field site in Alberta Canada, Dinosaur Provincial Park (near 456920 N, 5622350 E), as a potential analog environment for studying the age and exposure time of rock strata. The park features a badlands area (Fig. 1) that is accessible, well exposed and has been well studied. It has also been radiometrically dated [3, 4].

The sedimentary deposits are bounded by bentonite beds and there are also coal seams, providing both organic and inorganic lithofacies, the latter of which are of known age.

Figure 1. Dinosaur Provincial Park badlands exposure

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MARTIAN ANALOGUE SAMPLES, THEIR SPECTROSCOPIC BIOSIGNATURES, AND DEGRADATION BY THE COSMIC RADIATION ENVIRONMENT

L. R. Dartnell[1]
[1] Centre for Astrophysics and Planetary Science, School of Physical Sciences, University of Kent, Canterbury, CT2 7NH, UK. lewis@lewisdartnell.com

Introduction: The success of an astrobiological search campaign on Mars, or other planetary bodies in the solar system, relies upon the reliable detection of evidence of past or present microbial life, or so-called biosignatures. While conclusive proof of life may depend on discovery of isotopic fractionation or enantiomer bias, these methods require sample preparation and consumable resources (such as solvent for extraction or sample wells in the instrument). Spectroscopic methods, on the other hand, require little or no sample preparation, can be repeated essentially endlessly, and may be performed in contact or even remotely. Such methods are therefore ideally suited for triaging for targets containing biosignatures, which can be confirmed by supporting instrumentation.

Here we discuss the use of Raman and FTIR (Fourier Transform Infra Red) spectroscopy, both vibrational spectroscopy methods that are complementary to each other, for the detection and characterisation of biosignatures of microbial life colonising a diverse sample set. This sample set includes both hypolithic and endolithic extremophile colonisation of rocks and minerals from martian analogue sites around the world, including the Mojave desert, the Atacama desert and the Antarctic Dry Valleys [1].

Results are presented on the Raman and FTIR spectroscopic characterization of these martian analogue samples, both in terms of the mineralogical context and the detectable biosignatures. Raman spectroscopy is sensitive to specific biological pigments including carotenoids, chlorophyll and scytonemin, and FTIR reveals the presence of more generic cellular organic molecules including fatty acids, polysaccharides and proteins.

A further key consideration in the detectability of past or present microbial life on Mars by lander probe instrumentation is the degree to which these characteristic biomolecules will have been degraded by the long-term bombardment of the martian surface (and penetrating into the subsurface) by the energetic particle radiation of the unshielded cosmic ray flux [2,3,4]. Exposure to this complex ionizing radiation field over geological time scales will not only sterilize microbial life [5] but also act to erase biosignatures detectable by spectroscoptic techniques [6,7].

Modelling results on this martian cosmic radiation field, and on-going experimentation on the effects on detectable biosignatures, will also be presented.

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SURVIVAL OF HALOPHILIC ARCHAEA IN THE STRATOSPHERE AS A MARS ANALOG: A TRANSCRIPTOMIC APPROACH.

S. DasSarma[1], P. DasSarma[1], V. Laye[1], J. Harvey[2], C. Reid[2], J. Shultz[2], A. Yarborough[2], A. Lamb[2], A. Koske-Phillips[2], A. Herbst[2], F. Molina[2], O. Grah[2] and T. Phillips[2], [1]Department of Microbiology and Immunology, Institute of Marine and Environmental Technology, University of Maryland School of Medicine, Baltimore, MD 21202 and [2]Earth to Sky Calculus and Spaceweather.com.

Introduction: Idenifying potentially habitable regions of Mars is of great signifcance. In this context, seasonal dark streaks or recurring slope lineae (RSL) recorded on the walls of Garni crater captured by NASA's Mars Reconnaissance Orbiter are of interest [1]. The occurrence of RSLs at subzero temperatures suggest salty brine flows seasonally on the Martian surface melted by freezing-point depression, which is also supported by spectroscopic evidence for hydrated sodium and magnesium chloride, chlorate, and perchlorate salts in the Phoenix lander site [2-4].

On Earth, brines are nearly ubiquitous and generally thalassic. They harbor a great variety of halophilic microorganisms originating from all three branches of life, Archaea, Bacteria, and Eukarya [5]. Halophilic Archaea are able to tolerate the highest salinity due to negatively charged proteins which remain soluble and compete successfully with ions for hydration [6]. Discovery of brine flows on the surface of Mars has intensified interest in the polyextremophilic character of halophilic Archaea in relation to astrobiology [7].

Halophilic Archaeal Models for Astrobiology: Among halophilic Archaea (Haloarchaea), *Halobacterium* sp. NRC-1 has been extensively studied for its polyextremophilic character [8]. This species is capable of tolerating multimolar concentrations of sodium and potassium chlorides, including perchlorates. NRC-1 is also slightly thermotolerant with optimum growth at 42 ºC and survival at 49-50 ºC [9] and is resistant to UV and ionizing radiation [10,11]. Genomic and transcriptomic studies have established a range of mechanisms operating in NRC-1, including highly acidic proteins, and direct photorepair, double-stranded gap repair, and nucleotide excision repair systems.

Halorubrum lacusprofundi is another Haloarchaeon relevant to astrobiology, which was isolated from Deep Lake in the Vestfold Hills of Antarctica [12]. Deep Lake is perennially cold, with the temperature remaining subzero for more than 6 months of the year. However, Deep Lake does not freeze, even when temperatures drop to -18 ºC due to freezing-point depression from high salinity. *H. lacusprofundi*, which is capable of growth down to -2 ºC, is well-adapted to this environment. *H. lacusprofundi* biofilms have been reported as a possible mechanism for enhanced survival at the lowest temperatures. The *H. lacusprofundi* genome has been sequenced, a DNA microarray developed, and its proteins analyzed for cold activity, reduced surface acidity, and enhanced internal flexibility [13,14].

Haloarchaeal Models in the Stratosphere: Earth's stratosphere exhibits multiple extremes, including cold temperatures, high radiation, and low pressures, similar to those found on the surface of Mars [15]. In order to determine whether *Halobacterium* sp. NRC-1 and *H. lacusprofundi* may survive such extreme conditions, we launched live cultures of the mesophilic model *Halobacterium* sp. NRC-1 and the cold-adapted Antarctic isolate *Halorubrum lacusprofundi* into Earth's stratosphere on helium balloons. After return to Earth, the cold-adapted species showed nearly complete survival while the mesophilic species exhibited only slightly reduced viability.

Parallel studies in the laboratory showed that the cold-adapted species was better able to survive due to superior tolerance to freezing and thawing. Finally, genome-wide transcriptomic analysis [6] was used to compare the two haloarchaea at optimum growth temperatures versus low temperatures supporting growth. The cold-adapted species displayed perturbation of a majority of genes by cold temperature exposure, divided evenly between up-regulated and down-regulated genes, while the mesophile exhibited perturbation of only a fifth of genes, with nearly two-thirds being down-regulated. These results point to the importance of a regulation of a large number of genes in the cold-response of *H. lacusprofundi* likely important for survival in the stratosphere.

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Development of an Extraterrestrial Organic Analyzer (EOA) for Highly Sensitive Organic Detection on a Kinetic Penetrator.

Z. Duca[1*], G. Tan[1], T. Cantrell[1], M. Van Enige[1], M. Dorn[1], M. Cato[1], S. Foreman[2], P. Putman[3], J. Kim[2], R. Mathies[4], and A. Stockton[1†]. [1]Georgia Institute of Technology, GA, USA, [2]Texas Tech University, TX, USA, [3]Sierra Lobo, OH, USA, [4]University of California, Berkeley, CA, USA ([*]zduca4@gatech.edu, [†]astockto@gatech.edu).

Introduction: Quantitative, compositional, and chiral analysis of small organic molecules *in situ* provides important information for studying planetary formation and evolution, and, more excitingly, also can provide signatures of past or present life. EOA, with microchip capillary electrophoresis (µCE) and laser-induced fluorescence (LIF) detection, is the only technique currently ready for space flight that has the resolution, selectivity, and sensitivity to provide these analyses. Through both in-lab [1,2] and field [3] testing, µCE-LIF has demonstrated the capability to provide highly sensitive (sub parts-per-trillion, or pptr) automated quantitative compositional chiral analysis of multiple organic compound classes [4], including polycyclic aromatic hydrocarbons (PAHs) [5], amino acids [6], aldehydes and ketones [7], carboxylic acids [8], thiols [9], and amines [10]. Lander or fly-by missions have largely been the focus for the development of µCE-LIF, as proposed in the Mars Organic Analyzer (MOA) and the Enceladus Organic Analyzer.

Here, we show the continued development of the microfluidic and LIF subsystems for a kinetic impactor mission. Preliminary results have shown promising sustainability of microdevices during a 50000g impact, indicating that µCE-LIF is a valid *in situ* technique for this extreme planetary mission format.

Instrument Development: Programmable microfluidic architechtures enable automated, complex microfluidic manipulation on-chip, including mixing, dilutions, fluorescent derivatization, and transfer [11]. Recently, we have shown that microdevices retain functionality of their pneumatically-actuated monolithic membrane microvalves after 10+ years in storage [12].

However, the survival of these microvalves during a high g impact is not proven. The pneumatic microvalves use a compressible fluid for actuation, which could be succeptible to bursting at sudden high pressures induced upon impact. Hydraulically-actuated microvalves that use incompressibile fluids to control valve acuation may not experience these issues. Early tests show that these hydraulic valves function properly and can replace the pneumatic valves for high impact or high pressure (e.g. deep ocean) missions.

The precision optics of LIF can be succeptable to high impact collisions and has never been developed for these high g conditions. Proper permanent alignment of components is essential for absolute sensitivity, and optical stack placement and material bonding properties must be optimized. Recent modeling data has shown that in order to reduce internal mechanical stress ideal placement of the optical components is directly in the center of the microdevice (Figure 1). By placing proper support underneath the structure, the mechanical strength of the microdevice is not exceeded. Indium bump bonding will be used in the optical stack to permenantly and precisely weld non-glass/glass connections. Glass/glass conections will be made using a Schott Glass bonding technique to create a continuous glass construction, avoiding any possible optical interferences.

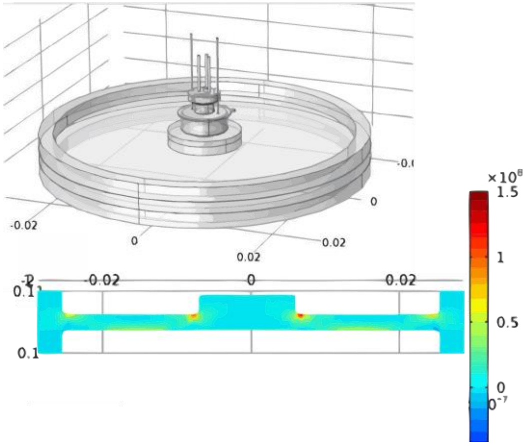

Figure 1: Structural (top) and stress (bottom) model of a centered optical stack without support structures.

Summary and Conclusions: This work shows the low-TRL development of EOA's LIF and microfluidic subsystems for future planetary impact penetrator missions. With correct structural decisions and optimizations, EOA can survive a 50,000g impact, making it the only current optical instrument with this capability.

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Mars Time and Martian Environments: Changing Habitability through Time and Prospects for Ancient Mars Biosignatures.

B. L. Ehlmann[1,2] [1]CDivision of Geological & Planetary Sciences, California Institute of Technology, Pasadena, CA 91125 (ehlmann@caltech.edu) for first author, [2]Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA 91109

Recent data permit refinement of relative Martian chronology (Fig. 1, after [1]). An important observation for habitability made by [1,2] is that while it is commonly assumed there was some period of time in Mars history when all conditions favorable to habitability "existed simultaneously (active magnetic field, valley formation, erosion and transport, aqueous alteration, etc.)….a variety of observations constraining the timing of these processes suggests that it may not be the most probable scenario" [2]. Rather, the magnetic field likely had significantly weakened well before the Hellas impact, which defines the base of the Noachian. Approximately 90% of the atmosphere of Mars was lost early, indicated by isotopic signatures of noble gases in Martian meteorites [e.g., 3]. In contrast, under the standard model for stellar evolution, the luminosity of the sun was greater later in history. The record of early Martian fluvial processes is most obviously preserved 3.5 Ga.

The presence of a magnetic field and thicker atmosphere would provide enhanced shielding from radiation. Yet, only three of the sites under consideration offer the potential of sampling rocks preserved from this time period, the enigmatic "deep phyllosilicates" in the lowermost strata at Nili Fossae, NE Syrtis, and Mawrth Vallis, which have been variously ascribed surface and subsurface origins. Landing sites with surface morphology preserving fluvial-deltaic systems occurred much later in time: Jezero (mid- to late-Noachian), Holden and Eberswalde (early-Hesperian), and Melas basin (late-Hesperian). The terrestrial fossil record begins around 3.5 Ga. The first fossils are found entombed in chemically precipitated sediments, indicated by macro- and micro-morphology, isotopic signatures, and sub-mm scale chemistry and mineralogy [4]. Indeed, though modern terrestrial fluvial systems concentrate organic matter for preservation: "Regions dominated by siliciclastic sedimentation are typically not prime localities in the search for Archean fossil life due to a very low level of in situ mineral formation and a generally poor preservation potential for biomass" [1]. Rather, silica, carbonate, and other minerals that entomb biochemistry over geologic time are favored for the preservation of Earth life, circa 3.5 Ga. We have little insight on mechanisms preserving earlier life, though look to the Archean record and modern chemolithotrophic biosphere for clues. The most crucial processes in Mars planetary evolution were (1) magnetic field evolution, (2) the rate and timing of atmospheric loss, (3) the timing and effects of the late heavy bombardment (if such a "spike" in fact occurred), and (4) the climate of the surface during the bulk of aqueous mineral formation. These all drive selection of a landing site that permits interrogation of Mars' earliest epochs.

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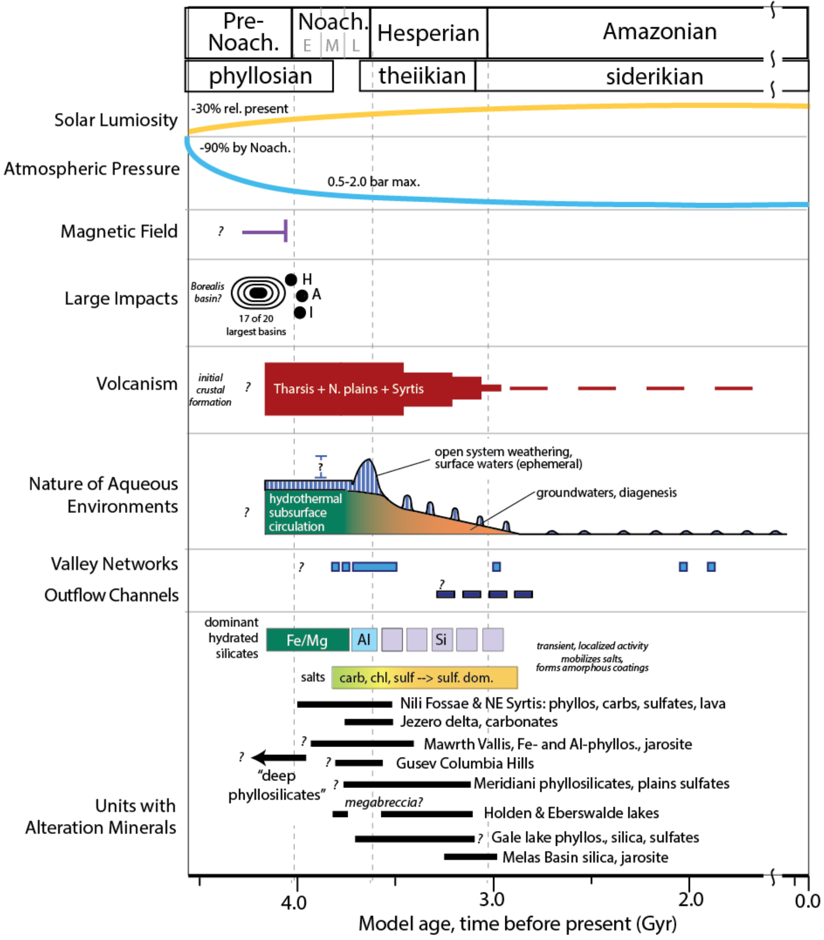
Figure 1. Revised timeline of Mars history [1] including key processes in planetary evolution and the age of rocks available for interrogation at each landing site.



IN SITU OBSERVATIONS OF REFRACTORY ORGANIC MATTER IN LACUSTRINE MUDSTONES OF GALE CRATER AND THEIR IMPLICATIONS FOR THE SEARCH FOR ORGANIC BIOSIGNATURES.

J. L. Eigenbrode[1], A. Steele[2], R. E. Summons[3], A. C. McAdam[1], B. Sutter[4], H. B. Franz[1,5], C. Freissinet[1,5], M. Millan[6], D. Glavin[1], D. W. Ming[7], R. Navarro-González[8], A. Pavlov[1], J. A. Hurowitz[9], J. Grotzinger[10], P. G. Conrad[1], P. R. Mahaffy[1], [1]Solar System Exploration Division, NASA Goddard Space Flight Center, Greenbelt, MD 20771, USA (Jennifer.L.Eigenbrode@nasa.gov), [2]Geophysical Laboratory, Carnegie Institution of Washington, Washington, DC 20015, USA, [3]Department of Earth, Atmospheric and Planetary Sciences, Massachusetts Institute of Technology, Cambridge, MA 02139, USA, [4]Jacobs, NASA Johnson Space Center, Houston, TX 77058, USA, [5]Center for Research and Exploration in Space Science & Technology, University of Maryland Baltimore County, Baltimore, MD 21250, USA, [6]Laboratoire Atmosphères, Milieux, Observations Spatiales, Univ. Pierre et Marie Curie, Univ. Versailles Saint-Quentin & Centre National de la Recherche Scientifique, Paris, France, [7]Astromaterials Research and Exploration Science Division, NASA Johnson Space Center, Houston, TX 77058, USA, [8]Instituto de Ciencias Nucleares, Universidad Nacional Autónoma de México Circuito Exterior, Ciudad Universitaria, P.O. Box 70-543, 04510 México D.F., México, [9]Department of Geosciences, State University of New York, Stony Brook, NY 11794, USA. [10]Division of Geological and Planetary Sciences, California Institute of Technology, Pasadena, CA, 91125.

Lacustrine sediments have long been hailed as a favorable environment for organic matter deposition and preservation on Mars, as they are on Earth [1]. Evidence of refractory organic matter has been discovered in the ancient lacustrine sediments of Gale Crater by the Sample Analysis at Mars (SAM) instrument suite onboard the Curiosity rover [2-3]. A diversity of organic molecules is observed after pyrolysis of drilled mudstone. Detection of this refractory organic matter in >3 Ga rocks that have been exposed to surface radiation, provides encouragement that potential remains of past life on Mars may be preserved and detectable. In this presentation, we will present SAM results juxtaposed with experimental radiation results from the laboratory [4] and discuss implications for the future search for organic biosignatures on Mars.

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SPRING MOUNDS IN EASTERN TUNISIA AS ANALOGS TO OPEN PINGOS IN ARGYRE.

Alberto G. Fairén[1,2], Esther R. Uceda[3], Elhoucine Essefi[4], J. Alexis P. Rodríguez[5], [1]Centro de Astrobiología (CSIC-INTA), 28850 Madrid, Spain (agfairen@cab.inta-csic.es); [2]Department of Astronomy, Cornell University, Ithaca, NY 14853, USA; [3]Universidad Autónoma de Madrid, 28049 Madrid, Spain; [4]Higher Institute of Applied Sciences and Technology, University of Gabes, Gabes, Tunisia; [5]Planetary Science Institute, Tucson, AZ 85719, USA.
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Pingos on Argyre: Possible ice-cored mounds, including candidate open-system pingos (OSPs), have been identified in Argyre [1]. We have shown that, on the basis of the available photo-geology, the OSPs within the Argyre basin are very recent features, dating from the Late Amazonian, and possibly still having some kind of activity. We proposed a combination of hydraulic, tectonic, and hydro-tectonic models of formation and functioning of the OSPs, involving freeze-thaw cycling [2]. The OSPs within the floor of Argyre basin could bear exceptional astrobiological interest, because the heat gradients produced hydrothermal activity resulting in upwelling processes: this upwelling of deep-seated water rich in volatiles and organic material would act as exhumation pockets into ancient environments, and therefore the groundwater associated with OSPs formation could be capable of delivering evidence of past/current microbial activity in the subsurface to the surface or near-surface, making fossilized or extant life more available to reconnaissance by in situ missions. In addition, mantling and sedimentation by eolian drifts or icy periods would have formed protecting layers, reducing the rates of sublimation and therefore providing a secluded environment for existing life or its remains. In summary, OSPs could be host to past (and maybe present) heat fluxes, ice, liquid water, and nutrients.

Biosignatures and habitats in mounds: Spring mounds on Earth and Mars would represent optimal niches for life development. At the MCSH system in Eastern Tunisia [3], depressions contain briny (salts content ~300 g/L) and slightly acid (pH=5.8) water, while springs mounds inject relatively fresh water (salts content 7.25 g/L) with neutral pH (6.8). On early Mars, both aqueous systems could have been appropriate for life. First, cold brines with similar salt concentrations to that measured at the MCSH depressions have been proposed to have existed on a “cold and wet” Early Mars [4], potentially adequate for biological development. Second, fresher water associated with springs might have not been as briny or acidic as water in terrestrial evaporating pools [5], and this may have provided a long-term habitable environment on a “warm and wet” early Mars [6]. Therefore, if life ever developed on Mars, ancient spring deposits would be excellent localities in which to search for morphological or chemical remnants of that life [5], with proper drilling into the accumulated materials [7]. These favorable conditions for life, which are exceptionally shown at the surface through spring mounds, may have been more frequent in the Martian subsurface, indicating that geodynamic and hydraulic conditions within the Martian subsurface could have been favorable for biological development.

Conclusions: OSP-like mounds within Argyre basin have an exceptional astrobiological interest. We have proposed that OSP-like mounds form and function following a combined hydraulic, tectonic and hydro-tectonic model [2], similar to the mounds in Eastern Tunisia [3], making them the best candidates for life development and protection on Mars. On the one hand, their formation through the upwelling of water, volatiles, and organic-rich material provides with the necessary elements for life development; and this upwelling also resulted in a significant hydrothermal activity, enhancing life development by providing energy (heat). On the other hand, the protecting layers, formed due to the wet eolian sedimentation or icy periods, provide with a safe cover shielding life or its remains. We propose that the MCSH system in Eastern Tunisia is an exceptional terrestrial analog which continuing analysis will help to make informed decisions regarding where to search for biosignatures on Mars.

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Abundance, distribution and cycling of organic carbon and nitrogen in University Valley (McMurdo Dry Valleys of Antarctica) permafrost soils with differing ground thermal and moisture conditions: analogue to C-N cycle on Mars.

B. Faucher and D. Lacelle, University of Ottawa (bfauc073@uottawa.ca; dlacelle@uottawa.ca); A. Davila, SETI; W. Pollard, McGill University; C.P. McKay, NASA Ames.

Introduction: One of the key ingredients for life as we know it is the presence of water and nutrients. On Mars, there are now two direct observations of ice-rich permafrost: 1) at high latitudes at the Phoenix lander site and 2) at mid latitudes in Amazonis Plantia (near the boundary of Utopia and Arcadia). Ice-rich permafrost at mid and high latitudes on Mars is considered the place of more recent habitability [1][2]. However, orbital changes over the past 20 Myr may have warmed the surface of the regolith [3][4], and because of the low elevation, and hence higher atmospheric pressure, liquid water would have been stable at these locations (e.g. [5], [1], [2]). Evidence of life in ice-rich martian permafrost could be found in the form of molecular biomarkers. Currently, the preservation potential of molecular biomarkers in extremely cold ice-bearing permafrost is unknown. On Earth, the permafrost in the high elevation McMurdo Dry Valleys of Antarctica ranks amongst the coldest and oldest; as such, it represents a valuable terrestrial analogue to inform about ground ice conditions and abundance, distribution and cycling of key nutrtients: organic carbon and nitrogen.

Previous studies on the carbon and nitrogen cycling in the permafrost of the MDV have mainly been undertaken in the low elevation valleys. The aim of our research is to characterize organic carbon and nitrogen content and isotopes in University Valley, one of the upper elevation valleys in the MDV, and to assess effects of liquid water in soils as a limiting factor.

Study area: University Valley is a northwest facing valley (1600-1800m a.s.l., 1.5 km long and 500 wide) situated in the stable upland zone of the MDV. The mean annual air temperature and relative humidity in University Valley is –24.3°C and 48%water, respectively, and the summer air temperature are always below the freezing point [6]. The origin of ground ice in University Valley was attributed to ground surface temperature and moisture conditions that separate the valley into two distinct zones: 1) a perennially cryotic zone (PCZ) in the north-east section of the valley that is characterized by ground surface temperatures always below 0ºC and that lacks geomorphic features associated with aqueous processes; and 2) a seasonally non-cryotic zone (NCZ) characterized by ground surface temperatures that rise above 0°C for at least a few hours on clear summer days and that contains geomorphic features associated with aqueous processes, such as frozen ponds and runoff deposits [6]. Based on δD-$\delta^{18}O$ analyses, the ground ice in the PCZ was attributed a vapour-diffusion origin; whereas the ground ice in the NCZ formed by the freezing of liquid water [7, 8].

Methods: In this study, we measured the organic carbon and nitrogen content, ^{13}Corg and ^{15}N and dissolved organic carbon (DOC) in 17 ice-bearing permafrost cores collected in the polygonal terrain in University Valley: 8 from the PCZ and 9 from NCZ. All measurements were made at the G.G. Hatch Laboratory (University of Ottawa).

Preliminary results: Concentrations of total organic carbon and nitrogen in the 17 ice-bearing permafrost cores is low throughout; although average concentrations from the PCZ (C: 0.93 mg g^{-1} soils, N :0.32 mg g^{-1} soils) is lower than those from the NCZ (C: 1.8 mg g^{-1} soils, N: 0.4 mg g^{-1} soils). Results from one core with differing ground ice origin (vapour-deposited in the upper section and freezing of liquid water in the bottom section) revealed that DOC was < 4 mg L^{-1} in the upper part, but reached values > 8 mg L^{-1}) in the bottom section. This points to distinct abundance of organic carbon and nitrogen following availability of liquid water (or lack thereof). Upcoming results (i.e. $\delta^{13}C$ and $\delta^{15}N$) and additional organic carbon, nitrogen and DOC will shed further light on the nature of carbon and nitrogen cyling in such extreme environments, especially in the PCZ where little evidence of life was detected [9].

Ultimately, this research will help us to further improve our scientific knowledge on the roles that the origin of ground ice and the concentrations of organic carbon and nitrogen have on the habitability of cryotic soils. In the long run, this study will potentialy be a contribution to the refining of sampling techniques and instrumentation for the upcoming 2018 Mars Icebreaker mission.

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PRESERVATION OF ORGANIC MOLECULES AT MARS' NEAR-SURFACE.

C. Freissinet[1,2] D. P. Glavin[1], A. Buch[3], C. Szopa[4], P. D. Archer Jr[5], W. B. Brinckerhoff[1], A. E. Brunner[1], J. L. Eigenbrode[1], H. B. Franz[1], S. Kashyap[7], C. A. Malespin[1], M. Millan[4], K. E. Miller[8], R. Navarro-González[9], B. D. Prats[1], R. E. Summons[8], S. Teinturier[1], P. R. Mahaffy[1]
[1]NASA Goddard Space Flight Center, Greenbelt, MD caroline.freissinet@nasa.gov, [2]CRESST, Baltimore MD, [3]Ecole Centrale Paris, Chatenay-Malabry, France, [4]LATMOS, Guyancourt, France, [5]Jacobs, NASA Johnson Space Center, Houston, [6]University of Massachusetts Amherst, Amherst MA 01003, [7]Massachusetts Institute of Technology, Cambridge, MA.

Introduction: One of the biggest concerns for the *in situ* detection of organics on extraterrestrial environment is the preservation potential of the molecules at the surface and subsurface given the harsh radiation conditions and oxidants they are exposed to. The Mars Science Laboratory (MSL) search for hydrocarbons is designed to understand taphonomic windows of organic preservation in the Mars' near-surface. The Sample Analysis at Mars (SAM) instrument on the MSL Curiosity rover discovered chlorohydrocarbon indigenous to a mudstone drilled sample, Cumberland (CB) [1]. The discovery of chlorohydrocarbons in the martian surface means that reduced material with covalent bonds has survived despite the severe degrading conditions.

Results and Discussion: The precursors of the chlorohydrocarbons detected by pyrolysis at CB remain unknown. Organic compounds in this ancient sedimentary rock on Mars could include polycyclic aromatic hydrocarbons and refractory organic material, either formed on Mars from igneous, hydrothermal, atmospheric, or biological processes [2] or, alternatively, delivered directly to Mars via meteorites, comets, or interplanetary dust particles [3]. It has been postulated that organic compounds in near-surface rocks may undergo successive oxidation reactions that eventually form metastable benzenecarboxylates, including phthalic and mellitic acids [4]. These benzenecarboxylates are good candidates as the precursors of the chlorohydrocarbons detected in SAM pyrolysis at CB. Indeed, recently, SAM performed a derivatization experiments on a CB sample, using the residual vapor of N-methyl-N-*tert*butylsilyltrifluoroacetamide (MTBSTFA) leaking into the system. The preliminary interpretations are compatible with the presence of benzocarboxylates, coincidently with long chain carboxylic acids and alcohols. The analysis of this interesting data set to identify these derivatization products, as well as future SAM measurements on Mt Sharp, should shed additional light on the chemical nature and the origin of the organic matter in near-surface materials in Gale Crater.

The future Mars Organic Molecule Organizer (MOMA) instrument onboard ExoMars 2018 should improve the detection of organic molecules in Mars subsurface in two ways. Firstly, by drilling a sample down to 2 meters, it will access more preserved area against deleterious radiations. Secondly, MOMA derivatization using dimethylformamide dimethylacetal (DMF-DMA) as a reagent is designed to assess the potential enantiomeric excess of complex chiral molecules of interest, such as amino acids, sugars or carboxylic acids, to aid at the determination of their biotic or abiotic origin.

Gale crater had recently been defined as an ancient habitable environment, due to the simultaneous presence of liquid water, energy source and a mild range of temperature, pH, pressure and salinity. The presence of organic molecules opens up habitability to another level, where the building blocks of life were available for more complex system to evolve. This view into ancient Mars begins to provide a context for habitable environments and is a first step toward understanding the presence and diversity of possible prebiotic or biotic molecular signatures. Moreover, it helps mapping out potential windows of preservation for chemically reduced organic compounds, which will help on sample and site selection on all bodies of the solar system for future missions, including MSL2020.

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MINERALIZATION AND POTENTIAL FOR FOSSILIZATION OF AN EXTREMOTOLERANT BACTERIUM ISOLATED FROM A PAST MARS ANALOG ENVIRONMENT.

Frédéric Gaboyer[1], Maria Bohmeier[2], Frédéric Foucher[1], Claude Le Milbeau[3], Pascale Gautret[3], Annie Richard[4], Audrey Sauldubois[4], Régis Guégan[3], Frances Westall[1] and the MASE team
[1]Centre de Biophysique Moléculaire, CNRS, Orléans, France, [2]Astrobiology group, DLR, Cologne, Germany, [3]Institut des Sciences de la Terre d'Orléans, Orléans, France, [4]Centre de Microscopie Electronique, Université d'Orléans, Orléans, France.

Introduction: Several decades dedicated to the study of Mars has enabled scientists to highlight that during its history, environmental conditions of Mars strongly contrasted with the present-day conditions, hostile for life.

Indeed, previous (Mars Express, Viking…) and more recent (MSL) missions confirmed that liquid water, heat (volcanism, hydrothermalism) organic matter and redox conditions probably occurred on the planet, thus enabling scientists to seriously consider early Mars as being habitable and suitable for the emergence of life [1].

However, the detection of past life on Mars, if it existed, also requires that biomarkers (i) be preserved over geological time scales and that (ii) they remained detectable.

Therefore, in the run for Mars analogues on Earth, astrobiologists are still addressing questions related to microbial adaptation, lifestyles and survival in extraterrestrial environments [2].

In this context, the European MASE project (Mars Analogues for Space Exploration) aims at better understanding habitability, microbial lifestyles and biomarker preservation in such environmental analogues. To do this, one of the goals of MASE is to better characterize the evolution and preservation of diverse biomarkers during the microbial fossilization process [3].

Methods and objectives : A poly-extremotolerant *Yersinia* strain isolated from a cold-acidic-oligotrophic lake in Iceland was artificially mineralized in SiO_2 and $CaSO_4$ to evaluate its potential for further fossilization over geological times. Morphological, biogeochemical, and physical aspects of the process were studied using GC-MS, SEM, TEM, FT-IR or RAMAN spectroscopy.

We also evaluated the impact of microbial stress induced by Mars-like conditions by studying mineralization of cells after exposing the model to both dessication and radiation stresses.

Results : We show that only a part of the cell culture was rapidly embedded in minerals even after 6 months of mineralization, and thus *Yersinia* populations remain largely viable after that time.

Considering our methodology, no difference could be observed with and without stress, suggesting that physiological responses to these stresses do not alter the in the mineralization process.

Geochemical data obtained with Rock-eval also confirmed that the fossilization potential of this strain over geological times is quite limited.

To conclude, astrobiologists should be kept in mind that, in the microbial world, not all groups are prone to fossilization, even those inhabiting past Mars analog environments. Nevertheless, the question of microbial remains preservation in anaerobic fine-grained sediments is distinct and also remains possible for this *Yersinia* strain.

References: Use the brief numbered style common in many abstracts, e.g., [1], [2], etc. References should then appear in numerical order in the reference list, and should use the following abbreviated style:

[1] Westall, F., Foucher, F., Bost, N., Bertrand, M., Loizeau, D., Vago, J.L., Kminek, G., Gaboyer, F., Campbell, K.A., Bréhéret, J.-G., et al. (2015) *Astrobiology*., *15*, 998–1029. [2] Cockell, C.S., Bush, T., Bryce, C., Direito, S., Fox-Powell, M., Harrison, J.P., Lammer, H., Landenmark, H., Martin-Torres, J., Nicholson, N., et al. (2016) *Astrobiology.*, 16, 89–117. [3] http://mase.esf.org/

Biomarkers Detection In Mars Analogue Sites Within Mase Project

L. Garcia-Descalzo[1] and. F. Gomez[2], and the MASE team: C.S. Cockell (UK), P. Schwendner (UK); P. Rettberg, K. Beblo-Vranesevic, M. Bohmeier, E. Rabbow, F. Westall, F. Gaboyer, N. Walter (F); M. Moissl-Eichinger, A. Perras (A); R. Amils, (ES); P. Ehrenfreund, E. Monaghan (NL); V. Marteinsson, P. Vannier (IS) [1,2]Extremophiles Laboratory. Center for Astrobiology (INTA-CSIC) Ctra. Ajalvir Km4. 28850 Torrejon de Ardoz. Madrid. Spain. [1]garciadl@cab.inta-csic.es. [2]gomezfg@cab.inta-csic.es.

Introduction: Life is a physico-chemical process by which tell-tale signals or traces are left on the environment. These signals are indicators of life and are known as biomarkers.

Besides, the traces of some kinds of microorganisms can be well preserved, provided that they are rapidly mineralized and that the sediments in which they occur are rapidly cemented [1].

The search for these traces of life is one of the main objectives of Mars exploration [1] and to improve and optimize the search and detection of them forms part of MASE project targets.

In MASE project (Mars Analogues for Space Exploration) we work to improve approaches and methods for biomarker detection in samples with low biomass from Mars analogue sites.

A developed antibody multiarray competitive immunoassay (MACIA) for the simultaneous detection of compounds of a wide range of molecular sizes or whole spores and cells [2] [3] has revealed as suitable option to achieve this purpose.

Methods and objectives: Samples from the three MASE campaigns in Iceland (Graenvatun Lake), United Kingdom (Boulby Mines) and Germany (Regensburg) was used in microarray immunoassays to determine the presence of biomarkers.

Within the MASE project some isolates have been achieved from these sample sites and some of them have been induced to mineralization/fossilization process.

Some of our objectives are the improvement of the biosignatures detection in these Mar´s analogous sites and to study its preservation in samples and fossilized isolates by the assessment of antigen-antibody binding.

Results: Signals of the presence of some microorganisms groups specially psycrophiles, iron and sulfur oxidizers (Iceland and Boulby), perchlorate reducers (Regensburg), cyanobacter group and others alike to those which frequently appear in rock and sedimentary environments have detected in MASE samples using microarrays in sandwich immunoassay.

Upcoming results will allow us to check the changes in biomarkers detection at different points along the mineralization/fossilization process. Which means that we will be able to evaluate the loss or preservation of signals in this process and to correlate it with our results from DTIVA technique (automated tools for microbial life detection).

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MARTIAN BIOSIGNATURES: TANTALIZING EVIDENCE WITHIN MARTIAN METEORITES.

Everett.K.Gibson[1], K.L. Thomas-Keprta[2], S.J. Clemett[2] and D.S. McKay[3], Astromaterials Research Office, XI3,NASA Johnson Space Center Houston, TX 77058 [everett.k.gibson@nasa.gov], [2]JETS at NASA/JSC, Mail Code JE23, Houston, TX 77058, [3]Deceased.

The Astrobiology Roadmap [1] notes that for evidence of life within a terrestrial or extraterrestrial sample selected biosignatures must be present within the sample. It must also be recognized that these biosignatures must have a spatial relationship within the sample. Catagories of biosignatures may include: cellular and extracellular morphologies, biogenic fabrics in rocks, bio-organic molecular structures, chirality, biogenic minerals, biogenic stable isotope patterns in minerals and organic compounds, and atmospheric gases [1,9]

Greater than 70 meteorites have been recognized as Martian in origin. These Martian samples offer an opportunity to study the history of Mars and any biogenic processes that have occurred on the red planet because they essentially span the age of the planet from 0.165 to 4.1Ga. However, only four or five of these 70+ Martian meteorites are suitable for study because they display the least amount of terrestrial contamination. Recognition [2,3,4,] that the Martian meteorites EETA 79001, Nakhla and Y000593 [5] contained indigenous organic matter from Mars showed the presence of reduced C on Mars, something the Viking 1 and 2's GC-MS instruments failed to detect in the 1970s [6].

The 1996 announcement by McKay et al. [7] that ALH84001 may contain features which could be interpreted as having a biogenic origin generated considerable excitement and criticism along with establishing the Astrobiology Program within NASA. The discovery that the >4.1+ Ga old Martian meteorite contained 3.9 Ga old carbonate globules formed at temperatures between 25°-30°C offered the first opportunity to study carbonates formed from subsurface fluids that had been present on early Mars. The carbonates contained magnetites of unusual morphologies, sizes and compositions [8] associated with reduced carbon components previously shown to be indigenous to Mars [3,6]. Further studies revealed these magnetites could not have been formed by either thermal decomposition or shock processes operating on iron-bearing carbonates [8]. The ALH84001 meteorite, formed in the first 600 million years on Mars when the planet had a magnetic field, and the subsequent recognition that the younger Nakhla and Yamato 000593 samples (~1.3 Ga formation ages showing aqueous alteration processes 500 to 700 million years after formation) along with the Shergotty meteorite (formation age of 165 ma) offer unique opportunities to examine the evolution of Mars' hydrosphere, atmosphere and possible biosphere over time. Despite the 20 years of intense study on ALH84001 by the world's scientific community, the original scientific evidence presented by McKay et al. [7] has not been refuted and still stands today. The biosignature criticism is on the interpretation of the data.

In 2001, Gibson et al. [10] reviewed the requirements for acceptance of life on the Earth and noted eight criteria are required. For geological samples to be accepted as possible representative of early life on the earth, a majority of the following criteria must be known: The geologic context of the sample, the age and history of the sample, any cellular morphologies present within the sample, associated biofilms and microbial colonies present within the sample, the sample contain representative biominerals or evidence of chemical disequilibria, the isotopic signatures of the biogenic elements are compatible with biogenic activity, there are significant organic biomarkers or components present in the sample, and finally, the features are indigenous to the sample.

For ALH84001, we know the sample is from Mars [10]. Specifically the oxygen isotopic composition of the silicates is identical to other meteorites known to be from Mars along with trapped samples of the Martian atmosphere. The crystallization age of the ALH84001 silicates is 4.09 Ga. The carbonates were formed at 3.9 Ga and represents a period during the Noachian epoch on Mars during which both the oldest extant Martian surfaces were formed, and perhaps the earliest global ocean existed. During this period of Martian history, the early Mars magnetic field was still present. Within the ALH84001 carbonates, Nakhla and Y000593 biomorphs with segmented structures are present [5,10].

The presence of indigenous organic or reduced carbon, of which PAHs (polycyclic aromatic hydrocarbons) are a subset, is spatially associated with the ALH84001 carbonate globules. Isotopic signatures of this reduced carbon are well within the ranges accepted for biogenic fractionation on Earth. Observations of rare biofilms-like morphologies within ALH84001 carbonate globules, as well as within aqueously altered zones in other Martian meteorites such as the Nakhla, Shergotty and Yamato 000593 are additional evidence [4,5, 10]. The reduced carbon phases have been shown to be associated with the secondary alteration phases (i.e. iddingsite clays) within the samples. After careful examination of the biomorphs in these meteorites, we conclude that they are indigenous features within the ALH84001, Nakhla, and Yamato 000593 Martian meteorites [5,10] and have been associated with the Martian groundwaters..

When comparing the criteria required for recognition of life in a geological sample with features observed in selected Martian meteorites, a majority of the criteria are met. Still since these samples are extraterrestrial (i.e. Martian), caution must be taken to positively identify signatures of life in these samples and the possibility of contamination cannot be ruled out.

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MICROBIAL SIGNATURES IN SULFATE-RICH PLAYAS.

M. Glamoclija[1], A. Steele[2], V. Starke[2], M. Zeidan[1], S. Potochniak[1] K. Sirisena[1,2] and I. H. Widanagamage[1], [1]Rutgers University-Newark, 101 Warren St, Newark, NJ 07102 (email: m.glamoclija@rutgers.edu), [2]Carnegie Institution of Washington, 5251 Broad Branch Rd, Washington, DC 20015.

Introduction: Martian surface-exposed sequences of sulfate-rich sedimentary formations are particularly interesting as they emphasize the importance of surface and near-surface aqueous processes during the planet's history. Playa/playa lake systems have received particular attention as the presence of Noachian/early Hesperian sulfate-rich deposits have been identified by the Mars Exploration Rover Opportunity at Meridiani Planum [1, 2] and by Mars Reconnaissance Orbiter (MRO) in sedimentary sequences within Gale crater [3, 4]. We are investigating playa systems from the White Sands National Monument (WSNM) in New Mexico as an excellent model system to study sulfate-rich evaporitic sequences that could help better understanding environmental parameters of playas, their potential for preservation of organics and exploration of biosignatures and habitability parameters that may be relevant for inferred playa deposits on Mars

Alkali Flat Settings: The White Sands' Alkali Flat includes sedimentary sequences that include a system of modern playas, which are a transient environmetns that include fresh to saline and hypersaline aqeous to dry desert settings. We have sampled shallow depth profiles (1.5 m) along the transect over the largest among modern playas (Lake Lucero) and transects with depth profiles along few drier playa locatins.

Results and Discussion: In our previous field campaigns near surface sediments from dune field had shown the presence of biofilm, and at some of the locations the surface had vesicular crust over green biofilm. However, this field sampling revealed no obvious presence of microbes within the sediments. The main characteristic of each sampling site was that top samples had very dry surface and the bottom samples are usually sampled at the groundwater table or near it. In this way the sampled profile includes samples from groundwater table (or capillary fringe) to the surface, which is the most geochemically active zone in this desert environment.

The surface samples of the playas are mainly composed of gypsum ($CaSO_4x2H_2O$) and mirabilite ($Na_2(SO_4)x10H_2O$) or thenardite ($Na_2(SO_4)$), some quartz (SiO_2) and halite (NaCl). Below the surface only gypsum and occasional halite were detected using powder X-Ray Diffractometer analysis.

Scanning Electron Microscope with Energy Dispersive X-Ray Spectroscopy (SEM-EDS) revealed only occasional presence of biological morphologies. Most of morphologies were found within the deposits of erosional escarpment and in the bottommost samples of the depth profiles.

The EDS analyses revealed high diversity of mineral precipitates within all of the samples. Interestingly, all of the samples (except surface samples) contained celestine. We have found in our previous study of surface dune field samples [5] that celestine was found only within thick biofilm at paleodunes site, which misled us to believe it was a potentially important as a mineral precipitated in microbial presence. However, now it is clear that celestine is present in all of the wet/moist samples and as they dry it gets blown away from the playa surface. We have found a diversity of magnesium precipitates through out the samples (Ca-Mg carbonates, hexahydrite ($MgCl_2xH2O$) or magnesium chlorite, epsomite ($MgSO_4x7H_2O$) etc.) which indicates that groundwater is likely Mg-rich. The high halite and mirabilite and lesser glauberite and epsomite presence points out the high-salinity content that microbes living here have to be able to overcome. The samples have further shown presence of clays, calcium carbonates, occasional presence of phosphor and potassium and carbon compound within salt precipitates.

Undergoing ion and nutrient analyses will help us understand major geochemical processes within upper meter of Alkali Flat playa deposits and reveal compounds that that may be indicative of microbial presence. The envirionmental data will be correlated with microbial metagenome data to obtain more realistic interpretation of potential chemical biosignatures.

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ATACAMA ROVER ASTROBIOLOGY DRILLING STUDIES: ROVING TO FIND SUBSURFACE PRESERVED BIOMARKERS.

B. Glass[1], A. Davila[1], V. Parro[2], R. Quinn[1], P. Willis[3], W. Brinckherhoff[4], J. DiRuggiero[5], M. Williams[1,6], D. Bergman[1], C. Stoker[1]. [1]NASA Ames Research Center, Moffett Field, CA 94305, USA, Email: brian.glass@nasa.gov, [2]Centro de Astrobiologia, 28850 Torrejón de Ardoz, Spain, [3]Jet Propulsion Laboratory, Pasadena, CA 91109, USA, [4]Goddard Space Flight Center, Greenbelt, MD 20771, USA, [5]Johns Hopkins University, Baltimore, MD 21218, USA, [6]Georgia Institute Of Technology, Atlanta, GA 30332, USA.

Introduction: The Atacama Desert in Chile is one of the most important Mars analog environments on Earth due to its extreme aridity. Geological and soil mineralogical evidence suggest that extreme arid conditions have persisted for at least 10–15 million years [1], but the sedimentary record indicates the region has been arid since late Triassic [2], making it the oldest continuously arid desert on Earth.

Approach: Mobile exploration of the subsurface is essential in achieving future astrobiology goals. Discovery of extant preserved biomarkers and perhaps past or extant life on Mars is unlikely without the ability to access the subsurface. Lightspeed delays for Mars missions (tens of minutes) are much longer than the time required (seconds) to get a drill stuck, so deep space rover drilling operations must be automated and fail-safe, or else risk anchoring the rover. Obtaining subsurface samples of regolith will require the ability to identify a suitable location, transport and emplace a drilling apparatus, and control the operation with high reliability.

Project: The Atacama Rover Astrobiology Drilling Studies (ARADS) project is a NASA Planetary Science And Technology Through Analog Research (PSTAR) project which in 2015-2019 will incrementally build up to a Mars rover analog mission as a field test of an integrated rover-drill system with prototype instruments (Fig. 1) that are themselves flight mission candidates or have flown (WCL). The fourth in a series of 1m-class autonomous rotary-percussive drills by Honeybee Robotics and NASA Ames, and a new autonomous mid-sized rover concept (K-REX) developed by NASA-Ames, will be integrated with four fielded in-situ instruments: the Spanish Signs of Life Detector (SOLID) [3] immunoassay instrument; the JPL Microfluidic Life Analyzer (MILA) [4] capable of extracting amino and fatty acids; a Wet Chemistry Laboratory (WCL) brassboard [5] and the GSFC Laser Desorption Mass Spectrometer (LDMS), a simplified version of the Mars Organic Molecule Analyzer (MOMA) [6] under development for the ExoMars rover mission.

The essential elements to ARADS are: 1) use of an integrated drill and rover at sites in the Atacama Desert in Chile in unprepared "regolith" (such as Fig. 2); 2) field use of in-situ instruments with the rover/drill that are flight prototypes comparable to those planned for ExoMars and Icebreaker; 3) acquire drilled cuttings and transfer to instruments; 4) on-board autonomy and monitoring to support drilling; mission and demonstrate science support (operations and control) for the rover/drill/instrument operations.

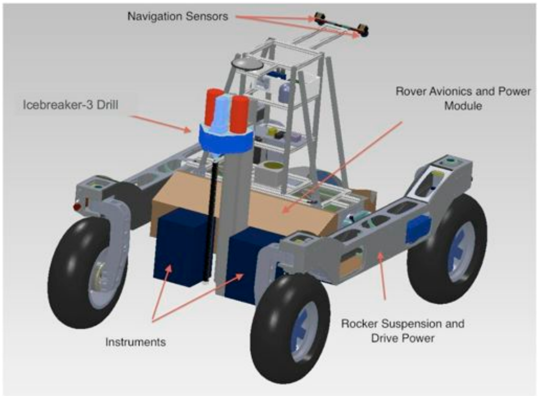

Fig. 1: ARADS integrated drill/rover.

The scientific objective of the proposed research is to understand the mobility and distribution of soluble salts, organic compounds, organic biomarkers, and life in extremely dry soils in the Atacama, as an analog system to Mars, down to the 1-2m depths proposed for exploration with ExoMars or Icebreaker/Red Dragon.

Fig. 2. Field science ground truth sampling from a pit at Yungay Station (ARADS site).

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SENSING BIOSIGNATURES WITHIN ROCKS OF THE ATACAMA DESERT - AN ANALOG FOR MARS ENVIRONMENTS.

T. J. Gnanaprakasa[1,2], K. Domanik[1], J. DiRuggiero[3], T. J. Zega[1,2 *]. [1]Lunar and Planetary Laboratory, The University of Arizona, Tucson, AZ 85721, United States [2]Department of Materials Science and Engineering, The University of Arizona, Tucson, AZ 85721, United States [3]Department of Biology, Johns Hopkins University, Baltimore, MD 21218, United States. (*tzega@lpl.arizona.edu)

Introduction: With the potential for a Mars sample return mission and the task of analyzing mineralogical samples for traces of biologic activity, it is essential to improve our knowledge of terrestrial analogs. Particulary important is how to distinguish biologically induced structure and organization patterns from inorganic phenomena. Biosignatures are the remnants of organisms, their macromolecules, and evidence of their metabolic activities. They are morphological, chemical, structural, and isotopic traces of organisms preserved in minerals, sediments, and rocks [1].

We have been investigating potential biosignatures and mineral microstructure alteration of rocks from the Atacama Desert in Chile. These materials represent Martian analogs and are known to contain colonizing bacteria [2]. Understanding the microstructural and crystal-chemical effects of bacterial colonization of these rocks could provide a useful reference for similar investigation of Martian rocks.

Samples and Analytical Methods: Two mineral substrates – ignimbrite and gypsum – from the Atacama Desert were analyzed for bacterial colonization. The samples were embedded in an epoxy resin and polished smooth to reveal regions of bacterial colonization in the pores within the minerals. Optical analysis was performed on a Leica DMI6000 multifunctional motorized inverted microscope, which can capture 5 megapixel color brightfield images through a Leica DCF450 camera. The microscope had fluorescent filter cubes for dyes such as DAPI (excitation wavelength: 320-400 nm), FITC/GFP (excitation wavelength: 440-520 nm), Rhodamine (excitation wavelength: 535-557 nm), and CY5 (excitation wavelength: 560-680 nm). The samples were analyzed across a range of excitation wavelengths to investigate the wavelength range at which we obtain autofluorescence. The images were captured and analyzed using the proprietary Leica LAS-AF software.

Microorganisms can induce natural fluorescence, most commonly called autofluorescence; which is the intirinsic fluorescence of bacterial cells without added dyes, and has been shown as a powerful tool for the detection of bacteria in environmental or industrial microbiology [3]. We adopt this phenomena to detect the presence of endolithic microbial organisms within the minerals.

To compliment our research work, the ignimbrite and gypsum samples were analyzed using an Electron Microprobe (Cameca SX-50). The X-ray maps showed the presence of Si, Mg, Ca, Fe, Na, Al, K, Ti, P, and S. Changes in microstructure between the colonized and non-colonized regions was also investigated using a FEI Helios Nanolab 660 focused-ion-beam scanning electron microscope (FIB-SEM), equipped with an EDAX energy-dispersive spectrometer (EDS).

Results and Discussion: Fluorescence microscopy analysis revealed the presence of endolithic bacteria within the pores of the mineral. The colonization was clearly visible when the CY5 filter with an excitation wavelength of 560 – 680 nm (short IR region) was used. Electron Microprobe analysis and data from X-ray mapping reveal the presence of Si, Mg, Ca, Fe, Na, Al, K, Ti, P, and S within the mineral deposits, with Ca and S deposits along the region where there was colonization. Scanning electron micrographs (SEM) clearly show morphological differences between the colonized and non-colonized regions. Here, the colonized regions showed a vesicular structure with 'cocci-like' particles. These particles were found to be bacterial colonization after correlation of the SEM micrographs with fluorescence microscopy images. Non-colonized regions show a smooth surface morphology. Continued investigation will reveal whether these signatures are unique to these samples or more broadly applicable to rocks from hyperarid regions.

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LIFE DETECTION SYSTEM DTIVA FOR MONITORING PARAMETERS IN FOSSILIZATION PROCESS

F. Gomez[1], L. Garcia-Descalzo[1] and. and the MASE team: C.S. Cockell (UK), P. Schwendner (UK); P. Rettberg, K. Beblo-Vranesevic, M. Bohmeier, E. Rabbow· F. Westall, F. Gaboyer, N. Walter (F); M. Moissl-Eichinger, A. Perras (A); R. Amils, (ES); M. Malki (ES); P. Ehrenfreund, E. Monaghan (NL); V. Marteinsson, P. Vannier (IS) [1]Extremophiles Laboratory. Center for Astrobiology (INTA-CSIC) Ctra. Ajalvir Km4. 28850 Torrejon de Ardoz. Madrid. Spain. gomezfg@cab.inta-csic.es.

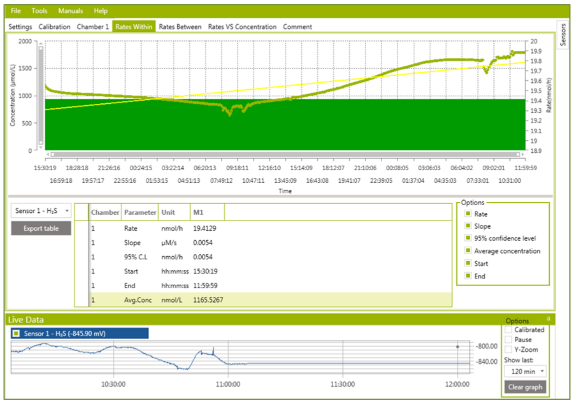
Introduction: The Life Detection System (DTIVA) is designed as a two modules system for microbial life detection under growing conditions. The microbes growth is followed by redox, pH and conductivity parameters but others parameters can be monitored as well if needed.

The experiments presented in this paper follow the physicochemical parameter in a growth culture under fossilization/mineralization-induced process with the objectives of biomarkers detection. The study of biomarkers detection [1] and fossilization process is crucial from an astrobiological point of view for the search for life on Mars as it has been reported that life can survive on Mars surface conditions under protected microniches [2]. At the same time, and using DTIVA system, we can follow the modification of some parameters on the media that could drive the process.

Methods and objectives: MASE (Mars Analogues for Space Exploration) is an European Commission funded project which selected three Earth analogues to be studied: Iceland (Graenvatun Lake), United Kingdom (Boulby Mines) and Germany (Regensburg). Samples from the three selected sites were study for microbial biodiversity study using different techniques including DTIVA system for growth monitoring but microarray immunoassays [3,4] to determine the presence of biomarkers as well. At the same time, isolates from those sites were used for induction of fossilization/mineralization process, which are being followed by DTIVA system as well.

Desulfovibrio sp. and *Yersinia sp.* isolates from MASE sites induced for a process of fossilization/mineralization with carbonates have been monitoring by continuous measurement of different parameters. Those parameters include changes in redox potencial (ORP), changes in pH as well as in concentration of H_2S. The signal is recorded by a pH/mV.meter and picoammperimetre, in each case.

Results: First results from our experiments with the two MASE isolates named suggest this technique as a promising method to follow evolution/changes of pH, redox potential (ORP) and reduction of sulfur as well along the fossilization/mineralization process in cultures. As an example of some of these experiments, the following plot shows a continuous measurement of H_2S concentration in an anaerobic culture of *Desulfovibrio sp.* along 45 hours. The behavior of the culture from the H_2S concentration point of view shows a cycle since the same types of changes occurs after twelve hours and 24 hours after these events. It was observed two similar events separate in time by 24 hours.



Chamber	Parameter	Unit	M1
1	Rate	nmol/h	19.4129
1	Slope	µM/s	0.0054
1	95% C.L	nmol/h	0.0054
1	Start	hh:mm:ss	15:30:19
1	End	hh:mm:ss	11:59:59
1	Avg.Conc	nmol/L	1165.5267

Options
- ☑ Rate
- ☑ Slope
- ☑ 95% confidence level
- ☑ Average concentration
- ☑ Start
- ☑ End

Options
- ☐ Calibrated
- ☐ Pause
- ☐ Y-Zoom

Show last: 120 min

Fig. 1 Monitorization of a growing Desulfovibrio sp. culture for H_2S production. pH changed during the growth from 7 to 5.9 after several days.

Acknowledgement: MASE is supported by European Community's Seventh Framework Programme (FP7/2007-2013) under Grant Agreement n° 607297.

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AUSTRALIAN ACID BRINE LAKE AS A MARS ANALOG: AN ANALYSIS OF PRESERVED LIPIDS IN SHORE AND LAKE SEDIMENTS.

H.V. Graham[1], J.C. Stern[1], A.M. Baldridge[2], and B.J. Thomsen[3]; [1]NASA Goddard Space Flight Center (8800 Greenbelt Rd., Greenbelt, MD 20771; heather.v.graham@nasa.gov), [2]Saint Mary's College of California (1928 St. Mary's Rd., Moraga, CA 94575), [3]Boston University (725 Commonwealth Ave., Boston MA 02215).

Introduction: The ephemeral, saline, acidic lakes on the Yilgarn Craton of Western Australia have been suggested as geochemical analogues to Martian paleoterrains that are characterized by the interbedding of large deposits of phyllosilicates and hydrated sulfates [1]. These areas indicate shifting environmental conditions, from the circumneutral wet to alkaline wet conditions that began in the Hesperian. The habitability of such a dynamic environment can be informed by investigating biomes of the Yilgarn Lake system. Previous work has found phospholipid fatty acids (PLFAs) evidence of microbial communities in sections of fresh sediment cores taken from Lake Gilmore [2]. These communities include both Gram-positive and –negative bacteria, Actinomycentes, and communities of up to 50% bacterial methanotrophs in certain strata. Given recurring detections of methane at the Martian surface, evidence of a methane cycling community in an analogous terrestrial environment is of particular interest [3]. This study attempts to confirm the presence of such a community and assess the preservation of microbial biosignatures in dried core sediments more similar to contemporary Mars.

Carbon Isotope Profile: In this study we quantify and analyze the carbon isotope composition ($\delta^{13}C$) of bulk organic material, as well as the extracted lipids from the Lake Gilmore sediment cores at both near-shore and mid-lake locations. These analyses reveal very low (<1% by weight) accumulations of organic carbon, concentrated primarily in a gypsum-rich near-shore core. The near-shore sediments showed a down-core decrease in the abundance of organic carbon as well as depletion in the carbon isotope composition with depth. The $\delta^{13}C$ of bulk carbon (-21‰ to -16‰) did not exhibit the highly depleted, diagnostic $\delta^{13}C$ signature (-85‰ to -30‰) often associated with methanotrophic biomass in any of the strata analyzed [4].

Analysis of Preserved Lipids: Preserved lipids were extracted from sediments by solvent sonication as well as modified Bligh-Dyer methods. Some long-chain fatty acids were identified but the majority of lipids extracted from the sediments were pristane, phytane, and *n*-alkanes - all molecules associated with terrestrial plants. The abundance of terrestrial plant material in the sediments could be responsible for the enriched carbon isotope signature of bulk organic carbon [5]. While the *n*-alkanes were not necessarily the chain length distribution associated with C4 grasses the enriched isotopic signature would indicate provenance of a C4 signal. Very little of the free lipids were particular to bacteria (hopanoids *e.g.*) and markers particular to archaea (the domain responsible for methanogenesis) such as glycerol dialkkyl glycerol tetraethers (GDGTs) and archaeol were not found [6].

While these lipid results do not show evidence of a methane producing community compound specific isotope analysis of carbon in extracted methanotroph PFLAs could still confirm the presence of a methane cycling metabolism at depth. The excess of terrestrial detritus may overprint any isotopic contribution of methanotroph-derived carbon preserved in these sediments, given the very low amounts of microbial biomass found in lake cores. These results could indicate either that methane cycling communities are not present in these sediments or that the lipid amounts are so minor as to not be detectable by these methods. This could indicate either that the communities are very small or that these lipids do not preserve well in these acid, saline sediments, even on the decadal timescales represented by this study.

Mineralogy and Preservation: X-ray diffraction analyses of strata in both core sections confirm that the best molecular preservation can be found in sediments with higher amounts of gypsum. These results can help guide further investigations by indicating preferable molecular preservation conditions. Further, the assemblage of minerals in the cores suggest oxic conditionsrather than anaerobic conditions which would not favor methanogens. This would does not rule out a methane cycling community but might indicate that mineral precipitation did not coincide with growth.

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ANCIENT LACUSTRINE MUDSTONES AND ASSOCIATED FLUVIO-DELTAIC STRATA AT GALE CRATER: MARTIAN SEDIMENTARY CONTEXTS IN THE SEARCH FOR ANCIENT BIOSIGNATURES.

S. Gupta[1], J.P. Grotzinger[2], D.Y. Sumner[3], D.M. Rubin[4], S.G. Banham[1], K. M. Stack[5], J.A. Watkins[2], N. Stein[2], K.S. Edgett[6], J. Hurowitz[7], K.X. Lewis[8], R.A. Yingst[9], M. E. Minitti[9], J. Schieber[10], A.R. Vasavada[5]

[1]Imperial College, London,UK (s.gupta@imperial.ac.uk), [2]Division of Geological and Planetary Sciences, California Institute of Technology, Pasadena, CA, [3]UC Davis Earth and Planetary Sciences, CA, [4]University of California, Santa Cruz, CA, [5]JPL, Pasadena, CA, [6]Malin Space Science Systems, San Diego, CA, [7]Stony Brook University, Stony Brook, NY, [8] Johns Hopkins University, Baltimore, MD, [9]Planetary Science Institute, Tucson AZ, [10]Indiana Univ., Bloomington, IN.

Introduction: Ancient lacustrine deposits are considered to be one of the prime targets in the search for biosignatures on Mars because lake environments provide a likely favorable setting for formation and preservation of such signatures. One of the major discoveries of the Mars Science Laboratory mission has been that of a thick succession of mudstone deposits in strata exposed at the base of Aeolis Mons (Mt. Sharp) [1]. These mudstones have been interpreted as ancient lake deposits. Here, we characterize their sedimentology and consider the implications of their physical and chemical characteristics in the search for ancient biosignatures on Mars.

Lacustrine deposits in Gale crater: The mudstones of the Murray formation, which were originally identified at the Pahrump Hills field site in Gale crater, are characterized by abundant fine-scale parallel laminations. The ~13 m thick section at Pahrump Hills is dominated by such laminated deposits which are interpreted to be suspension fall-out sediments in an ancient lake system in Gale crater. Towards the top of the Pahrump Hills section interbedded cross-stratified sandstones are considered to record fluvio-deltaic incursions into the lake. Since leaving Pahrump Hills, the *Curiosity* rover has climbed up stratigraphic section through the Murray formation, with an ~40 m thickness of Murray formation (predominantly mudstones) recorded between Pahrump Hills and the Bagnold dunes field site. This succession of mudstones is characterized by pervasive development of fine-scale lamination throughout the succession, although significant diagenetic features such as nodules are also present.

The Gale example provides a significant sedimentary context for future exploration for biosignatures on Mars in deltaic-lacustrine systems. In this presentation, we will present detailed results of sedimentological observations that permit reconstruction of ancient lake systems and the later effects of diagenesis, and discuss the implications of these in the search for biosignatures.

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INTERACTIONS OF SNOW ALGAE, MICROORGANISMS AND MINERALS IN SNOWY MARS-ANALOG ENVIRONMENTS PROVIDE POTENTIAL ELEMENTAL AND MINERALOGICAL BIOSIGNATURES

E.M. Hausrath[1], Z. Harrold[1], A.E. Murray, O. Tschauner[1], A.H. Garcia[1], C.L. Bartlett[1] and J. Raymond[3], [1]Department of Geoscience, UNLV, 4505 S. Maryland Parkway, Las Vegas, NV 89154-4010 Elisabeth.Hausrath@unlv.edu, [2]Desert Research Institute 2215 Raggio Parkway Reno, NV 89512, [3]University of Nevada, Las Vegas, School of Life Sciences, 4505 S. Maryland Pkwy., Las Vegas, NV 89154

Introduction: Biological activity such as the release of organic acids can form important biosignatures used to interpret paleoenvironments on Earth. These biosignatures include changes in elemental composition and mineralogy, which can persist for long time periods allowing future detection. In laboratory experiments, for example, direct microbial extraction of elements from minerals has been documented [1] which can form elemental biosignatures. Organic acids secreted by organisms or produced by cell lysis can also result in elemental signatures [2], and Fe and P are examples of such elemental biosignatures observed in terrestrial paleosols [3]. Analyses of serpentinite- and diabase-derived soils also indicate that organic acid production by Fe-oxidizing bacteria at the rock: soil interface may generate elemental biosignatures [4, 5].

Differences in solution chemistry, mineral composition and temperature on Earth and Mars can impact the interpretation of such elemental and mineralogical biosignatures. Early Mars received more abundant organic carbon from meteorites and interplanetary dust particles than did early Earth [6]. These organic compounds can impact elemental mobility [7], which, together with differences in dissolution of phosphate minerals [8], can affect the interpretation of potential P biosignatures. Mars also has much less available water than Earth, resulting in high salinity brines, which can slow dissolution [9-12] and precipitate salts such as anhydrite [10]. Much of the water present on Mars today also occurs in polar ice caps. Potential elemental and mineral changes occurring due to biota-mineral interactions in such cold environments are therefore needed to understand potential biosignatures on Mars.

Investigating biosignature formation in snowy Mars-analog environments:

In order to investigate potential biosignatures formed under Mars-relevant cold, water- and nutrient-limited conditions, we are examining interactions between snow algae, microorganisms and minerals in both field environments and laboratory experiments. Snow, dust, snow algae and microorganisms were sampled from our field area on Mount Anderson Ridge, CA. Samples were density separated to isolate snow algae and particles strongly attached to the snow algae surfaces from bulk dust present in the snow. Synchrotron microXRF of algae-attached particles indicate that they are Fe-rich and may therefore be an important micronutrient source. Laboratory experiments growing the xenic snow algae culture *C. brevispina* with Fe-rich minerals show close association between the minerals and the snow algae (Figure 1) and enhanced growth of cultures in the presence of the minerals. Importantly, secondary Fe precipitates were also observed by synchrotron microXRD in minerals in the presence of snow algae cultures that were not present in minerals in abiotic controls, indicating the potential for Fe-rich mineral biosignatures. Ongoing and future work includes experiments, analyses, and field work to better understand potential elemental and mineral biosignatures, their presence in terrestrial field environments, and their potential detection on Mars.

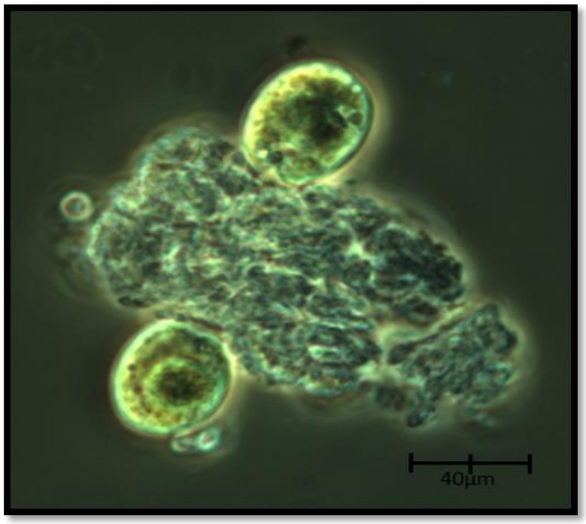

Figure 1. *Optical image of C. brevispina and the Fe-rich mineral nontronite showing close association of the snow algae with the mineral surfaces.*

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2015 NASA ASTROBIOLOGY STRATEGY DOCUMENT AND THE EXPLORATION OF MARS.

L.E. Hays[1], Michael H. New[2], and M.A. Voytek[2]. [1]Jet Propulsion Laboratory-Caltech, [2]NASA Headquarters.

Introduction: In 2015 the NASA Astrobiology Program released the Strategic Plan [1] to outline the goals of the research program for the next decade. The grass roots process of creating this document took over a year, involved almost 200 scientists from various aspects of the field of Astrobiology, and created an inclusive document that is 257 pages long. This document was designed to be as all-encompasing as the field of Astrobiology itself – so that any scientist who explores a field with broad astrobiological relevance can see their work reflected within the Strategy. Importantly, the structure of the document was not centered around targets (Mars, Europa, exoplanets, etc.), but instead focused on seven major topics of research in the field today. This means that research that addresses the field of Mars Exploration can be found in multiple places within the Strategy, which we will highlight here.

Major Topics: The seven major topics covered in the Astrobiology Strategy are below:

1. Identifying Abiotic Sources Of Organic Compounds

2. Synthesis And Function Of Macromolecules In The Origin Of Life

3, Early Life And Increasing Complexity

4. Co-Evolution Of Life And The Physical Environment

5. Identifying, Exploring, And Characterizing Environments For Habitability And Biosignatures

6. Constructing Habitable Worlds

7. Challenges And Opportunities In Astrobiology

Within these topics, research focusing on Mars exploration is most strongly focused in topics #1 and #5, but also came up throughout the other chapters.

Within topic #5, the Exploration of Mars fell primarily under two of the four highlighted areas of research. The first "How can we enhance the utility of biosignatures to search for life in the solar system and beyond?" addresses not only the six forms of terrestrial biosignatures highlighted in the Mars 2020 Science Definition Team report [2], but also additional biosignatures such as "technosignatures" that might be more relevant to exoplanet research. Many of the key research questions within this highlighted area of research are those that have relevance to this conference on Biosignature Preservation – such as "how are habitability and biosignatures interrelated?" and "what are the fundamental characteristics of life (even as we do not know it) that may translate into biosignatures?"

The second highlighted area of research within topic #5 addresses the question: "How can we identify habitable environments and search for life within the solar system?" This section focuses primarily on Earth Analog Environments, Mars and Icy Worlds. The first two sections contain key research questions that are relevant to the goals of this conference – such as "what are the potentials for preserving the signatures of life in extreme environments?" and "what major processes on Mars work to either degrade or preserve signatures of habitability and life?"

Summary: This paper will focus on highlighting the areas of overlap between the goals of this conference and the suggested key research directions highlighted in the Astrobiology Strategy. The goals of Mars exploration and those of astrobiological investigation can both be enhanced by careful consideration of where missions to Mars such as Mars 2020 are landed.

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CARBONACEOUS MICROSTRUCTURES OF THE 3.46 GA STRATIFORM 'APEX CHERT', PILBARA, WESTERN AUSTRALIA: PRESENTING A NEW SUITE OF EARLY ARCHAEAN MICROBIALLY INDUCED SEDIMENTARY STRUCTURES.

K. Hickman-Lewis[1,2], R.J. Garwood[3], M.D. Brasier[1]†, T. Goral[4], H. Jiang[5], N. McLoughlin[6], D. Wacey[7,8]. [1]Dept. Earth Sciences, Oxford, UK, [2]*Present Address*: CNRS-CBM, Orléans, France (keyron.hickman-lewis@cnrs-orleans.fr), [3]Univ. Manchester, UK, [4]Natural History Museum, London, UK, [5]Univ. Oxford, UK, [6]Univ. Bergen, Norway, [7]Univ. Bristol, UK, [8]Univ. Western Australia, Perth, Australia.

Introduction: Black chert veins of hydrothermal genesis, intruding the 3.46 Ga Apex Basalt, contain some of Earth's oldest putative microfossils[1], whose biogenicity has been extensively questioned[2-3]. Comparatively little is known about the stratiform sedimentary cherts (the stratiform 'Apex chert') that are conformably interbedded with volcanic rocks of the Apex Basalt at Chinaman Creek.

Within this stratiform chert, we assign five lithological designations: silicified volcaniclastics, banded black-grey-white chert, metalliferous chert, clotted carbonaceous chert and microgranular chert. Carbonaceous material occurs mostly within the latter two lithologies, and is present in lobate grains throughout. Microgranular chert contains a suite of four carbonaceous microstructures possessing probable microbially induced sedimentary structures (MISS): i) laminated clasts and ii) roll-ups (both Fig. 1a), iii) flaky grains, iv) persistent, undulose, filament-like laminae (Fig 1d).

Methods: We used optical petrography and confocal laser scanning microscopy (CLSM) for morphology coupled with SEM, laser Raman microspectroscopy and NanoSIMS for geochemistry to assess the biogenicity against accepted criteria[4-5].

Biosignatures: Laminated clasts comprise multiple, non-isopachous, wrinkled laminae, with noted thickening towards some ridge crests[6], as determined by CLSM (Fig. 1c). Raman spectroscopy demonstrates the antiquity of the carbon, and, coupled with NanoSIMS, proves a close correlation between carbon, nitrogen, and often sulphur, in dark brown-black bands (Fig. 1b). The roll-up structures either occurring as part of, or independent to, these laminated clasts indicate an initial plasticity of the structures, possibly reflecting binding by extracellular polymeric substance (EPS).

Persistent, undulose, filament-like laminae are similarly non-isopachous and are seen to entrain relict sediment grains, similar to biofilm-type MISS cf. [7]. Flaky grains bear some morphological resemblance to ripped up fragments of microbial mats, though an abiogenic, purely sedimentary formation mechanism[8] could not be disproved by our study.

Edifices without architects: Morphologies and chemical compositions observed within this suite of structures are consistent with, and encouraging of, a biological interpretation, suggesting that microscopic MISS were present in the microgranular Apex chert. However, since neither macroscopic MISS nor *bona fide* microfossils have yet been recorded at this site, and since high-temperature hydrothermal activity was proximal throughout deposition, we urge a note of caution. Nonetheless, there may yet be evidence of life in the 'Apex chert', and the microgranular members of similar stratiform cherts could prove promising targets for future biosignature research.

Martian relevance: The suitability of the stratiform Apex chert in light of the search for biosignatures on Mars lies in its similarity to current Mars analogue rocks with sedimentary protoliths, particularly the Kitty's Gap chert [9]. Both of these units reflect a shallow marine, anaerobic depositional environment, with a significant volcaniclastic input which may be important to primitive life. It is also proximal to hydrothermal effusion, which is proposed as a nutrient source for chemotrophic life, the relavent metabolism for Mars, in the Josefsdal Chert, South Africa[10].

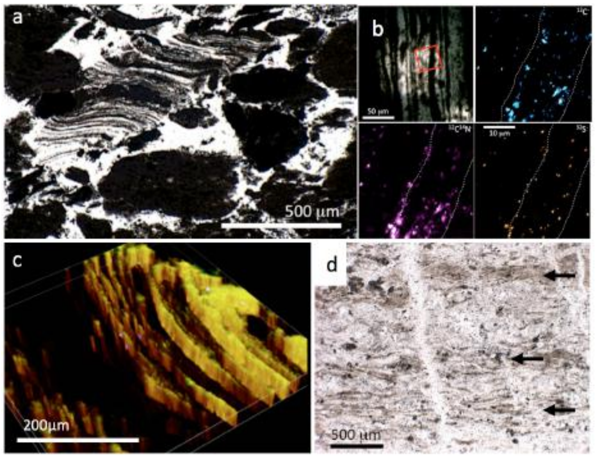

Fig 1. Candidate biosignatures of types i), ii) and iii).

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DIAGENETIC CHANGES IN COMMON HOT SPRING MICROFACIES.

N. W. Hinman[1], T. A. Kendall[2], L. M. MacKenzie[3], and S. L. Cady[4], [1]Department of Geosciences, University of Montana, Missoula, Montana, 59812; treavor.kendall@gmail.com; lindsay.mackenzie1105@gmail.com, [3]Department of Geosciences, University of Montana, Missoula, Montana, 59812; sherrycady@gmail.com, Environmental and Molecular Science Laboratory, Pacific Northwest National Laboratory, Richland, WA 99354.

Introduction: Evidence of biogenicity can be preserved in sinter deposits because of high mineralization rates. Rapid entombment of microbial structures is well documented in modern day systems [1-8]. However, the porous, friable nature of these sinter deposits makes them susceptible to mechanical weathering. Significant diagenesis, including secondary mineralization, replacement, and pore filling, must occur for these rocks to persist in the geologic record. Work on lithification of siliceous sinters has focused on the initial generation of biogenic and abiogenic fabrics [3, 8-12]. It is, however, a more resistant chalcedonic/quartz-style permineralization that characterizes ancient fossil examples of spring deposits [13-17]. Modern sinter samples were collected from two outcrops in Yellowstone National Park, WY, USA to assess early diagenetic processes in thermal spring deposits, with an emphasis on the pathway by which microbial evidence is preserved.

The Excelsior Geyser Crater (EGC, Midway Geyser Basin) section comprised 2.2 m of siliceous sinter. The Potts Cliff section (PB, Potts Hot Spring Basin) comprised 1.1 m siliceous sinters deposited on hydrothermally altered, silica-cemented, lacustrine sand and gravel. Two microfacies, sinter breccia and sinter with palisade fabric, were identified at each site. Images of thin sections were used to determine porosity and estimate permeability of these and mixed microfacies.

EGC: Porosity and permeability of EGC samples were not depth dependent ($p=0.523$; $p=0.888$ respectively). However, trends emerged between texture and porosity ($p=0.002$) at Excelsior; palisade fabrics have significantly lower porosities than sinter breccias ($p=0.004$) and sinter breccias with palisade subtextures ($p=0.022$). Similar trends are identified in permeability values where palisade permeabilities are significantly lower than permeabilities in breccias with palisade fabric ($p =0.003$).

PB: Site-wide porosities and permeabilities were lower but more variable at Potts' Basin compared to Excelsior ($p=0.000$, $p=0.002$). Similar to EGC, there appears to be a textural control on the two parameters. Upon establishing a general, significant relationship between texture and porosity (p-value=0.000), multiple comparison procedures indicated the sinter breccias with palisade subtexture have lower porosity and permeability than palisade sinters ($p=0.000$, $p=0.005$) and than sinter breccias, although no significant difference was detected between the porosities of the palisade and the sinter breccias.

The porous nature of the breccias led to an initial sequence that was more permeable and less resistant in outcrop. Conversely, sinters with palisade fabric were initially more resistant but less porous than the breccias. The EGC sequence represented these initial conditions with palisade layers protruding from the outcrop and the more saturated breccia layers receding into the crater wall. As early diagenesis proceeded, variations in the hydraulic properties of each microfacies appeared to control consolidation. Although the palisade fabric possessed a greater initial structural coherence, the increased flow through the more transmissive breccias led to advanced consolidation such that the breccias surpassed the palisade sinters as the more resistant layer. The result was a PB-type deposit, which presumably represented a later stage in the same diagenetic sequence. Here the breccia layers were massive, had undergone marked textural degradation and increased pore filling, and appeared more resistant than the palisade layers. The textural degradation and clast dissolution that also resulted from the increased flow may explain the lack of brecciated textures in ancient spring deposits in spite of their ubiquity in modern systems.

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STRATEGIES FOR SEARCHING FOR BIOSIGNATURES IN ANCIENT MARTIAN SUB-AERIAL SURFACE ENVIRONMENTS.

B. Horgan, Purdue University (briony@purdue.edu).

Introduction: Sub-aerial surface environments are often cited as poor locations for biosignature preservation [1]. However, hypothesized sub-aerial environments on Mars present a unique astrobiological opportunity to search for possible biosignatures and to evaluate the chemical and physical environment in which the microbial community lived.

Ancient pedogenic environments on Earth: Pedogenesis on land to form soils was an important nutriet source for early marine microbial communities, and also provided a potential sub-aerial habitat on the early Earth. Indeed, organic carbon has been identified in Archean soils on Earth, and is used as evidence of early colonization of land by microbes [2,3].

We are currently testing the hypothesis that the key characteristics that affect organic preservation in a soil are (1) high clay content and (2) the degree of leaching that the soil experienced during formation. High clay content prevents later diagenesis of soils upon burial – for example, in the John Day Fossil Beds, Oregon, paleosols containing 30-40 wt. % smectite clays were altered to celadonite during burial to several hundred meters, while paleosols the same sequence containing 80-95 wt. % clay were not significantly altered upon burial [4,5]. Thus, if organic carbon is present in a soil prior to burial, then a high clay content can help preserve those organics over the long term.

However, the main challenge for organic carbon preservation in soils is concentration and preservation in the soil environment. Most well-drained soils are leached, highly oxidizing and gradually stripped by surface runoff. Together these processes work to break down and physically remove organic matter from the system over time. However, soils forming in poorly drained environments like wetlands rapidly become reducing instead of oxidizing, and do not undergo significant leaching. These soils can thus become local sinks for organics and, depending on the organic input, potentially produce large organic concentrations. With high organic input on Earth, these environments produce coal precursors like lignites and tonsteins [6]. Much lower organic input can still be preserved in reducing soils. For example, organic carbon is present in the Archean Denison paleosol at abundances of 0.014-0.25%. The organics are concentrated in the upper 2 meters of the soil profile, and are attributed to near-surface microbial communities [2]. Thus, reduced and clay-rich paleosols on Mars could be sites of high organic preservation potential.

Possible pedogenic environments on Mars: The most widespread evidence for pedogenic processes on Mars is the presence of leaching profiles across the Noachian southern highlands [7]. However, because these profiles are hypothesized to have been produced by extensive long-term leaching, these sites are not good targets for biosignature preservation. Among the proposed Mars 2020 sites, the clays in the Columbia Hills within Gusev Crater are an example of this type of pedogenic feature [8].

In contrast, the Mawrth Vallis clay sequence in Arabia Terra is ~200 m of layered deposits with some of the strongest clay spectral signatures on Mars [9]. The context and mineralogy of Mawrth is primarily consistent with a paleosol sequence, most likely formed under a semi-arid climate [10]. The uppermost units at Mawrth exhibit evidence for redox and pH gradients formed during variably stagnant water conditions [10]. Similar redox gradients potentially formed in reducing surface environments may also be preserved within the mound in Gale Crater [11], providing a near-term opportunity to invesetigate these paleoenvironments at the rover scale. These sites provide not only a clear energy source for microbes (Fe/S oxidation/reduction pathways), they also provides a mechanism for preservation of organics and other biosignatures in reducing (perhaps wetlands-like) surface environments [11].

Astrobiological targets in pedogenic environments: The most promising target for *in situ* organics and biosignature detection in sub-aerial surface paleoenvironments on Mars are areas exhibiting mineralogies and chemistries indicating soil formation under reducing conditions. But pedogenic environments preserve more than just soils – they are records of diverse surface environments that often include rivers, lakes, ponds, etc. [4]. These smaller scale environments thus provide another astrobiological target within the larger pedogenic environment. While these landscape features can be difficult to identify from orbit due to their small stratigraphic exposure, they should be clear to rover insturments at the outcrop scale.

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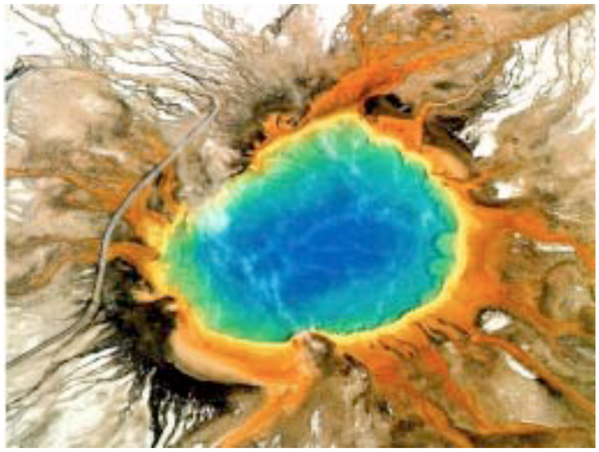
Organic Biomarker Preservation in Silica-Rich Hydrothermal Systems with Implications to Mars.

L.L. Jahnke[1], M.N. Parenteau[1,2] and J.D. Farmer[3], [1]NASA Ames Research Center, M/S 239-4, Moffett Field CA 94035 (linda.l.jahnke@nasa.gov), [2] SETI Institute, 189 Berardo Ave, Mountain View CA 94043, [3]School of Earth and Space Exploration, Arizona State University, Tempe AZ 85287.

The microbial community structure and preservation of organic matter in siliceous hydrothermal environments is a critical issue in astrobiology, given the discovery of potentially hydrothermal vents and silica on Mars. We have studied several silica-depositing hydrothermal ecosystems in Yellowstone National Park to characterize the extent of lipid biomarker biosynthesis within these microbial communities and its potential for preservation. The degradation/alteration products of organic biomarkers representative of microorganisms similar to those in Yellowstone are preserved within the sedimentary record of early Earth. The lipid carbon skeletons associated with hydrothermal microorganisms derive from membrane lipids. These hydrophobic molecules can be considered broadly characteristic of all aqueous-based life, extending potentially to an early wet Mars. By identifying phylogenetic diversity and establishing lipid biosignatures for extant microbial ecosystems, the diagenetic overprint associated with various depositional environments may be assessed and provide support for biological interpretation of organic matter preserved in ancient rocks on Earth and, perhaps also, on Mars.

Here we are interested in the microbial communities supported by the outflows of Clepsydra Geyser and Grand Prismatic Spring within the silica-depositing Lower and Midway Geyser Basins. A range of thermal outflow waters supports vast areas of diverse cyanobacterial primary productivity.



Grand Prismatic Spring: *Synechococcus* dominate production of smooth-mat in the higher temperature regions of outflow while below 55°C Oscillatoria-type '*Phormidium*' mats display a variety of morphological structure (e.g. streamers, tuffs). In the coolest distal margins of vent outflows, *Calothrix* form sheet-flow biofilm mats. Primary production supports highly diverse secondary community structure, which transforms organic input and lead to a 'secondary-alteration' biosignature.

Results: The *Phormidium* and *Calothrix* mats analyzed throughout this region are rich in cyanobacterial lipid biomarkers. Hopanoids are present primarily as bacteriohopanepolyols (BHP), which have C31 and C32 structures as both desmethyl and 2-methyl forms. Major alkanes include normal chain *n*-16 to *n*-19, mid-chain branched methylalkane (e.g. 5-, 6-, 7-methylheptadecane and 7,11-dimethylheptadecane), and a series of unsaturated C17-C19 (e.g. *n*-18:1, *n*-19:1, *n*-19:2). Analysis of pure cultures of *Phormidium* and *Calothrix* indicate that a variety of hopanoid structures are distributed in both genera, however, for alkane, the methylalkanes have only been detected in *Phormidium* cultures and unsaturated alkanes in *Calothrix* cultures.

Examination of several types of sinter mats including 1) surface silicified tuffed-*Phormidium*, 2) underlying/subsurface silicified tuffed-*Phormidium*, 3) flow-sheet *Calothrix* sinter over depth, and 4) downslope transects of both *Phormidium* and *Calothrix* flow-sheet sinter indicate a relatively good preservation of alkane and hopanoid biomarkers and of other cellular lipid components with exception of the subsurface sample (2).

The surface of *Phormidium* mat in the mid-terrace ponds of Clepsydra continually silicifies as vent channels migrate resulting in a topographic range from fully submerged tuffs to heavily silicified. The surface/entombed *Phormidium* cells exhibit excellent initial preservation potential. However, the organics within underlaying mat are rapidly degraded. On the more distal sheet flows, the *Calothrix* mats continually form and are buried by constant silica-deposition. The organic biomarkers present are representative of *Calothrix* but indicate the presence of *Phormidium* as well. Analysis of this mat over a 6 cm depth indicates excellent organic preservation during this burial. Variable biomarker composition was also noted. At Grand Prismatic, the *Calothrix* transect contained higher amounts of alkane relative to BHP, while those of *Phormidium* had higher BHP relative to alkane. Variations at each transect site were noted with depth. These and other results will be expanded and discussed within our presentation.

BIOSIGNATURES IN MARS ANALOG ACID SALT LAKES.

S. S. Johnson[1], M. L. Soni[1], D. J. Collins[1], K. C. Benison[2], M. R. Mormile[3], M. G. Chevrette[4], and B. L. Ehlmann[5]. [1]STIA, Georgetown University, Washington, DC, sarah.johnson@georgetown.edu, [2]Dept. of Geol. and Geography, WVU, Morgantown, WV, [3]Dept. of Biol. Sciences, Missouri S&T, Rolla, MO, [4]Dept. of Bacteriology, UW-Madison, Madison, WI, [5]GPS, Caltech, Pasadena, CA.

Introduction: Paleolake sites on Mars, particularly buried deposits that have been shielded from surface radiation, serve as intriguing targets for the search for life. Mars-like ephemeral playa lakes here on Earth can offer insights and perspectives on the possibilities for physical, metabolic, and biomolecular biosignature recovery from similar environments on Mars.

Acid Salt Lakes: Naturally-occurring acid salt lakes in Western Australia have received attention in recent years as a terrestrial Mars analog [1-4]. Hosted within the deeply weathered Archaean rocks of the Yilgarn Craton, these lakes range in size from m^2 to km^2 and are marked by cycles of flooding, desiccation, and evapoconcentration. The lakebeds are home to a distinctive mix of iron oxides, sulfates, chlorides, and clays, including hematite, kaolinite, some smectites, halite, gypsum, alunite, and jarosite [1,2,5]; sedimentary and alteration features also suggest similarities to Mars [1]. Despite the extreme conditions (pHs as low as 1.4, high fluxes of solar radiation, water stress during desiccation, high metal concentrations, and large shifts in diurnal temperature), these sites are highly habitable, home to a diverse array of organisms living in both lake waters and sediments [4,6].

Effects of Biology on Patterns of Mineralization. Our work in this analog environment suggests that we could be meaningfully underestimating the potential effects of biology on the chemistry of clay- and sulfur-rich environments on Mars. Metagenomic results indicate that genes associated with sulfur metabolism may be producing or consuming acidity in the local depositional environment [4]. In addition to potentially altering mineral stability fields, microbes can generate characteristic minerals as a byproduct of their metabolism; for instance, *Acidithiobacillus*, found in our community surveys, can precipitate a type of crystalline jarosite in both aerobic and anaerobic environments at a much wider range of pH conditions than abiotic processes alone, and thus its detection on Mars, particularly in the context of persistent aqueous processes, could serve as a biomarker for microbial sulfide oxidation [7]. Whether the coetaneous presence of acid sulfates and clays within these lakes, mineral groups that are thought to form under distinct pH conditions, could itself be a result of biology remains unknown.

Lipid Biomarkers. Because lipids are among the most resistant biological molecules, they have been used to characterize both physical environments and biological systems on the early Earth. Organic matter is commonly codeposited in evaporites, but it is generally believed that decay should proceed rapidly as long as oxidants, such as Fe(III) minerals, remain present in a sedimentary environment [8]. However, there are diagnostic microbial lipids in acid salt lake sediments, such as 1-*O*-alkylglycerols [See Fig 1] [9]. Moreover, terrigenous plant lipids that have been washed into the catchment zone of the lakes are present; the surprising resilience of these lipids, chemically similar to microbial lipids but certainly dead, lends support to other studies (e.g. [10]) that suggest sulfates, as well as clays, should be targeted in astrobiological investigations. Older acid salt lake facies, dating back to the Permian, are currently being analyzed.

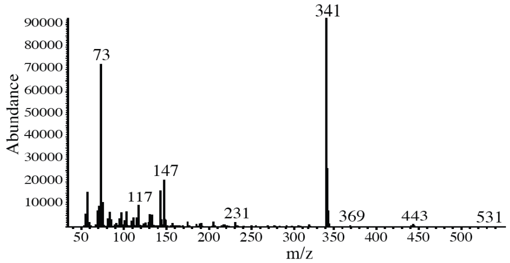


Fig 1. Mass spectrum of a 1-*O*-C16 glycerol monoether, likely formed by the *Thermodesulfobacteria* detected in our genetic data.

Solid and Fluid Inclusions. Organic compounds such as beta-carotene and long-chain hydrocarbons have also been identified by UV-vis microscopy and laser Raman spectroscopy in acid-precipitated halite and gypsum associated with the lakes [11,12]. During times of evapoconcentration, when salinities in the lakes can reach as high as 32% TDS, the formation of solid and fluid inclusions provides another means for trapping organic material and preserving biosignatures.

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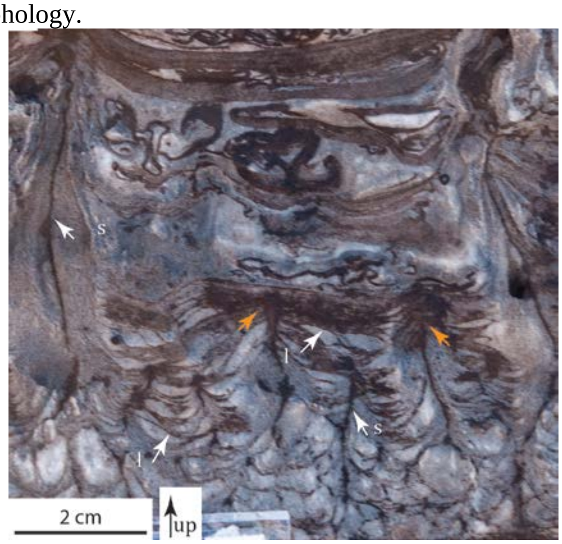
RECREATING MICROBIAL ECOSYSTEMS OF THE LATE ARCHEAN.

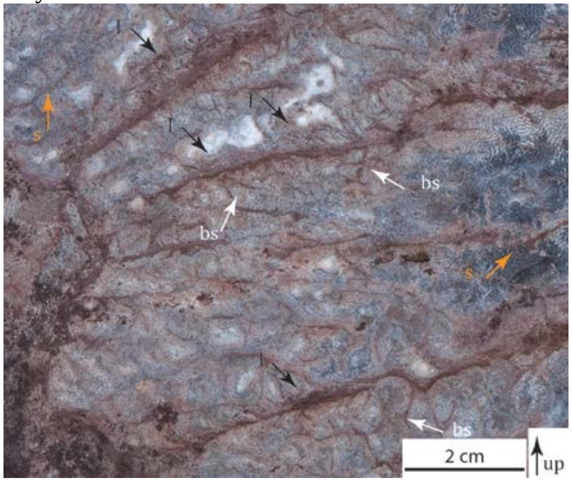
M. Juarez Rivera[1] and D. Y. Sumner[2], [1]School of Earth and Space Exploration, Arizona State University, 781 E. Terrace Mall, Tempe, AZ 85287 (mjuarez4@asu.edu), [2]Earth and Planetary Sciences Department, University of California, Davis, One Shields Avenue, Davis, CA 95616.

Introduction: Microbialites are important deposits for studying early Earth ecosystems. The morphology in the millimeter- to meter-scale structure of some microbialites can be used to understand the microbial communities that created them even when all microbial cells have degraded [1-3]. Archean fenestrate microbialites from the Gamohaan Formation, South Africa, display complex morphologies that are distinctly microbial [4]. Two of the most complex textures consist of cuspate and plumose microbialites. Whereas plumose microbialites are not generally represented in the rock record, cuspate microbialites have been reported from several sites.

Motivation: The morphology of cuspate microbialites has been suggested as a marker for phototaxis and possibly oxygenic photosynthesis [5-6]. If cuspate structures were created exclusively by oxygenic cyanobacteria, their appearance and distribution would greatly improve our understanding of the rise of oxygen on Earth. However, other growth models for cuspate structures have been proposed, including the upward growth of supports due to random gliding and entanglement of filamentous communities [5, 7] or due to chemical gradients rather than phototaxis [8]. Thus, it is important to fully understand the microbial processes giving rise to this intricate microbialite morphology.



Using the growth orientation and relationships between the microbialite components of cuspate and plumose microbialites we show that their growth can be reconstructed in terms of three microbial communities with distinct growth forms. Our new growth model for cuspate microbialites suggests that the outward and sometimes downward growth of supports is not consistent with growth towards light, instead diffusion-limited growth is most likely. Caution is suggested when using cuspate microbialites as markers for photosynthesis.



Left Laminae (l) drape from supports (s) to create fenestrate cuspate microbialites [4]. Changes in cuspate microbialite occur as the number of supports decrease and the thickness of laminae groups increase towards the top of each bed. Orange arrows point to supports that end under groups of laminae. **Top** Cuspate microbialite. Supports that grew on inclined surfaces grew horizontal to near-horizontal. Outward and sometimes downward growth of supports is not consistent with growth towards light.

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Matrix Embedded Organic Synthesis (MEOS).

Uma Gayathri Kamakolanu[1], **Friedemann T. Freund**[1,2] [1] SETI Institute, Carl Sagan Center/NASA Ames Research Center, 189 Bernardo Ave, Mountain View, CA 94043 k_umagayathri@yahoo.com, [2] NASA Ames Research Center, MS 245-4, Moffett Field CA 94035, Friedemann.T.Freund@nasa.gov.

Introduction: Copious amounts of the gas/fluid phase components $H_2/H_2O/CO/CO_2/NH_3/N_2/H_2S/SO_2$ become incorporated during planetary accretion. As minerals crystallize out of magmas, gas/fluid components dissolve in the matrix of minerals such as olivine forming a solid solution. Solute species are OH^- as well as carboxy, nitroxy and sulfoxy anions. Under non-equilibrium conditions the solutes exsolve. During cooling, a redox reaction causes electrons to be transferred from the oxygens onto the low-z elements (which are electropositive relative to oxygen), oxidizing oxygen to the peroxy state (valence 1^-), while the low-Z-elements become chemically reduced. For instance, hydroxyl pairs: $O_3Si\text{-}OH\ HO\text{-}SiO_3\quad O_3Si\text{-}OO\text{-}SiO_3 + H_2$.

To the extent that the solute species are still diffusively mobile, the now reduced low-z "impurities" are being pushed into dislocations and other segregation sites inside the mineral matrix. The denser the mineral matrix, the stronger the segregation force. At the internal segregation sites such as dislocations or subgrain boundaries. There the chemically reduced solute C, N, and S precipitate within the 3-dimenionally structured lattice environment forming C-C-, C-N-, C-S and C-O bonds. The lattice-bound H_2 will follow suite forming -C-H, -C-OH, -COOH and similar functional groups. We assign to the polyatomic CHONS segregates a formula $[C_xH_yO_zN_iS_j]^{n-}$ and call them proto-organics.

This is confirmed by the appearance of the spectroscopic signature of "organic entities" suggestive of mostly aliphatic hydrocarbons. Fig.1 shows the C-H stretching bands recorded from upper mantle derived gem quality olivine and melt grown MgO single crystals[1, 2]. The organics associated with interstellar dust display a similar, through broadened aliphatic signature [3, 4]. **Figure 3** shows a model of a densely packed polycrystalline material consisting of single crystals with grain boundaries between them and subgrain boundaries within them. These act as "dumping places" for solute C which probably diffuse via a mechanism that can be described as a coupled diffusion of a C atom bonded to O^- and the diffusion of the holes associated with the oxygen (O^- state) [3]. When H_2 join, they tie C–H bonds forming aliphatic groups.

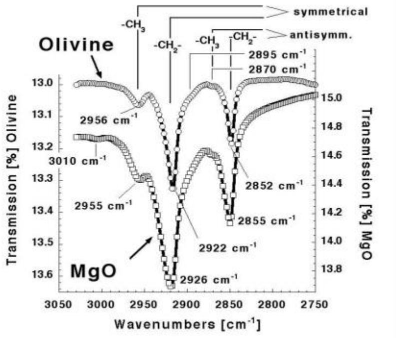
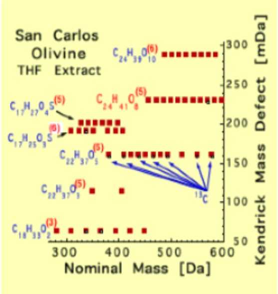


Fig.1 *C−H stretching bands at 3.4 μm recorded from a melt-grown high purity MgO and a gem-quality olivine crystal from the upper mantle.*



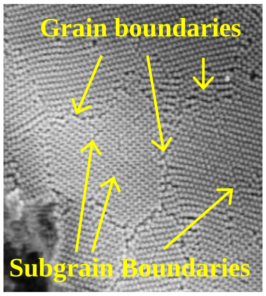


Fig. 2 *Examples of complex organics, THF-extracted from crushed gem-quality olivine crystals*, **Fig. 3**: *Model of grain and subgrain boundaries as sites for C-H assembly.*

Discussion: If an exoplanet in the habitable zone possesses oceans and landmasses as early Earth surely did, weathering will free $[C_xH_yO_zN_iS_j]^{n+}$ segregates from the tight embrace of their host minerals turning them into $C_xH_yO_{(z+n)}N_iS_j$ molecules. This is a powerful source of matrix embedded , complex organic CHONS, O-rich, probably carboxylic-type.

Solvent extraction of crushed MgO single crystals have yielded carboxylic acids in sufficient quantities to grow mm-sized succinic acids crystals [1]. Recently THF extraction of crushed gem-quality, upper mantle-derived olivine single crystals produced series of homologous, O-rich, sometimes S-bearing compounds with molecular weights up to 600 amu.

Summary: The redox conversion of traces of the fluid phase components $CO/CO_2/H_2O/N_2/SH_2/SO_2$ to H_2, organic C, reduced N and S inside the matrix of minerals leads to the new concept of **Organic Chemistry in the Solid State**. We are exploring this concept to understand the biosignatures and precursors of possible Life on Mars and beyond.

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DISTINCTIVE BIOPATTERNS FOR DETECTION AND CHARACTERIZATION FROM A ROBOTIC PLATFORM.

H. S. Kelly[1], P. J. Boston[1, 2], and A. J. Parness[3]. [1]New Mexico Institute of Mining and Technology, Socorro, NM 87801, [2] National Cave & Karst Research Institute, Carlsbad, NM 88222, [3]Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA 91109.

Introduction: Biosignature detection is a key objective for future missions to Mars. Much of the current focus centers around examination of orbital and rover data depicting geomorphological features as harbingers of life [1], verification of existing traces of organic compounds (via spectroscopic and molecular characterization), or lab simulations under Martian conditions [2,3]. We propose an intermediate scale approach using macro-visual inspection at the local scale through the use of a novel exploration robot (Fig. 1) to access challenging terrains. We leverage previous work characterizing many local-scale biosignatures found in Mars-analog environments and this as a basis for sample selection for landed robotic missions before other more costly life detection methods are employed. One such distinctive local-scale biosignature is known as *biovermiculation* (Fig. 2; [4-17]).

Biovermiculations: Biovermiculations (Fig. 2) are microbial mat communities often indurated with a significant amount of biomineral content and trapped exogenous particulates that grow in specific, identifiable patterns putatively to optimize resource accessibility when those resources are limited [18,16]. Under certain sets of conditions, they exhibit geometrically elaborate patterns consisting of lines, circles, and pitted amorphous splotches [19]. These patterns often lithify thus producing characteristic microbial-mineral deposit textures on rock or other surfaces, even after the organisms themselves may no longer be active. Such biopatterns often resemble each other at the macroscopic scale from one environment to another. For instance, a cryptogamic soil in an arid region may have the same spatial partitioning and geometric organization as a biovermiculation coating a cave wall. Therefore, we hypothesize that these selfsame fractal-like patterns may be looked upon as universal biosignatures for life detection even though the details of organism identities, geochemistry, and other conditions may differ markedly. If this claim is valid, then these examples of patterned growth may also be used as indicators of ancient Earth life in preserved geological materials, and potentially a means of life detection in similar environments on other planets [10]. Such biopatterns are arguably prime targets for robotic missions amenable to computerized autonomous pattern analysis as well as being plainly distinguishable to the human eye [16].

Exploration Robot: We are developing an instrument-robot package to test the detectability of biovermiculation patterns in Mars analog environments. This initial proxy suite of robot-mounted instruments will serve as a proof-of-concept that such a macroscopic imaging approach works with real biosignatures in nature. One of the primary technological and operational challenges is to gain access to currently rover-unfriendly sites. Advances in robotic capabilities are being developed at JPL with the LEMUR III rock climbing robotic platform (Fig. 1; [20]) allowing first pass reconnaissance and testing of the detectability of biovermiculations.

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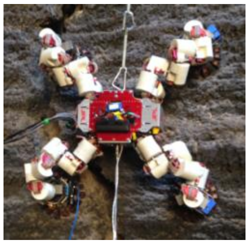

Figure. 1: LEMUR III demonstrates rock-climbing capabilities to better detect biopatterns.

Figure 2: Examples of *biovermculations* in many environments. From Boston et al., unpublished results, 2015.

We first present a compilation of chemical structures of biochemical compounds that are involved in metabolism of (poly)extremophiles. Our focus is on the molecules which are involved in the energy harvesting and transport. Next, we look for the chemical features that make such compounds uniquely suitable for their functions. We then consider such chemical features as potentially universal for a putative (poly)extremophile life on Mars. We explore the idea if these universal chemical features are "chosen" via chemical evolution, as is the case in which nature "chose" phosphate in our genetic system. Both actual compounds and the proposed universal compounds could be used as biomarkers for life on Mars. Finally, we present a compilation of Infrared (IR) frequencies of both actual and proposed universal compounds that could be useful in their identification by the IR, both as the *in situ* measurements on Mars or on the samples returned from Mars. The IR spectroscopic technique would supplement the Raman spectroscopy. The latter often suffers from complications due to the background interference, while the former does not.

Variations in biosignature preservation: Geochemical analysis of kerogen comparing two Mars analog environments.

K. N. Lorber[1,3], A. D. Czaja[1], and P. Lee[2,3,4], [1]University of Cincinnati (Lorberkn@mail.uc.edu), [2]SETI Institute, [3]Mars Institute, [4]Nasa Ames Research Center.

Introduction: Mars exploration has revealed evidence for a variety of potential life-supporting habitats, past or present, from near-surface aqueous environments to potential subsurface habitats. While the Earth and Mars are different planetary bodies, and have experienced different evolutionary histories, comparative planetary geology investigations between the Earth and Mars may lead to developing promising strategies that could help identify and characterize potential habitats and biosignatures on Mars, past and/or present. Of particular interest is gaining an understanding of the preservation through time of ancient microbial habitats in the geological record. In this context, investigations of the preservation of biosignatures from Early Earth, and also studies of the preservation of microbial biosignatures following impacts on Earth, are particularly relevant for the search for biosignatures on Mars.

We report here on new studies of the preservation of biosignatures from Early Earth and from impact crater environments on Earth, both of which may be viewed as first order analogs for common geologic settings on Mars. We focus on geochemical biosignatures preserved in the form of kerogen. Kerogen is an organic chemical biosignature in rocks that can be present either in the form morphologically preserved fossils of microorganisms, i.e., microfossils, or in the form of amorphous kerogen. Analyses of kerogen biosignatures preserved in rocks from Early Earth and in rocks subject to impact processing on Earth, whether in microfossil or in amorphous form, may shed light on how potential biosignatures might have been preserved - or altered - on Mars [1,2].

Methods and Results: We investigated two distinct paleo-biosignature environments on Earth: 1) Archean-age (2.5 Ga-old) deep marine microfossil-bearing chert units from the Tsineng Member of South Africa, and 2) Ordovician-Silurian marine carbonates of Devon Island, High Arctic, which were affected by the Miocene-age Haughton impact event. For samples from each site, microscopy and Raman spectroscopy were used to identify and characterize any variability in the morphological and geochemical preservation of the microfossils and of their organic matter (kerogen), or of amorphous kerogen.

The Tsineng cherts were sampled from four different localities (two drill cores and two outcrops). Observed are the same taxon of filamentous microfossils in each sample site, providing a unique opportunity to understand how microfossil morphology relates to geochemical variations in kerogen signature. Differences in the physical (morphologic) preservation of the microfossils are stark, ranging from highly fragmented to complete filaments. Variations in the geochemical signatures of the microfossil kerogen are also pronounced, suggesting differences in thermal alteration. Kerogen preservation is thought to be a function primarily of thermal alteration, but the regional geology indicates all of the specimens experienced the same thermal history, so variations in thermal alteration are unlikely to be the cause of the observed variations in biosignature preservation.

For the Haughton Crater site, we compared samples of dolomitic country rock (non-impact affected rocks) from the Allen Bay Formation to those from the same formation that were significantly affected (shocked and brecciated) by the impact event. We examined specifically the extent to which amorphous kerogen was altered by the impact event. Geochemical variations were noted in the Raman spectra.

Conclusions: Investigations of Archean cherts presented here show that the preservation of microfossils may present variations that are not due to small scale changes in temperature between localities within the same region, but may be due to other factor(s) affecting microfossil preservation not yet well understood at that site. For the Devon Island site, although only amorphous kerogen was studied, preliminary results provide insights on how impact events may contribute to altering microbial biosignature records preserved in rock. Our investigations are providing new insights into the preservation of kerogen and the factors that may affect it. Through morphological and geochemical characterization of the earliest known forms of fossilized life on the earth, and parallel investigations of the preservation of biosignatures following impact processing, we hope to achieve a greater understanding of how biosignatures might be preserved and found on Mars.

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The Pilot Valley Basin, Utah: A Modern Habitability and Preservation Model for Groundwater-fed Martian Paleolake Basins.

K. L. Lynch[1], J. F. Biddle[2], R. J. Schneider[3], K. A. Rey[4], J. J. Wray[5], and R. F. Rosenzweig[1,5], [1]University of Montana, Missoula, MT (kennda.lynch@mso.umt.edu), [2]University of Delaware, Newark, DE. [3]St. John's University, New York, NY, [4]Brigham Young University, Provo, UT, [5]Georgia Institute of Technology, Atlanta, GA.

Introduction: Martian paleolake basins are prime exploration targets for future surface missions [1, 2]. The majority of terrestrial paleolakes transitioned to modern day evaporite basins with clay, sulfate and chloride compositions similar to the aqueous minerals identified across the martian surface. Paleolakes harbor a diverse array of microbial life and enhance the preservation of organic matter and fossils. As such, these terrestrial systems are considered excellent analogs for habitability studies that can be used to identify and explore paleolake systems on Mars [3].

We investigated the microbial ecology of a terrestrial groundwater-fed paleolake basin along mineralogical and geochemical gradients; our goals were to: 1) Characterize microbial diversity in this understudied environment 2) Assess the correlation between microbial diversity and mineralogical and geochemical variation. 3) Assess the influence of this relationship on biosignature preservation in order to better model groundwater-fed paleolake systems on the red planet such as Columbus Crater.

Field Site: The Great Salt Lake Desert (GSLD) and the Great Salt Lake are remnants of ancient Lake Bonneville, the largest of several North American paleolakes from the Pleistocene Epoch. Of the three main sub-basins of the GSLD, only the isolated Pilot Valley has remained relatively untouched, and thus is the focus of this investigation.

Pilot Valley is a closed basin system with a subsurface hydrology comprised of three distinct aquifers: an alluvial fan aquifer, a deep basin-fill aquifer at a depth of ~30 meters, and a shallow brine aquifer that encompasses the upper ~6 meters of the basin sediment fill. The shallow-brine aquifer is maintained by ground water flow from mountain front recharge of the alluvial aquifer flanking the Silver Island Range [4]. The only loss mechanism from the Pilot Valley basin is capillary wicking and evaporation from the playa surface [5].

Methods: Sediment core samples down to depths of 2 meters were taken along geochemical and mineralogical gradients in the Pilot Valley basin. Mineralogy of the sediments was determined by X-Ray Diffraction (XRD), automated scanning electron microscopy (QEMSCAN), and visible-near-infrared spectroscopy (VNIR). DNA was extracted from each sample and subjected to 454 pyrosequencing of the 16S rRNA gene. The resulting data were processed using the Qiime workflow software and analyzed using ecological statistic packages in Qiime, PAST and R.

Summary: Results show that the ecosystem present in Pilot Valley is organized into three distinct community groups (Figure 1). This discrete assembly is most likely influenced by grain size among other factors. Because grain size seems to influence community structure, this variable could impact which biosignatures get preserved within the basin. Pilot Valley can therefore serve as a model to gain insight into preservation processes possible in martian paleolake sediments.

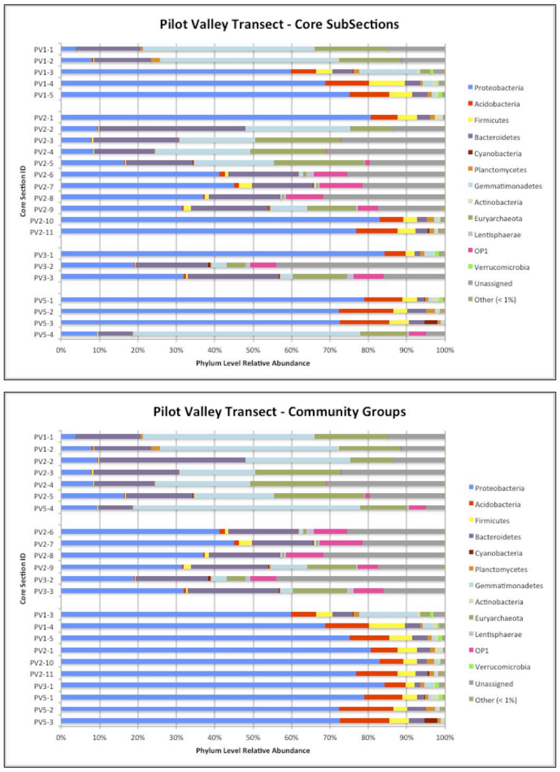

Figure 1. Phylum level relative abundances for Vertical Transect Study. a) Core sub-sections b) Community groups

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POTENTIAL FOR PRESERVATION OF BIOSIGNATURES FROM ENDOLITHIC MICROBIAL COMMUNITIES IN A MARS ANALOG FUMAROLE ENVIRONMENT.

T. M. McCollom[1], B. M. Hynek[1,2] and K. L. Rogers[3], [1]Laboratory for Atmospheric and Space Physics, University of Colorado, Boulder, CO 80303 (mccollom@lasp.colorado.edu), [2]Department of Geological Sciences, Univeristy of Colroado, [3]Rensselaer Polytechnic Institute, Troy, NY.

Introduction: Mars has been a volcanically active planet throughout its history, and the scarcity of water at the surface through most of this time suggests that fumaroles may have been more common than hot springs. In fumarolic environments, condensation of volcanic vapors would have provided localized warm, moist habitats for life on Mars, even when dry and cold conditions prevailed over most of the planet. In an effort to understand more about the potential for life and biosignature preservation in fumarolic systems, we have begun studying endolithic photosynthetic communities that inhabit fumaroles at Cerro Negro volcano, Nicaragua (Fig. 1a). These communites inhabit environments where condenstation of steam-rich vapors provide a continuous source of moisture and elevates temperatures well above ambient conditions.

Geologic setting: Cerro Negro is a young, basaltic cinder cone that last erupted in 1999. Within the volcano's crater, steam-rich vapors discharge to the surface in two principal modes: (1) localized areas of focused, high temperature (to >200°C) venting of strongly acidic, SO_2-rich steam, and (2) broad areas where vapor flows diffusively through cinders and altered mineral deposits [1,2]. In the diffuse areas, condensation of vapors leaves a layer of moisture on the mineral deposits, where temperatures range from ~100°C down to ambient and the pH of condensed fluids range from mildly acidic (~4) to circumneutral (~7).

Endolithic communities: The presence of photosynthetic communities within the fumarolic deposits is readily recognizable by layers of green pigmentation (Fig. 1a). The pigment layers are enclosed within mineral deposits, typically 0.5 cm or more below the surface. While temperatures in areas of diffuse vapor discharge can range to over 100°C, the pigmented deposits are confined to areas with T <65°C. Pigmented layers are found in a number of different settings, encompassing a range of mineral substrates (amorphous silica, gypsum), pH (acidic to circumneutral), and fluid compositions (e.g., high vs. low sulfate).

Initial analysis of one endolithic community indicates it is dominated by acidic red algae (*Cyanidiales*), accompanied by a highly diverse microbial population that includes aerobic bacterial heterotrophs (*Ktedonobacteria*) and archaeal thermoacidophiles (*Hyperthermus, Caldisphaera,* and *Thermofilum*) [3]. Examination of the pigmented layers by SEM revealed widespread spherical shapes ~5 µm in diameter that presumably represent photosynthetic cells (Fig. 1b).

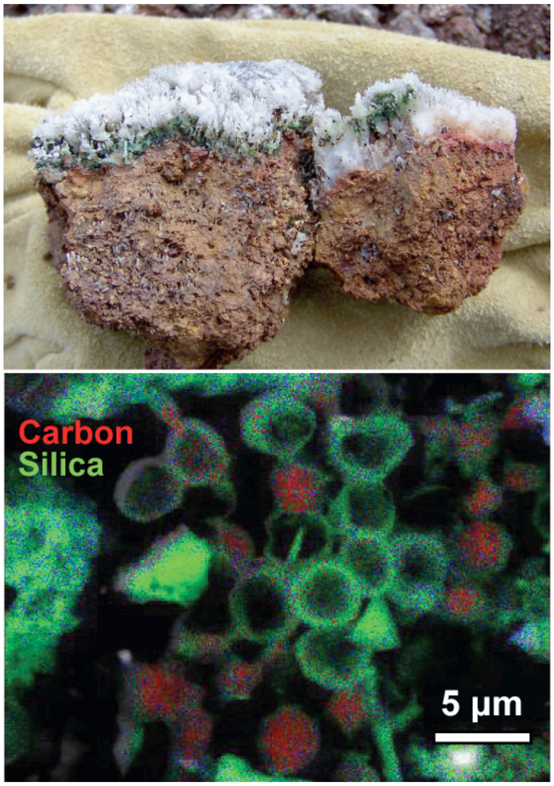

Figure 1. (a) Photosynthetic endolith community embedded in amorphous silica deposited on top of basalt. (b) Elemental map of pigmented layer, showing carbon-rich coccoidal cyanobacteria cells and SiO_2-coated spheroids presumably deposited on relict cells.

Biomarker preservation: Because the endolith communities inhabit sites of active mineral precipitation, there is a high potential for preservation of morpholigical and chemical biosignatures. For example, initial analyses show algal cells become coated with deposits enriched in Si and Mg (Fig. 1b), which preserves morphological evidence for cells in older deposits. Efforts are underway to further charactize these preserved cells and any carbonaceous deposits that may be associated with them.

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MARTIAN GEOLOGIC SETTINGS OF INTEREST TO THE SEARCH FOR BIOSIGNATURES, AS SEEN FROM ORBIT.

A. S. McEwen[1], [1]LPL, University of Arizona (mcewen@lpl.arizona.edu)

Introduction: A sequence of successful orbiters provide a wealth of information about geologic settings on Mars. Typically the highest resolution data available at particular wavelengths are the most useful for considering future landing sites and landed activities (Table 1). This presentation will summarize the datasets and introduce key terrain types of interest for biosignature preservation.

Table 1. Mars Orbiters and High-Resolution Mapping

Orbiter	Investigations
Mars Global Surveyor (MGS)	MOC (1.5 m/pixel visible) [1] LOLA (global topography) [2]
Mars Express (MEX)	HRSC (>10 m/pixel color, stereo) [3] OMEGA (>0.1 km/pixel hyperspectral) [4]
Mars Odyssey (MO)	THEMIS (100 m/pixel thermal IR) [5]
Mars Reconnaissance Orbiter (MRO)	HiRISE (0.3 m/pixel visible) [6] CTX (6 m/pixel visible) [7] CRISM (18 m/pixel hyperspectral vis-NIR) [8] SHARAD (subsurface radar) [9]
Trace Gas Orbiter (TGO)	CaSSIS (4.6 m/pixel, stereo, 4 colors) [10]

Mars Orbital Experiments: Visible imaging is provided by multiple cameras (Table 1), although MGS has ceased operation. HiRISE provides the highest spatial resolution, better than 1 m (~0.3 m/pixel), but has covered only 2.5% of the martian surface in 5 Mars years. CTX has provided nearly global (>85%) coverage at ~6 m/pixel. All of these cameras also acquire stereo data, but HRSC and CaSSIS (beginning in late 2017) are designed to map systematically in stereo, providing more coverage. HiRISE has covered <0.5% of Mars in stereo, but concentrated over candidate landing sites [11].

Mineralogic data is provided by NIR spectrometers such as OMEGA and CRISM. CRISM does so at the highest spatial resolution (~18 m/pixel) but has covered only a few % of Mars at this scale. CRISM has covered >80% of Mars at 200 m/pixel. THEMIS near-global coverage provides additional compositional constraints and maps temperatures, from which thermal inertia is derived [12]. SHARAD can map some subsurface interfaces at depths >10 m.

Superresolution modes: MOC and CRISM have acquired selected observations with along-track oversampling (ATO). ATO does not change the intrinsic resolution of the raw data, but the oversampled data can be processed to improve resolution in one dimension by as much as a factor of two [13]. Superresolution processing of multiple overlapping HiRISE images has produced intriguing results [14], but potential artifacts make the images difficult to evaluate.

Geologic Settings of Interest: This will be the topic of many presentations at this conference, but here is a very quick summary without citations.

Lacustrine and Deltaic Sediments: MSL is exploring probable lacustrine sediments in Gale crater, and some of the highest priority candidate landing sites are deltas in Eberwalde and Jezero craters. A unique sub-lake fan in southwest Melas Chasm is a Mars2020 candidate landing site.

Near-Surface Chemical Sediments: A prime candidate for potential pedogenesis is Mawrth Vallis. Also of great interest are the playa deposits containing what are likely to be chlorides. Chemical sediments being deposited today may be found at the depositional fans of the recurring slope lineae (RSL).

Deep Crustal Rocks (including Hydrothermal): The region northwest of Isidis Basin (including Nili Fossae) includes high-priority candidate landing sites based on exposure of deep crustal rocks. Hydrothermal and lake deposits in Gusev crater are of interest, explored by Spirit rover.

Also of great interest in the search for biosignatures is identification of sites where active erosion is exposing materials that have been shielded from radiation, where complex organics may be preserved. This includes sites with no small impact craters, evidence for scarp retreat, and recent or active abrasion by sand.

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Nontronite and Montmorillonite as Nutrient Sources for Life on Mars.

R. L. Mickol[1], P. I. Craig[2] and T. A. Kral[1,3], [1]Arkansas Center for Space and Planetary Sciences, University of Arkansas, Fayetteville, AR 72701, [rmickol@uark.edu], [2]Lunar and Planetary Institute, Universities Space Research Association, Houston, TX 77058 [3]Department of Biological Sciences, University of Arkansas, Fayetteville, AR 72701.

Introduction: Spectral data from the martian surface indicate the presence of various clay minerals in some of the planet's oldest terrains. The presence of clay minerals suggests long-term water-rock interactions. The most commonly identified clay minerals on Mars to date are nontronite, an Fe-rich smectite clay, and montmorillonite, an Al-rich phyllosilicate [1]. Both clays can contain variable amounts of water both adsorbed on their surface and absorbed within their structural layers. Over Mars' history, these clay mineral-water assemblages may have served as nutrient sources for microbial life.

Methods: *Experiment 1*: Two methanogen species, *Methanobacterium formicicum* and *Methanosarcina barkeri*, were tested for their ability to grow in the presence of nontronite or montmorillonite, without the use of additional nutrients. Two grams of each clay were added to each of five test tubes, and transferred to a Coy Anaerobic Chamber to deoxygenate overnight. Ten milliliters of bicarbonate buffer were added to each tube and the tubes were sterilized via autoclave. Before being inoculated into the sterilized clay solutions, methanogens were subjected to an aerobic washing procedure to remove residual media following the methods of McAllister and Kral [2]. Next, 0.5 mL cells+buffer were added to each test tube prepared above. The test tubes were pressurized with 170 kPa H_2, incubated at 37 °C, and monitored over time for methane production. Negative control tubes consisted of buffer or buffer plus clay.

Experiment 2: In a second experiment, test tubes consisted of a clay mixture of 1 g nontronite plus 1 g montmorillonite.

Following growth periods, clays will be analyzed for the presence of possible biosignatures in the form of mineralogical changes using X-Ray Diffraction (XRD), Near InfraRed spectroscopy (NIR) and Scanning Electron Microscopy (SEM).

Results: *Experiment 1*: *M. barkeri* failed to produce significant methane in any of the 2 g nontronite or 2 g montmorillonite sets. *M. formicicum* produced methane using montmorillonite as a nutrient source, but was unsuccessful with nontronite (Fig. 1).

Experiment 2: *M. barkeri* and *M. formicicum* both produced increasing methane during 30 days of incubation at 37 °C in a nontronite/montmorillonite clay mixture (Fig. 2).

For both experiments, growth in the presence of clays+buffer was much more delayed than growth in normal media (Fig. 2).

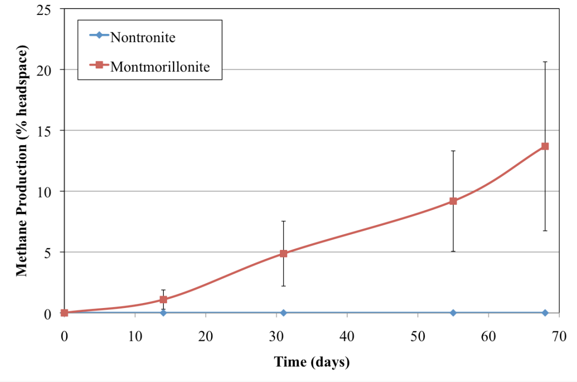

Figure 1. Methane production by *M. formicicum* in media containing solely bicarbonate buffer and clay (nontronite or montmorillonite).

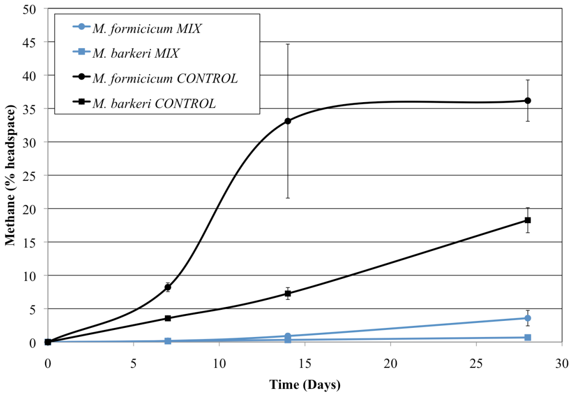

Figure 2. Methane production by *M. formicicum* and *M. barkeri* in media containing solely bicarbonate buffer, nontronite and montmorillonite (mix) or in normal anaerobic growth media (control).

Discussion/Conclusions: Nontronite and montmorillonite have been identified in the oldest terrains on Mars [1, 3]. We have shown that methanogens can utilize nutrients from montmorillonite without supplemental media. Clay minerals are of particular interest in astrobiology because of their water content and have been hypothesized to preserve organic matter and possibly biosignatures on Mars [4]. We will compare our laboratory data to observations of Mars in order to identify potential biosignatures on Mars.

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BRISTOL DRY LAKE, CALIFORNIA: AN ANALOG FOR ANCIENT LACUSTRINE ENVIRONMENTS ON MARS.

J. L. Mitchell[1*] and P. R. Christensen[1], [1]School of Earth and Space Exploration, Arizona State University. *Julie.L.Mitchell@asu.edu

Introduction: Bristol Lake is a dried lake bed at the foot of a young volcano in the Mojave Desert. It is considered a Mars analog for several reasons. First, the chemistry and distribution of the evaporite deposits are very similar to putative lake deposits observed on Mars from orbit [1]. Second, the volcanic geology surrounding the lake is similar to much of the martian surface in that it is dominated by basalt [2]. Third, brines found in the playa are believed to be sourced primarily from hydrothermal groundwaters, which are rich in chloride, sodium, and calcium, and were heated by near-surface magma [3]. Waters on ancient Mars are thought to have at least partially evolved from hydrothermal fluids [4] and therefore have a similar origin to those found at Bristol Lake. Fourth, the dry nature of the Mojave Desert, where Bristol Lake is located, is similar to the dry environment on the surface of Mars.

Few Mars analog studies have been conducted at the Bristol Lake playa, though the volcano nearby has been used for Mars and autonomous rover testing [5]. The playa is therefore a prime site for astrobiological and geochemical investigations. This study aims to investigate the geochemical environment at Bristol Lake (BL) within the context of Mars remote sensing studies by addressing the following questions:

- What is the distribution of evaporites in BL and how is it similar to analogous sites on Mars?
- What type of chloride is most likely to exist on Mars based on analyses of Bristol Lake?
- What is the chemistry of the brines at BL? Would this site qualify as a "Special Region?"
- Do brines vary in composition across BL? Are they similar to current/ancient martian brines?

By comparing the mineralogy at Bristol Lake to sites on Mars, conclusions can be drawn as to the nature of brines that existed in Mars' late-Noachian/early Hesperian [6] and could exist temporally on Mars today.

Methods: The distribution of evaporite minerals will be compared to lacustrine sites on Mars using a combination of field samples, remote sensing data, and existing field maps of the region. Field samples will be characterized using thin sections and electron microprobe analyses. Thermal emission and near-infrared reflectance spectra will be collected for samples representative of each mineralogic unit in the evaporite sequence. These spectra will be compared to those collected by instruments orbiting Mars: thermal emission spectra from the Thermal Emission Spectrometer (TES) and Thermal Emission Imaging System (THEMIS), and near-infrared spectra from the Compact Reconnaissance Imaging Spectrometer for Mars (CRISM). Basalt samples from the nearby young volcano, Amboy Crater, will also be collected and subject to the same analyses as the evaporite samples.

Figure 1. Bristol Lake salt deposits, field excursion 1 (03/11/16).

Brine samples from ponds distributed throughout the playa will be analyzed for pH, conductivity, major ions, and trace metals. Changes in the composition of dissolved solids in the brine will be compared to the surrounding geology to better understand the context in which the brines and evaporite deposits formed.

Discussion: Compositional, spectroscopic, and chemical analyses of geologic and water samples will allow the geochemical environment at Bristol Lake to be characterized. Comparisons in mineralogy and morphology will be made between Bristol Lake and lacustrine sites on the martian surface. The constraints set by the Committee on Space Research (COSPAR) for astrobiological Special Regions will be used to assess whether Bristol Lake is representative of Mars Special Regions [7]. If distinct commonalities are found between Bristol Lake and sites on Mars such as Miyamoto Crater [8], the astrobiological context of current and ancient Mars will be better constrained. Further characterization of the microbial communities (if such exist) in the Bristol Lake region could provide clues as to the type of microorganisms that could be found on Mars. Field excursions at Bristol Lake will also characterize the hazards future crews or rovers could experience during surface exploration operations.

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DIFFERENT TOPOGRAPHY AND COMPOSITION OF EARTH- AND MARS-TYPE SURFACES,

Y.Miura[1] and T. Tanosaki[2], [1]Yamaguchi University (Yamaguchi City, Japan; yasmiura50@gmailcom), [2]Kogakuin University (Tokyo, Japan).

Introduction: Higher lands of solid rocks are considered to be similar formations and compositions in the Solar System (including Earth and Mars). This is mainly because higher lands are formed by plate-tectonics of plate movement studied on water-Earth. If there are no plate-tectonics on other waterless planets (including Mars), higher lands would show different location and shape compared with water planet Earth. Compositions (including carbon) would be shown also different concentration process on the these surfaces.

The main purpose of the present paper is to elucidate different topography and composition of water-Earth and waterless-Mars from the global system.

Earth topography with global water system: Global water system on planet Earth shows recent plate-tectonics probably triggered by extraterrestrial impacts on ocean site which are easily disappeared from original crater-structure and remained rocks for long activity of the water planet. In fact, Figure 1 shows completely different locations and sizes of present Earth, which suggests that Earth's higher topography has been formed by successive movements by many sea-floor plates probably induced by Earth's rotation (called as tidal force) with many ocean impact processes. Therefore, random direction and size of higher lands are characteristic for active water-Earth finally as shown in Fig.1.

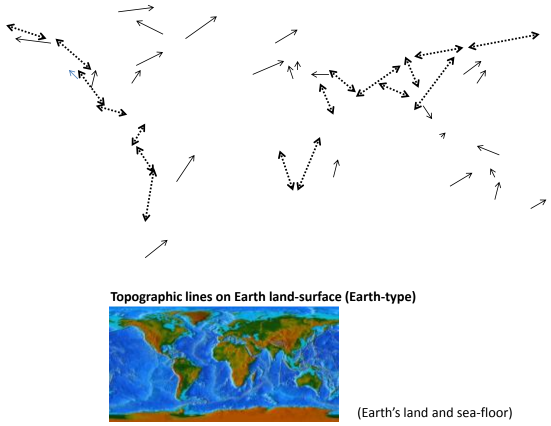

Fig.1. Topography of high lands of Earth, which are obtained from Earth's geographical map. The present data show that random direction and size of higher lands are characteristic for active water-Earth [1-2].

Mars topography with global waterless system: Global waterless system on planet Mars shows high lands and lower floor probably triggered by volcanic activity induced by Mars rotation (called as Mars tidal force) found near the Equator site.. In fact, Figure 2 shows higher lands near the Equator of present Mars, which suggests that Martian higher topography has been formed by solid-rich movements by many "local fluid" contribution probably induced by Martian tidal force with many Martian volcanic activity to be formed as Martian cold atmosphere finally. Therefore, high lands for rotational and longitude-like direction near the Equator are characteristic for "global waterless-Mars" finally as shown in Fig.2.

Compositional differences of Earth and Mars: Volatiles-elements has significant memory and role for active planets. In fact carbon-bearing compounds which as only one volatile element with stable at higher temperature and pressure environments. Carbon concentration can be found at shock-wave sites of meteoritic impacts, quakes and volcanic eruptions. Global water planet Earth form many sedimentary rocks on the ocean floor-bottom. Waterless Mars in global system shows carbon-concentration sites at impact crater process, which probably global distribution on global and many impact process on long history on Mars. Life formation and activity on Mars are dependent on Martian fluids distribution, whereas primordial rocks on Mars will be shown the details of Martian carbon.

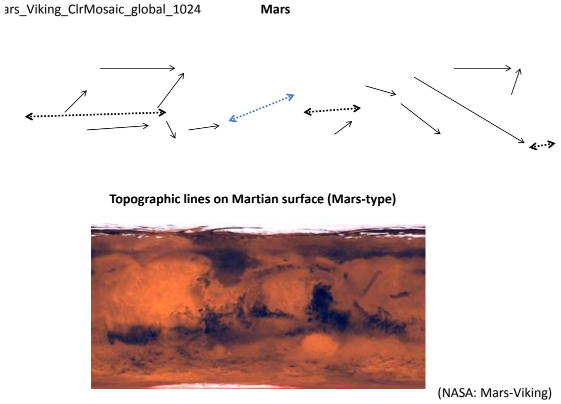

Fig.2. Topography of high lands of Mars. The present data show that random direction and size of higher lands are characteristic for global waterless-Mars [1-3].

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MASE MARS ANALOGUE SITES: PHYSICOCHEMICAL CONTEXT SYNTHESIS AND ORGANIC INVENTORY.

E.P. Monaghan[1] and the MASE team: P. Ehrenfreund (NL), C.S. Cockell, P. Schwendner (UK); P. Rettberg, K. Beblo-Vranesevic, M. Bohmeier, E. Rabbow (G); F. Westall, F. Gaboyer, N. Walter (F); M. Moissl-Eichinger, A. Perras (A); F. Gomez, R. Amils, L. Garcia (ES);; V. Marteinsson, P. Vannier (IS), [1]Huygens Laboratory, J.H. Oort Building, Niels Bohrweg 2, NL-2333 CA Leiden, The Netherlands, monaghan@strw.leidenuniv.nl

Introduction: The MASE (Mars Analogues for Space Exploration) [1] project is a four year collaborative research project supported by the European Commission Seventh Framework Contract. The aim of the project is to understand how combined environmental stresses—e.g. low pH and temperature—affect the habitability of a number of Mars analogue environments on Earth, specifically for anaerobic organisms.

Crucial to assessing the habitability of any environmental system, whether for anaerobes specifically or for life more generally, is a detailed understanding of the geological, physiochemical and biological context in which the environment is set. One of the key outcomes of the MASE project is a comparison and synthesis of just such a collection of context data from a varied set of Mars analogue sites.

This work will further our knowledge of Mars-like environments on Earth and allow us to field test and improve the next generation of life detection instrumentation that will be sent to Mars.

Field sites: Field sites already sampled for MASE include deep subsurface salts at Boulby Mine in the UK, sulfidic springs in Germany, acidic cold lakes in Iceland and acidic deep subsurface environments at the Río Tinto in Spain. Permafrost samples are to be investigated in the next phase of the project.

Context data: This work synthesises physiochemical data (including mineralogy, environmental temperature and pH; carbon and nitrogen analyses; cations and anions; H_2S, sulphite and nitrite measurements) with biological data (FISH analysis, DNA extractions, studies of isolated organisms).

This work synthesises physiochemical and biological data and is complemented by a detailed analysis of field samples to detect and quantify amino acids, organics and other biologically relevant molecules in the system.

The first release of results, including synthesis and comparison for field sites, are discussed here. This work will further our knowledge of Mars-like environments on Earth and allow us to field test and improve the next generation of life detection instrumentation that will be sent to Mars.

References:

[1] www.mase.esf.org

Additional Information: The MASE project is supported by European Commission Seventh Framework Programme (FP7/2007-2013) under Grant Agreement n° 607297

TEXTURAL BIO-SIGNATURES OF GEYSERITES IMAGED BY µXRT.

C. Munoz-Saez[1], and J.I. Gutierrez[2], M. Manga[1]. [1]EPS Department, University of California, Berkeley, 169 McCone Hall, Berkeley, CA, 94720 (carolimunoz@berkeley.edu). [2]MCB Department, University of California, Berkeley, 393 LSA, Berkeley, CA, 94720 (gutierrez@berkeley.edu).

Introduction: Silica sinter on Earth is generated when hot water that circulates underground, dissolves silica from the host rock, is discharged by hydrothermal vents, and then precipitates at the surface as the water cools. Similar opaline silica deposits have been identified in two areas on Mars, by Spirit Rover at Home Plate [1], and Nili Pater Caldera in the Syrtis Major volcanic complex [2], in both cases suggesting past hydrothermal activity [3].

Discharge of water from hot springs generates extensive sinter formations: terraces, platforms, cones and conduits. Those environments are inhabited by microorganisms. The sinter may thus preserve biological signatures, providing important information about mineral-microbe-environmental associations in hydrothermal systems [4-5]. We studied the structural fabric produced by microbial material that reveals past environmental conditions including temperature and flow.

Methodology: We collected samples of a fresh sinter terrace from El Tatio, Atacama. The samples were collected ~15 cm beneath the surface. They were still saturated of water. These rocks are formed by fine layers (10 to 5mm) and include organic material.

In the laboratory, we studied the rock texture and micro-organisms. Thin sections were made by drying the saturated rock samples. We also drilled 2.5 mm diameter cores from individual layers to image them with a non-destructive micro X-Ray tomography (µXRT), which produces a 3D high-resolution (1.3µm/voxel) scan of the rock (Figure 1). These 3D images were obtained to characterize microstructure and the distribution and volume of microbial material [6]. Last, we dissolved the rock and analysed individual micro-organisms.

Results and discussions: Preliminary results suggest that the microbes present in the rock are cyanobacteria, which form filaments >2.5 mm long and ~10 µm diameter (Figure 1 bd). These filaments are consistent with low to medium temperature environments [7].

Filaments are covered by silica but not yet fossilized. The volume of bacterial material reached up to 20% of the sample. The total porosity of the sample was estimated to be 50%, and the pores are elongated in the same direction as the filaments [6]. These observations imply that filaments provide a surface for silica precipitation [7], which leaves a signature in the pore structure of the rocks (Figure 1 ab).

There are no signs of diagenetic processes in the rock. We observed that living filaments mats are oriented in the direction of water flow. The orientation of the filaments and thus the pores in the rock - perpendicular to ~70° angle from the horizontal layering – preserve information about the flow direction.

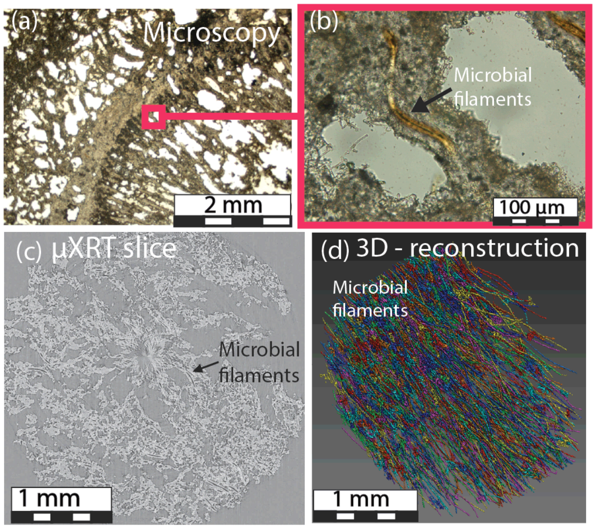

Figure 1: (a) and (b) Thin sections imaged with transmitted light. (c) XRT slice and (d) 3D reconstruction of filament microbes.

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BIOSIGNATURES FROM A DEEP BIOSPHERE: THE LARGEST AND LONGEST-LIVED HABITABLE ENVIRONMENTS ON MARS

H. M. Sapers[1], K. Cannon, J. Mustard, J. Amend, D. Beaty, C. Cockell, D. Des Marais, T. Hoehler, T. McCollom, J. Michalski, K. Nealson, G. R. Osinski, T. Onstott, V. Orphan, B. Sherwood-Lollar, A. Templeton, G. Wanger.
[1]Centre for Planetary Science and Exploration University of Western Ontario, Canada (hsapers2@uwo.ca)

Introduction: The current surface conditions on Mars are incompatible with life as we know it: the surface atmospheric pressure precludes standing water[1]. Harsh UV [2] and gamma radiation will destroy complex organic molecules in the surface and near surface environment hindering detection of organic biosignatures. These harsh surface conditions potentially extended to the Noachian/Hesperian boundary, so surface environments including lakes/deltas may not have habitable at the surface. However, subsurface refugia may have extended the window of habitability and putative subsurface pockets of habitable conditions could potentially still exist harboring extant life and their biosignatures.

Subsurface Habitats on Earth: The minimum requirements for subsurface life include space, carbon, and energy linked in a substrate allowing for an adequate supply of nutrients and removal of toxic waste products[3]. Subsurface environments may harbor the majority of microbial life on Earth [4], [5] and Archaean biosignatures suggest the existence of a terrestrial biosphere for billions of years e.g.[6]. Subsurface microbial communities are sustained through chemolithoautotrophic metabolic processes adapted to energy limitations[7] limited by the geothermal gradient reaching the upper temperature limits of life[3]. Extant subsurface metabolisms in these terrestrial Mars analogue habitats include coupling oxidation of H_2 generated by serpentenization reactions to reduction of oxidized iron and sulphate minerals[8], [9]. Methane can be generated through subsequent reactions with CO/CO_2[10] supporting methanotrophic communities.

Subsurface Habitability on Mars: The subsurface represents the most temporally extensive habitable and potentially inhabited environment on Mars [11]. The presence of past liquid water is evidenced by the association of phyllosilicates with ancient crustal terrains, and subsurface liquid water interacted with the surface environment in catastrophic outflows from the Hesperian [12] to as recently as a few million years ago [13], [14]. Modern subsurface water may be present in pockets due to radiogenic heating and lithostatic pressure and the presence of brines depressing the freezing point[15].

Impact cratering is an important geological process on Mars, and large basin-forming events would have potentially connected the cryosphere to the surface[16], [17]. Impact-generated hydrothermal systems would have generated transient habitable environments [18], [19]. Outcrops of serpentine has been identified in several geological settings on Mars [20] indicative of past serpentinization diagnostic of highly reducing, alkaline, <400°C hydrothermal alteration of ultramafic rock. Subsurface systems may still exist.

Biosignature Detection: Ionizing radiation rapidly degrades complex organic molecules in the near surface environment. Both UV and ionizing radiation are damaging to organic molecules posing a challenge to both habitability and detection of organic biosignatures. UV radiation results in highly oxidizing conditions and wind-induced mixing of oxidants in the upper ~1m soil presents a hazard[21]. Detection of complex organic molecules will be 'problematic' within the top 10 cm with an exposure age of more than 300 Myr [22]. 1.5 – 2 m drilling is required before 3 Ga amino acids can be detected [23]. Subsurface aqueous interactions with pyrite have also been suggested to produce oxidants affecting the preservation of organic biomolecules and ice-rich permafrost regions may have a better preservation potential[24]. It is essential to access the subsurface to detect and characterize complex organic biomolecules. In addition to drilling, subsurface access is possible through the exploration of A) impact structures and their associated products including central uplifts and ejecta and B) surface mineral deposits precipitated from fluids sourced from the subsurface.

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PRESERVATION OF ORGANICS AT THE PAINTED DESERT: LESSONS FOR MSL AND BEYOND.

E.Z. Noe Dobrea[1,2], A.C. McAdam[3], C. Freissinet[3], H. Franz[3], I. Belmahdi[3], M.R. Hamersley[4], C.R. Stoker[2], W.G. Parker[5], D.P. Glavin[3], F. Calef[6], and A.D. Aubrey[6]. [1]Planetary Science Institute (eldar@psi.edu), [2]NASA/ARC, [3]NASA/GSFC, [4] Soka University of America, [5]Petrified Forest National Park, [6]NASA/JPL.

Introduction: One of the foci of the Mars exploration program is the search for organics and evidence for past life. Phyllosilicate and sulfate deposits are widely observed on Noachian and Early Hesperian terrains on Mars, and the association of similar ancient terrestrial deposits with high concentrations of organics makes these martian deposits viable and attractive targets. Here, we examine sediments from a Mars-analog material, the Painted Desert sediments, to investigate the mechanisms of organic preservation in fluvio-lacustrine systems.

The Painted Desert of northern Arizona consists of 215 My old, interbedded layers of mudstones, sandstones, and limestone deposited in a fluvio-lacustrine and deltaic environment [1]. Trapped in some of these layers is biogenic organic carbon that was rapidly buried in the prograding beds and floodplains of the system [2,3].

The spectral and morphological character of the Painted Desert appears analogous in many ways to that of the Al-phyllosilicate-bearing units at Mawrth Vallis, Mars. Both regions present evidence for fluvial activity and have thick Al-phyllosilicate sequences containing Al-smectites, kaolins, hydrated silica, and jarosite [*e.g.* 4]. These similarities make the Painted Desert a potential geological and compositional martian analog. We seek to understand how the chemistry and textural character of these units play a role in the preservation of organic compounds.

Previous Work: In a previous study, we focused on relationships between organic content, rock-type, and color of the host rock [5]. We found typical concentrations of a few tens of mg C/kg in smectite deposits and C:N ratios between 1 and 10. The latter are lower than would be expected for terrestrial flora, indicating either diagenetic loss of C or allochthonous sources of N during diagenesis. We also found organic-rich (>300 mg C/kg) pieces of dark calcite (interpreted as calcified wood) coated by a jarosite rind and embedded in the clay beds. We noted the contrast with silicified logs that were embedded in sandstone-rich layers.

In the present study, we tested new hypotheses:

H1. The calcite nodules are calcified trees.

H2. Silicification occurs preferentially in highly permeable sandstone beds, whereas calcification occurs in the lower permeability mudstone beds.

H3. Silicification does not preserve organic carbon as effectively as calcification in these beds.

H4. A correlation exists between organic carbon content and the presence of jarosite in these rocks.

Current Results: High organic carbon concentrations (500-1500 mg C/kg) were found in jarosite-bearing mudstones targeted via remote sensing, in dark calcite nodules, in jarosite precipitates coating the calcite, and in sandstones encasing these nodules. Low organic carbon content (ca.30 mg C/kg) was found in the jarosite-free clay beds and in the silicified wood. In general, we found neither host rock tonality nor grain size to be a good predictor of organic content.

Unexpectedly, we also found dark calcite nodules and jarosite precipitates in the same sandstone layer as the silicified wood and only a few tens of meters away from it. Hence, the mechanism by which organics are calcified, rather than silicified, remains unknown. Further sampling and analysis of this layer will be one of the objectives of future study.

GCMS and EGA analyses provided greater insight into the presence and distribution of organics. Organic fragments evolved at the same temperatures of gas releases (SO_2, H_2O, CO_2) that result from mineral decomposition at high temperatures, suggesting that some organics were trapped within sample minerals. Data from GCMS flash pyrolysis to 900ºC indicated the presence of aromatics with up to three rings. Subsequent water/isopropanol extraction of the organic content of the sample followed by MTBSTFA derivatization, allowed measurement of the most refractory organic molecules present in the samples: numerous amino acids were detected, in addition to carboxylic and dicarboxylic acids, alcohols, aliphatics and other complex molecules.

Discussion: Although the identification of organics in these rocks is not necessarily surprising, the apparent lack of correlation in organic carbon concentration and rock type is somewhat perplexing, as one expects organics to be better preserved in mudstones than in sandstones. This suggests that additional parameters must be taken into account when considering the preservation of organics. The detection of organics in association with jarosite precipitates points to a mechanism of preservation that should be of high interest to MSL and future missions. These results are especially compelling in light of the recent identification of organics by MSL/SAM in the Murray mudstones [6,7].

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Biomarker Preservation Potential of Subsurface Ecosystems. T.C. “Outsider” Onstott[1], R.L. Harris[1], B. Sherwood Lollar[2], K.A. Pedersen[3], F.S. Colwell[4], S.M. Pfiffner[5], T.J. Phelps[5], T.L. Kieft[6] and C. Bakermans[7] [1]Dept. of Geosciences, Princeton University, Princeton, NJ, USA 08544 (tullis@princeton.edu; rlh6@princeton.edu), [2]Dept. of Earth Sciences, University of Toronto, Toronto, Ontario, Canada M5S 3B1 (bslollar@chem.utoronto.ca), [3]Microbial Analytics Sweden AB, Mölnlycke, Sweden (kap@micans.se), [4]College of Earth, Ocean, and Atmospheric Sciences, Oregon State University, Corvallis, OR, USA 97331 (rcolwell@coas.oregonstate.edu), [5]Center for Environmental Biotechnology, University of Tennessee, Knoxville, TN, USA 37996 (pfiffner@utk.edu; tphelps@utk.edu), [6]Dept. of Biology, New Mexico Tech, Socorro, NM 87801 (tkieft@nmt.edu), [7]Altoona College, The Pennsylvania State University, Altoona, PA, USA (cub21@psu.edu)

Introduction: During the past 30 years investigations of the continental and marine deep subsurface biosphere have revealed a biomass abundance and diversity that rivals that comprises a significant fraction of Earth’s total biosphere. The utilization of physical and chemical tracers during coring was critical in the discovery of the deep biosphere because the tracers were able to distinguish biomarkers that represented indigenous subsurface prokaryotes from those introduced by drilling. The data used to characterize the abundance, diversity and long term activity includes: 1) cellular counts; 2) DNA/RNA/protein/ATP analyses; 3) phospholipid fatty acid (PLFA)/diglyceride fatty acid (DGFA)/Archaeal lipid analyses; 4) stable isotopic analyses of gases, aqueous species, biominerals and authigenic minerals; and 5) textures and composition of biodegraded glass and petroleum.

Biomass: The prokaryote cellular abundance in the subsurface ranges from 10^9 cells/gram to below the limit of detection by microscopic techniques (~6 cells/gram) and PLFA and qPCR of 16S rRNA (~10^2 cells/gram). Cellular abudance slowly diminishes with depth, but spikes in cellular abundance occur often at the interfaces between organic-rich shale and organic-poor sandstone. Although cellular abundance tends to be higher in sedimentary rocks, values as high as $10^{5\text{-}8}$ cells/gram have been reported for ash flow tuffs and metamorphic rocks. Cellular abundances on fracture surfaces are ~10^5/cm^2[1] and in ice are ~$10^{2\text{-}9}$/cm^3.

In Cretaceous Period sandstone and shale in the San Juan Basin of New Mexico the PLFA, indicative of active bacterial communities, concentrations ranged from 3,000 to 0.1 pmoles/gram and diminished with depth up to 200 meters. The DGFA, indicative of recently dead and inactive bacteria, concentrations ranged from 0.2 to 8,000x pmoles/gram (equivalent to ~$5\text{x}10^3$ to ~$2\text{x}10^8$ cells/gram) and increased with depth. The absence of DGFA from the thermal aureole of a 3.3 myr basaltic intrusion not only illustrated the thermal lability of these biomarkers but also implied that the DGFA was greater than the intrusion age [2].

Biodiversity: Culture based analyses, nonculture based 16S rRNA/18S rRNA amplicon, microscopic observations, and metagenomic/metatranscriptomic analyses have revealed that the active subsurface biosphere is dominated by Bacteria and to a lesser extent Archaea. These analyses have also revealed the presence of micro-Eukaryotes (e.g. fungi and protists) and multicellular meiofauna (e.g. nematodes)[3]. Viruses are present at 10× the abundance of prokaryotes and are active as well.

Subsurface Microbial Activity: The signatures of subsurface metabolic activity during the thousands of millenia of isolation in the subsurface are preserved in the biodegradation signatures of petroleum deposits (anaerobic alkane-degrading bacteria), in the C and H isotopic composition of CH_4 (methanogenic and methanotrophic Archaea and methanotrophic bacteria)[4], and in the C isotopic composition of carbonate mineralized fractures (both heterotrophic and autotrophic microorganisms). The fossilized remains of subsurface microbial biofilms have been reported in fracture-filling calcite[5]. Trace fossils ranging in size from tens to hundreds of microns of chemolithotrophic bacteria have been reported in volcanic glass. These features have also been found in Archean pillow basalt metamorphosed to greenschist facies[6]. Reduction spheroids and carbonate concretions created by subsurface anaerobic bacteria have been reported ranging in size from millimeters to meters.

Implications for Mars Sample Return: If life emerged on the surface of Mars it may have succumbed to a Gaian bottleneck[7] of a rapidly diminishing atmosphere. The subsurface biosphere whether sheltered in sedimentary or igneous rocks in subfreezing saline pore water [8] would have continued to grow and evolve and their remains preserved in freshly excavated rock today.

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DEFINING ANALYTICAL STRATEGIES FOR MARS SAMPLE RETURN WITH ANALOGUE MISSIONS.

G. R. Osinski[1,2], H. M. Sapers[1], R. Francis[1,3], A. Pontefract[1,†], L. L Tornabene[1], T. Haltigin[4]. [1] Centre for Planetary Science and Exploration/ Dept. of Earth Sciences, University of Western Ontario, [2]Dept. of Physics and Astronomy, University of Western Ontario, Jet Propulsion Laboratory, California Institute of Technology, [4]Canadian Space Agency [†]Current affiliation: Department of Earth, Atmospheric and Planetary Sciences, Massachusetts Institute of Technology (gosinski@uwo.ca)

Introduction: One of the highest priority goals for the international planetary science community is Mars Sample Return (MSR) [1],[2]. The top three science objectives identified by MEPAG [2] are:

1) Identify habitable environments;
2) Assess the potential for preservation;
3) Determination of biosignatures

Successful selection of a habitable environment, acquisition of samples with a high probability of biosignature preservation, and detection and characterization of putative Martian biosignatures, will require a rigorous integrated analytical pipeline across instrumental platforms and observational scales. Analogue environments and full-scale analogue missions provide context for implementation and assessment of such technologies and methodologies.

Over the past two years, we have conducted simulated Mars Sample Return missions. In November 2015, the Canadian Space Agency (CSA), MacDonald Dettwiler and Associates Ltd. (MDA), and the Centre for Planetary Science and Exploration (CPSX) at the University of Western Ontario designed and conducted one of the highest fidelity MSR mission simulations to date [3]. The 2015 "CanMars" deployment (#CanMars on Twitter) involved over 50 participants from 6 Canadian institutions organized into operational teams using a suite of integrated instruments onboard the CSA Mars Exploration Science Rover (MESR), built by MDA. The deployment site, near Hanksville, Utah, in the area known informally as Kissing Camel Ridge, was chosen based on an extensive assessment of its suitability from both scientific and engineering perspectives. The landing site region consists of a variety of clastic and chemical precipitates comprising potential samples corresponding to the three highest priority MSR sample suites: sedimentary, hydrothermal, and low temperature[2].

Defining Science Analysis Needs for MSR: The primary focus for continued work with the CanMars team is the science analysis needs for MSR and on the development of systematic protocols to be performed on samples selected and returned from a MSR mission, and an analytical pipeline specifically designed to achieve the 3 main MSR science Objectives. We assume that the Mars 2020 (M2020) will commence the MSR mission sequence with adaptive caching of samples. The overall Aim, broken into 4 goals (below) is to determine the optimum approaches (methodology) and requirements (instrumentation) during deployment (science operations and sample acquisition on Mars) and subsequent laboratory investigations (after the sample has been returned to a sample receiving facility on Earth). The 4 main goals are to:

1) Determine the optimal approach to using the M2020 instruments to select a sample site;
2) Determine what measurements need to be taken with the M2020 instruments in order to adequately characterize the sample in preparation for eventual Earth-based analysis including potential sample prioritization and down selection;
3) Determine the extent that autonomous geological feature detection be used to identify potential sampling sites faster;
4) Determine how best to optimize the detection of organic molecules and other potential biosignatures.

Rover-based instrumentation: The instrument suite includes a number of technologies that when combined will complement and simulate the NASA Mara 2020 payload instruments including: 532 nm Raman spectrometer, visable-near infrared (VIS-NIR) spectroscopy, X-Ray Diffraction/Fluorescence and laser-induced breakdown spectroscopy (LIBS). Three integrated camera systems: a high-resolution, multispectral, stereoscopic mast-mounted panoramic camera (PanCam), a high-resolution zoom-enabled camera (ZoomCam), and a three dimensional exploration multispectral microscope imager (TEMMI).

Laboratory-based methods will be used to assess the fidelity of field analyses and develop an optimized scalar-integrated analytical pipeline: spatially correlated 532, 785, and 980 nm Raman spectroscopy, inductively coupled plasma mass-spectrometry, micro-X-ray diffraction, micro-X-ray fluorescence, optical petrography, electron beam based techniques (including scanning electron microscopy, transmission electron microscopy and electron microprobe analyses, Fourier transform infrared spectroscopy, confocal Raman, and synchrotron beam based spectroscopy.

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ORGANIC GEOCHEMISTRY OF A 1.4-BILLION-YEAR-OLD EVAPORITIC LAKE: INSIGHTS FOR THE MARS 2020 SHERLOC INSTRUMENT.

J. T. Osterhout[1], A. D. Czaja[1] and Fralick P. W.[2], [1]University of Cincinnati (Department of Geology, 500 Geology-Physics, Cincinnati, OH 45221, osterhjt@mail.uc.edu; andrew.czaja@uc.edu), [2]Lakehead University (500 University Avenue, Orillia, ON, pfralick@lakeheadu.ca).

Introduction: Evaporitic lacustrine deposits on Earth provide a useful context for future investigations of early life on Mars. Ancient lacustrine systems are known to exist in many places on Mars [1], and have been considered interesting targets for future astrobiological exploration [2, 3]. Data from the *Curiosity* rover has revealed the presence of a previously habitable fluvial-lacustrine environment at Yellowknife Bay in Gale Crater [4] with ancient sedimentary rocks containing organic compounds native to Mars [5]. The upcoming *Mars 2020* rover mission will be equipped with a Raman spectrometer as part of the SHERLOC instrument, with the ability to detect and characterize organic compounds *in situ* [6]. Thus, similar studies of organic compounds in paleolacustrine settings on Earth can provide valuable insights for future astrobiological investigations.

Materials and Methods: This project examined the organic geochemistry and stable isotope geochemistry of carbonaceous chert-carbonates within the Mesoproterozoic (1.4-Ga-old) Middlebrun Bay Member of the Rossport Formation, Sibley Group in Ontario, Canada. The Rossport Formation has been described in detail and is interpreted as a shallowing-upward sequence of fluvial-lacustrine sediments exposed to increasingly arid conditions and heightened salinity levels [7]. This study will constrain the effects of thermal alteration on sedimentary organic matter by measuring $\delta^{13}C_{org}$ values and independent proxies of thermal maturity in kerogen. Initial Raman spectroscopic analyses of organics within the Middlebrun Bay Member suggest a thermal gradient diffusing outward from a mafic sill that intruded within the Rossport Formation, and this sequence of alteration is evident in the overall appearance of the unit (Fig. 1). Samples from the altered and unaltered zones have been classified according to their Raman Index of Preservation (RIP), a metric that allows for the *in situ* determination of relative geochemical alteration in fossil organic matter [8].

Results: Preliminary Raman spectroscopic measurements show RIP values for kerogen ranging from 7.7 to 6.8 (lower values record greater thermal maturity; Fig. 1), indicating that the degree of thermal maturity decreases with vertical distance away from the sill. Initial bulk carbon isotope analyses of extracted kerogen have yielded $\delta^{13}C_{org}$ values of -28.2 ± 0.1‰, signifying the presence of a microbial community dominated by photosynthetic metabolisms [9]. Further analyses will investigate the vertical succession of $\delta^{13}C_{org}$ values, RIP values and Deep-UV spectra across more than 0.5 m of section. The measured isotopic ratios and Deep-UV spectra will then be compared to their documented spectrum of thermal maturity. These results will provide a detailed geochemical context to facilitate astrobiological interpretations following future detections of organic compounds on Mars by the *Mars 2020* SHERLOC instrument.

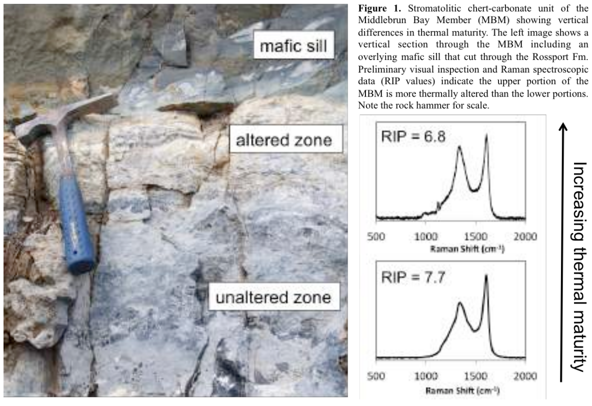

Figure 1. Stromatolitic chert-carbonate unit of the Middlebrun Bay Member (MBM) showing vertical differences in thermal maturity. The left image shows a vertical section through the MBM including an overlying mafic sill that cut through the Rossport Fm. Preliminary visual inspection and Raman spectroscopic data (RIP values) indicate the upper portion of the MBM is more thermally altered than the lower portions. Note the rock hammer for scale.

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PRESERVATION OF ORGANIC COMPOUNDS IN CIRCUMNEUTRAL IRON DEPOSITS.

M. N. Parenteau[1,2], L. L. Jahnke[2], T. F. Bristow[2], S. M. Som[2,3], D. J. Des Marais[2], J. D. Farmer[4]. [1]SETI Institute, Mountain View, CA (mary.n.parenteau@nasa.gov), [2]Exobiology Branch, NASA Ames Research Center, Moffett Field, CA, [3]Blue Marble Space Institute of Science, Seattle, WA, [4]School of Earth and Space Exploration, Arizona State University, Tempe, AZ.

Introduction:

Today liquid water is unstable at the Martian surface due to the low temperature and atmospheric density. However, evidence suggests that during the Noachian (4.1–3.7 Ga) and Early Hesperian (3.7 to ~3.4 Ga), an active hydrologic cycle once existed on Mars [1, 2].

Data collected by the Mars Science Laboratory and Mars Exploration Rover missions from the surface of Mars have provided (and continue to provide) mineralogical insights regarding this hydrologic cycle, including the redox cycling of Fe. The *Opportunity* rover gave the first detailed look at Fe-bearing sedimentary rocks of the Burns formation of Meridiani Planum, Mars [3, 4]. These sediments contain mineralogical and textural evidence of Fe(II) mobilization and oxidation within acidic (pH ~2-4) brines [4, 5]. Acidity was generated through oxidation of upwelling circumneutral Fe(II)-bearing groundwater sourced from an underlying basaltic aquifer [5, 6]. Hurowitz et al. [5] describe how the flux of groundwater to the surface was a key control on the degree of oxidation and pH of resulting brines.

Recent observations made by the MSL rover *Curiosity* highlight the importance of ancient martian sedimentary deposits that experienced a smaller degree of Fe(II) oxidation (and thus, less acidity generated), allowing more benign – low salinity and circumneutral pH conditions to persist [7, 8, 9, 10].

Microbes such as chemolithotrophs can exploit the oxidation of Fe(II) to power their metabolism in both acidic as well as circumneutral settings [11]. We are investigating the capture and retention of chemolithotrohpic and phototrophic biosignatures in modern circumneutral Fe springs to (1) characterize the composition of lipid biomarkers produced by the microbial communities, and (2) determine how lithification by Fe oxides affects the biomarker signature of the communities. The aim is to characterize the taphonomy of the lipid biomarkers in this Fe-rich system, namely, which compounds survive microbial degradative processes within the mats and through the earliest stages of diagenesis in the Fe deposits beneath the mats.

Results:

We analyzed two distinct microbial populations: phototrophic mats containing photoferrotrophs, and a loose biofilm composed of chemolithoautotrophs such as *Leptothrix* and *Gallionella*. The phospholipid and glycolipid fatty acid profiles of the highest-temperature microbial mats indicate that they are dominated by cyanobacteria and green nonsulfur filamentous anoxygenic phototrophs (FAPs). Diagnostic lipid biomarkers of the cyanobacteria include midchain branched mono- and dimethylalkanes and, most notably, 2-methylbacteriohopanepolyol. Diagnostic lipid biomarkers of the FAPs (*Chloroflexus* and *Roseiflexus* spp.) include wax esters and a long-chain tri-unsaturated alkene. Surprisingly, the lipid biomarkers resisted the earliest stages of microbial degradation and diagenesis to survive in the Fe oxides beneath the mats. Understanding the potential of particular sedimentary environments to capture and preserve fossil biosignatures is of vital importance in the selection of the best landing sites for future astrobiological missions to Mars. This study explores the nature of organic degradation processes in Fe(II)-rich groundwater springs— environmental conditions that have been previously identified as highly relevant for Mars exploration.

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PRESERVATION OF ORGANIC MOLECULES UNDER COSMIC RAYS IN MARTIAN SURFACE ROCKS.

A. A. Pavlov[1] D. Glavin[1], H. McLain[1], J. Dworkin[1], J. Elsila-Cook[1] and J. Eigenbrode[1] [1]NASA Goddard Space Flight Center, Greenbelt MD 20771 (alexander.pavlov@nasa.gov).

Introduction: Organic molecules in the top meter of Martian rocks are poorly protected from Cosmic Rays radiation. Yet, the entire strategy of the Mars Exploration Program's search for the extinct life on Mars is based on the assumption that some original complex organic molecules would be able to survive for hundreds of millions - billions of years in the ancient Martian outcrops. Therefore, it is critical to understand the preservation of organic molecules under various dosages of ionizing radiation.

Recent modeling studies [e.g. 1] suggested that amino acids with masses >100 amu would be effectively destroyed in less than 1 billion years in the top 5 cm of the Martian rocks. However, Pavlov et al (2012) calculated the fraction of the survived organic molecules using conservative radiolysis constants derived from the gamma irradiation experiments on pure dry amino acid mixtures [2]. Cosmic rays can produce oxidative radicals in the immediate vicinity of the organic molecules within the rocks and increase the rate of organic degradation.

Methods: To evaluate the rate of amino acids degradation by cosmic rays in Martian rocks we exposed amino acids (AAs) mixed with SiO_2, hydrated SiO_2 and SiO_2/perchlorate powders to gamma ray ionizing radiation (an analogue of CRs) at room and -50 C temperatures. For the analysis of AAs abundance and distribution in SiO_2 powder we used the extraction procedure and liquid chromatography time of flight mass spectrometry techniques from [3]. The effects of accumulated dosage of up to 2 MGy were investigated by comparing the amount of AAs compounds in control (nonirradiated) samples relative to irradiated materials.

New radiolysis constants for aminoacids were derived. Radiation accumulation rates in the Martian rocks were derived with the state of-the-art GEANT4 code. Newly derived radiolysis constants were then combined with the radiation accumulation rates to determine the rate of organic destruction and alteration by Galactic Cosmic Rays (GCRs) and Solar Cosmic Rays (SCRs) on Mars.

Results: 1) The destruction rate of amino acids in silicate powder mixtures is dramatically higher than in pure dry amino acid mixtures. Therefore, all amino acid molecules, which were either produced (by biosphere or deposited (by meteorites) on Mars earlier than 50-100 million years ago would have very little chance of survival without alteration in the surface Martian rocks.

2) The destruction rate of all amino acids increases dramatically even further if several percents of H_2O are added to the SiO_2. Therefore, hydrated minerals are the worst place to look for the intact ancient organic molecules on Mars.

3) Cold temperatures (-50 C) slow down the rate of amino acid degradation slightly. However, even under cold temperatures amino acids would be mostly destroyed in just 50-100 million years of cosmic ray exposure in the top meter of Martian rocks.

4) Efect of perchlorates will be reported at the meeting.

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IDENTIFICATION AND VALIDATION OF BIOGENIC PRESERVATION: DEFINING CONSTRAINTS WITHIN MARTIAN MINERALOGY.

S. M. Perl[1,2], P. A. Vaishampayan[1], F. A. Corsetti[2], O. Piazza[2], M. Ahmed[1,3], P. Willis[1], J. S. Creamer[1], K. W. Williford[1], D. T. Flannery[1], M. L. Tuite[1], B. L. Ehlmann[1], R. Bhartia[1], B. K. Baxter[4], J. Butler[4], R. Hodyss[1], W. M. Berelson[2], K. H. Nealson[2], [1]California Institute of Technology / NASA Jet Propulsion Laboratory 4800 Oak Grove Drive, Pasadena, CA 91109 (scott.m.perl@jpl.nasa.gov) [2]Department of Earth Sciences, Zumberge Hall of Science, University of Southern California, 3651 Trousdale Pkwy, Los Angeles, CA 90089 (scott.perl@usc.edu) [3]Biological Sciences, Cal Poly Ponoma [4]Westminster College, Salt Lake City, UT

Introduction & Motivation: Minerals precipitated from former and currently receding lake beds can capture and entomb biogenic evidence within its crystal structure. We seek to understand how preservation of DNA and proteins, within such aqueous settings, can sustain preservation on different timescales in order to confine how we view minerals observed within the Martian shallow subsurface both from orbit and on the surface. We have chosen to investigate the evaporate minerals halite and gypsum due to their confirmed detection by the CRISM instrument [1], their physical transparency, and short-term precipitation timescales. These minerals have been observed within the subsurface of Mars [2] in proximity to ancient aqueous settings either via groundwater or evaporated lake beds.

Methodology: In order to understand how archaea is preserved and how to uncover these biogenic features in-situ we have employed the use of two independent investigations. Microbiologically, we intend to extract and confirm entombed DNA within the evaporate crystals gypsum and halite. After successful extraction and confirmation preserved DNA will be sequenced to understand what forms of life can inhabit and thrive in such saline environments. Both gypsum and halite have been collected from our sites with careful field procedures in mind to avoid introducing contamination into our sample sets. Our DNA extraction techniques and protocols allow for solid samples to be examined directly to allow for a direct field-to-lab analysis [3]. After sequencing information is known we will attempt to geographically correlate known archaea to other field sites that share common aqueous histories. Laboratory spectral analyses will also be made to compare mineral information from the CRISM instrument on MRO to field samples to compare diagnostic absorption bands from minerals observed on Mars to our samples [4]. Complementary analyses will also measure proteins and bulk organics. Analogous to the above experiments we will also use instrument concepts selected for the next Martian rover to analyze our known biogenic-filled minerals [6] to determine differences in instrument datasets

Current Results & Ongoing Efforts: We have successfully developed protocols for solid sample DNA extraction and verified via qPCR the presence of entombed DNA in our halite crystals. SEM (Fig. 1) and lab spectrometer investigations have shown that our field gypsum and halite have similar absorption bands to minerals observed by the CRISM instrument. Ongoing investigations continue to determine protein and bulk organic carbon content.

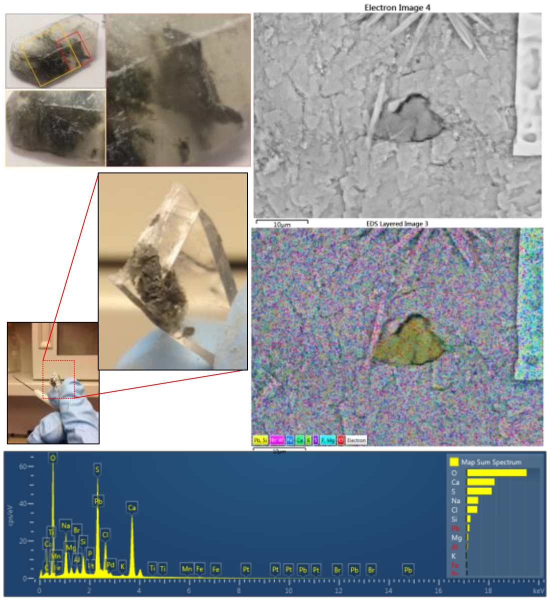

Figure 1. Gypsum crystal with entombed clays and organics (Top-L). SEM image showing micron-scale organic and clay mixture (top-R). Image under EDS filter (mid-R). Elemental spectrum of clay/organic mixture within gypsum parent constituent (bottom).

Future analyses include comparing datasets with the Mars 2020 instrument concepts [5,6] and their instrumentation such as green and deep UV (SHERLOC) and X-Ray fluorescence (PIXL) to understand how organics will be analyzed in-situ if found in the Martian shallow subsurface [7].

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VISIBLE NEAR-INFRARED REFLECTANCE SPECTRA OF HYDROTHERMAL SILICA SINTER DEPOSITS AND EXTREMOPHILES.

J. B. Plescia[1] and J. R. Johnson[1], [1]Applied Physics Laboratory, The Johns Hopkins University, Laurel, MD 20723 (jeffrey.plescia@jhuapl.edu; jeffrey.r.johnson@jhuapl.edu).

Introduction: Silica has been recognized in reflectance spectra of Mars [1,2] and hydrothermal activity would be expected on the surface given the close spatial and temporal association of volcanism and water. Martian hydrothermal sites have also been suggested to be areas where life may existed (or exist). We present visible near-infrared (VNIR) reflectance data on hydrothermal sinter deposits and on hyperthermophile organism.

We collected data from a variety of sites including Yellowstone National Park WY and Beowawe, Steamboat Springs and Fish Lake NV. The silica ranges in age from modern (i.e., being actively deposited) to Pleistocene. In addition, we collected reflectance spectra of extremophile organisms from a number of springs in Yellowstone.

Data Source: Reflectance spectra (0.35 to 2.5 µm) were acquired using an ASD Field Spectrometer with both artificial and natural light. *In-situ* sinter samples were not prepared and thus have variable grain size, porosity, alteration and coatings. When possible, data were collected of dry sinter. Spectra for the hypertherophiles were collected *in situ* (under water) and from samples where the surface water was not present.

Results: Figure 1 illustrates example VNIR data for sinter deposits at several sites. The major absorptions are related to the presence of H_2O and OH in the sample including 1.4 and 1.46 µm (overtone -OH stretch), 1.9 and 1.96 µm (-OH stretch and H-O-H bending) and 2.21 and 2.26 µm (-OH stretch and Si-OH bending). The crystalline phase (micro- and nanocrystalline opal) will influence the location of the 1.4 µm absorption.

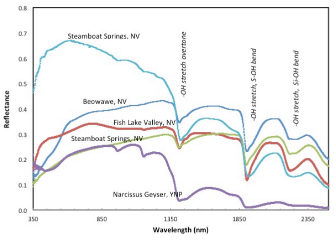

Figure 1. VNIR reflectance spectra of sinter deposits.

In addition to H_2O and OH features, a variety of absorptions occur due to the presence of coatings, particularly at Beowawe. Many of the coatings are due to post deposition alteration. The degree of alteration varies considerably and thus the spectra vary (Figure 2). The most common alteration species is iron-bearing (Fe^{2+}, Fe^{3+}), as well as clay minerals [3,4]. These produce a drop off <0.6 µm and broad absorptions near 0.8-0.9 µm. The positions of the features are a function of the degree of hydration. The absorptions associated with bound water become more complicated due to interaction with absorptions due to phyllosilicates and other species.

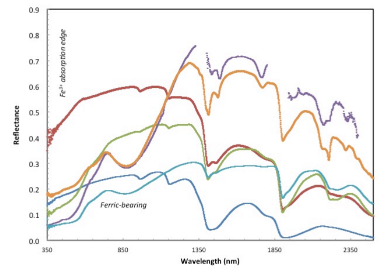

Figure 2. Altered sinter, primarily Fe-based species.

Spectra were collected on silica associated with the hyperthermophiles deposited along the course of the outflow channel. As soon the organism die due to changes in the outflow, silica rapidly looses it coloring and become dry and friable.

Spectra were collected of the various hyperthermophiles and acidophiles found in the springs. The principal species have similar spectra among different springs and can be separated from other major species. Figure 3 illustrates the VNIR spectra for *Synechococcus* and *Chloroflexus* from Octopus Spring at Yellowstone National Park.

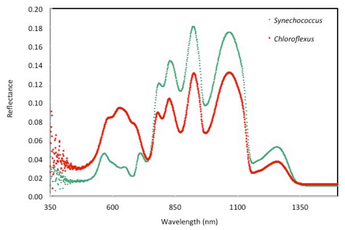

Figure 3. VNIR spectra of *Synechococcus* and *Chloroflexus in situ.*

Conclusions: VNIR spectra of hydrothermal sinter shows a range of absorptions due to H_2O and OH as well as due to alteration and secondary minerals. Spectra of extremophiles shows that species can be differentiated base on the absorption wavelength. Even though the same pigments are present in different species, the manner in which they are hosted in the cell changes the absorption wavelength.

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PROGRESSIVE DIAGENETIC ALTERATION OF MACRO- AND MICRO-SCOPIC BIOSIGNATURES IN ANCIENT SPRINGS AND SPRING-FED LACUSTRINE ENVIRONMENTS.

S.L. Potter-McIntyre[1] J. Williams[1], C. Phillips-Lander[2], and L. O'Connell[1]. [1]Southern Illinois University, Geology Department, Parkinson Lab Mailcode 4324, Carbondale, IL, 62901, Email: pottermcintyre@siu.edu, [2] University of Oklahoma, School of Geology and Geophysics.

Introduction: Biosignatures can be preserved via microbial enhancement of mineral precipitation during deposition and/or early diagenesis [e.g., 1,2,3]. Preservation of any type of microbial fossil or chemical or textural biosignature depends on the degree of alteration during diagenesis and factors such as exposure to diagenetic fluids [1,2]. Microbial carbonates have been extensively examined in modern systems; however, little is known about the transformation of biosignatures during diagenesis over geologic time [4,5]. Understanding the alteration and preservation of biosignatures is essential for recognizing these signatures in the rock record of both early Earth and Mars.

Purpose of study: Mineralogical and morphological biosignatures in modern spring deposits are compared with the Quaternary (100-400ka) and Jurassic examples to show how these biosignatures are altered during diagenesis. These successively older carbonate microbialites provide a novel opportunity to investigate how macroscopic features diagnostic of spring deposits and microscopic biosignatures are progressively altered and preserved on geologic time scales.

Study site: Spring systems are important because they also may represent a formation mechanism of some carbonates in the solar system, particularly analogous to those present in lacustrine settings such as the carbonates at Gale crater, Mars [6]. Ten Mile Graben, UT, USA hosts a cold spring system that is an exceptional site to evaluate diagenetic alteration of biosignatures due to the presence of modern springs with actively precipitating microbial mats and a series of progressively older tufa terraces (<400ka) preserved in the area from the same spring system [7]. A Jurassic laminated carbonate deposited in a restricted spring-fed hypersaline lake environment within the upper part of the Brushy Basin Member of the Morrison Formation is also exposed in Ten Mile Graben [8]. Silcretes (bedded silica-rich lenses) that increase in abundance beneath the thickest parts of the carbonate provides additional evidence that this carbonate was spring-fed and the presence of barite suggest the spring was hot [8].

Macroscopic Spring Features: Macroscopic features associated with spring deposits are preserved throughout geologic time, even delicate macroscopic features such as terracettes and bushy spheres. Secondary processes such as vein precipitation during early diagenesis and Ostwald ripening likely does affect and degrade some of these macroscopic features; however, these processes do not completely destroy the identifying structures.

Two Types of Biomineralization: The data highlight two distinct methods of biosignature formation: 1. microbial metabolic activity induces mineral precipitation in a solution with nearly undetectable amounts of reactants, and 2. minerals nucleate on charged cell surfaces [9]. Minerals such as hematite and ferrihydrite precipitate from very low to undetectable amounts of iron suggesting microbial metabolisms are responsible for the iron minerals that render spring deposits red. Microbes also produce trace fossils by creating an environment conducive to mineral precipitation and, in turn, the presence of these minerals help preserve these features.

Although organic matter may decompose in oxidizing near-surface conditions, this study shows that some microbial body fossils and trace fossils such as honeycomb textures can persist due to encasement by iron (oxyhydr)oxides and/or by entombment via Ostwald ripening of carbonates. For example, early permineralization of sheaths of Leptothrix render this microbial population particularly resistant to destruction and degradation during early diagenesis. Features such as sheaths and honeycomb trace fossils were preserved in the Jurassic example due to Ostwald ripening encasing these features and shielding them from diagenetic alteration and destruction on hundred million year time scales.

This field site preserves an excellent record to understand the taphonomy of macroscopic and microscopic biosignatures preserved in discrete time slices in the geologic record. Recognizing spring-fed, biogenic tufas is crucial for astrobiological research and the search for life on Mars.

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RADIOLYTIC ALTERATION OF BIOSIGNATURES ON MARS.

R. C. Quinn[1], [1]Carl Sagan Center, SETI Institute (NASA Ames Research Center, M/S 239-4 Moffett Field, CA 94035, Richard.C.Quinn@nasa.gov)

Introduction: A major objective of the Mars 2020 mission will be to "explore an astrobiologically relevant ancient environment on Mars to decipher its geological processes and history, including the assessment of past habitability and potential preservation of possible biosignatures" [1]. This exploration strategy follows on the success of the remarkable geological discoveries made with the Mars Science Laboratory (MSL) and Mars Exploration Rovers (MER), including evidence of ancient environments, which based on evaluation of geological context, may have once been habitable. For example, a habitable fluvio-lacustrine environment at Yellowknife Bay in Gale Crater has been explored by MSL [2]. The discovery of clay minerals in Esperance by the Opportunity rover on the rim of Endeavour Crater, suggests that the area was once a habitable aqueous environment with a circum-neutral pH [3]. Much earlier in the MER mission, the Sprit rover uncovered ample evidence for the presence of potentially habitable environments in the form of sedimentary outcrops including sulfates and carbonates [e.g., 4]. These are just a few examples and with each successive Mars mission the geological evidence for, and distributions of, ancient habitable environments increases.

However, while contextual information derived from in situ observations has lead to the identification of numerous preserved geological formations that were likely habitable on early Mars, examination of some of these materials on a molecular scale indicate that extensive chemical alteration has occurred. The results of the biological and chemical analyses performed at the Viking, Phoenix, and MSL landing sites highlights the current knowledge gaps in our understanding of the alteration of ancient habitable environments and potential impacts on chemical and biosignature preservation. It appears that chemical alteration mechanisms on Mars, driven by surface and subsurface radiation environments, is remarkably different from environments on Earth, and calls into question the current state knowledge about the chemical state of martian geological formations and preservation state of biosignatures on Mars.

Experimental: Spatially and temporally evolved alterations in synthetic and natural Mars analogs materials are experimentally probed using X-ray Photoelectron Spectroscopy (XPS). The technique allows the characterization of localized chemical alteration induced in situ in the XPS system using X-ray, e-beam, and ion-gun ionizing radiation sources.

Figure 1 shows an example of the transformation of calcium perchlorate into lower oxidation state chlorine species by ionizing radiation (1.487 keV X-rays) as measured by XPS in the lab.

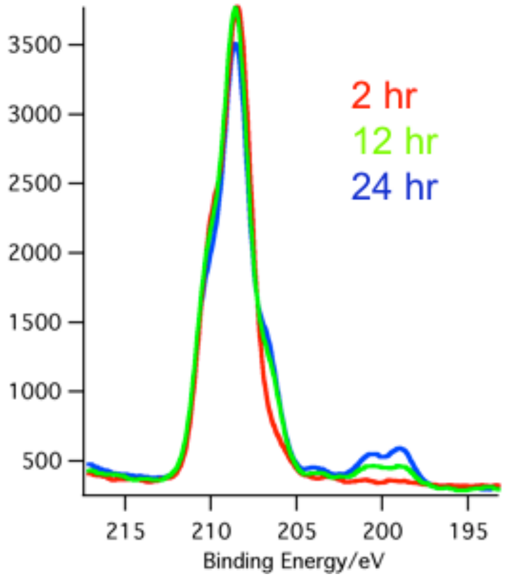

Fig. 1. Calcium perchlorate XPS spectra of the chlorine 2p region ($2p_{3/2}$ $2p_{1/2}$ doublet). Formation of peaks at binding energies 204-198 eV over time indicate the formation of chlorine dioxide, hypochlorite and chloride upon sample to exposure to ionizing radiation.

Our results show a that, when exposed to ionizing radiation, a complex distribution of redox states and reactive intermediates form in both perchlorate and nitrate salts. These reactive species, in turn act to alter associated organic biosignatures in situ. These results will be discussed in the context of organic biosignature alteration mechanisms and forms organic biosignatures that may be preserved on Mars.

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MINIATURE LIMS SYSTEM FOR IN SITU DETECTION OF BIOSIGNATURES.

A. Riedo[1,2], M. Tulej[1], M.B. Neuland[1] and P. Wurz[1], [1]Physics Institute, Space Research and Planetary Sciences, University of Bern, Switzerland (andreas.riedo@space.unibe.ch), [2]Leiden Observatory, Sackler Laboratory for Astrophysics, University of Leiden, Netherlands.

Introduction: In situ detection of biosignatures and biomarkers on planetary surfaces is highly challenging and continuously drives the development of new sample collection strategies, extraction procedures, and measurement techniques and protocols with improved figures of merit, including e.g., quantitative nature of measurement and detection sensitivity, for future space missions.

In our contribution, we will present the current measurement performance and capabilities of our miniature Laser Ablation Ionization Mass Spectrometer (LIMS, instrument name LMS) for sensitive and quantitative in situ chemical analyses (element, isotope and molecular) of solids on planetary surfaces. The studies are performed with high spatial resolution (lateral and in depth) suitable for investigations of grain-size samples.

LIMS Instrument and Measurements: The LIMS system developed in our group is a miniature (160 mm x 60 mm) reflectron-type time-of-flight laser ablation ionization mass spectrometer designed for in situ space research. The high detection sensitivity (10 ppb, atomic fraction), the high dynamic range (about ten orders of magnitude) and the application of a femtosecond laser system (λ = 775 nm, τ = ~ 190 fs) for ablation and ionization of sample material allow to conduct sensitive and quantitative measurements of the chemical composition (element, isotope and molecular) of highly heterogeneous solids with high lateral (10–15 µm) and vertical resolution (sub-nanometer) [1].

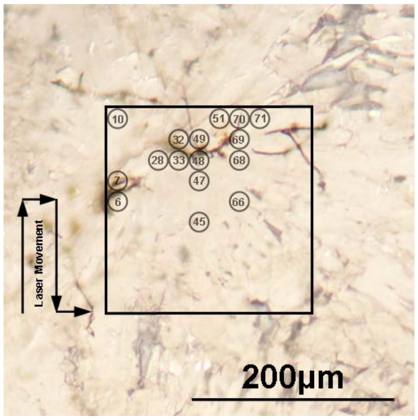

Figure 1: Fossils (black veins) of micrometer dimensions are embedded in a host matrix. The spot-wise sensitive chemical analysis using the miniature LIMS system allowed the identification of fossil structures within the heterogeneous sample material. Image taken from Tulej M. et al., 2015 [2].

Measurements conducted on various complex sample structures will be discussed in detail to present the current measurement capabilities of the miniature LIMS system, including e.g., fossils of micrometer dimensions embedded in serpentinized harzburgite matrix (see Fig. 1), mineral phases in a heterogeneous rock sample, or chemical heterogeneity in Pb-Bronze alloys [2, 3].

Furthermore, the current design of the LMS instrument allows switching between the harsh atomization and the gentle desorption mode at sample depth of interest. Including the high spatial analytical capabilities of the instrument and the in situ onscreen visualization of measurements molecular studies at interfaces between different crystalline domains within the sample material can be conducted [4]. This measurement protocol will be presented as well and is of considerable interest in various field of research, ranging from geology to astrobiology.

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OPALINE SILICA OCCURRENCES IN THE COLUMBIA HILLS OF MARS: A CASE STUDY IN THE HUNT FOR BIOSIGNATURES.

S. W. Ruff[1] and J. D. Farmer[1], [1]Arizona State University, School of Earth and Space Exploration, Tempe, AZ 85287-6305, steve.ruff@asu.edu.

Introduction: Occurrences of opaline silica (amorphous $SiO_2•H_2O$) have been recognized on Mars with orbiter and rover assets [e.g., 1; 2; 3]. The Spirit rover encountered opaline silica rocks and soil adjacent to Home Plate in the Columbia Hills of Gusev crater that were interpreted to be the products of a volcanic hydrothermal system [2]. The silica rocks commonly occur in nodular masses that have a rubbly appearance but are considered outcrops because of their stratiform expression and resistance to deformation by the rover wheels. Their origin via acid-sulfate leaching of basaltic precursor materials by fumarolic steam condensates was the favored hypothesis in the initial analysis, based largely on geochemical arguments [2]. An origin as hot spring siliceous sinter deposits produced from alkali-chloride waters also was considered in that work. A subsequent analysis presented salient observations of the silica outcrops that support a hot spring and/or geyser origin [4]. We now find remarkable similarities in the silica at Home Plate and El Tatio, a geothermal field at ~4300 m elevation in Chile's Atacama Desert.

Spectral Features: Spectra of Home Plate silica outcrops obtained by Spirit's Miniature Thermal Emission Spectrometer (~340 – 2000 cm^{-1}) commonly display a strong absorption near 1260 cm^{-1} that typically is weak or absent in terrestrial opaline silica [4]. Based on silica sinter samples from El Tatio, we can now attribute this feature to a thin (10s of micrometers) patchy crust of halite that accentuates a feature of opal-A. The inferred halite crust on Home Plate silica implies chloride-bearing solutions rather than fumarolic gases, consistent with a hot spring/geyser origin.

Morphologic Features: The nodular appearance of the Home Plate silica outcrops and their common digitate structures (Fig. 1A) were interpreted to be the result of aeolian erosion of a formerly more extensive rock unit [4]. However, El Tatio hot spring/geyser discharge channels produce silica sinter with characteristics comparable to the Martian silica outcrops (Fig. 1B). The digitate structures typically are found within channels of shallow (<5 cm depth) flowing water that support microbial mats of diatoms and filamentous bacteria, where water temperature is <40°C. Water pH is circum-neutral (~6.5-7.5) throughout El Tatio [5].

Scanning electron microscopy supported by energy dispersive spectroscopy of El Tatio digitate silica structures reveals: internal microlaminations with fenestral porosity; silica encrusted microbial features on both internal and external surfaces; and C enrichment consistent with organic matter. Petrographic thin sections of these structures reveal laterally persistent, lenticular to wavy laminations dominated by distinctive palisade microtextures oriented roughly perpendicular to laminations, with local populations of heavily ensheathed fossil cyanobacteria resembling *Calothrix* (family Rivulariaceae). Based on the suite of textural and microbial features, supported by spectroscopy, we infer that El Tatio digitate silica structures are microbially mediated microstromatolites and that the Martian structures are thus potential biosignatures.

Fig. 1. Nodular silica with digitate structures adjacent to Home Plate, Mars (A) and in El Tatio, Chile (B) at the same scale. The latter are biomediated.

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HABITABILITY AND BIOSIGNATURE PRESERVATION IN IMPACT-DERIVED MATERIALS. H. M. Sapers[1], A. Pontefract[1,†], G. R. Osinski[1,2], K. M. Cannon[3], J. F. Mustard[3] [1]Centre for Planetary Science and Exploration/ Dept. of Earth Sciences/ [2]Dept. of Physics and Astronomy, University of Western Ontario, [3]Department of Earth, Environmental and Planetary Sciences, Brown University, [†]Current affiliation: Department of Earth, Atmospheric and Planetary Sciences, Massachusetts Institute of Technology (hsapers2@uwo.ca)

Introduction: The catastrophic biological effects of meteorite impact events are well established. However, meteorite impact events also create unique microbial niches that may have been widespread habitats on early Earth and, as such, are important astrobiological targets on other rocky bodies such as Mars [1]. Impact materials represent understudied microbial substrates both for microbial colonization as well for the potential to preserve evidence of biological activity. Any large enough impact into a H_2O-bearing planetary body will result in an impact generated hydrothermal system (IGHS) [2] that will cool to temperatures capable of supporting thermophilic (heat-tolerant) life, persisting anywhere from thousands to millions of years.

Impact-generated hydrothermal systems: IGHS have been documented in 70 of ~180 terrestrial impact structures [3] and mineralogy and morphology consistent with impact generated hydrothermal activity has been described at several Martian impact crater [4].The interaction of water with heated impact materials forms a high-temperature rock-water circulatory system that can dissolve, transport, and precipitate various mineral species [5]. IGHS and associated mineral deposits are characterized by chemical and thermal disequilibria rendering them attractive systems for microbial colonization. It has been suggested that warm and wet conditions are required to form hydrated silicates on Mars, therefore, clay forming epochs and regions are used to indicate potential habitability [6] and that warm, wet conditions are restricted to the earliest period of Martian history implying that both habitable and phyllosilicate-forming environments are limited to the Noachian Period (e.g., [7]). However, spatially and temporally extensive IGHS and weathering of impact-derived materials provide an alternative mechanism for hydrated silicate generation [4]. IGHS may provide transient, local warm, wet conditions associated with clay formation temporally extending periods of habitability on Mars.

Biosignatures:

Hydrothermal systems: Evidence of microbial colonization has been described in several IGHS deposits. Titanium oxide 'biomineralized' rod-shaped features and associated etch pits on hydrothermal clinoptilolite at the Ries structure [8]; rod-shaped biomorphs in post-impact hydrothermally altered sediments from the Chesapeake Bay structure [9]; evidence of extracellular polymeric substances in a hydrothermally precipitated calcite vein from the Siljan structure [10]; and filamentous 'fossils' hosted in hydrothermally precipitated mineral assemblages within fractured impact breccia from the Dellen structure [11]. We have also reported microbial etching [12] and putative evidence of microbial Fe reduction [13] in hydrothermally altered impact glass clasts from the Ries structure.

Shocked crystalline rock: The process of shock metamorphism is capable of altering pre-existing terrestrial environments such that they become viable biotic habitats [14]. These endolithic habitats offer warm, moist, and UV-protected environments. Studies of impact-generated lithologies indicate that shock metamorphism increases the porosity of the target rocks [15] and increases the colonizable area providing a refugia for microorganisms. Biomass increases with increasing exposure to pressure within the target [16].

Impact glass: Impact glasses also comprise a unique substrate for microbial colonization. Microbial alteration of natural glasses is a widespread natural phenomenon and the habitability of subaerial (e.g., [17]) and submarine (e.g., [18]) natural glasses suggests that impact glasses are potential habitats. Impact generated glasses have been shown to preserve both evidence of pre-impact biological material [19] and evidence of post-impact microbial colonization [13]. With the recent spectral identification of glasses associated with Martian impact craters [20], impact generated lithologies represent exciting new astrobiology targets for future exploration.

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IMPACT OF DIAGENESIS ON BIOSIGNATURE PRESERVATION POTENTIAL IN PLAYA LAKE EVAPORITES OF THE VERDE FORMATION, ARIZONA: IMPLICATIONS FOR MARS EXPLORATION.

S. Shkolyar and J. D. Farmer, School of Earth and Space Exploration, Arizona State University, Tempe, AZ, sshkolya@asu.edu.

Introduction: NASA's two major priorities for Mars science include (1) seeking biosignatures that can reveal whether Mars hosted life and (2) characterizing the biosignature preservation potential (BPP) of habitable environments [1,2] (i.e., aqueous sedimentary environments such as evaporitic sulfates, including gypsum [3]). This work addresses both priorities with a two-task study of evaporite deposits in the Upper Pliocene Verde Formation in Verde Valley, AZ [4,5]. Evaporites studied include bottom-nucleated halite and displacive growth gypsum in magnesite-rich mudstone. These evaporite lithotypes provide what we consider to be a potentially relevant, but little-studied example of a high priority ancient habitable environment on Mars: Gale Crater.

Goals: The two goals of our study were to (1) identify different evaporite subfacies within the playa sequence and the diagenetic pathways for each and (2) assess how diagenetic processes affected biosignature preservation potential.

Methods: Methods combined outcrop-scale field observations and lab analyses, including: (1) thin-section petrography to understand diagenetic processes and paragenesis; (2) X-ray powder diffraction to obtain bulk mineralogy; (3) Raman spectroscopy to identify and place phases (and kerogenous fossil remains) within a microtextural context; (4) Total Organic Carbon (TOC) analyses to estimate weight percentages of preserved organic carbon for each subfacies endmember; and (5) electron microprobe to create 2D kerogen maps in order to quantify kerogen preservation *in situ* and at the microscale in each subfacies.

Results: Results revealed eight distinct diagenetic histories for each evaporite subfacies and inferred pathways for organic matter preservation. Fine grained sediments (including phyllosilicates) were deposited on ephemeral playas from proximal alluvial fan sources. Evaporative processes formed concentrated brines that accumulated as $CaSO_4$-enriched zones of saturation just below the playa surface. Early diagenetic gypsum grew displacively within the mudstone playa sediments, forming crystal clusters. Gypsum was altered in three diagenetic processes. During periods of lower salinity, displacive growth gypsum dissolved, leaving behind external crystal molds in the host mudstone. In many instances, gypsum crystal clusters were recrystallized. In some instances, molds were infilled with secondary gypsum crystals. Some secondary crystals experienced Na-Ca-Sr cation-substitution, after Na-, Ca-, or Sr-rich brines came into contact with the molds. Gypsum also experienced dehydration to anhydrite, likely when shallow brines reached temperatures of 35°C and pore-fluid salinity reached halite saturation. Another subfacies is represented by haite-thenardite (Na_2SO_4) pods. The pods are interpreted to have formed by localized karsting of older evaporites, forming brine ponds where crystal growth occurred in low areas on the playa surface. This resulted in bottom-nucleated halite (and gypsum) crystallization, followed by later stage thenardite replacement. Ca consumption by sulfate and carbonate precipitation may have lead to progressive enrichment of SO4, Na, and Cl in ponded surface brines. Burial and basin filling, the development of a younger lacustrine lake system dominated by carbonate sedimentation during the Pleistocene, and the cementation of the Verde playa sediments (by magnesite and calcite) were completed by the introduction of Mg and Ca carbonate cements.

Although playa lakes are known to have high rates of organic matter production, diagenesis likely had an impact on biosignature retention following initial capture of organic matter. TOC analyses suggest that post-diagenetic mudstones had the highest BPP. BPP was lower and comparable among displacive growth gypsum and halite-thenardite subunits.

Discussion: These observations help refine taphonomic models for biosignature preservation potential in evaporite environments originating from Mg-Na-Ca-SO_4-Cl brines in hydrologically closed continental basins. This work has the potential to inform *in situ* target identification, sampling strategies, and data interpretations for future Mars Sample Return missions such as NASA's Mars 2020 mission.

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SPECTRAL EVOLUTION OF BIOREDUCED FERRIHYDRITE BY HYPERTHERMOPHILES.

E. C. Sklute[1], S. Kashyap[2], J. F. Holden[2], and M. D. Dyar[1], [2]Mount Holyoke College, Dept. of Astronomy, South Hadley, MA, 01075, [2]University of Massachusetts, Amherst, Dept. of Microbiology, Amherst, MA. 01003, ecsklute@mtholyoke.edu.

Introduction: It is likely that any putative life on Mars, past or present, is microbial. Yet finding distinct evidence of that life is challenging because all organic signatures may have been lost. Thus, understanding mineralogy associated with microbial activity is important as it could reveal and identify extinct or extant life in extraterrestrial environments. Microorganisms that reduce Fe^{3+} oxide minerals to form other iron oxide minerals are among the more favorable organisms to study for microbial mineral transformations. Hyperthermophiles (T_{opt} >80°C) occupy the deepest and least evolved branches in the phylogenetic tree of life [1], and thus may represent extraterrestrial life elsewhere.

Most of what is known about microbial Fe^{3+} reduction has been established for mesophiles rather than the hyperthermophiles, and the analytical tools used are often incompatible with extraterrestrial capabilities. Here, we characterize biogenic minerals produced by hyperthermophilic Fe^{3+} reduction through a combination of instrumentation that could reasonably appear on remote or landed missions. We critically examine how sample preparation techniques influence end products of these transformations to enable understanding of how signatures on Mars may differ from laboratory spectra and how those signatures change with time.

Methods: Ferrihydrite was synthesized [2] and stored as a liquid suspension to maintain mineral-fluid surface properties. *Pyrodictium* sp. Su06 was grown [3] using four variations for each experiment to add controls to the study: 1) a sample with no cells added (but with growth medium and oxide) left at room temperature (RT); 2) a sample with no cells incubated at 90º C; 3) a sample with cells left at RT; and 4) a sample with cells incubated at 90 ºC. Growth and Fe^{2+} were determined [4] and transformed mineral products were characterized using mid-infrared attenuated total reflectance (Thermo Fisher Nicolet 6700 FTIR, 256 scans per spectrum), visible near infrared (ASD Fieldspec3 Max), and Raman (WiTec alpha300R confocal imaging system; 532 nm Nd YAG laser; 50X; 360 1-sec. integrations) spectroscopies as well as transmission electron microscopy (TEM; Philips CM 100, tungsten filament, 80KV). Mössbauer (See-Co.W100; 50-30 mCi ^{57}Co in Rh; referenced to α-Fe foil) spectra were acquired for both freeze-dried samples (initially frozen samples dehydrated under vacuum at RT) as well as frozen suspensions.

Results: In all cases, ferrozene assays showed that that Fe^{2+} resides in or on the mineral phase. Yet Mössbauer results show that the freeze-dried sample has >10% $Fe^{2+,}$ where the frozen sample has at least 23%.

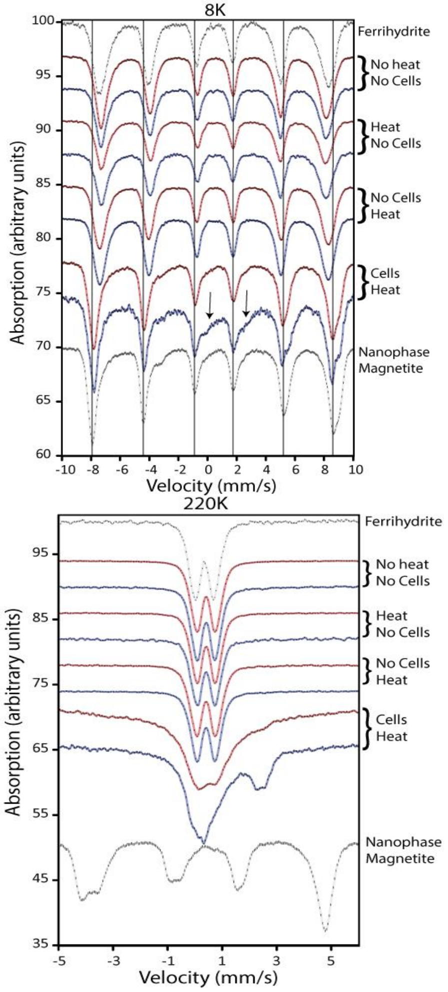

Figure 1. Mössbauer spectra of frozen (blue) and freeze dried (red) bioreduced samples and controls.

Conclusions: These results indicate that even under vacuum, bioreduced samples may oxidize during drying. Alternatively, the solutions phase may create an energetically different coordination environment for a percentage of the iron in these samples. These represent two possible spectral signatures of microbial life.

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SEEKING SIGNS OF LIFE IN ANCIENT MARTIAN HOT SPRINGS WITH ICELANDIC ANALOGS.

J.R. Skok[1], J.D. Farmer[2], G. Jerman[3], J. Gaskin[3], N. Lindsey[4], C. Munoz-Saez[4], H. Kaasalainen[5], D. Tobler[6], M. Parente[7], K. L. Craft[8]. [1]SETI Institute, Mountain View, CA. jrskok@seti.org. [2]Arizona State University, Tempe, AZ. [3]NASA Marshall Space Flight Center, Huntsville AL, [4]University of California, Berkeley, CA. [5]Luleå University of Technology, Luleå, Sweden. [6]University of Copenhagen, Denmark. [7]UMass Amherst, MA, [8]Applied Physics Lab, Johns Hopkins University, Laurel, MD.

Introduction: The Mars community is actively developing strategies to explore for biosignatures in a variety of geologic environments. Here we describe an ongoing effort to develop a mission profile for biosignature detection in ancient siliceous hydrothermal systems. This is motivated by the spectral and chemical identification of silica deposits the Nili Patera caldera of Syrtis Major [1, Figure 1] and the Home Plate deposit in Gusev crater [2,3].

Analog Sites: Three field sites in Iceland have been selected for examination during the summer of 2016. Sites have been chosen to represent a range of hydrothermal activity from active, pristine sinter deposits to extinct systems that have undergone significant degradation.

Hveravellir: This active system has multiple hot springs, with boardwalk accessible environments that range from active vents, to outflow channels, ponds and older overlapping sinter apron deposits. This site provides access to biofilm communities over a broad temperature and pH range, where there is active sinter deposition and where biofilms are undergoing active mineralization. Hveravellir provides access to the earliest stages of biosignature capture and preservation, as well as silica diagenesis

Gunnuhver: The Gunnuhver [Figure 2] site is a siliceous sinter mound on the Reykjanes Peninsula that developed upon local basaltic flows. The sinter mound is today dominated by acidic fumarolic activity that has altered the original basaltic host rock. Here we will refine strategies for the physical exploration of sinter mounds and their effects on local bedrock sequences, particularly role of acid sulfate weathering of basalt and the associated mineral and textural changes that accompany acidic alteration [3].

Lysuholl: This is an older, inactive siliceous hydrothermal field consisting of multiple vents and coalescing sinter aprons that have experienced widespread surface brecciation and weathering. This site provides access to a complete array of sinter mound facies where the impacts of post-depositional processes (diagenesis) can be fully explored. This site is probably most closely analogous to what could be encountered on Mars. Operational strategies and approaches to sampling will be an important focus for this site.

Instrumentation: This project will determine the datasets and instrumentation that will be required for the detection and characterization of biosignatures in sinter deposits. Field instrument deployment will focus on Visible and Near Infrared (VNIR) imaging and geophysical exploration while an extensive sample collection and laboratory analysis campaign will test most known spectral, geochemical and imaging techniques common to planetary science. We expect that the critical datasets will include an electron scanning microscope and microscopic imager for textural and elemental identifications and spectral imaging for phase mapping. Testing these types of datasets with others will develop the optimal suite.

Mission Design: We will test different mission designs by collecting samples and imaging data over a broad a range of scenarios that will mirror potential missions from a lander to sample return. Each mission design will have different payload and sample access abilities. Comparing the results from the different scenarios will determine which scenarios are optimal, acceptable or unlikely to yield definitive results.

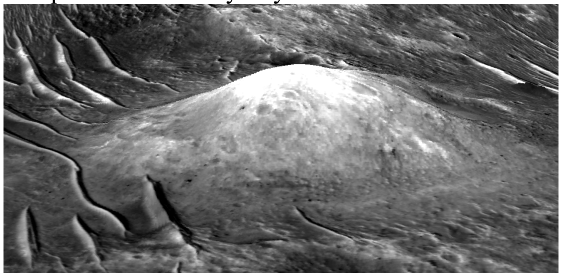

Figure 1. South Mound in Nili Patera is 20 m tall and 100 m wide. The white, surfical material has a 2.21μm Si-OH absorption.

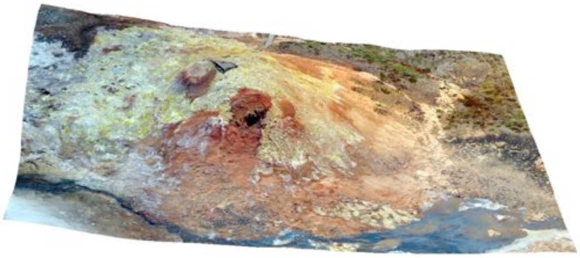

Figure 2. Gunnuhver, Iceland is 10 m tall and 100 m wide and is a silica sinter covered mound of altered basalts.

References: [1] Skok et al., 2010, *Nat Geosci.,* 3 (12) [2] Squyres et al., 2008, *Science*, 320(5879) [3] Ruff et al., 2011, *J. Geophys. Res.,* 116.

Biosignatures of Hypersaline environments (Salt Crusts) an analog for Mars. H. D. Smith (1) A. G Duncan (2) A. Davilla (1) and C.P. McKay.(3) 1 SETI Institue, NASA Ames Research Center. 2. Desert Sensors, Logan, Utah. And 3 Space Science Divison, NASA Ames.

Introduction:

Halophilic ecosystems are models for life in extreme environments including planetary surfaces such as Mars (Osterloo et al 2008). Our research focuses on biosignatures in a high organic preservation environment of salt crusts and the detection of these mineral and organic biomarkers by ground and orbital assests.

Halophiles contain pigments with identifiable spectroscopic features. We examine the salt crust layer by layer to determine the spectral properties of these halophilic extremophiles.

Method: In-situ spectroscopic measurements are taken to identify the biosignatures and characteristic spectroscopic features within each of the stratified microbial layers shown in Figure 1.

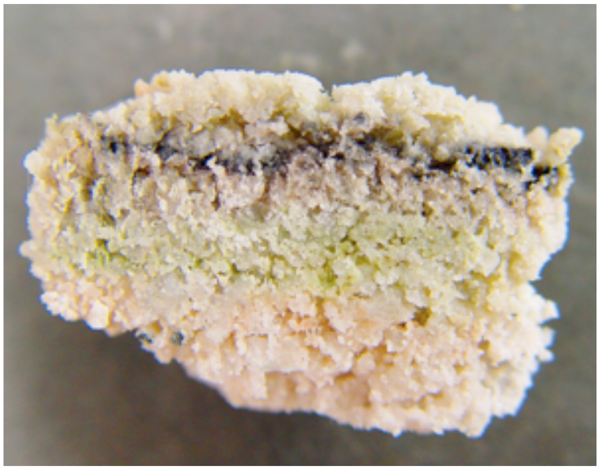

Figure 1.

We then subject the salt crust to extreme conditions to determine the biosignatures preservation in rapidly changing stressful mileu for the halophiles.

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IN-SITU EXPLORATION OF HABITABLE ENVIRONMENTS AND BIOSIGNATURES IN ARCTIC COLD SPRINGS AND ANTARCTIC PALEOLAKES.

P. Sobron[1], D. Andersen[1], Wayne H. Pollard[2]. [1]SETI Institute Carl Sagan Center. Mountain View, CA. psobron@seti.org [2]McGill University, Montreal, Canada.

Introduction: The scientific motivation for this investigation is the need to add *flight-instrument signatures of life* data from high priority analogs to the spectral libraries of laser-based spectroscopy instruments on the ESA ExoMars 2018 (RLS) and NASA Mars 2020 (SHERLOC and SuperCam) missions.

Our work maps to the SETI Institute *Signatures of Life* NAI team's goal of characterizing Earth analogs of high-priority environments for identifying traces of ancient life in changing planetary environments.

Our results are: a) furthering our scientific understanding of cold springs and paleolakes as high-fidelity analogues to putative inhabited/habitable environments on Mars, b) advancing our technological readiness for their exploration, and c) yielding new scientific data of relevant Arctic and Antarctic analogs.

Results: In July 2015 we carried out *in-situ* Raman investigations at three perennial springs and one paleospring site located at Axel Heiberg Island in the Canadian High Arctic (Fig. 1). At nearly 80° N, these springs are located in a region of thick, continuous permafrost. From the springs we collected samples of well-developed travertine, icing pastes and nearby salt deposits resulting from efflorescence. Concurrent with sample collection, we deployed a Raman spectrometer and an IR reflectance spectrometer for *in-situ* measurements at the four sites. We recorded 100+ Raman spectra and 50+ IR reflectance spectra on those sites. We identified gypsum, iron sulfates, kerogens, elemental sulfur, organics, halite, hydrated, iron sulfates, and thenardite. These results are helping us evaluate the role of spring deposits as high-priority targets for the search for life on Mars.

In November 2015 we travelled to Lake Untersee in the mountains of Queen Maud Land, Antarctica (Fig. 2) to continue a series of studies aimed at understanding the lake ecosystem, its sedimentary history, local climate, and to begin detailed investigations of a paleo-basin located to the east of the lake. At these sites we deployed a Raman spectrometer, IR reflectance spectrometer, and an X-ray diffraction/fluorescence (XRD/XRF) spectrometer for *in-situ* measurements. Our investigations include studies of the physical and biogeochemical characteristics of the lake, deposition and preservation of biomarkers, and the use of *in-situ* analytical techniques to identify organic signatures within a mineralogical context while developing synergistic operational concepts for *in-situ* analyses in paleolakes analog to early or present Mars.

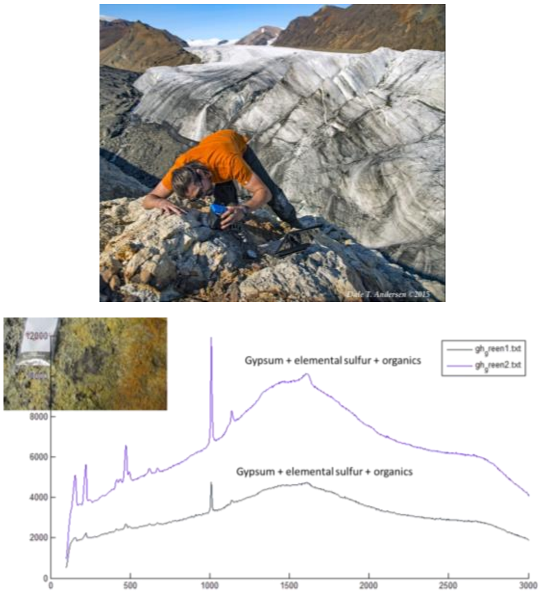

Figure 1. *In-situ* analyses and Raman spectra of Axel Heiberg paleosprings.

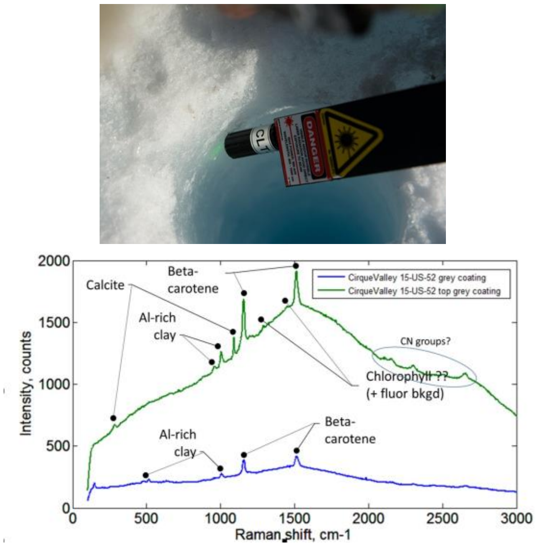

Figure 2. *In-situ* analyses and Raman spectra of Untersee glacier ice and paleolake deposits.

Acknowledgements: Primary support for this research was provided by the Tawani Foundation, the Trottier Family Foundation, the Arctic and Antarctic Research Institute/Russian Antarctic Expedition, and NASA NAI. Logistics support was provided by the Polar Continental Shelf Program (PCSP), and the Antarctic Logistics Centre International (ALCI), Cape Town, SA. We are grateful to fellow field team members for their support during the expedition.

Life detection with minimal assumptions – Setting an abiological background for Mars.

A. Steele[1]. [1]Carnegie Institution of Washington, Geophysical Laboratory, 5251 Broad Branch Rd, Washington DC, 20015. asteele@carnegiescience.edu

Life detection with minimal assumptions

The simplest form of extraterrestrial life detection with minimal assumptions on the nature of the organism or a potential "alien biochemistry" to be detected, is to understand the possible abiotic organic chemical reactions given the context of the samples and look for perturbations to that signal. More precisely, life chooses only a few of the many known organic chemicals produced by abiotic processes. Therefore anomalous deviations from predicted abiological yields of organic chemicals under given conditions may be the easiest life detection protocol. The assumptions are minimal; life is carbon based and it chooses only a subset of possible abiotic chemicals available. An example would be the organic chemistry responsible for the inventory of organics in the Murchison meteorite and abiotic processes such as the Miller-Urey reaction and Fischer –Tropsch (FTT) synthesis. In the case of the Murchison meteorite, it appears that all possible isomers of a particular carbon number or compound are present but only a very limited subset of these molecules used by terrestrial biology (Schmidt-Koplin 2010). In the case of FTT as chain length increases, yield decreases and although analysis of the products this is subject to analytical problems, mainly volatile loss, the kinetics of this reaction are very well understood and predictable. Life on the other hand tends to use ~ C17 to C31 alkanes and produce an odd even preference that is not present in FTT products (Donnelly, 1989). A final and perhaps extreme example of this philosophy is that if terrestrial life uses A,T,C,G and U for information storage a Martian organism may use L.M.N.O and P. Again the probability is that life will choose only a few of the possible choices of, in this case, purine and pyrimidine isomers. Therefore, knowing the abiotic reactions are possible in a certain context provides a baseline value from which any anomalous concentrations of organics that may be a 'biosignature' can be detected.

This strategy depends on several key points for implementation.

1) An understanding of possible abiotic chemistry undertaken in Mars environments (including meteoritic infall) and the preservation / diagensis of that signal with time.
2) A clear understanding of the geological context in which measurements are made.
3) A multidisciplinary and multi-measurement approach with convergent data sets from each measurement.
4) Commitment to a null hypothesis that all observations are treated as non-life signatures until a wealth of evidence exists to falsify this hypothesis.
5) Clear operating guidelines and peer review of results and data. It is after all the community and not a single investigator or measurement that will ultimately define a positive "Life Detected" result.

While apparently biased towards the detection of molecular biosignatures, the invocation of a null hypothesis demands similar rigorous examination of data from the detection of possible mineral, isotopic or morphological biosignatures.

Mars meteorites – Setting an abiotic background.

Care has to be taken in the interpretation of organic compounds in Martian meteorites due to terrestrial microbial and organic contamination (Steele et al., 2000, Toporski and Steele 2007). The challenge is then to distinguish between the terrestrial organic material (and organisms) and possible indigenous Martian organics. For many years to come these Martian meteorites will remain the only material available for analyses in terrestrial laboartories. Therefore, the wealth of information they contain, which should not be summarily dismissed simply because they may be contaminated, is essential for setting a background that give context to in-situ or returned sample measurements on Martian samples. The microbial contamination in these meteorites provides us with the best model we have for testing life detection instrumentation and rationales on a truly Martian substrate before the possibility of receiving return samples from this planet. The characterization of these organisms and their metabolic/diagenetic products will also be crucial in the search for biogenic activity in other extraterrestrial samples. These meteorites do show evidence of Martian abiotic chemistry in the form of graphitic carbon, macromolecular carbon, polycyclic aromatic hydrocarbons and nitrogen containing aromatic molecules (Steele et al., 2016, 2013, 2012a, b 2007, Wright et al., 1989, 1992). Steele et al., (2016) reviews these types of organic molecules and there potential synthesis mechanisms which can be summarized as follows; 1) impact generated graphite in Tissint, 2) secondary hydrothermal gener- ated graphite in ALH 84001, 3) primary igneous reduced carbon in 12 Martian meteorites associated with spinels 4) primary hydrothermally formed organic carbon / nitrogen containing species in the Tissint meteorite. These studies show that Mars has produced reduced carbon / organic carbon via several mechanisms and reveal that the building blocks of life, if not life itself, are present on Mars and have been manufactured over much of its history. The context of these organics in terms of the life detection strategy outlined earlier is extremely valuable allowing the beginnings of setting t non-life background from which to work from.

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SPATIAL VARIABILITY AND CORRELATION OF MULTIPLE BIOMARKERS IN ICELANDIC MARS ANALOGUE ENVIRONMENTS AND THE IMPLICATIONS FOR LIFE DETECTION MISSIONS.

A. H. Stevens[1], E.S. Amador[2], M. L. Cable[3], T. Cantrell[4], N. Chaudry[5], T. Cullen[5], Z. Duca[4], D. M. Gentry[6], M. B. Jacobsen, H. McCaig, G. Murukesan[7], V. Rennie[1], E. W. Schwieterman[2], G. Tan[4], C. Yin[8], A. Stockton[4], D. C. Cullen[5], W. Geppert[8], [1]UK Centre for Astrobiology, University of Edinburgh, UK adam.stevens@ed.ac.uk, [2] Astrobiology Program, University of Washington, USA [3] NASA Jet Propulsion Laboratory, California Institute of Technology, USA [4] School of Chemistry & Biochemistry, Georgia Institute of Technology, USA [5] School of Engineering, Cranfield University, UK, [6] Biospheric Science, NASA Ames Research Center, USA [7] Department of Biochemistry, University of Turku, Finland, [8] Astrobiology Centre, AlbaNova University Center, Royal Institute of Technology or Stockholm University, Sweden

Introduction: We conducted expeditions to Mars analogue sites in Iceland to investigate the variability and correlation of three common biomarker assays: cell quantification via fluorescence microscopy, ATP quantification via bioluminescence, and quantitative PCR with universal primer sets. Sample sites were nested at four spatial scales (1 m, 10 m, 100 m, and > 1 km) in areas of volcanic tephra that appeared homogeneous at 'remote imaging' resolution. Full details of the initial expedition methodology are given in [1].

Understanding the spatial and temporal distributions of biomarkers will assist in planning life detection strategies for future planetary missions. The landing site for a hypothetical life-detection or sample-return mission will be chosen using remote sensing data, but the specific sampling locations may not be representative of the wider context, especially if a difference of a few tens of meters or centimeters makes a significant difference in the results, and the most scientifically lucrative locations may be missed.

Results: Our results suggest that the biomarkers under scrutiny in such a mission must be carefully selected. Statistical analysis shows that all spatial scales were highly diverse in ATP, bacterial 16S, and archaeal 16S DNA content (see Figure 1 for an example); nearly half of sites were statistically different in ATP content at $\alpha = 0.05$. Cell counts showed significant variation at the 10 m and 100 m scale. At the > 1 km scale, the mean cell counts were not distinguishable, but the median cell counts were, indicating differences in underlying distribution. Fungal 16S DNA content similarly varied at 1 m, 10 m, and 100 m scales only. Cell counts were not correlated with ATP or DNA content at any scale. ATP concentration and DNA content for all three primer sets were positively correlated. Bacterial DNA content was positively correlated with archaeal and fungal DNA content, though archaeal correlation was weak.

Discussion: While the biomarkers chosen for this study might not be the most applicable to extra-terrestrial life detection missions, these results highlight the difficulty of choosing a 'good' biomarker. The high spatial variability and variation in correlation between biomarkers that are measuring similar things suggests that not only may different methods yield conflicting results, but they may also be differentially representative of the overall area.

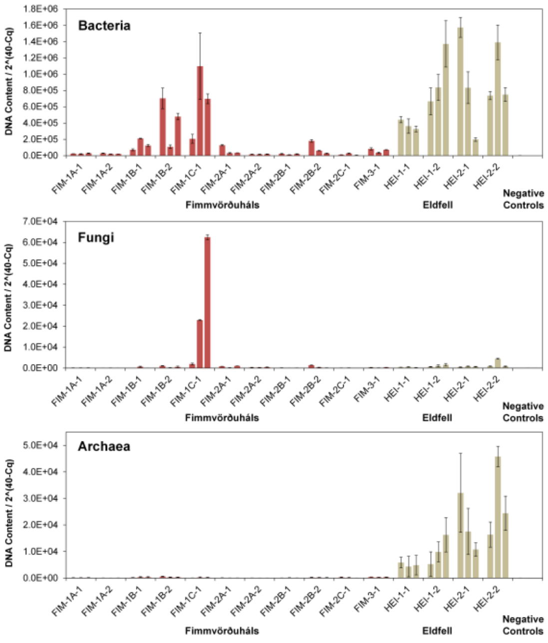

Figure 1 - An example of the variability in DNA concentration in samples at different scales.

A further expedition repeated the sampling strategy, with the addition of a smaller-scale sampling grid of 10 cm and a third > 1 km location and more are planned. We have also incorporated ‘remote sensing’ equivalent measurements using aerial drones, and IR and Raman spectroscopy in order to better distinguish between effects of geochemical variation and intrinsic biomarker variation. Correlating remote sensing data with the variability of different biomarkers will allow us to identify methods

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FATE OF ORGANIC MOLECULES IN THE MARS REGOLITH UNDER UV RADIATION DEDUCED FROM THE MOMIE LABORATORY EXPERIMENT.

C. Szopa[1,6], P. Coll[2], F. Stalport[2], O. Poch[3], M. Jaber[4], J.F. Lambert[5], L. Rouquette[2], and J. Lasne[2], [1] LATMOS, UMR CNRS 8970, UPMC Univ. Paris 06, Universite Versailles St-Quentin, Institut Pierre Simon Laplace, Quartier des Garennes, 11 Boulevard d'Alembert, 78230 Guyancourt, France (cyril.szopa@latmos.ipsl.fr), [2] LISA, Universites Paris Est Creteil and Paris Diderot, CNRS, Institut Pierre Simon Laplace, UMR 7583, 61 Avenue du General de Gaulle, 94010 Creteil cedex, France, [3]Center for Space and Habitability, University of Bern, Sidlerstrasse 5, CH-3012 Bern, Switzerland, [4]LAMS, UMR 8220, 4 Place Jussieu, 75005 Paris Cedex 5, France, [5]LRS, UMR CNRS 7197, UPMC Univ. Paris 06, 3 Rue Galilee, 94200 Ivry, France, [6]Institut Universitaire de France, Paris, France.

Introduction: Among bioindicators or biosignatures, organic molecules present on Mars could be retrieved in the regolith near the surface due to erosion of rocks and gardening of the soil from meteorites bombardment through the Mars history. Once their, the organic molecules are submitted to the harsh surface environmental conditions, including UV radiation. In order to evaluate the influence of these radiation on organics, the MOMIE experiment [1] is devoted to expose pure molecules, or mixture of molecules with minerals, to a UV spectrum simulating the one reaching the Mars surface. From these experiments, it can be deduced their lifetime and/or their possible transformation into other molecules

Experiment: The MOMIE setup enables both to simulate the *in situ* Mars-like UV irradiation and to proceed to FTIR (Fourier Transform Infrared Spectroscopy) monitoring of the sample, at a temperature (218±2 K) and pressure (6±1 mbar) representative of the mean conditions at the Mars surface. The studied sample consists of thin uniform layers (micrometric scale) made of pure organics [2], or a mixture of minerals with organics [3], deposited on a ~2 cm diameter magnesium fluoride (MgF_2) optical window. The samples are prepared via sublimation/condensation for pure organics, and evaporation/sedimentation of a minearl-organic suspension when introducing a mineral.

Experiment: In this communication, we present the influence of UV radiation on various pure organic molecules either potentially derived from meteorites (e.g. mellitic acid) or of interest for astrobiology (e.g adenine). We also present the influence of the presence of nontronite, a mineral present on Mars, on the evolution of these molecules. From this result, a discussion about the potential survival of bioindicators or biosignatures from organic origin can be done, as well as heir potential for being detected in sample collected in the regolith of Mars.

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References:

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Ackowledgements: Authors acknowledge the Programme National de Planétologie (PNP), the Pierre Simon Laplace Institute (IPSL) and the Institut Universitaire de France (IUF).

SULFUR BIOSIGNATURES IN CONTINENTAL HOT SPRING, STREAM AND CRATER LAKE SEDIMENTS AFFECTED BY HYDROTHERMAL H_2S GAS EMISSION.

A. Szynkiewicz[1] and J. Mikucki[1]. [1]University of Tennessee, 1412 Circle Drive, Knoxville, TN 37996 (aszynkie@utk.edu).

Introduction: The major goal for the exploration of Mars in the coming decades is to determine whether life is, or was, present [1]. The Mars 2020 Rover will be “Seeking the Signs of Life” (e.g., biosignatures) through a broad and rigorous investigation using *in situ* instruments and archiving the most promising samples for potential return to Earth at a later time [1]. Our ability to successfully detect and interpret potential biosignatures of extant and/or extinct microorganisms on Mars can be improved by better understanding how well these biosignatures are preserved in geological record on Earth.

Sulfur (S)-bearing compounds are common on the Martian surface as sulfate and sulfide minerals[2]. The presence of S compounds on Mars has been mainly linked to hydrothermal activity in the past when Mars was more volcanically active and water was stable on the surface [2]. Similarly, gas- and dissolved-phase S-bearing compounds are abundant at modern volcanic systems on Earth, particularly continental springs where hydrothermal water discharges on land. These habitats support diverse microbial ecosystems that host metabolic guilds capable of S oxidation and reduction (i.e. redox reactions) for energy [3]. Therefore, investigating biosignatures associated with hydrothermal microbial S cycling on Earth is critical for identifying potentially similar biosignatures on Mars.

Goals & Research Approach: In this study, we focused on identifying two types of biosignatures in a continental volcanic complex of Valles Caldera, New Mexico:

1) *Metabolic ^{34}S-^{32}S isotope biosignatures* - characteristic imprints upon the environment of the processes by which life extracts energy and material resources to sustain itself.

2) *Molecular (genomic) biosignatures* - structural, functional, and information-carrying molecules that characterize life forms and their metabolism.

Between 2007 and 2014, water and sediment samples were collected from hot spring, stream and crater lake sediments affected by hydrothermal H_2S gas emission. The method of S sequential extraction was used to characterize isotope composition of mineral phases containing S^{6+}, S^0, and S^{2-} [4]. To link microbial metabolic potential with observed metabolic isotope signatures, we examined the presence of adenosine-5-phosphosulfate (APS) reductase, a gene involved in both dissimilatory (i.e. energy yielding) sulfate reduction or S oxidation reactions.

Results & Discussion: S isotopes have been used for interpreting modern and ancient metabolism because of large S isotope fractionations (~20 to 60‰) between oxidized (S^{6+}, S^0) and reduced (S^{2-}) species formed due to microbial sulfate reduction and disproportionation of elemental S [5]. In volcanic complex of Valles Caldera, biogenic sulfides with distinctive negative $\delta^{34}S$ of -40.3 to -9.9‰ were mainly preserved in stream sediments showing small and/or negligible hydrothermal H_2S emission. Conversely, in hot spring and stream sediments with high gas emission the $\delta^{34}S$ of sulfide minerals had higher values of -1.2 to +2.2‰ suggesting greater inputs of inorganic S from hydrothermal H_2S gas emission (+0.8 to +4.8 ‰). Molecular biosignatures were indicative of S-oxidizing acidophiles (*Desulfurella, Thiobacillus*) [6] and novel sequences related to both S oxidizers and reducers [this study] in hot spring and stream sediments. The $\delta^{34}S$ of sulfides from ancient crater lake sediments (~560 ka years) varied in a similar range (-3.9 to +4.0‰) as in the S-rich volcanic bedrock (-2.2 to +3.3‰) and modern hydrothermal H_2S gas. This, in turn, implies poor preservation of metabolic S biosignatures in lake sedimentary record resulting either from limited microbial S metabolism or complete microbial transfromation of oxidized S^{6+}/S^0 species to sulfides.

Looking for Biosignatures on Mars: The SuperCam instrument on the Mars 2020 Rover will measure elemental and mineralogical compositions during in situ investigation and collect samples for return to Earth. Generally, biogenic sulfides (metabolic biosignatures) with negative $\delta^{34}S$ showed very small content of <0.01 wt. S^{2-} % in the stream sediments of Valles Caldera and were below detection limit by Terra (XRD) Instrument. Also, DNA content (molecular biosignatures) was relatively low and challenging to extract from S-rich materials. Therefore, similar metabolic and molecular biosignatures on Mars could be only detected on the samples returned to Earth. Nevertheless, current orbital instruments such as HiRISE and CRISM could be used to detect potential hydrological drainage sites associated with hydrothermal H_2S activity and habitabile conditions, thus, guide the Mars 2020 rover for sample return collection.

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BIOLOGIC ANALOG SCIENCE ASSOCIATED WITH LAVA TERRAINS.

N. K. Thomas[1], J. C. Hamilton[2], A. Veillet[3], and C. Muir[4]. [1]Dept. of Biology, University of Hawaii at Hilo. nkthomas@hawaii.edu. [2]Dept. of Physics & Astronomy, University of Hawaii at Hilo. jch@hawaii.edu. 200 W. Kawili St. Hilo, HI 96720.

Introduction: The goal of the B.A.S.A.L.T. project is to determine the upper bounds of the biomass that could have been supported on Mars and investigate how those upper bounds inform future requirements to detect extinct life on Mars. Fieldwork is conducted on the Big Island of Hawaii at the latest lava flow in Pahoa and an older flow in the Hawai'i Volcanoes National Park's Ka'u Desert. These two flows serve as analogs to present day and Noachian era Mars respectively. At the two sites, I collect samples of basalt and analyze them in the lab for bacteria and archaea. Once the yield of genetic material is determined, a segment of that DNA is amplified and then prepared for sequencing. This undergraduate research, funded by the Hawai'i Space Grant Consortium, is preliminary work for a larger NASA funded inquiry.

My methods for retrieving the samples from the flows went as follows: All samples were collected with a rock hammer that was sterilized with a 70% bleach solution before and after each use. Bleach was used instead of ethanol because bleach will completely destroy any genetic material residue [1]. Sterile gloves were used to handle the samples and place them into sterile ziplock bags. Each sample was then taken to the lab and crushed with a corresponding mortar and pestle under a specially enclosed hood. The crushed samples were then placed in 50mL sterile tubes and put in a -20°C freezer. Before using the mortar and pestles, rather than autoclaving them, they were baked in an oven at 230°C to ensure no contaminates were there. 230°C is the temperature at which you can achieve DNA pyrolysis, which is when DNA will dissipate [2].

The method of DNA extraction that is being used is called solid phase binding which is when the sample is run through a silica membrane that captures the DNA allowing you to remove impurities [3]. Using a nanodrop, an analytical instrument used to determine the average concentrations of nucleic acids, I am able to determine how successful I was at removing impurities and extracting a large amount of genetic material (see Figure 1).

The section of DNA that is being amplified is the 16S ribosomal RNA (rRNA) fragment which is often used in phylogenetic studies to differentiate microbial organisms from one another. This particular fragment has highly conserved primer binding sites and sequences containing variable regions that are species-specific signatures [4]. After amplifying the 16S rRNA section of the DNA using PCR, Agarose Gel Electrophoresis is used to separate the fragments and analyze them based on their size (see Figure 2).

No conclusions can currently be made about the results of this work because more data needs to be gathered and analyzed.

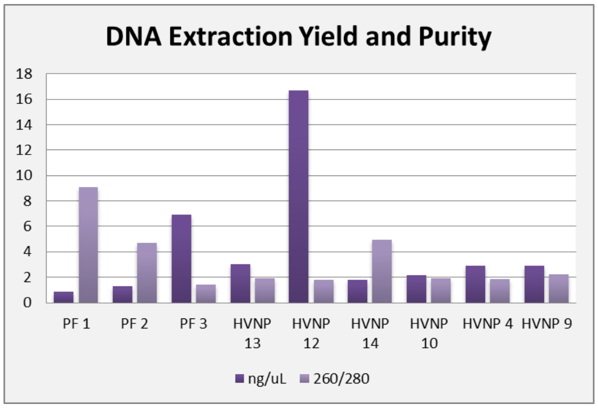

Figure 1. This graph shows the results of my initial DNA extractions and the amount of genetic material measured by the nanodrop instrument in nanograms per microleter. It also shows the 260/280nm ratio where ~1.8 is considered "pure" for DNA.

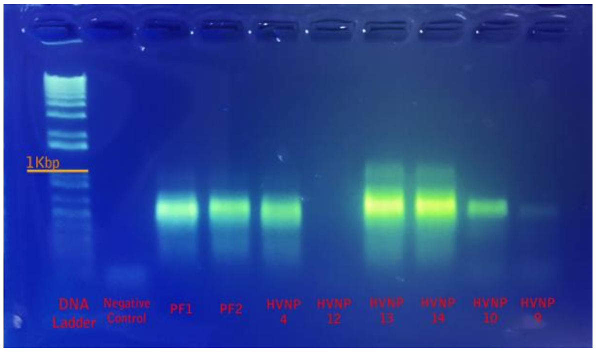

Figure 2. This figure shows the gel electrophoresis results of my PCR products. The bands shown are around 600bp which is the expected size for my 16S rRNA amplification.

References:

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CRATER FLOOR FRACTURES: PROBES INTO HABITABLE MARTIAN ENVIRONMENTS.

R. J. Thomas[1] and B.M. Hynek[1,2], [1] LASP, University of Colorado, Boulder, CO 80309, USA, [2] Department of Geological Sciences, University of Colorado, 399 UCB, Boulder, CO 80309, USA. Rebecca.thomas@lasp.colorado.edu

Introduction: Over 400 Martian impact craters have floor materials that have been cross-cut by fractures, often long after crater formation [1]. These fractures form by a number of processes, but in a sizable subset, interaction of near-surface water or ice with a localized or regional magmatic intrusion is indicated [1,2,3]. The late formation and aqueous/volcanic genesis of the floor-fractures give them strong potential for exposing biosignatures dating from a range of periods in Mars' history. Specifically:

1. Where fractures form in the floor of a crater that underwent aqueous infilling in the Noachian (~4.1–3.7 Ga), they can create a deep cross-section through sediments within which early biosignatures may be preserved.
2. Where aqueous fluids welled up through floor-fractures in the Hesperian to Amazonian (<3.7 Ga), any material deposited at the surface may contain signatures of extant (at that time) life in deep aquifers. Potentially warmed by magmatic heat, these aquifers may represent the prime habitable environment during this more recent period when surface conditions were less clement.

We analyzed numerous floor-fractured craters in Margaritifer Terra, a region of Mars with a long history of aqueous activity, for evidence that biosignature exposure and preservation at floor-fractures is feasible, and for the presence of hydrated minerals indicative of past habitable environments.

Margaritifer Terra (34 to 14°W, -13 to 5°N) lies east of Valles Marineris and south of Mars' global crustal dichotomy. It consists of ancient (middle Noachian) highland terrains [4] that are cross-cut by extensive regions of chaos, where the surface is broken up into many slumped and angled blocks. The chaos is thought to have formed during a period of intense aqueous outflow activity in the Hesperian, possibly triggered by regional magmatic intrusion related to Tharsis volcanism [2,4,5].

We have investigated the morphology and stratigraphy of numerous floor-fractured craters here using mid-resolution CTX [6] and high-resolution HiRISE [7] images from the Mars Reconnaissance Orbiter (MRO) in order to assess whether fractures have exposed ancient Noachian sediments, and/or sourced outflow of later aqueous fluids. We have also used targeted hyperspectral data from MRO's CRISM spectrometer [8] and thermal inertia data from THEMIS on Mars Odyssey [9] to investigate the mineralogy and physical properties of units within each crater to determine whether these sediments are of a type consistent with formation under habitable conditions.

Results: We have identified several impact craters where fractures up to 1-km-deep cross-cut thick sedimentary infills, at some of which we have detected hydrated minerals (phyllosilicates) in the exposed units. Additionally, within several craters there is morphological evidence for erosion of older floor deposits by fluids sourced from the fractures, and for deposition at fracture margins (Fig. 1). Together, these observations indicate that floor-fractured craters here are excellent probes into ancient surface and Hesperian-aged deep habitable environments and should be considered candidate landing sites for future astrobiological missions to Mars.

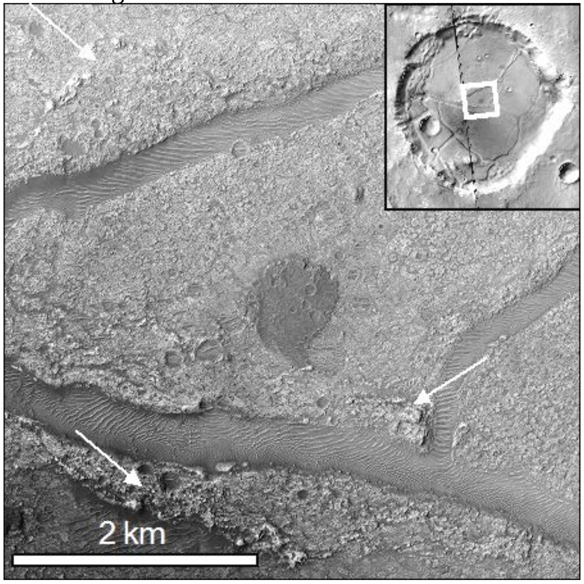

Fig 1. Raised units (white arrows) along fractures in the floor of an unnamed crater at 18.3° W, 10.6° S within which biosignatures could potentially be preserved.

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OCEAN FERTILIZATION FROM GIANT ICEBERGS ON EARTH AND EARLY MARS.

Esther R. Uceda[1], Alberto G. Fairén[2,3], J. Alexis P. Rodríguez[4], Christoper Woodworth-Lynas[5]. [1]Universidad Autónoma de Madrid, 28049 Madrid, Spain (mariae.ruiz@uam.es); [2]Centro de Astrobiología (CSIC-INTA), 28850 Madrid, Spain; [3]Cornell University, Ithaca 14853, USA; [4]Planetary Science Institute, Tucson, AZ 85719, USA; [5]PETRA International Ltd., Newfoundland & Labrador, Canada A0A 2B0.

Ocean fertilization from icebergs: On Earth's oceans, giant icebergs release melting water containing nanoparticulate iron and other micronutrients, which support biological metabolism and growth to the near-coastal euphotic ecosystems, many of which are iron limited [1]. This iron limitation of primary producers has been documented in large regions of the Earth's oceans, most notably in polar areas proximal to significant glacial activity, and is counterbalanced by the substantial enrichment of terrigenous material supplied by icebergs [2-4]. The biological productivity extends hundreds of kilometres from the giant icebergs, and persists for over one month after the iceberg passes [1]. Here we propose that iceberg activity on early Mars could have promoted a similar enhancing of biological productivity on the planet's oceans. The identification of specific biosignatures in icebergs trails on Earth could give clues as to what kind of biosignatures could be expected on the ancient Mars ocean floors, and where to look for them. In particular, assuming that life existed on Mars coeval to glacial activity, enhanced concentrations of organic carbon could be anticipated near iceberg trails, analogous to what is observed in polar oceans on Earth.

Identification of iceberg rafting on Mars: We have previously presented [5-9] evidence for furrows, dump structures and chains of craters (Figs. 1-3) that we interpret as indication for iceberg transport and grounding on very cold oceans on early Mars, both in the northern plains and in the Hellas basin. Structures include:

1. Furrows: The furrows are located in elevated areas or on local topographic highs, particularly on the Hellas basin (Fig. 1). We interpret these features in terms of iceberg rafting and grounding. We propose that the furrows were formed in submerged unconsolidated sediments, when floating ice keels touched down and displaced loose material to the sides as they continued to move forward, possibly driven by both wind and water currents.

2. Chains of craters: High-resolution images of Utopia and Isidis Basins also reveal chains of crater-like structures several hundred meters wide and 1 to 5 km long (Fig. 2). We interpret that overlapping pits are formed by periodic liftoff of the scouring keel as the floating ice mass moves forward. They may be caused by large amplitude deep ocean swell or by instabilities in the ice mass causing it to "wobble".

3. Dump structures: Dark boulder clusters are revealed at large scales by their slightly darker tonality with respect to the surrounding terrain (Fig. 3). These clusters have sizes ranging from several hundred meters to 1-2 km. We suggest that large boulder concentrations originated when debris-rich icebergs grounded and remained stationary for a lengthy period of time as they melted, resulting in localized clusters of boulders and cobbles.

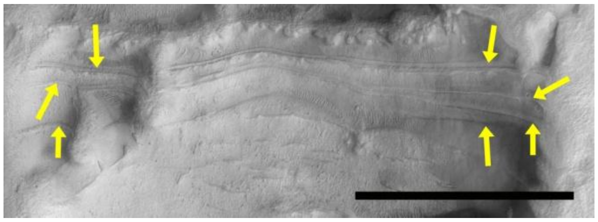

Fig. 1: Scour marks (arrows) in Hellas Basin (HiRISE image PSP_009548_1420). Scale bar = 1 km. HiRISE image credit: NASA/JPL/University of Arizona.

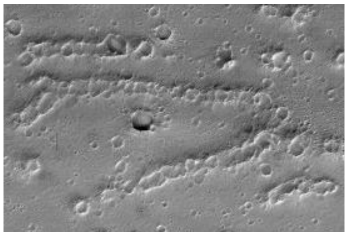

Fig. 2: Chains of crater-marks in Utopia Planitia.

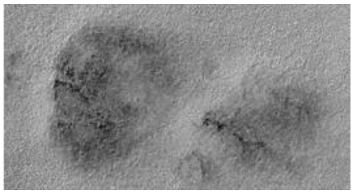

Fig. 3: Dark regions with a high concentration of boulders.

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EARLIEST LIFE ON EARTH PRESERVED IN HOTSPRING DEPOSITS: EVIDENCE FROM THE 3.5 Ga DRESSER FORMATION, PILBARA CRATON, AUSTRALIA, AND IMPLICATIONS FOR THE SEARCH FOR LIFE ON MARS.

M. J. Van Kranendonk[1], T. Djokic[1], K. A. Campbell[2], M. R. Walter[1], T. Ota[3], and E. Nakamura[3]. [1]Australian Centre for Astrobiology, University of New South Wales, Kensington, NSW 2052: m.vankranendonk@unsw.edu.au, [2]University of Auckland, School of Environment, Private Bag 92019, Auckland 1142, New Zealand; [3]University of Okayama, Misasa, Japan;

Introduction: Repeated visits to the c. 3.5 Ga Dresser Formation of the Pilbara Craton, Australia, have refined our knowledge of the geological setting of the earliest life on Earth and uncovered many types of biosignatures preserved in deposits that we now recognize include a wide array of hotspring facies. These new discoveries have significantly changed our view of the setting of earliest life on Earth, lends support to an origin of life in terrestrial hotsprings, and have profound implications for the search for life on Mars.

Ancient Earth: Newly discovered hotspring facies include: hydrothermal feeder veins with concentrated organic matter, pyrite, and apatite; mineralized hotspring pools; stratiform-columnar geyserite, a siliceous sinter with laminated anatase and kaolinite-illite; tourmaline-rich boratic sinter; hydrothermally-fed evaporative lake facies; silicified microbial mats fragmented in a hotwater creek; lacustrine chert[1,2].

Within these facies, the Dresser hotspring deposits preserve a rich, diverse array of biosignatures, including: pyrite-replaced, morphologically highly variable stromatolites over m-dm scales, typical of hotspring facies but atypical of marine environments; dendroid to anastomosed hematite microbialites near vents; pallisade fabric in siliceous sinter; organic matter of probable biological origin in siliceous sedimentary rocks and hydrothermal veins; fractionated carbon and sulfur isotopes; methane fluid inclusions in hydrothermal veins; microbial linings of hotspring pools[3-6].

Origin of life: These findings, together with research in prebiotic chemistry[7] and genomics[8], support Charles Darwin's 1871 suggestion that life originated on land, in "..some warm little pond…". Specifically, our findings show that ancient geothermal fields concentrated many of the inorganic elements critical for prebiotic chemistry, including: Boron, which guides the formation of ribose found in RNA; Phosphorous, which is used in ATP, the "molecular unit of currency" of intracellular energy transfer; and habitats with a high K^+/Na^+ ratio and concentrations of Zn and Mn apparently required by the earliest life.

In contrast, submarine hydrothermal vents are unable to satisfactorily concentrate simple, dilute organic compounds and have high salt concentrations and total divalent cations (e.g., Ca^{2+} and Mg^{2+}) that inhibit lipid membrane assembly and the formation of protocells.

Geothermal fields, on the other hand, are prime sites for the wetting-drying cycles required to polymerise common, simple organic molecules to the more complex forms required to make RNA and DNA[9]. They also provide variable pH environments and three highly reactive interfaces (atmosphere/water, atmosphere/mineral, mineral/water) that promote energetic complexity over several orders of magnitude, and innovation pools leading to greater fitness. Through these cycles, any simple organic compounds present as solutes in geothermal pools become highly concentrated as films on mineral surfaces during drying and these films have the potential to polymerize organic molecules that become trapped in lipid membranes [10].

Life on Mars: These findings impact the search for life on Mars in two ways. 1) If origin of life was in deep sea vents, as currently favoured, then the probability of success in the search for life on Mars would be low, as compelling evidence for Martian oceans is lacking. On the other hand, a terrestrial origin of life would bolster the probability of success in the search for life on Mars, given that hotspring deposits are known from Columbia Hills and Nili Patera[11]. 2) Hotspring deposits throughout the geological record - extending now right back to include the 3.5 Ga deposits that host the oldest evidence of life on Earth - preserve a diverse array of biosignatures. Thus, a carefully selected suite of samples from an area with known hotspring deposits on Mars may provide the best target for signs of life in our nearest neighbor.

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WHERE IS NECESSARY TO SEARCH TRACES OF LIFE ON MARS? A. P. Vidmachenko[1], [1]Main Astronomical Observatory of National Academy of Sciences of Ukraine, Str. Ak. Zabolotnogo, 27, Kyiv, 03680, vida@mao.kiev.ua.

The presence of clays on Mars is an important indication of the liquid water presence on the planet's surface. But the wet period of history was too short for the development of terrestrial-type life. In addition, the latest data have shown that any water on the Martian surface may have been too salty and acidic for support regular Life [6]. It was at early stages of Mars history about four billion years ago. Mars looked like an ancient Earth: had a thick atmosphere of carbon dioxide, water vapor and ammonia, with the liquid ocean on the surface; and there were a much warmer than it is now. That is, the planet was once a much more appropriate than it is today, for the existence of the Life. In those years Life originated on Earth. It is possible that the same thing has happened on Mars too. Impact craters, that formed on Mars surface in a result of falling of numerous meteorites and cometary nuclei [1, 2], in due time could lead to formation and, later, to conservation of some signs of life [5]. However, a catastrophic collision with a large asteroid resulted to the formation of a huge astrobleme Hellas. Ejection for thousands of kilometers around a million tonnes of soil, covered a considerable part of the planet's surface together with Life, which was formed on it before that time. The dust which has risen into the atmosphere, has blocked access to the surface of the sunlight, and together with other factors has transformed the planet into a cold and lifeless desert. It is clear that desertification of Mars happened a long time ago. At that time neither on Mars nor on Earth yet did not exist advanced forms of Life. Now Mars is geologically almost completely dead [7, 8]. On Mars, practically there is no magnetosphere, and there is a very thin atmosphere. And this is clearly insufficient to protect the life against bombardment of solar wind and hard ultraviolet. But there is a possibility that if Life nevertheless appeared on Mars, it does not disappear without a trace. But Life has moved from the planet's surface to subsoil and and preserved there. The traces of that life and should be search there. Thus, on Mars were identified a small amounts of methane and formaldehyde. They can talk about possible evidence of life on Mars [3, 4]. It was also found that, for example, lichens of Earth are able to survive even in modern conditions of Mars.

Suffice quick rotation period (>24 hours) suggests the possibility of existence of the intrinsic magnetic field of Mars. From observations with "Mars Global Surveyor" it was found that the magnetic field near the surface of the planet is now small ~40 nT. But there were found "spots" of magnetic field ~400 nT at the surface. Are registered about a dozen areas with a length of several hundred kilometers, which are independent and variously directed magnetic fields with different magnetic intensity. These vast areas of the Martian crust solidified millions or even billions of years ago in the presence of a strong magnetic field of the planet, which many years ago was generated in liquid (at least then) core of Mars. This can be explained by the fact that the various fragments of the observed crust of Mars were formed at different polarity had once existing of magnetic field.

And then in the presence of a strong magnetic field of Mars, were much more likely to save the Life from the effects of the primary hard radiation of the active Sun. In this context, it is necessary to search for traces of Life, not only in those places where once there was a lot of water, but also in those layers of sedimentary rocks, which relate to the first geological era (Phyllocian), which lasted for the first ~500-700 million years. That's when Mars was very wet planet, that had a strong magnetic field, which could then protect nascent Life. The soil contains clay minerals, phyllosilicates. For their formation is necessary in a considerable quantity water, temperature greater than 273 K and the lowered acidity. It has now found thousands of scattered areas of the planet with such rocks, which are commonly found in young volcanic rock, and that there are many places on the surface in the presence of a strong magnetic field. *But in order to identify possible relict Life on Mars, needs to carefully examine the areas on the surface of the planet, which are located in the areas of the soil emission in Hellas valley at latitudes near –(40-50)°, where there are strong evidence of modern water outputs from under the planet's surface* [9].

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Hydrothermal chemotrophic biosignatures on Mars.

F. Westall[1], Kathleen A. Campbell[2], Pascale Gautret[3], Jean Bréhéret[4], F. Foucher[1], F. Gaboyer[1], Jorge L. Vago[5], Gerhard Kminek[5], A. Hubert[1], K. Hickman-Lewis[1], Charles S. Cockell[6] , [1] CNRS-CBM- Orléans, France (frances.westall@cnrs-orleans.fr), [2] School of Environment, Univ. Auckland; New Zealand, [3]CNRS-ISTO-Orléans, France, [4]LGHCO, Univ. Tours, France, [5]ESA-ESTEC Noordwijk, The Netherlands, [6]School Phys. Astron., Univ. Edinburgh, UK.

Introduction: Our approach to the search for biosignatures on Mars is based on the hypothesis that habitable conditions on Mars, even early in its history, were never very clement and not of long term duration [1,2], although present understanding of the early habitability of the planet may change [3]. In view of what we term a “punctuated” habitability scenario, we consider that the most likely life forms to have appeared on Mars are chemotrophic organisms.

Fossilisation of hydrothermal chemotrophs: Experiments have shown that different species of chemotrophs react in different ways to exposure to mineral solutions, some becoming fossilised (mineral-coated) and others not [4]. However, the most common biosignatures are probably those produced by degraded organic molecules either disseminated within a mineral matrix (either detrital and/or primary/secondary), while morphologically preserved biosignatures (microfossils) may be rarer.

Examples of fossil chemotrophs and their hydrothermal environment: The most relevant analogue for early Mars is the early Archaean Earth, where anaerobic environmental conditions from the local to microscopic scale were very similar to those on the early Mars [1,2,5]. This is the only more or less completely O_2-free period that the Earth has experienced.

We have documented the very profound influence of hydrothermal activity on the early Earth and the influence of hydrothermalism on the distribution and biomass of chemotrophic life forms [6]. Basaltic volcanic sediments deposited in shallow to intertidal water depths at around 3.33 Ga (Josefsdal Chert, Barberton Greenstone Belt, South Africa) were influenced to varying degrees by seawater/hydrothermal mixtures. Macroscopic to microscopic sediment deformation features document the influx of hydrothermal fluids during sediment deposition while trace element compositions (Fe, Ni, Co, Mn, As, Ba, Mo etc.) track the hydrothermal influence on the micron scale in primary and secondary precipitated minerals, as well as the carbonaceous remains of the presumed chemotrophic colonies.

We identify relatively high density colonisation of volcanic particles in the vicinity of hydrothermal conduits, as well as the formation of “floating” colonies in silica-rich hydrothermal fluids [2] Fig. 1. In the former case, the volcanic particles are coated with irregular (spiky) layers of carbon up to several tens of µm in thickness whose structure is incompatible with an abiotic origin. *In situ* carbon isotope compositions (-21 to -28‰ $\delta^{13}C$) are compatible with microbial fractionation. As a result of the high carbon content and its mineral-bound distribution, the sediment has a characteristic clotted appearance. Primary deposits of hydrothermal silica without volcanic particles formed next to major fluid-conducting faults also present a clotted appearance. The clots have an irregular, spiky morphology incompatible with transported, detrital carbon and must have formed *in situ*. The biomass produced is at times high enough to form mm-cm thick carbon-rich layers. With *in situ* instrumentation, both layers and clotted textures could be microscopically identifiable. Spectral (Raman and IR) signatures of carbon associated with such structures, together with MS analyses of carbon molecules, isotopes and chirality, could confirm the carbonaceous composition and potentially determine the biogenicity of the organic carbon.

Conclusions: Early life was chemotrophic and, although it was apparently widely but tenuously distributed, significant biomass development was controlled by access to nutrient-rich hydrothermal fluids. Thus, it is in such environments that we should be searching for Martian biosignatures.

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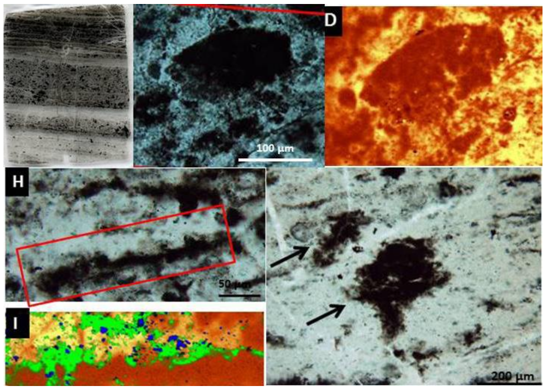

Figure 1. Clotted textures, chemotrophic coated volcanic grains and “floating colonies in 3.33 Ga old sediments [2].

XEROPRESERVATION OF FUNCTIONALIZED LIPID BIOMARKERS IN HYPERARID SOILS IN THE ATACAMA DESERT, CHILE.

M. B. Wilhelm[1,2] A. F. Davila[1,3], J.L. Eigenbrode[4] M.N. Parenteau[1,3], L. L. Jahnke[1] X. Liu[5], R.E. Summons[5] B. N. Stamos[6], J.J. Wray[2] S.S. O'Reilly[5], A.J. Williams[7]; [1]Space Science and Astrobiology Division, NASA Ames Research Center, Moffett Field, CA 94035 (marybeth.wilhelm@nasa.gov), [2]School of Earth and Atmopsheric Sciences, Georgia Institute of Technology, Atlanta, GA 30332). [3]SETI Institute, Mountain View CA 94043 [4]Planetary Environments Laboratory, NASA Goddard Space Flight Center, Greenbelt, MD 20771 [5]Department of Earth, Atmospheric, and Planetary Sciences, Massachusetts Institute of Technology, Cambridge, MA 02141 [6]Department of Chemistry and Biochemsitry, The University of Texas at Arlington, Arlington, TX 76019 [7]Department of Physics, Astronomy, and Geosciences, Towson University, Towson, MD 25251

Abstract: The accumulation and preservation of lipid biomarkers was investigated in hyperarid soils in the Yungay region of the Atacama Desert. This region experiences <<2 mm of precipitation annually[1], leading to water activities in the surface soil that are always below the threshold for microbial growth[2], and has experienced continuous hyperaridity for at least the last ~2 Ma[3]. Lipids from seven soil horizons in a 2.5 m vertical soil profile were extracted and analyzed using GC-MS and LC-MS[4]. Diagnostic functionalized lipids and geolipids were detected, and increased in abundance and diversity with depth (*Figure*). Deeper clay units within the soil pit known to have fossil biomass sealed off from exposure to rainwater for the last 2 Ma[5] contained lipids with functional groups and unsaturated bonds in carbon chains. This indicates that minimal degradation of lipids has occurred in these soils since the time of their deposition at least 2 Ma ago. The excellent degree of structural biomarker preservation is likely due to the long-term hyperaridity that led to minimal microbial activity and extracellular enzyme action[6], a taphonomic process that we term xeropreservation (i.e. preservation by drying). The degree of biomarker preservation allowed us to reconstruct major changes in ecology in the Yungay region that reflect a shift in hydrological regime from wet to dry since the Neogene.

Preservation of functionalized lipid biomarkers over million-year timescales in hyperarid terrestrial settings supports potential preservation of lipid-like hydrocarbons under similar conditions elsewhere in the Solar System. This is particularly true for Mars where arid to hyperarid conditions have dominated the environment for approximately the last two billion years and perhaps only geologically recently has the window for habitability closed[7].

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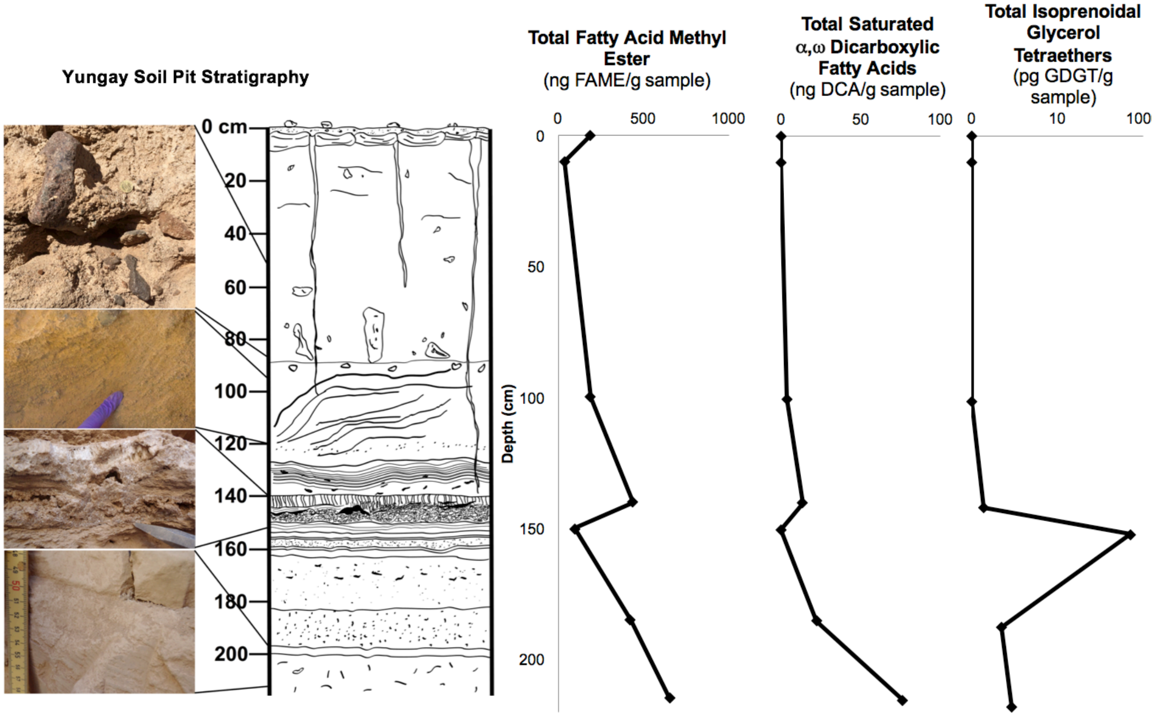

PHYSICAL AND MOLECULAR BIOSIGNATURE PRESERVATION IN HYDROUS FERRIC OXIDES: IMPLICATIONS FOR DETECTION ON MARS WITH MSL AND FUTURE MISSIONS.

A. J. Williams[1] , D.Y. Sumner[2], J. L. Eigenbrode[3], M. B. Wilhelm[4,5], C. Cook[1], P. R. Mahaffy[3], [1]Towson University, Towson, MD 21252 (ajwilliams@towson.edu), [2]University of California, Davis, Davis, CA 95616, [3]NASA Goddard Space Flight Center, Planetary Environments Laboratory, Greenbelt, MD 20771, [4]Georgia Institute of Technology, Atlanta, GA 30332, [5]NASA Ames Research Center, Space Science and Astrobiology Division, Moffett Field, CA 94035.

Introduction: An ideal biosignature preserves both physical and molecular evidence of the organism(s) of interest. Here, we document the detection of physical biosignatures (mineralized microbial filaments) co-occurring with molecular biosignatures (fatty acids detected as methyl esters [FAMEs]) in hydrous ferric oxides (HFO) ranging in age from modern to 1000's of years old from the Iron Mountain gossan, CA. Gossans, dominated by iron oxides, have been proposed as Martian environmental analogs [1]. Organic molecules can be thermodynamically unstable in the presence of iron oxides [2], but may be preserved in mineralogically diverse sediments [3,4].

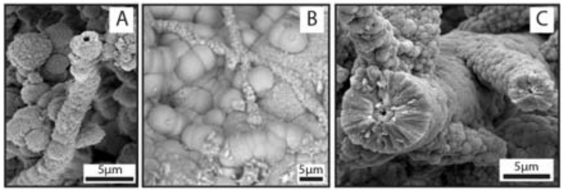

Figure 1. HFO-mineralized filaments in modern (A) and older (B, C) hydrous ferric oxides.

Methods: HFO samples were collected from the gossan in 2011 and a mine water effluent pipe in 2012.

Physical biosignatures (Fig. 1) were characterized by identifying mineral and microbial textures with scanning electron microscopy (SEM). We evaluated mineral filament biogenicity using published criteria [5,6], which include A) a mineral precipitating environment, B) structures observable as a part of the host rock, and C) biological morphology (e.g. cellular lumina, uniform diameters, and evidence of flexibility).

For molecular biosignatures, rock samples were broken open and sampled from their interior under organically clean conditions. Powdered rock samples were reacted with tetramethylammonium hydroxide (TMAH): MeOH (25%) and underwent thermochemolysis at 600°C to hydrolyze and methylate fatty acids. Subsequently, FAMEs were detected with gas chromatograph mass spectrometry (GCMS).

Results and Interpretations: HFO filaments all fit criteria A, B, and C. Based on fulfillment of the criteria, mineral filaments are interpreted as mineral-coated microbial filaments preserved as biosignatures.

FAMEs were detected in modern (SS, Table 1) and 100s-1000s of years old (PS) HFO. Fe-oxidizing bacterial isolates (ES) and environmental samples (IFS) were tested, with similar FAMEs detected. Terrestrially, FAMEs are microbial markers. These results demonstrate that FAME biomarkers are detectable with the thermochemolysis method in microbes, modern HFO, and older HFO, and indicate that FAMEs may be preserved over longer timescales than previously expected in HFO on Earth and possibly on Mars.

Table 1. FAMEs present in Fe(III)-dominated biologic and HFO samples. + = identified. - = not identified.

		n-C10:0	*n*-C12:0	*n*-C14:0	n-C15:0	*n*-C16:0	*n*-C16:1ω7	*n*-C17:0	*n*-C18:0	*cis*-C18:1ω9	*trans*-C18:2ω9
Bio-logic	ES1	+	+	+	+	+	+	+	+	+	-
	ES2	+	-	+	-	+	-	-	+	+	-
	IFS6	+	+	+	+	+	-	-	+	+	-
HFO	SS12	-	+	+	+	+	+	-	+	+	+
	SS6	-	+	+	+	+	+	+	+	-	-
	PS5G	+	+	+	-	+	-	-	+	+	-
	PS17	+	+	+	-	+	-	-	+	+	-

Conclusions: Mineral filament biosignatures provide insight into biosignature detection by instruments on MSL and future missions. Individual filaments are below the resolution of the MSL MAHLI instrument, but sinuous filaments forming mat-like textures are resolvable [5]. Future missions which utilize SEM-like imaging may be capable of detecting these features.

The MSL SAM instrument will use a similar thermochemolysis method. SAM-like analyses on a laboratory GCMS indicate SAM is capable of detecting FAMEs in HFO. Future missions that utilize alkaline thermochemolysis would be capable of detecting these biosignatures if they are sufficiently abundant.

Current and future surface missions have the ability to detect biosignatures similar to those described here. The dual identification of physical and molecular biosignatures would be a powerful way to instill confidence in martian biosignature detection. If present, these features could be preserved in HFO-bearing environments including Hematite Ridge on Mt. Sharp.

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Astrobiology strategy for Mars 2020. K. H. Williford[1] and K. A. Farley[2], [1]Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA 91109 USA, [2]California Institute of Technology, Pasadena, CA 91125.

Introduction: Mars 2020 will be the first NASA mission since Viking to seek signs of life on Mars. A critical distinction between Viking and Mars 2020, however, is that the Mars 2020 surface mission will seek evidence of *ancient*, rather than *extant* life, with an exploration strategy informed by the search for the most ancient signs of life on Earth. Sample selection and collection by Mars 2020 will also focus on the search for evidence of ancient life, although assays for extant martian organisms would be among the key investigations on Earth should the samples eventually be returned. Here we present an exploration strategy designed to address a primary astrobiological question: *did life ever emerge on Mars?*

Landing site selection: Eight potential landing sites are now under consideration for Mars 2020. Depositional models for these sites range from crater lakes to serpentinizing hydrothermal systems rooted in the oldest martian crust. Each category offers strengths and weaknesses relative to a site's potential to reveal signs of ancient life and planetary evolution, and settling upon the preffered exploration environment is a key near-term challenge for the scientific community and the Mars 2020 science team.

Fundamentally, the exploration process of a planetary rover mission involves identifying and acting upon distinctions observed at decreasing spatial scales from orbit to outcrops to individual grains. This process is already underway as landing site proposers interpret geomorphologic and mineralogic signatures of ancient environments from orbital data, working closely with the mission team at JPL to identify and prioritize ROIs and evaluate traversability of the terrain between them. This mapping effort will intensify upon ultimate landing site selection and may enable optimization of mission systems to specific characteristics of the site.

Balancing exploration and sampling: The first step toward possible Mars sample return, Mars 2020 represents an evolution in strategy from previous rover missions in which sampling supported exploration, to a mission in which *exploration supports sampling*. This evolution is analogous to typical geologic exploration on Earth, where early field observations support geologic mapping and lead to hypotheses eventually tested via focused sampling and laboratory analysis. Mars 2020 must establish geologic context using the scientific payload in order to support the simultaneous collection, and eventual interpretation of samples in the returnable cache. The history of Mars rover missions demonstrates that balancing mission requirements for driving, in situ analysis, data interpretation, and sampling requires landing with a science team capable of careful and constant strategic planning, discipline and flexibility, and a willingness and ability to make difficult, high stakes decisions on the basis of incomplete information. In other words, Mars 2020 requires *extraordinary operational efficiency*.

Exploration. Upon landing, and during initial systems checkout, the science team will prioritize multiple, km-scale ROIs previously identified from orbit, guided by the proximity of opportunities to efficiently access, investigate and sample materials with high biosignature preservation potential and geologic diversity. Exploration of each ROI will comprise multiple campaigns designed to test hypotheses generated from orbital data and progressively refined by surface observations. "Strategic" campaign planning, guided predominantly by orbital data, will proceed in parallel with "tactical" campaign implementation, guided predominantly by evolving interpretations of mission data.

Remote science instruments including Mastcam-Z, SuperCam, and RIMFAX will establish regional to outcrop-scale geologic context based on surface and subsurface stratigraphic relations, mineralogy, and elemental chemistry. Proximity science locations will be selected initially from orbit and refined based on remote science to enable the progressive identification of formation and alteration processes as revealed by rock textures, mineralogy, and chemistry observed in cross-cutting stratigraphic and petrologic context. Targeted deployments of PIXL and SHERLOC (including the WATSON imager) on natural and abraded surface targets will respond to the strategic necessity to maximize the potential of individual observations to test hypotheses emerging from science team discussions.

Sampling. Exploration and sampling are intimately related: in situ science observations will establish the geologic context for and provide the data necessary to select materials with the highest biosignature preservation potential. Informed by the search for early evidence for life on Earth, Mars 2020 will establish the formational and preservational context of an ancient environment, and determine whether the environment was once habitable. Textures, mineralogy, organic and inorganic chemistry indicating strong preservation potential, or perhaps the former influence of biology will further guide analytical target and sample selection. Spatially correlated morphologic and chemical disequilibria would represent particularly compelling potential biosignatures.

Diagenetic Changes in Microstromatolites from a Modern Cool-Water Travertine Spring.

J. Zaloumis[1] and J. D. Farmer[2], [1]University of Washington (jzaloumi@uw.edu), [2]Arizona State University (Jack.Farmer@asu.edu)

Introduction: Located along the banks of the Green River in Utah, Crystal Geyser is a saline and mildly acidic cool-water geyser that has formed a spectacular terraced travertine mound. Terraces are comprised of smaller microterracette ponds that range from one to several cm deep and contain a variety of microscale columnar stromatolite forms, as well as other potential morphological biosignatures [1]. Each terracette pond records changes between subaerial and subaqueous microenvironments and are inhabited by a variety of microorganisms including cyanobacteria, α-proteobacteria, and δ-proteobacteria among others [2]. The typically rapid rate of carbonate precipitation from Crystal Geyser promotes the capture and preservation of morphological and chemical biosignatures within the finely laminated stromatolitic framework.

This cool-water carbonate spring represents a unique environment where modern microstromatolites actively form. These features may be analogs for yet to be discovered travertine spring deposits on Mars. The young age (<80 yr) of the Crystal Geyser deposits provides an opportunity to constrain early taphonomic and diagenetic processes. Furthermore, older travertine deposits located in close proximity to Crystal Geyser provide an opportunity to observe late stage diagenetic changes in travertine deposits from similar depositional environments that formed over a much longer period, perhaps thousands of years.

Methods: Mineralogy and microtextural features of samples were observed in 30μm thick thin-sections viewed through a standard petrographic microscope. Further mineralogical characterization was carried out using X-Ray Powder Diffractometry (Siemens D5000 and Panalytical X'Pert Pro instruments). Additional compositional information (mineralogy and fossil kerogen) was obtained using 532 nm Raman laser spectroscopy with a spatial resolution of 15 microns.

Microstructure was also studied using a Leica SP5 confocal imaging system and an XL30 ESEM-FEG Scanning Electron Microscope. Travertine samples were etched in a 5% HCl dilution, and a 30 second Au/Pd coating was applied. Samples were mounted onto SEM stubs using colloidal silver. Spot elemental composition was acquired using the EDX capabilities of the ESEM-FEG.

Micro-cores of the travertine were sent to the University of Arizona Environmental Isotope Laboratory for $\delta^{13}C$ measurements. Finally, in an effort to characterize near-IR spectral characteristics of the Fe-bearing travertine samples, infrared spectra were analyzed via ASD Fieldspec 3 Portable Spectroradiometer.

Results: Branching, microdigitate stromatolites were observed in sample cross-sections, where they formed regular, repeating depositional cycles underlain by flat laminae. Stromatolitic intervals were succeeded by porous layers infilled by sparry calcite. Within stromatolites, the relief of columns and lamina definition appeared to decrease down-section and was eventually replaced by zones of amorphous, amber globules faintly representing their original microdigitate form. Despite fluorescence effects, kerogen was identified by Raman spectroscopy in both relatively pristine and degraded stromatolite forms. Kerogen was rarely preserved as cellular forms, but mostly occurred in a degraded, particulate form.

The Crystal Geyser travertines are composed primarily of calcite and aragonite. However, orange laminae inferred to be enriched in amorphous ferrihydrite were also identified in thin section and confirmed by VNIR. SEM images showed abundant filamentous structures as well as extracellular polymeric substances (EPS) embedded within carbonate lamina. EDX measurements of these structures also showed elevated carbon concentrations. Carbon isotope measurements of microcores taken in both microstromatolitic regimes and sparry calcite regimes show high $\delta^{13}C$ enrichments from +7.38‰ to +8.24‰, likely an effect of rapid CO_2 degassing.

Discussion: Previous work at Crystal Geyser [2] suggested that micritic laminae bands comprising the stromatolites precipitate during daylight hours following geyser eruptions. Conversely, sparry calcite cements appearing as porous basal laminae have been shown to grow during nighttime eruptions when photosynthesis is inactive [2]. Once the travertine accumulates to a few centimeters thickness, the stromatolite forms begin to degrade quickly as a result of the onset of diagenesis. Despite morphological degradation, chemical signatures of life in the form of kerogen can still be detected with Raman. A key mechanism for the degradation of these stromatolites may be the mineralogical transformation from metastable fibroradial aragonite to micrgranular calcite.

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