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Analog Sites for Mars Missions II: Past, Present and Future Missions to Mars

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Preface

This volume contains abstracts that have been accepted for presentation at the Analog Sites for Mars Missions II: Past, Present and Future Missions to Mars, August 5–7, 2013, Washington, DC.

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THE TUNNEL VALLEY ANALOG OF THE INNER CHANNELS OF KASEI VALLES, MARS: KEY SITES IN THE MARS CHANNEL/TROUGH DEBATE. John D. Arfstrom, 3820 Losco Rd, #625, Jacksonville, FL 32257, www.JohnArfstrom.com 904.200.2619.

Introduction: The two inner channels of Kasei Valles share several characteristics with tunnel valleys (Figure, right mosaic), which are only formed under ice sheets and glaciers [1]. Elevation data also supports the interpretation of the inner channels as tunnel valleys, which supports a glacial interpretation of Kasei Valles, and, as such, they are keystone landforms in the glacial and flood hypotheses debate [2].

As part of the broader perspective (Figure, left pair), it appears that the head of the main trough or channel (Kasei Vallis Canyon) of Kasei Valles contains the remnant of a valley glacier [3]. The region of the main trough shows geomorphology consistent with both ice sheets and valley glaciations, and may indicate a change of glacial erosion from areal to slope only. This may reflect a winding down of glacial activity over time as related to Mars climate history. However, the remnant may be of a more recent cold-based glaciation.

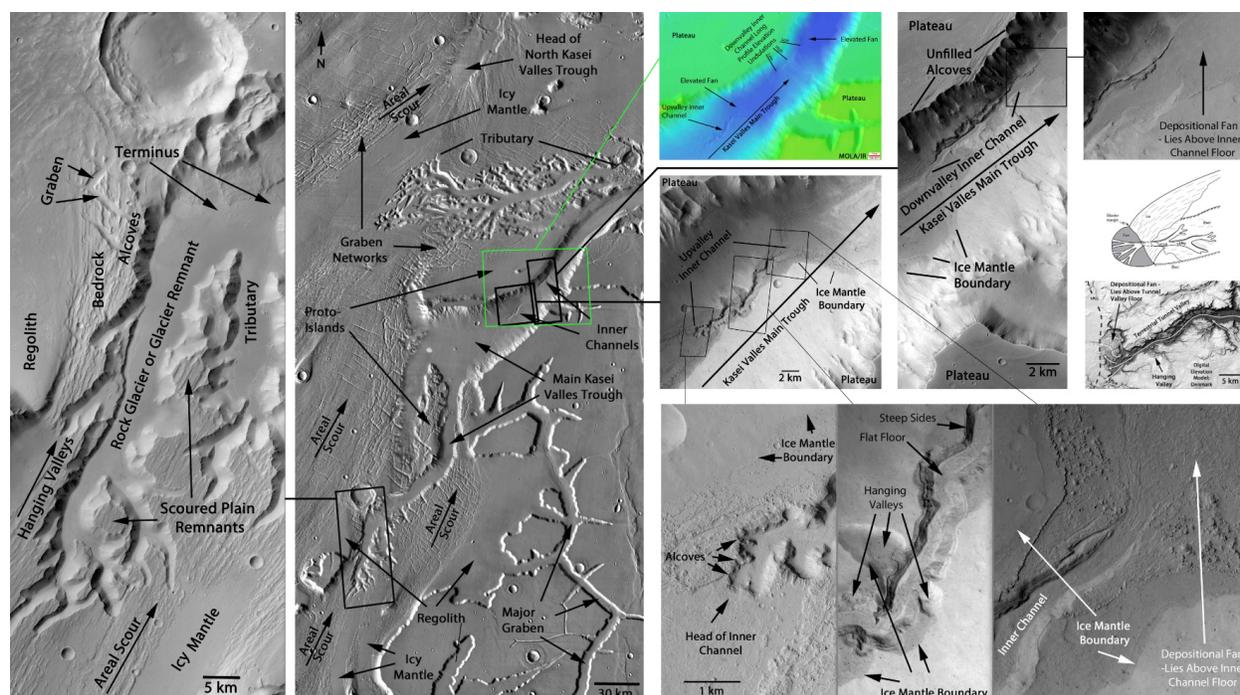
Another noteworthy feature in the area adjacent to the inner channels is a boundary between widespread ice mantled surfaces and less ice mantled surfaces straddling the inner channels. Ice mantling is also apparently present on the surrounding plains, which show groves consistent with glacially generated areal scour. It is probable that the ice mantle boundaries visible in the images below reflect a recent phase of orbital cycle driven surface ice mobilization not related to the period of the formation of the valley and the possible tunnel valleys.

In a hypothetical mission scenario (refer to Figure), a rover could land on the scoured plains near the head of the main trough to evaluate the erosion as glacial or fluvial, and sample the possible ice mantles. The rover could then descend into the main trough to determine the composition of the filling material and likewise take samples of the possible glacier remnant. Following these investigations, the rover could continue down the main trough toward the inner channels, sampling icy remnants along the way, where the possible tunnel valleys could be scrutinized.

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Figure, left pair: (See “West Kasei Poster” at Scribd.com for higher resolution) **(left)** The head of main trough of Kasei Valles. CTXP180078911987XN18N074W. **(right)** Western Kasei Valles, Themis IR.

Figure, right mosaic: (upper left) MOLA topography (100m) and THEMIS Day IR **(middle):** Downvalley inner channel. P180079702014XI21N072W, CTX: NASA/JPL/Un. of AZ. **(middle left):** Upvalley inner channel. G170247032009XN20N072W, CTX. **(middle right):** Digital elevation model, Vejle Tunnel Valley, Denmark.



HI-SEAS (Hawaii Space Exploration Analog and Simulation, hi-seas.org) as an opportunity for long-duration instrument/protocol testing and verification. K. A. Binsted¹ and J. B. Hunter², ¹University of Hawaii at Manoa, binsted@hawaii.edu, ²Cornell University, jbh5@cornell.edu.

Introduction: HI-SEAS (Hawaii Space Exploration Analog and Simulation, hi-seas.org) is a habitat at an isolated Mars-like site on the Mauna Loa side of the saddle area on the Big Island of Hawaii at approximately 8200 feet above sea level. HI-SEAS is unique, in addition to its setting in a distinctive analog environment, as:

- we select the crew to meet our research needs (in serendipitous analogs, such as Antarctic stations, crew selection criteria are not controlled by researchers);
- the conditions (habitat, mission, communications, etc.) are explicitly designed to be similar to those of a planetary exploration mission;
- the site is accessible year round, allowing longer-duration isolated and confined environment studies than at other locations;
- the geologically Mars-like (in some aspects) environment offers the potential for analog tasks, such as geological field work by human explorers and/or robots.

The ability to select crew members to meet research needs and isolate them in a managed simulation performing under specific mission profiles makes HI-SEAS ideal for detailed studies in space-flight crew dynamics, behaviors, roles and performance, especially for long-duration missions.

Future missions: HI-SEAS is funded by the NASA Human Research Program for three more missions, of four, eight, and twelve months in length. The funded research on these missions will focus on crew cohesion, roles and function.

Opportunistic Research: Astronauts on real space missions typically work on a wide range of research projects, in addition to being subjects in psychological or biomedical studies. So, in order to raise the fidelity of the HI-SEAS mission workload, we will assign our crews a set of research projects to carry out during their missions. We refer to these projects as “opportunistic research”, since they are not the focus of the funded research, and yet will hopefully produce useful results. Each of the three crews will have the same set of opportunistic research projects, and the crew’s effectiveness at carrying out this research will be one measure of the crew’s success.

Call for Opportunistic Research Proposals: Opportunistic projects can be proposed by researchers in academia or industry, or at one of the space agencies. They will be selected according to their feasibility and expected value, and must not confound the primary study.

The planned HI-SEAS missions are an excellent opportunity to raise TRL/CRL levels on technologies and countermeasures in a long-duration human exploration analog environment. We welcome proposals for tests that require a long-duration analog environment, and that complement the funded research.

The timeline is quite tight, as the primary research requires that the conditions for the three crews be as consistent as possible. The first crew will start in January 2014. So, we have set an internal deadline for opportunistic research for the end of August 2013.

THE SKOURIOTISSA MINE: A NEW TERRESTRIAL ANALOGUE FOR HYDRATED MINERAL FORMATION ON EARLY MARS.

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Introduction: Recent exploration of Mars has provided abundant evidence for hydrous alteration processes occurring primarily during the first 1.5 billion years of its history [1]. The Mars Exploration Rovers and the orbiters Mars Reconnaissance Orbiter and Mars Express detected minerals formed by aqueous alteration during hydrothermal activity and weathering at various temperatures and pH conditions. Better understanding of the mechanisms taking place during these processes is essential because some of these environmental conditions are compatible with the emergence and development of life. Study of terrestrial analogue sites in which volcanic rocks have undergone similar alteration processes is therefore extremely useful.

One such site is the Volcanogenic Massive Sulphide (VMS)-mine, Skouriotissa, in Cyprus, where we have made a mineralogical study of exposed crustal basalts that have been altered by seafloor and crustal hydrothermal processes. The Skouriotissa mine is located on the northern flank of the Troodos ophiolite. These exposed crustal rocks offer a complete section through the oceanic crust lying on harzburgitic mantle, ranging from plutonic, to intrusive and volcanic rocks overlain by sediments.

The Skouriotissa mine is located in the very low grade metamorphosed Upper Pillow Lava formation. Mining activities related to copper exploitation have resulted in additional acidic aqueous alteration of the basalts. The outcrop (Fig. 1) consists of a vertical succession of lithological benches weathered by a drainage stream that becomes increasingly acidic with distance from the mine.

Mission description: The objective of this study is to support the *in situ* missions on the surface and subsurface of Mars, particularly for geological characterization and the search for traces of fossil life in the rocks. These are the objectives of the present MSL mission and of the future ExoMars mission. A secondary objective of this study of the Skouriotissa mine is to supplement the collection of planetary analogue rocks, made available to the planetary community through the International Space Analogue Rock Store (ISAR, [2]).

Scientific Merit: We describe a location in Cyprus, the Skouriotissa mine, that exhibits a large variety of basaltic weathering products (e.g. phyllosilicates

and sulfates), similar to the minerals observed on the Martian surface.

The basalt was initially altered by seawater and hydrothermal processes on the seafloor and then subaerially by acidic waters (pH increasing from 5 to 3 with increasing distance from the source) associated with mining activities (Fig. 1). Hydrothermal alteration resulted in a quartz-chlorite alteration facies, sea water hydrothermal alteration in a smectite facies, while the acidic alteration favoured the formation of clays, such as smectites at pH 5 and zeolites and sulphates (gypsum and natrojarosite) at pH 3-4. Most of the mineral assemblages described from the Skouriotissa exposure have been observed on early Martian terrains, sometimes over areas several km²-wide [3]. The site shows different types of alteration facies associated with hydrothermal circulation and weathering. The association of these different alteration facies within a small readily accessible area makes them particularly relevant for the Martian exploration.

Logistic and environmental informations: The site is situated in the island of Cyprus at the eastern end of the Mediterranean Sea. The outcrops are regularly refreshed due to the mining activity. The site is easily accessible for field testing with scientific instruments. The environmental conditions are clement (mediterranéan conditions !), and relatively dry.

Conclusion: The alteration facies observed at the Skouriotissa Mine are similar to those found on Mars resulting from aqueous alteration of basalts at different temperature and pH conditions. By analogy, the presence of smectites over large areas of the Martian surface could provide arguments in favour of extensive aqueous alteration at low to high temperatures, whereas chlorite-bearing facies on Mars could be indicative of hydrothermal alteration. Obviously, they imply active circulation of hot fluids in the crust, driven either by volcanism, impact and/or geodynamic processes. Indeed, hydrothermal processes on Mars are highly relevant to considerations of habitability and the emergence of life. Basalts and their alteration products in general can provide important information relating to past habitability.

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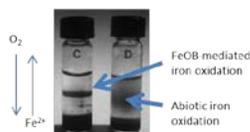
UTILIZING THE MAUNA KEA SUBSURFACE ENVIRONMENT TO MODEL EXTANT OR ANCIENT CHEMOLITHOAUTOTROPHIC IRON-OXIDIZING ACTIVITY IN AN ANOXIC ENVIRONMENT.

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Introduction: Neutrophilic, iron-oxidizing bacteria (FeOB) occupy environments where gradients of O₂ and ferrous iron (Fe (II)) exist. These bacterial communities are widespread in freshwater, marine, and subsurface environments, and utilize the energy liberated from the oxidation of iron, one of the most abundant and important elements in the Solar System (and the predominant interstitial cation in the basaltic crust of Mars. Iron oxidation readily occurs under anoxic conditions when appropriate electron acceptors and redox potential are available. Compounds such as perchlorate, demonstrated on Mars, as well as nitrate reduction species are implicated in anoxic iron oxidation in the subsurface, forming a cycle in conjunction with subsurface iron reduction, which also may be harnessed for microbial energy utilization. Prior to the generation of oxygen in the early Earth environment, the microbially-mediated iron redox cycle is thought to have been important in early earth microbial biogeochemistry, and geologic deposit of banded iron formations.

Figure 1, A. Gradient-stabilized gels containing oppositely-migrating gradients of O₂ and Fe²⁺. Abiotic and biotic iron oxidation can be easily compared and contrasted. In addition, iron oxides can be observed with biotically-produced characteristics (not shown). 1, B. Table of alternate oxidizing species potentially available for anoxic iron oxidation in the Earth subsurface and on Mars [1-5].

A



B

Fe species	Redox pair	Eh (mVolts), pH7*	Reference
Fe(OH ₃)/Fe ²⁺	NO ₃ ⁻ /½N ₂	713	Straub et. al., 1996, Weber et. al., 2006, Weber et. al., 2001, Hafenbradl et. al., 1996, Weber et. al., 2006
	NO ₃ ⁻ /NO ₂ ⁻	431	
	NO ₃ ⁻ /NH ₄ ⁺	36	
Fe(OH ₃)/Fe ²⁺	ClO ₄ ⁻ /Cl ⁻	873	Bruce et. al., 1999, Weber et. al., 2006
	ClO ₃ ⁻ /Cl ⁻	616	

Mission Description: We propose the utilization of a site on Hawaii's Mauna Kea volcano, and modeling the presence of communities containing FeOB zeta-proteobacteria (proposed class). The genome of one such zeta-proteobacteria, *Mariprofundus ferrooxydans* has recently been sequenced, and *M. ferrooxydans* has been shown to catalyze the formation of

iron oxide biominerals externally, which have characteristics that can distinguish them from abiotically-produced iron oxides [6]. The utility of these biominerals as current and ancient biomarkers has also been proposed [7]. The use of a site with these native conditions, or with artificially-induced, anoxic conditions, should provide an excellent model for characterization and development of detection technologies for this kind of potential extant, recent, or ancient microbial life on Mars. Finally, communities will be modeled / located 1 meter beneath the surface for adequate accessibility for a digging/drilling spacecraft, as well as to model protection from oxic-atmospheric conditions and UV-radiation.

Scientific Merit: Recent data returning from the Curiosity rover has confirmed previous spectral observations of a regolith very similar to the soil of Mauna Kea. The use of this environment to model active biotic, vs non-biotic iron-oxidation will provide a means to differentiate characteristics of those processes. In addition, various anoxic Fe²⁺ oxidizing agents can be added to model the resulting community dynamics of iron-oxides with biotic-life deposition characteristics.

Logistic and Environmental Constraints: The site at Mauna Kea has logistical advantages over other Mars-analogue sites such as the Chilean Atacama desert and Antarctica, in that travel logistics would be made easier by not leaving the US. Additionally, the Mauna Kea Observatory of the University of Hawaii is already there and would provide an operations base for researchers carrying out experiments. Finally, accommodations for researchers are only 7 miles away at the Onizuka Center for International Astronomy, which also provides altitude acclimatization time prior to deployment.

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EXTENSIVE GROUNDWATER DIAGENEIS ON MARS: TERRESTRIAL ANALOG INSIGHTS TO DEDUCING AQUEOUS HISTORY. M. A. Chan¹, C. H. Okubo², W. H. Farrand³, B. B. Bowen¹, J. Ormö⁴, G. Komatsu⁵, ¹University of Utah, Department of Geology and Geophysics, 115 S. 1460 E. Rm. 383 FASB, Salt Lake City, UT 84112-0102 marjorie.chan@utah.edu, ²U.S. Geological Survey, Flagstaff, AZ 86001. ³Space Science Institute, 4750 Walnut St., #205, Boulder, CO 80301, ⁴Centro de Astrobiología (CSIC-INTA), Ctra de Torrejón a Ajalvir, km 4, 28850 Torrejón de Ardoz, Spain. ⁵International Research School of Planetary Sciences, Università d'Annunzio, Viale Pindaro 42, 65127 Pescara, Italy.

Introduction: Future explorations of Mars must include overarching science questions of understanding diagenesis (post depositional change) and its relationships to astrobiology and habitable environments. It is clear that sedimentary rocks hold great potential for understanding Mars as a planetary system, yet the additional “bonus” records of watery, diagenetic environments should not be overlooked. Over the last decade of NASA Mars rover explorations, each site with sedimentary rocks has revealed records of authigenic minerals, alteration products, concretionary forms, veins, and secondary porosity [1-3]. This is not surprising since diagenesis is ubiquitous throughout sedimentary sequences of the watery planet Earth.

Mission Description: Terrestrial analogs provide valuable environmental constraints on boundary conditions of physical, chemical, and potential biological parameters. With the growing evidence for abundant aqueous activity on Mars, the diagenetic records suggest great geologic and geographic/widespread diversity for groundwaters of different compositions, and actually enlarge the possibility of more habitable environments where water cycled through the Martian crust. Mars exploration missions need the best possible tools to detect and characterize diagenesis. We discuss four major categories of terrestrial analogs, with their diagenetic implications for Mars.

Scientific Merit: 1. Concretions. Terrestrial analog studies [4-7] show the common and widespread occurrence of concretions from many geologic ages and sedimentary rock types. These cemented mineral masses have distinctive cement compositions and common self-organized in-situ distribution and spacings. Despite basic differences of siliceous host grains that might be relatively inert (chemically non reactive) on Earth, similar diagenetic concretionary forms and compositions could have formed on Mars. Analog studies can be used to help interpret both Meridiani Planum “blueberries” and “newberries” water compositions, histories, and timings.

2. Veins. Tabular, sheet-like veins are distinguished by mineral compositions and their cross cutting relationships in the host rock. In terrestrial examples, the diagenetic precipitates are commonly of gypsum, calcite, or quartz from secondary aqueous solutions that

hydraulically force their way along discontinuities (fractures, bedding planes, etc.). Terrestrial gypsum veins are commonly related to uplift in late stage diagenesis [8], with relevance to Homestake gypsum veins [2, 3].

3. Alteration Zones. Distinctive chemical or mineralogic gradients can show alteration or overprinted patterns in the original host rocks, similar to the walls of Endurance and Victoria craters [9] or the hydrothermal mineralogies of Home Plate [10], that may contain mineral “thermometers” [11].

4. Secondary Porosity. Secondary porosity developed during diagenesis is typically recognized for its evidence of corrosion, dissolution, or modified effects on primary grains or earlier diagenetic phases. Empty crystal molds such as those at Meridiani Planum [1], oversized pores, and vugs, show later water effects on chemically susceptible grains.

Logistic and Environmental Constraints: In all four of these diagenetic cases, the potential for biomediation in the terrestrial examples is strong, yet not fully evaluated. This is a growing field of study in geobiology and astrobiology that requires a solid geologic context that analog studies can provide. Diagenetic minerals may also preserve fossil biomarkers such as filaments and geochemical traces. Terrestrial analogs [12] will: inform NASA exploration strategies, provide environmental records for determining the spatial and temporal range of habitable environments, and providing testable “ground truth” to leverage the best possible results from instrumentation.

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VOLCANOGENIC ARCTIC MARS ANALOGS. C. R. Cousins¹, S. Mikhail², C. S. Cockell¹, J. Harris³. ¹UK Centre for Astrobiology, School of Physics and Astronomy, University of Edinburgh, Edinburgh, UK, c.cousins@ucl.ac.uk, ²Geophysical Laboratory, Carnegie Institute of Washington, Washington D.C., USA, ³Dept. Earth and Planetary Science, Birkbeck, University of London, London, UK.

Introduction: Volcanism has been prevalent on Mars throughout its history, along with cryospheric and hydrothermal processes [1]. Active and extinct volcanogenic terrains on Earth can provide valuable analogs to such past and present environments on Mars. Arctic localities in particular have been a mainstay of Mars analog work, including terrains in the Canadian High Arctic, Siberia, and Scandinavia. Here, we provide a comparison of three major Arctic localities (Fig. 1) that have Mars analogs produced through basaltic volcanism: (1) Iceland (Kverkfjöll, Eyjafjallajökull, and Krafla volcanoes), (2) Greenland (Tertiary Disko Island basalts), and (3) Svalbard (Sigurd fjell and Sverefjell volcanoes).

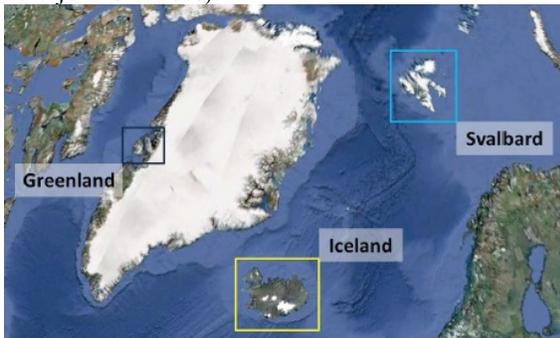


Fig. 1. Location of arctic Mars-analogue environments.

Mission Description: The different geochemistry, geography, and activity of these sites lends them to a variety of applications, including: volcanically-driven biogeochemistry potentially analogous to early Martian biology; hydrated mineral alteration terrains dominated by sulfates, phyllosilicates, zeolites, carbonates and ferric oxides, providing geological testbeds; and mineralogy that can be used to infer geochemistry within a reducing Martian mantle. These wide applications are appropriate for current and future rover missions focused on understanding the past habitability of Mars and how evidence of early Martian life can be detected.

Scientific Merit: The value of each is as follows:

Iceland: The Eyjafjallajökull volcano erupted in 2010, forming pristine volcanic habitats. Kverkfjöll is dormant, with hydrothermal activity produced by the interaction of fumaroles and glacial ice [2]. Both are isolated from complex biological systems and hydrological interaction (oceans, groundwater), allowing volcanically-driven biogeochemical activity to be understood (Fig. 2). The expanse of vegetation-free lava

flows from the 1975-84 Krafla fissure eruptions and associated hydrothermal activity provide geological analogues to acid-neutral paleoenvironments.

Svalbard: The extinct subglacially-erupted Sverefjell and Sigurd fjell volcanoes are unique in that their hydrothermally-deposited carbonate globules bare a striking similarity (both in mineralogy and morphology) to those identified in the Martian meteorite ALH84001 [3].

Disko Island: This island is 1 of the 2 locations on Earth where exposed reduced basalts are found to contain native iron-nickel alloys, iron carbides and iron phosphides of terrestrial origins [4]. Coupled with the geographical isolation (low anthropogenic input) means Disko Island is a unique locality to examine the role of native/reactive metals for prebiotic organic reactions [5] and/or biogenic communities in nature.



Fig. 2. Example geothermal environments in Iceland.

Logistic and Environmental Constraints: Arctic environments are fragile and sensitive to human disturbance. Fieldwork must be carried out within the legal and ethical framework of the host country. Krafla, Kverkfjöll, and Eyjafjallajökull lie within national parks, and require research permits. On Svalbard, polar bears are a significant danger, with strict rules on firearm requirements and camping practices. Strict sampling rules also apply. Disko Island has restricted zones concerning wildlife. Geological sampling requires permits from the Bureau of Minerals and Petroleum.

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EXTREME DESERT ANALOGS FOR ASTROBIOLOGY STUDIES. A. F. Davila¹ and C. P. McKay²,
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Introduction: Deserts are the Earth's largest terrestrial biome. Mars is a desert planet. Our group is specialized in inter-disciplinary research that integrates an overall investigation of extreme deserts on Earth, with application to Mars. Our research focuses on two complete and absolute deserts: the Atacama Desert and the Antarctic Dry Valleys.

Mission Description: Based on cumulative decades of research experience, we have developed a science framework that integrates biological, chemical and physical processes in extreme deserts. A large number of projects with researchers from the US and abroad has resulted in a wealth of data and a deeper understanding of life in extremely dry (hot and cold) environments. We now understand how life adapts to increasingly cold and dry conditions, and what is the sequence of events that leads to the disappearance of life in an environment that becomes increasingly dry [1-3]. We have investigated the number and type of microorganisms that are found in the most extremely dry and cold environments [4]. We have established the mechanisms that generate oxidative chemistry in extreme dryness, and their implications for habitability, and for the preservation of organic compounds and biosignatures. We have developed models that explain the distribution and stability of permafrost similar to than found on Mars [5]. We have also developed and tested prototype instrumentation for Mars missions. This framework is the foundation for current studies of the distribution, quantity and quality of molecular biomarkers in extreme deserts. We will present a summary of research collaborations conducted in the Atacama Desert and the Antarctic Dry Valleys and its relevance to Mars Astrobiology

Scientific Merit: Extreme desert analogs can help address the following key goals of the Mars Program: (1) Search for evidence of life, extinct or extant; (2) Determine the long-term evolution of habitability; (3) Determine the nature and evolution of the geologic processes (glaciers, ground ice, evaporites, ephemeral lakes and rivers, catastrophic floods, climate change). Extreme desert analogs can also help address the following specific questions:

1. What are the most likely environments to find evidence of life?
2. What were the most recent habitable environments on Mars —*the last footholds of life*?
3. Is liquid water possible under current conditions? Or during high obliquity?
4. What is the origin of the chemical reactivity of Martian regolith?

5. What is the preservation potential of molecular biomarkers in Martian surface deposits?
6. What biomarkers should we search for to establish whether life ever existed on Mars?
7. What tools (analytical and sampling) do we need to search for life on Mars?

Logistics and environmental constraints of the field site: Extreme deserts are by definition remote and uninhabited. However, both the Atacama Desert and the Dry Valleys are accessible and relatively safe. While extremely dry and inhospitable, the Atacama Desert is a site of intense mining activity and therefore there is infrastructure in place that facilitate enormously access to field sites. Local Chilean companies offer full services for scientific fieldwork. Research in the Antarctic Dry Valleys is conducted under the NSF Office of Polar programs, which provides full logistical support.

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The Altiplano-Puna Plateau of the Central Andes as an Analog Laboratory for Mars S. L. de Silva¹, M. Spagnuolo¹, N. Bridges², J. Zimelman³, J.G. Viramonte⁴, B. Bills⁵, and J. Bailey⁶ ¹College of Earth, Ocean, and Atmospheric Science, Oregon State University, Corvallis, OR 97331-8507, USA; desilvas@geo.oregonstate.edu; ²JHUAPL, Laurel, MD 20723; ³CEPS/NASM MRC 315, Smithsonian Institution, Washington D.C. 20013-7012; ⁴Universidad Nacional de Salta, Av Bolivia 5150, 4400 Salta, Argentina; ⁵JPL, Pasadena, CA 91109; ⁶University of Alaska Fairbanks, 3352 College Road Fairbanks Alaska, 99709

Introduction: The Altiplano-Puna Plateau of the Central Andes of Peru, Bolivia, and Argentina (~10° to 28°S) has experienced a climatic and geologic evolution that has resulted in an enticing array of potential Martian analog geologic environments and features. Elevated ~2 to 3 km above the adjacent Atacama desert, the Altiplano-Puna is the highest plateau in the world associated with extensive volcanism; it is second only to Tibet in height and extent. The Andes mountains act as a large meridional barrier to low level moisture transport and so the Altiplano-Puna plateau (4000m average a.s.l) receives little precipitation (<300mm/year). The high elevation adds extreme cold and lower atmospheric pressure to a hyper-arid climate making this region a compelling analog environment for Mars. The plateau consists of two interrelated major physiographic provinces: the *Altiplano* basin, which developed as a major intermontane basin, and the *Puna*, the higher volcano-tectonic plateau.

The analog features of the Altiplano-Puna: The Altiplano basin preserves a long Pleistocene lake history recorded in a well-preserved lake shore geomorphology consisting of both erosional and depositional features [1,2] These features are easily identified and studied in the field and on remotely sensed images and may lend valuable insight into the debate over putative paleoshorelines in the northern plains of Mars. Throughout the basin are several smaller volcanic features (maars, cinder cones, buttes) and rare large composite cones. These monogenetic and polygenetic features represent potential analogs to smaller volcanic features on Mars.

Major volcanic provinces dominated by regionally extensive ignimbrite sheets and associated eruptive centers are amongst the largest known volcanic features in the world. Of particular interest are ignimbrite shields with a central lava dome complex and an apron of gently dipping ignimbrite that are potentially analogous to Hadriaca, Alba, and Tyrrhena paterae. The region has proven to be an excellent natural laboratory for remote sensing and field-based studies of volcanism with analogs for regions on Mars like Amazonis Planitia, as well as the enigmatic Medusa Fossae Formation (MFF) materials.

The Puna is proving to be a fantastic aeolian field laboratory with strong analogs for Mars. The surface is dominated by thick Neogene ignimbrites of varying

degrees of induration in which the persistent and powerful northwesterly winds have carved spectacular yardang fleets. These have informed about the enigmatic Medusa Fossae Formation (MFF) materials [3,4,5]. A by-product of aeolian erosion of ignimbrites on the Puna are extensive lag gravels that are eventually organized into aeolian megaripples [6,7,8]. These are morphologically and contextually similar to small ripple-like Transverse Aeolian Ridges (TARs) on Mars. Moreover, the Puna gravels are bimodal and have similar equivalent weight (*mg*) to clasts composing granule ripples at Meridiani Planum [9]. Their local origin may have implications for the origin of sediment in martian aeolian bedforms [10]. Finally, the stable yet dynamic character of the Puna megaripples could help reconcile current models of TARs with periodic bedrock ridges (PBR) [11] that may be produced by aeolian erosion.

Other features of the Altiplano-Puna plateau hold similar promise. We suggest that several science themes of critical relevance to understanding the surface of Mars can be addressed in this region. 1) Physical weathering, erosion, and depositional features in cold deserts dominated by volcanic deposits; 2) The geomorphology, volcanology, and remote sensing of volcanic deposits and associated eruptive centers; 3) The geomorphic expression and features of a major paleolake basin; and 4) The geomorphology, volcanology, and remote sensing of small-scale volcanic phenomena

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ROCK MICROHABITATS FROM THE ATACAMA DESERT AS ANALOGS FOR THE MARS ENVIRONMENT. J. DiRuggiero¹, J. Wierzchos², CK. Robinson¹, A. Crits-Christoph¹, and J. Ravel³. ¹The Johns Hopkins University, 3400 N.Charles Street, Baltimore MD 21218, jdiruggiero@jhu.edu; ²Museo Nacional de Ciencias Naturales, MNCN - CSIC, Madrid, Spain; ³Institute for Genome Sciences, University of Maryland School of Medicine, Baltimore, MD.

Introduction: While the Mars regolith might be uninhabitable due to the combined effects of cold, dryness, and radiation, chloride- and sulphate-bearing deposits have been discovered in many areas of the planet and ignimbrite rocks were tentatively identified in Gale Crater, the landing site of the Mars Science Laboratory (MSL) mission [1]. The existence of Martian habitats similar to habitats capable of supporting phototrophic and heterotrophic life in the Atacama Desert - an environment that precludes almost all life forms - suggests that these should be considered important analogs for the search for extant life on Mars.

Mission Description: Investigating endolithic habitats in the Atacama Desert is therefore well suited for the goals of (1) understanding the dry limits for life as we know it and of (2) informing environment selection for future life detection missions to Mars. It is also critical to further our understanding of the interactions between minerals and microorganisms in colonized terrestrial analogs to enhance the possibilities of identifying traces of past life in valuable samples from Mars sample return missions.

Scientific Merit: The Atacama Desert is the oldest and driest desert in the world and its hyper-arid core is described as “the most barren region imaginable. It is also an analog environment for Mars and as such an excellent system to probe the dry limits for life and to

improve our understanding of the potential for life in extraterrestrial environments.

Under extreme water deficit, rapid thermal fluctuation, and high solar radiation fluxes found in cold and hot deserts around the world, lithobiotic - inhabiting the inside of rocks - microbial ecosystems are considered environmental refuges for life [2]. These communities are phototrophic-based, with primary producers supporting a diversity of heterotrophic microorganisms, which develop inside translucent rock substrates [2]. The overlying mineral substrate provides protection from incident UV radiation, physical stability, and enhanced moisture availability.

We use a combination of geochemistry, climate data, and molecular methods to determine the factors driving the colonization of rock substrates in the Atacama Desert, to estimate the diversity of microbial communities in these habitats, and to understand the functioning of these unique ecosystems.

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SULFATE-RICH PLAYA DEPOSITS FROM WHITE SANDS NATIONAL MONUMENT, A TERRESTRIAL ANALOG TO MARTIAN PLAYAS. M. Glamoclija¹, A. Steele¹, M. L. Fogel² and V. Starke¹,
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Introduction: Sulfate-rich sedimentary formations have been identified as a widespread component of Martian surface-exposed sequences. They are particularly interesting as they emphasize the importance of surface and near-surface aqueous processes during the planet's history. Furthermore, 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, the Mars Science Laboratory (MSL) landing site [3, 4]. We are proposing 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 playa formation, climate reconstruction and exploration of biosignatures and habitability parameters for inferred playa deposits on Mars.

Mission Description: Multiple missions to Mars have identified sedimentary sulfates and sulfates are one of the priority targets of the current MSL mission to Gale Crater. The orbiting missions have detected sulfate-rich deposits at different latitudes across the Martian surface indicating the importance of this kind of sedimentary formations. Understanding the depositional history of these formations will provide a significant insight into Martian geological history and potential habitability; which is also one of the major MSL goals and potentially interest of the future missions to Mars.

Scientific Merit: The geological history of the playas at White Sands includes sedimentary sequences that are very similar to those identified on Mars. The lacustrine sediments of pluvial Pleistocene Lake Otero include facies composed mainly of siliciclastic and carbonate mud, which are found together with underlying/surrounding sulfate and carbonate deposits, suggesting episodes of enhanced precipitation and contribution of relatively fresh water into an otherwise saline lake during its high-stand [5, 6]. About 9,000 to 12,000 yrs ago, the onset of significant regional aridity caused evaporation and deflation of Lake Otero [7]. Most of the fresh water strata were removed by the initial onset of aridity. The subsequent erosion and continuing aridity through the Holocene created several erosional escarpments into playa lake deposits [7, 8]. This defla-

tionary process provided the most significant contribution of sediment supply for the nearby dune field. At the western margin of Alkali Flat, the lacustrine Otero sediments consist of clays, carbonates and evaporites indicating deposition in a semi-permanent saline lake [6, 7], whereas the siliciclastic mud, corresponds to fresh water deposits with fossilized plants and mollusks [6]. The White sands playa sequences are offering the present day playa deposits (found in the southern part of the monument) and lacustrine sequences transitioning to saline lake and playas covering the span of the last 12,000 yrs. This is a unique environment to study deposits similar to lithological sequences identified at Meridiani planum and Gale Crater to learn more about their history, habitability and their potential for biosignatures preservation.

Logistics and Environmental Constraints: White Sands playas are located within the monument area that is shared with the Holman Air Force Base. This part of the monument is not open to tourists, therefore having very low probability of anthropogenic contamination within the sampling area. The White Sands area has typical Southwestern desert climate, which should be taken into consideration when planning the fieldwork. By being part of the national monument, this site has great advantage of the park infrastructure, which includes park rangers who can help during the sampling, a few utility transportation vehicles, office space and lab storage, camping grounds and accommodation for researchers. Additionally, the site benefits from being near town of Alamogordo, which can provide additional infrastructure support and connection with "the rest of the world".

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“DRILL HILL” IN HAUGHTON CRATER, DEVON ISLAND, CANADA. ¹ B. Glass ¹ P. Lee. ¹NASA-Ames Research Center, Moffett Field, CA 94035; (650) 604-3512; brian.glass@nasa.gov.

Introduction: The Arctic “Drill Hill” drilling site is located inside the broader Haughton Crater Mars-analog site, on an approx. 200 m-thick deposit of impact breccia rubble and bedrock matrixed with ground ice, with fluvio-glacial materials present secondarily as sparse surface drift. The impact breccia deposit, in combination with permafrost, make Drill Hill a superior high-fidelity analog site for specifically testing drilling and sample acquisition methods and prototype equipment.

Mission Description: Looking for volatiles, extant or fossil life and accessing subsurface ices and organics will require the ability to drill and transfer samples without getting stuck or compromising the sample or the planetary environment. Exploration of the subsurface will be essential in the search for life and water, given the desiccated, irradiated, and highly oxidized conditions on the surface. A spacecraft intended to drill on Mars or beyond must also be capable of hands-off operation for hours at a time without human oversight or control. Developing and testing the operational methods, hardware prototypes, and automated control software for planetary drilling and sample acquisition requires both laboratory and chamber testing (viz. under Mars conditions) and field testing at analog sites. The best analog sites for drilling tests are those which resemble the intended planetary target environment in multiple aspects: textural and particle/clast sizes, presence or absence of ices, chemical composition of drilled materials, presence/absence of microbes, and surface features (boulders, tilt, overburden).

Site Scientific Merit: Haughton Crater offers examples of continuous permafrost developed on a variety of impact-related outcrops i.e., massive melt breccia deposits, intracrater paleolacustrine deposits, and fluvio-glacial deposits [1]. The breccia and fluvio-glacial deposits are polymict, and offers a complex variety of Precambrian basement crystalline, dolomites, and limestones. The melt breccia deposit is a close terrestrial analog to impact-worked regolith on other planetary bodies, and in combination with subsurface ice lenses and ice-cemented layers closely resembles the near-subsurface textures and mechanical properties from Mars mid-latitudes northward.

Drill Hill was the field site used in several past drill test seasons at Haughton (with the DAME drill in 2004 and 2006 [2]; CRUX drill in 2009 and 2010 [3]; Icebreaker drill in 2011 and 2012 [4]). Therefore, there exists a substantial baseline of past drilling data and performance data at the Drill Hill site, with three different space-prototype drills tested there over six field

seasons. It therefore offers a baseline for comparison with newer drill designs and techniques. Figure 1 shows the Icebreaker drill in July 2012 tests.



Fig. 1. Icebreaker Drill in July 2012 tests at Drill Hill.

Logistics and Environmental Constraints: The Drill Hill site is approximately 5km SE of the Haughton-Mars Project’s (HMP) base camp. A Humvee- and ATV-capable trail connects the sites. Inuit-Owned Land access permits are via the seasonal HMP umbrella permit. Access to Haughton Crater is via chartered Twin Otter aircraft or helicopter from Resolute, Nunavut. While cold-season access is possible, thus far HMP base camp operations have limited Drill Hill’s accessibility to the summer months of July and August.

HMP provides several 1kW portable generators, fuel, all-terrain vehicles and a Humvee (used for personal transport to/from HMP base camp) and mechanical and medical support on-site. Two Ka-band satellite ground stations (each providing approx. 1 Mbps data service) are set up at the Drill Hill site and the HMP Base Camp.

Summary: Drill Hill is a high-fidelity terrestrial analog whose near-subsurface textural and mechanical resemblances to planetary regoliths make it a superior analog for testing subsurface sample acquisition methods and prototypes. Support and logistics available from the nearby HMP base camp make it an easily-accessed analog site. A nearly decade-long past test history with successive NASA-developed planetary prototype drills supports baseline apples-to-apples performance comparisons with other drill designs and techniques.

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DRILL AND SAMPLE ACQUISITION TESTING USING PLANETARY ANALOGS. B. Glass¹ and M. New²¹ Intelligent Systems Division, NASA-Ames Research Center, Moffett Field, CA 94035; (650) 604-3512; brian.glass@nasa.gov,² Planetary Sciences Division, NASA Headquarters, Washington, DC 20024.

Introduction: Future planetary or asteroidal sample acquisition will require autonomous drilling and sample transfer systems, both for robotic exploration and to support future human exploration, as energy, mass and human presence will be scarce. NASA has developed a series of planetary-prototype drilling projects over the past decade that have field-tested drilling automation and robotics technologies at Mars analog sites, for projected use in missions during the 2020s. These have demonstrated automated control of the drilling process and topside drill string and sample handling.

Background: A workshop on Planetary Drilling and Sample Acquisition (PDSA) was held at NASA-GSFC in May 2013. Its purpose was to bring together the past decade of results to define a framework for consistently and completely describing sample acquisition tasks, to survey the current state of knowledge of sample acquisition methods, and for each high priority application of sample acquisition technology, determine what has been demonstrated and what areas of ignorance remained.

In the context of the PDSA workshop's findings, past automated drilling and sample acquisition results were discussed in field tests at analog sites, as well as the tradeoffs between the use of planetary analog sites and laboratory testing. Also discussed were several different terrestrial analog sites (Arctic sites, Antarctic dry valleys, US southwest, Atacama, Mauna Kea, Rio Tinto) in the varying roles needed to support the validation of the technologies needed for exploration of the subsurface on other planetary bodies, as well as contrasting these locations.

Future missions requiring subsurface samples will require lightweight, low-mass planetary drilling and sample handling. [1] As discussed in the workshop rubric and findings, unlike terrestrial drills, these future exploration drills will likely work dry (without drilling muds or lubricants), blind (no prior local or regional seismic or other surveys), and weak (very low downward force or weight on bit, especially on small bodies, and perhaps 100W of power available).

Merit of Drilling Analog Sites: Terrestrial analog environments have three dominant uses in space exploration. The first is as a relevant environment for testing technical maturity, pushing prototypes and beta-versions harder, more unpredictably and with higher overall fidelity than in laboratory bench tests. Going to a terrestrial extreme environment also tends to flush

out buried assumptions about durability, connectors, vibrations and component failure rates, far less expensively than on-orbit tests. By placing systems in full-scale, high-fidelity environments while posing challenges similar to what they would encounter on a given mission, terrestrial analog sites are valuable for testing and developing new operations concepts. In automated drilling tests, this manifests as methods in initial deployment, leveling, and retrieving samples and drill strings from boreholes. Analog sites, given their natural strata and outcrops, also give a more-widely-varied set of inputs for drill automation training than laboratory bench tests. Figure 1 shows one example (the CRUX drill in tests at Hughton Crater, an Arctic Mars-analog site).[2]

Constraints and Observations: Not every proposed planetary mission which includes drilling and sample acquisition will optimally fit a given analog test site. Mars and deeper drilling missions will require



Fig. 1. CRUX rotary-percussive lunar prospecting prototype drill tests at Hughton Crater in July 2009.

better automation than lunar or libration-point missions, and automation verification needs higher-fidelity analog sites and test facilities. [3]

Permafrost sites in the Arctic and Antarctic are generally better Mars analogs than are the warmer desert sites. For lunar drilling mission development, ice is less necessary, as is extensive software validation, so cheaper and easier domestic basaltic sites are preferable. Initial life and organics detection instrument tests in conjunction with drilling are more easily done at in desert or polar environments with subsurface anaerobes.

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RIO TINTO FERRIC SULFATES AND IRON OXIDES AS MINERALOGICAL ANALOGS TO MARS.

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Introduction: In situ missions such as the Mars Exploration Rovers, Mars Phoenix and, most recently, the Mars Science Laboratory, have obtained elemental and mineralogical ground truth for orbital spectral measurements, confirming the presence of iron oxides and ferric sulfates such as hematite and jarosite [1]. Partial environmental analogues to these Mars-relevant mineralogies may be found within the Rio Tinto Basin in southwestern Spain. During the dry season, ferric sulfates form from the precipitation and evaporation of Rio Tinto headwaters rich in sulphuric acid and ferric iron, generated by biologically mediated oxidation of pyritic orebodies [2]. Hydrolysis of sulfates during the wet season leads to the precipitation of nanophase goethite, subject to increasing crystallinity and replacement with hematite in ancient river terraces [3]. Phyllosilicates generated from acidic weathering of volcanosedimentary bedrock are also present within the system, and co-precipitate in the dry season as nanophase oxyhydroxides with sulfates [4]. The geologic history of the river itself is recorded in diagenetically stabilised iron oxide/hydroxide river terraces ranging in age from 2.1 Ma to 10 Ka. Mineralogical characterization of the river deposits using hyperspectral visible-near infrared data across several scales from orbital satellite datasets from the Hyperion instrument onboard EO-1 to ASD laboratory spectra show recent deposition dominated by copiapite during the dry season, jarosite in the wet season and goethite in older terrace materials [5].



Bright orange Rio Tinto waters in the wet season

Mission Description: The primary aims of MSL and the future ExoMars rover are to study the habitability of Mars. Ongoing and future investigations of the Rio Tinto area directly underpin that goal, by establishing links between the expression of Mars-relevant surface mineralogy in orbital data and the potential for biosignature detection in analogous terrestrial environments, combining existing Mars data with an in depth characterisation of terrestrial analogue environments to identify high priority materials for satellite and in situ targeting by NASA and ESA orbiter and rover elements.

Scientific merit: Despite obvious differences in physical setting and water availability, the application of Rio Tinto as a Mars analogue is based on the abundant sedimentary ferric sulfates and iron oxides associated with the river deposits, with the added advantage of a highly active ecosystem operating in this extreme environment. The potential of iron-sulfur minerals in Rio Tinto to contain biosignatures has been previously demonstrated [6]. The presence of minerals on Mars which require the presence of water during their formation point to sites of past habitability and could represent paleobiological repositories for preserved biosignatures. The depositional environment at Rio Tinto provides not just a window into the formational processes of such minerals but insights into how these minerals and the biosignatures they may contain survive over time.

Logistic and environmental constraints: The Rio Tinto river locality is within several kilometers of nearby villages and local accommodation, providing a highly accessible range of depositional sites ranging in age from two million years to ephemeral efflorescences. Seasonal variability in water availability lead to a range of minerals being deposited at different times of year.

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MAUNA KEA VOLCANO, HAWAII: A MINERALOGIC AND GEOCHEMICAL ANALOG FOR MARS.

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Introduction: Mauna Kea Volcano, Hawaii has a peak altitude of 4205 m above sea level, or 10200 m above the ocean floor, and is the southernmost of the eight main islands of the Hawaiian Island Chain. The volcano is ~1 million years old and last erupted ~4500 years ago. During the volcano's late, or post-shield stage, eruptive activity was characterized by the formation of hundreds of large cinder cones spread across the volcano's summit and flanks. The summit region of Mauna Kea was repeatedly glaciated; various glacial deposits and features are well preserved.

Mission Description: Numerous basaltic cinder cones near the summit and upper slopes of Mauna Kea underwent hydrothermal alteration (probably sub-areally) while the volcano was active [1]. Subsequent to these eruptions, the altered basaltic tephra has been leached by near neutral pH water (from precipitation), so that only water-insoluble residues of the original alteration products likely remain. Since the Martian surface is largely basaltic in composition [e.g., 2,3], characterization of the Mauna Kea alteration mineral assemblages provide a template for mineralogical assemblages expected on the surface of Mars as a result of hydrothermal alteration and subsequent leaching.

Scientific Merit: Sulfates have been identified on the martian surface during robotic surface exploration and by orbital remote sensing. Measurements at Meridiani Planum by the Alpha-Particle X-ray Spectrometer (APXS) and Mössbauer (MB) instruments on the Mars Exploration Rover Opportunity document the presence of a ubiquitous sulfate-rich outcrop (20-40% SO₃) that has jarosite as an anhydrous Fe³⁺-sulfate [4-6]. The presence of jarosite implies a highly acidic (pH <3) formation environment [7]. Jarosite and other sulfate minerals, including kieserite, gypsum, and alunite have also been identified in several locations in orbital remote sensing data from the MEx OMEGA and MRO CRISM instruments [e.g. 8-10].

Acid sulfate weathering of basaltic materials is an obvious pathway for formation of sulfate-bearing phases on Mars [e.g. 7, 11, 12]. To constrain acid-sulfate pathways on Mars, we have examined the mineralogical and chemical manifestations of acid sulfate alteration of basaltic compositions in terrestrial environments such as Mauna Kea. We have previously shown that acid sulfate alteration of tephra under hydrothermal conditions on the Puu Poliahu cone (near summit region of Mauna Kea) resulted in jarosite and alunite as sulfate-bearing alteration products [13-16].

Other, more soluble, sulfates may have formed, but were leached away by rain and melting snow. Acid sulfate processes on Mauna Kea have also been shown to formed hematite spherules similar (except in size) to the hematite spherules observed at Meridiani Planum as an alteration product [16]. Phyllosilicates, usually smectite ± minor kaolinite are also present as alteration products [15].

Logistic and environmental constraints: The Mauna Kea Science Reserve is an 11,288 acre area of land leased by the University of Hawaii from the State of Hawaii for use as a scientific complex. The Office of Mauna Kea Management (OMKM) is charged with the day-to-day management of the Mauna Kea Science Reserve as prescribed in the Master Plan [17]. A Mauna Kea Management Board (MKMB) and a council made up of Hawaiian cultural resource persons (the Kahu Ku Mauna) serve to best represent and respect Hawaiian cultural beliefs, environmentally sensitive habitats, recreational uses, astronomy, and other scientific research. The Pacific International Space Center for Exploration Systems (PISCES), a university-based organization, was specifically established to facilitate aerospace related research and education for space exploration; thru PISCES permitting and logistical services can be coordinated.

Winter conditions (snow covered summit region) and high altitudes are the main environmental considerations for geologic research on Mauna Kea. Support facilities are available at Hale Pōhaku and the cities of Hilo and Kona are within practical driving distance. A 4-wheel-drive vehicle is required for summit access.

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THE MARS2013 MARS ANALOG MISSION IN MOROCCO. G. Groemer¹ and G. Ori², ¹Austrian Space Forum (Sillufer 3a, 6020 Innsbruck, Austria, gernot.groemer@oewf.org), ²International Research School for Planetary Sciences (IRSPS, Università d'Annunzio, Italy) and Ibn Battuta Center for Exploration (Université Cadi Ayyad, Marrakesh, ggori@irsps.unich.it).

Introduction: During February 2013, a four-week Mars analog field test in the Northern Sahara (Fig. 1). 19 experiments were conducted by a field crew in Morocco under simulated Mars surface exploration conditions, supervised by a Mission Support Center in Innsbruck, Austria. A Remote Science Support team analyzed field data in near-real time, providing planning input for the management of a complex system of field assets: two advanced spacesuit simulators, four robotic vehicles and a stationary sensor platform in a realistic workflow were coordinated by a Flight Control Team. A dedicated Flight Planning group, external control centers for the rover tele-operation and a biomedical monitoring team supported the field operations. The fields of research for the experiments were geology, human factors, astrobiology, robotics, telepresence and general exploration and operations research.

Mission Description: A series of field activities were conducted in an emulated spaceflight environment, taking into account the limited flexibility and workflow patterns pertinent to human surface exploration missions [1]. The work included technical tests with two spacesuit simulators, four robotic vehicles as well as a set of carefully selected instruments. Geoexploratory experiments included the application of infrared imaging to measure the thermal inertia for cave detection, the application of a rover-mounted fluorescence laser system (L.I.F.E., [2]) to investigate samples for biomarker molecules, planetary protection experiments [3] and general remote geoscience activities utilizing a remote science support team at the Mission Support Center in Innsbruck/Austria with reduced situational awareness to direct a simulation in the Northern Sahara.

Logistics and environmental constraints

The test site [4] was selected from 17 candidate sites in the north-eastern part of Morocco near the city of Erfoud for the following criteria: 1) Acceptable within the performance envelope

of the spacesuit simulator, 2) terrain diversity and 3) available infrastructure.

The test site was near Erfoud in the Tafilalt region, in the eastern Anti-Atlas, Morocco. The area is dominated by a Precambrian crystalline basement and a thick deformed upper-Precambrian and Paleozoic setting, and overlaid by an undeformed Cretaceous and Tertiary sedimentary rocks. In the Early Devonian submarine eruptions have created the topographic high of the Hamar Laghdad Ridge. Volcanic sediments have been overlaid by the Early Devonian crinoidal limestone: the Kess Kess Formation, which holds an astrobiological potential for detection microfossils.

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Fig. 1: Planetary protection experiment ("microEVA", a joint NASA/ARC-OeWF experiment on contamination vector analysis). (Photo by OeWF/K. Zanella-Kux).

THE JUNO II ROVER AS AN EXPLORATION TEST BED FOR MARS MISSIONS, SOLO AND HUMAN ASSISTED . J. C. Hamilton¹, P. Visscher² and C. B. Andersen¹, ¹Pacific International Space Center for Exploration Systems (PISCES) and Univ of Hawaii, Hilo, 200 West Kawili St., Hilo Hawaii 96720 (jch@hawaii.edu), ²Ontario Drive & Gear / Argo, 220 Bergey Court, New Hamburg, Ontario, Canada,

Introduction: Hawaii Island, the largest island of the Hawaiian archipelago, has been noted as a high-fidelity analog testing site for Lunar and Mars research. This has been “ground-truthed” from Mars Science Laboratory CHEMIN¹ announced the close similarity between Mars soils and the tephra materials on the lower slopes of Mauna Kea² (where the CheMin instrument was field tested at PISCES in 2008). The 2012 Joint NASA/CSA Analog Field test successfully operated the JUNO II rover at two analog sites³.

Analog Sites: Test site 1 was at 11,500 feet elevation on the south slope of Mauna Kea volcano near the terminus of the ancient glaciers in an area dubbed “Apollo Valley”. Varied loose rock and lava outcrops along with slope variability proved an operational challenge. Test site 2 was at 9,500 feet elevation with more gentle slopes with a deeper loose tephra more similar to dusty open plains and dune terrain.



Fig 1. ODG JUNO II rover in Apollo Valley at Mauna Kea, Hawaii

Traction testing: Traverses across each of these sites were performed with mission simulation objectives and waypoints, along with path selection algorithms.

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Understanding the Sources of Oxygen Isotopic Anomalies in Martian Meteorites A.Hill^{1,2}, R. Shaheen¹, K. Chong¹, and M. H. Thiemens¹

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Most of the information on the chemical composition of the rocks and evolutionary history of the Martian atmosphere have been obtained from martian meteorites such as NWA 7034 (basaltic breccia), ALH 84001 (Orthopyroxenite), and EETA79001 (Shergottite). The oxygen triple isotopic composition of silicates and water has provided a clue to the interaction of atmosphere-hydrosphere-geosphere. NWA 7034 has shown a greater ¹⁶O depletion than other Martian meteorites, including Shergotty, Nakhla, and Chassigny (named for the city in which they fell) [1]. Determining the source of the measured oxygen isotopic compositions of these Martian meteorites is a question that remains enigmatic to geochemists suggesting that there are different chemical or photochemical processes responsible for the differences in their observed oxygen isotopic composition. Defining this source is an important problem in planetary formation and evolution.

To understand the variation in the oxygen isotopic compositions of the host rock of the martian meteorites, simulation experiments were conducted with an Antarctic Dry Valley soil (a Martian analog). Mainly comprised of SiO₂, ADV was chosen because SiO₂ is a fundamental building block of all stony planets. In addition to SiO₂, ozone and water was used as an important ingredient to represent the exchange of O₃ and H₂O with SiO₂. These three ingredients may currently coexist on the planet, and may have in the past.

During the procedure, 1 g of ADV soil was allowed to react with O₃ in the presence of H₂O. The O₃/H₂O ratio was varied to study the exchange process. The first exchange process was done using of 500 μ liters of H₂O in the presence of 30 μ moles O₃. With this reaction (Fig. 1), there was an increase in $\Delta^{17}\text{O}$ (+ 0.22 ‰). The second exchange process was repeated using 60 μ moles of O₃ with 500 μ liters of H₂O in which $\Delta^{17}\text{O}$ continued to increase (~ + 0.14 ‰). Figure 1, displays that the products of SiO₂ have been altered from this reaction, thus, the basic mineral composition has also been changed. As a result, this reaction produces a distinct mass-independent isotopic signature which would mimic chemical processes that may occur on Mars.

The goal of the project was to represent processes that would reproduce the meteoritic isotopic compositions, which are isotopically unique. This increase in isotopic composition may also be seen in Mars simulant. Mars simulant contains ~50% SiO₂; the reaction that occurs in ADV

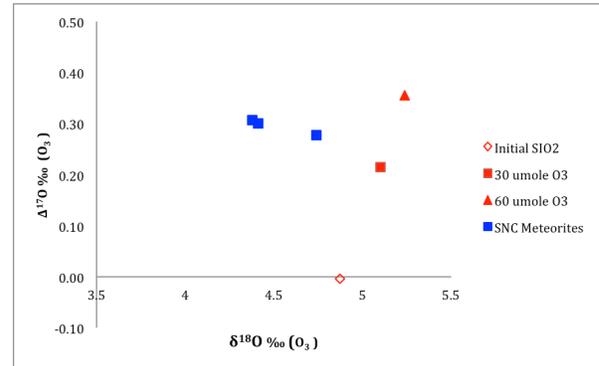


Figure 1: ADV Bulk Soil, H₂O, O₃ exchange and SNC Mars Meteorites; $\Delta^{17}\text{O}$ vs. $\delta^{18}\text{O}$

soil in the presence of O₃, H₂O, and SiO₂ can also occur in Mars simulant soil. This reaction is particularly fast, which would suggest that if this reaction were to occur on Mars, it would be a surface reaction with the atmosphere. Since this process can possibly alter the basic rock composition on Mars, and can explain the observed differences in meteorites. This suggests that the atmosphere of Mars may have changed the planet; or, perhaps, Mars has been heterogeneous from the beginning of its creation and cannot be altered.

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VOLCANICLASTIC PALEOSOL SEQUENCES: AN ANALOG FOR RECONSTRUCTING SURFACE ENVIRONMENTS FROM CLAY-BEARING LAYERED DEPOSITS ON MARS. B. Horgan and P. Christensen, School of Earth and Space Exploration, Arizona State University, Tempe, AZ (briony.horgan@asu.edu).

Introduction: Clay mineral-bearing deposits have been identified in a wide variety of terrains on Mars, and many of these deposits are consistent with aqueous alteration at the surface [1]. However, many of these deposits are regionally extensive and are not topographically confined (*e.g.*, the Mawth Vallis region), and thus are not consistent with either hydrothermal alteration or subaqueous deposition [1-3]. We propose that these deposits are morphologically and mineralogically consistent with terrestrial paleosol sequences, and specifically propose the John Day paleosol sequence (Oregon) as a terrestrial analog (Fig. 1) [4,5].

Paleosol Sequences: The majority of terrestrial non-marine clays are formed via pedogenic weathering in soil profiles. When soils are buried, they are preserved as paleosols, and can be used to reconstruct ancient surface environments and paleoclimates [6], such as oxygenation of the Earth's atmosphere [7]. When sediments are repeatedly deposited over long periods (*e.g.*, alluvial, deltaic, or volcanoclastic sediments) paleosol sequences can form that track paleoenvironmental changes at high temporal resolutions (10^3 - 10^6 years). Paleosols can be regionally extensive (hundreds of km in extent), especially when they are developed on volcanoclastics. Here we focus on the paleosol sequence preserved in the John Day Fossil Beds National Monument [5]. This 440-meter thick volcanoclastic deposit contains over 500 individual clay-rich (30-90%) paleosols. The deposits span 15 My around the Eocene-Oligocene boundary, a period of global cooling. The paleosol mineralogy reflects this climatic shift by transitioning from kaolinites, to smectites, to poorly-crystalline phases and zeolites.

Pedogenic Minerals: As demonstrated in the John Day paleosols, the clay mineralogy of soils is determined by both climate and environment [5-12]. The primary control is precipitation rates, as smectite dominated soils tend to form under the lowest precipitation rates (<1 m/year, an arid or highly seasonal climate), while kaolinite dominated soils form under high pre-

cipitation rates (>1 m/year) [8-10]. Under rapid weathering in monsoonal or alpine (snow-melt controlled) climates, poorly crystalline phases like halloysite/allophane are favored [8,11]. Acidity inhibits allophane and can alter smectites to kaolins [12], and poor drainage produces smectites [5]. Oxidation is also key, as while Fe-oxides are common in most soils, water-logged environments are reducing and produce poorly-crystalline Fe(II)-bearing clays [3,5]. Minor burial alteration (hundreds of meters depth) of poorly-crystalline phases produces zeolites and celadonite [5].

Mission Description: Developing better methods for detecting paleosols and interpreting paleoclimate is relevant to all present and future missions that have encountered clay-bearing deposits, including the Endeavour Crater and Mt. Sharp clays currently being investigated by MER Opportunity and MSL.

Scientific Merit: The John Day paleosols are mafic in composition and volcanoclastic in origin, making them an excellent analog for regionally extensive layered deposits on Mars, many of which may also be volcanoclastic in origin [13]. Identifying and studying paleosols on Mars may be critical for constraining early martian climate and surface habitability.

Logistical and Environmental Constraints: Exposures of the John Day paleosol sequence are easily accessible year-round within the National Monument, which is managed by the National Parks Service.

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Figure 1: Paleosol sequences in the John Day Fossil Beds National Monument, Oregon (44.652°N, -120.266°E). Every colorful “layer” corresponds to dozens of paleosols, each recording 10^3 - 10^5 years of environmental history.

DEVELOPING AND OPTIMIZING IN SITU X-RAY PHASE CONTRAST MICROIMAGING CAPABILITIES THROUGH ANALOG STUDY AND FIELD TESTING FOR MARS SAMPLE RETURN.
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Introduction: Answering the question of whether Mars has ever been an abode of life in the context of solar system evolution is perhaps the most compelling reason for Mars exploration. The 2020 Mars Science Rover mission, as stated by NASA, will advance the scientific priorities elaborated in the Planetary Science Decadal Survey [1], and is intended to investigate an astrobiologically relevant ancient environment on Mars to decipher its geological processes and history, including the assessment of its past habitability and potential for preservation of biosignatures within accessible geological materials. While its science objectives remain to be seen, given what science questions have been addressed and/or will be addressed by ongoing and upcoming Mars missions in the next few years, it is reasonable to assume that the 2020 Mars Rover or a future Mars mission may include selection of martian samples for eventual return to Earth to address the questions of habitability and the potential origin and evolution of life on Mars in detail through laboratory study.

Mission Description: If this is the case, then a question naturally arises: Given the diversity and complexity of Mars and martian materials and a limited amount of material that could be returned, what would be effective approaches to identifying high-priority martian samples, e.g., those with the potential of preservation of biosignatures? An in situ microscope, which combines high resolution and high sensitivity (to low-density structures) with high penetrability, may be needed to nondestructively detect cells and fossils potentially preserved in martian materials as well as microscopically textural evidence for formation in aqueous environments. We have been exploring the use of X-ray phase contrast imaging for in situ mapping of textures and biosignatures of martian materials [2]. To this end, conducting analog research and instrument field testing, as part of the effort to develop a portable X-ray phase contrast microimaging instrument for Mars exploration, would be crucial, which enables imaging capabilities and analysis procedures to be developed and optimized for in situ measurements on Mars as well as relevant scientific data to be acquired. This will directly help solve a challenging science issue concerning selecting samples for return to Earth, which may be relevant to the 2020 Mars Rover or a future Mars mission.

Scientific Merit: X-ray phase contrast microimaging is intrinsically sensitive to structural/compositional heterogeneities such as morphological biosignatures, pores, cracks, different phases and/or different states of matter, and microscopic textures relevant to sedimentary rock formation. Hence, a miniaturized X-ray microimaging instrument to be developed would allow in situ measurements to be performed on Mars to help assess its past habitability and search for possible microscopic evidence of biosignatures such as microfossils and biofilms, which may be relevant to future Mars sample return missions. Testing on various analog samples, followed by field testing in a terrestrial location similar to astrobiologically relevant martian environments using an X-ray microimaging system, would result in (1) valuable experience that will considerably benefit the development of optimum in situ X-ray phase contrast imaging capabilities for the assessment of aqueous environments and the potential of preserving biosignatures within martian materials, and (2) new knowledge that will facilitate well-informed data interpretation. New information to be acquired from terrestrial analogs, e.g., morphological data of microbes and textural evidence for the presence of liquid water or sedimentary rock formation, would directly help in situ identification of high-priority martian materials for return to Earth to answer the major scientific questions of habitability and life in the solar system, including whether life has ever arisen on Mars, through detailed laboratory study. Given the possibility that morphological biosignatures potentially preserved in martian materials are on small scales, it is important to optimize the advanced imaging capabilities using analogs and terrestrial analog environments in order to effectively deal with a needle-in-a-haystack problem to be likely encountered on Mars.

Logistic and Environmental Constraints: Easy access is preferred but is not required.

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NORTHWEST NILI FOSSAE: A POSSIBLE ANCIENT HOT SPRINGS AREA. Zachahry Kaiser¹ and Christopher Konen²,
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Introduction: Our team searched for possible hot springs on Mars that could have once hosted ancient life. Sulfur rich hot springs found on Earth are teeming with life. [1] Hot springs have been tentatively identified in Vernal Crater, and a volcanic cone in the Nili Patera caldera on Mars has been identified to contain potential hydrothermal mineral deposits. [2]

We examined 132 HiRISE hydrothermal images and geological maps to select an area of study. We selected northwest Nili Fossae, specifically the IRB non-map projected version of HiRISE image PSP_008637_2035 and the FRT 0000D6D6 CRISM image.

Phyllosilicates form in a prolonged wet and often warm environment. [4] Clays are great at holding and preserving organic matter. [5] With phyllosilicates in our area, there is a chance that we could find the chemistry of life. [6]. Phyllosilicates have been found in Nili Fossae, but most publications seem to focus on areas east of it or in the main depression. [7] Phyllosilicates have been found concentrated on the slopes of mesas and along canyon walls, which shows that water played a sizable role in changing the minerals in a variety of terrains. [6] Iron oxides have been altered by water and are typically found in places where there are hot springs. [8] Sulfate minerals form in a relatively acidic environment. A common environment involves contact with hot water solutions. [9] Hydrated silicates can be dissolved by hot water and transported via hydrothermal vents into hot springs. [10] Some hydrated silicates such as opal have been found on Mars in deposits that are younger than Noachian-aged rocks, implying that hot springs may have been active in more recent times. [11] We also looked for carbonates, since the ones previously found in Nili Fossae are like the Pilbara carbonates that are in Australia which contain stromatolites. [12] Carbonates had been a missing rock type on Mars and are not very common there. [13]

Mission Description: Northwest Nili Fossae is an area that may have contained hot springs. This would provide a great area for microbial life to grow. The presence of a hot spring in Nili Fossae would to determine if life could exist on the surface of Mars.

Scientific Merit: We conclude that northwest Nili Fossae was a hydrothermal area based on these criteria: 1) Observed mounds range in diameter from 3 meters to 453 meters, making them a suitable size to be considered as hot springs or stromatolite reefs. 2) Vermiculite, saponite, nontronite, chlorite, glauconite, biotite and phlogopite were detected. They seem to be eroding out from a layer of rocks along the cliffs

and filling the bottoms of low channel areas. This layer is not associated with the youngest surface, so it may agree with Noachian aged rocks.

3) The presence of large quantities of water is supported with the detection of desiccation cracks.

4) We did not detect any kaolinite, sulfates or hydrated silicates, which suggests these waters were not acidic in pH, but more neutral. This implies the environment of Mars at the time of their formation was wetter and at temperatures more hospitable to life. [2, 17, 18]

We also conclude northwest Nili Fossae has not undergone serpentinisation, because there was no spectral detection of olivine, magnetite, serpentine, or talc. Therefore methane could not have formed through serpentinisation on our site, leaving the possibility open that it is of biological origin.

Magnesite, siderite and dolomite were detected. Since carbonates were found, there is a very slim possibility that they may be associated with a biological origin. However, carbonates can form as a result of geological processes as well. [19]

Logistic and Environmental Constraints of the Field Site: Northwest Nili Fossae is near an area that was previously considered as a Mars landing site for the Curiosity rover (Nili Carbonate). [20] Some area constraints might be the slope of the land and the fact that most of the detected phyllosilicates and mounds are in channels that constrain a landing ellipse.

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HAUGHTON IMPACT CRATER AND SURROUNDING TERRAIN, DEVON ISLAND, HIGH ARCTIC: A MULTI-MISSION MARS ANALOG SCIENCE SITE. Pascal Lee^{1,2,3}, Terry Fong³, Brian Glass³, Stephen J. Hoffman⁴, Christopher Hoftun¹, Kira Lorber¹, Christopher P. McKay³, Robert Mueller⁵, John Parnell⁶, John W. Schutt¹, Kris Zacny⁷, ¹Mars Institute, NASA Research Park, Bldg 19, Suite 2047, Moffett Field, CA 94035, pascal.lee@marsinstitute.net, ²SETI Institute, 189 Bernardo Ave., Suite 100, Mountain View, CA 94043, ³NASA Ames Research Center, MS 245-3, Moffett Field, CA 94035-1000, ⁴NASA Johnson Space Center, ⁵NASA Kennedy Space Center, ⁶University of Aberdeen, UK, ⁷Honeybee Robotics, Inc.

Introduction: The Haughton impact structure (D = 20 km; Age = 21Ma) is located at 75°25'N, 89°49'W on Devon Island, High Arctic. Devon (55,247 km²) is the largest uninhabited island on Earth. Haughton is the only terrestrial impact crater set in a polar desert, *i.e.*, an environment that is simultaneously cold (annual mean T=-15°C), dry, barren, rocky, ground-ice-rich, and underlain with continuous permafrost. For a crater of its size and age, Haughton is remarkably well preserved. Fragile and generally ephemeral features such as impact breccia deposits, impact ejecta blankets, and impact-induced hydrothermal vents may still be identified and investigated. Aside from the impact structure itself, Devon Island presents a wide variety of potential geologic and geomorphic analogs to Mars, in particular glacial meltwater channels, glacial trough valleys, glacial deposits, paleolacustrine deposits, and periglacial patterned ground. In addition to its relevance as an analog for Mars *science*, the site offers unique opportunities for Mars *exploration* studies (testing of instruments, exploration systems, and operations; studies human factors, etc.) as it presents real and relevant exploration challenges, e.g., a truly “hostile” environment, remoteness, isolation, and vast areas to explore.

Mission Description: The following key investigations on Devon Island address together all three NASA major science goals relevant to understanding Mars: *Life*: a) Under what physical conditions is microbial life possible and its record preserved in extremely cold deserts, particularly in shallow subsurface (endolithic) and ground-ice-rich environments? b) What microbial signatures are recorded in transient, impact-induced hydrothermal systems and how might similar signatures be identified on Mars? *Climate*: a) Was the climate on Early Mars warm or cold, and what does Devon Island’s climate record of cold-based glaciation and deglaciation tell us? *Geology*: a) How did Mars’s small valley networks form, and are Devon Island’s subglacial meltwater channel networks plausible analogs? b) How did Mars’s canyon valleys (e.g., Eos Chasma, Ius Chasma) form and are Devon Island’s glacial trough valleys plausible analogs? c) How did ground physical and chemical conditions evolve following impacts on Mars, and what does Haughton crater’s record of these conditions tell us?

Scientific Merit: The investigations listed above all address central Mars science goals and questions identified by NASA’s SMD and the NSF’s Decadal Survey. Haughton Crater and Devon Island are unique in that they offer opportunities to conduct these investigations synergistically. For instance, the glacial climatic and geologic history of Devon are reflected in an *array* of surface features whose potential counterparts and interrelations may also be investigated on Mars. Haughton also allows the study not only of any impact-associated hydrothermal microbiology, but the potential preservation of its signatures in ground-ice on Mars, etc.

Logistics and Environmental Constraints: In spite of its remote location in the Arctic, and perhaps contrary to common perception, access to Haughton Crater is relatively easy and cost-effective (an order of magnitude lower in cost than deploying to Antarctica). Since 1997, the Haughton-Mars Project (HMP) (PI: P. Lee) has been hosting NASA-supported investigations and investigators (including graduate students) at the site each summer. July and August are the best time to access the site for most types of Mars analog studies, as the ground is then free of snow. The HMP is jointly managed by the Mars Institute (MI) and the SETI Institute. The HMP operates the HMP Research Station (HMPRS), the largest polar research station in the world and the only one dedicated to analog studies. The station is accessed by air on Twin Otter aircraft from Resolute Bay (YRB), Nunavut, Canada. Permits to access, use, and conduct research at the HMP site are held by MI and cover NASA and/or Canadian Space Agency-supported research and E/PO activities.

Conclusion: Haughton Crater and Devon Island present a unique *combination* of attributes that make the site highly relevant and valuable for Mars analog science studies in relation to past, ongoing, and future NASA Mars missions. The site has been used annually by NASA and other space agencies for Mars/planetary science and exploration work since 1997, and is anticipated to remain relevant and useful far into the future.

Additional Information: For more information, please visit: HMP: www.marsonearth.org; MI: www.marsinstitute.info; SETI Institute: www.seti.org, or contact P. Lee at pascal.lee@marsinstitute.net.

MSL SAM-LIKE EVOLVED GAS ANALYSIS OF MARS ANALOG SAMPLES FROM THE ARCTIC MARS ANALOG SVALBARD EXPEDITION: IMPLICATIONS FOR ANALYSES BY THE MARS SCIENCE LABORATORY. A.C. McAdam¹, J.C. Stern¹, P.R. Mahaffy¹, D.F. Blake², R.V. Morris³, D.W. Ming³, T. Bristow², A. Steele⁴, H.E.F. Amundson⁵, ¹NASA Goddard Space Flight Center, Code 699, Greenbelt, MD 20771, Amy.McAdam@nasa.gov, ²NASA Ames Research Center, MS 239-4, Moffett Field, CA 94035, ³NASA Johnson Space Center, Houston, TX 77058, ⁴Geophysical Laboratory, Carnegie Institution of Washington, 5251 Broad Branch Rd., Washington, DC 20015, ⁵Earth and Planetary Exploration Services, Jac Aalls gt 44b, N-0364 Oslo, Norway.

Introduction: The Arctic Mars Analog Svalbard Expeditions (AMASE) have investigated a range of geologic settings on Svalbard, using methodologies and techniques being developed for Mars missions, such as the Mars Science Laboratory (MSL). The Sample Analysis at Mars [SAM, e.g., 1] instrument suite on MSL consists of a quadrupole mass spectrometer (QMS), a gas chromatograph (GC), and a tunable laser spectrometer (TLS), which analyze gases created by pyrolysis of samples. During AMASE, a Hidden Evolved Gas Analysis-Mass Spectrometer (EGA-QMS) system set up to operate under SAM-like pyrolysis and gas flow conditions represented the EGA-QMS capability of SAM. Another MSL instrument, CheMin, uses x-ray diffraction to perform quantitative mineralogical characterization of samples [e.g., 2]. Field-portable versions of CheMin were used during AMASE. Here we will discuss SAM-like EGA-QMS analyses of samples from several field seasons, together with AMASE CheMin team results.

Organic materials and organic-mineral associations: Organic materials evolved from all samples over a range of temperatures. In general, this can indicate that the organics have a range of thermal maturity and/or are bound in different ways to their matrix. Most often, organics that were outside of mineral grains were the dominant pool of organic material inferable from EGA-QMS, but organics encapsulated within mineral grains were also inferred. Fig. 1 shows an example of organic fragments released on heating of a sample from Colletthøgda. Organic fragments released coincident with CO₂ from decomposition of sample carbonate implies that organics were trapped within them (e.g., in fluid inclusions). Organic-mineral associations can influence organic preservation potential and detection. Our SAM-like EGA-QMS analog analyses demonstrate the potential to understand the organic chemical characteristics in materials sampled by MSL, even when utilizing the simplest type of SAM solid sample analysis. Any organic chemical information inferred from EGA-QMS could then be followed by SAM EGA-GCMS and/or EGA-TLS.

Constraints on Mineralogy: AMASE analog studies also indicate that SAM EGA-QMS can be expected to support and/or supplement CheMin-derived mineralogical analyses of martian materials sampled by MSL.

Key potential contributions include additional constraints on minor abundances of volatile-bearing phases or additional insights into the crystallinity of clays or clay mineraloid phases. An example of this is shown in Fig. 2, which presents EGA-MS data from a basalt sample from the Sigurdjell Volcanic Center. The CheMin team derived mineralogy did not include any carbonates, but CO₂ evolved near 650°C during EGA suggests the presence of minor (below the CheMin-like analysis detection limit) of Fe- or Mg-carbonate. This carbonate could be in carbonate globules known to present in some of these basalts [e.g., 3]. The higher T CO₂ peak could be from cracking of igneous minerals or glass which contained trapped magmatic CO₂ (in fluid inclusions or in crystal structures).

The types of secondary minerals in a martian assemblage, as well as their nature (e.g., crystallinity), can help constrain alteration conditions. Our detailed comparisons between SAM-like and CheMin-like analyses of Mars analogs provides information that is directly relevant to interpretation of MSL flight data.

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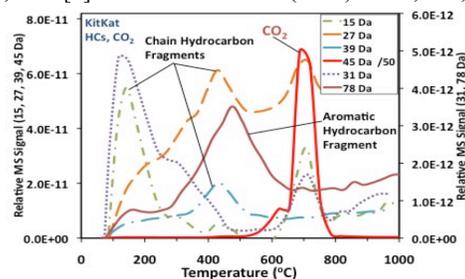


Figure 1. EGA traces from Colletthøgda carbonate.

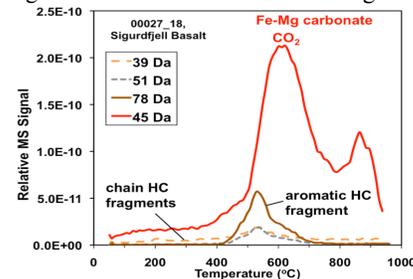


Figure 2. EGA traces from Sigurdjell basalt.

ACID-SULFATE ALTERATION OF BASALT AT CERRO NEGRO VOLCANO, AN ANALOG FOR FORMATION OF SULFATE DEPOSITS ON MARS. T. M. McCollom¹, B. M. Hynek^{1,2}, and K. L. Rogers³,
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Introduction: Over the last couple of decades, orbital and lander missions have revealed that sulfate-bearing deposits are widespread across the surface of Mars, and their formation may represent a major era in martian geologic history [e.g., 1]. A number of different scenarios have been proposed to account for the origin of the sulfate deposits, including evaporation of sulfate-bearing groundwater, acid-fog weathering of basalt, low-temperature weathering of glacial deposits, and hydrothermal acid-sulfate alteration in volcanic settings [e.g., 2-5]. The ability to infer which of these scenarios may be responsible for the formation of specific deposits on Mars requires an in-depth understanding of the geochemical processes leading to precipitation of sulfate minerals in each scenario, and comparison of the types of minerals that are formed under a range of conditions. To investigate the contribution of acid-sulfate alteration to martian sulfate deposits, we are studying geochemical and mineralogical trends during the alteration of pyroclastic basalt by sulfur-bearing vapors in fumaroles at Cerro Negro volcano, Nicaragua (see photo of fumaroles and altered deposits along interior crater wall, ~150 m across) [6,7].

Mission Relevance: Every landed mission to Mars has encountered sulfates beginning with S-bearing duricrusts encountered by Vikings 1 & 2 and Pathfinder. Sulfate deposits were encountered at both MER landing sites, and are a major target of the current Curiosity rover mission in Gale Crater. Additionally, orbital missions continue to study sulfate-bearing deposits across the surface of Mars. Understanding the origin of the sulfate deposits, and their implications for Martian geological history and potential habitability, are major objectives of each of these missions.

Scientific Merit: Cerro Negro (CN) volcano provides an opportunity to examine ongoing acid-sulfate alteration of pyroclastic basalt by sulfur-rich volcanic vapors. It is likely that similar settings and processes were common during the early history of Mars, when widespread basaltic volcanic activity, discharge of sulfur-rich gases, and limited water supply would have combined to alter rocks under vapor-dominated hydrothermal conditions. At Cerro Negro, acid-sulfate alteration results in a very limited suite of secondary phases dominated by amorphous silica, gypsum, and Fe-bearing natroalunite, along with minor amounts of hematite. Cinders at CN are vesicular and composed of plagioclase, augite, and olivine phenocrysts embed-



ded in a glassy matrix. During alteration, the phenocrysts react rapidly with sulfuric acid formed by condensing vapors, while the glass reacts much more slowly. In the initial stage of alteration, much of the Ca, Na, Al, and Fe released from dissolution of the primary silicates precipitates as sulfates (gypsum and natroalunite), while Mg is transported out of the system and Si remains behind as amorphous silica. With continued alteration, the glass breaks down and sulfates formed in the initial stage redissolve and are mobilized, which ultimately produces deposits composed almost entirely of amorphous silica. In some areas, sulfate salts transported out of the altered cinders reprecipitate at the ground surface as crusts of gypsum, Fe-bearing natroalunite or, more rarely, jarosite.

Reaction path models based on the alteration pathways observed at CN but adapted to Martian conditions predict that acid-sulfate alteration pyroclastic basalts on Mars should produce a secondary phase assemblage dominated by amorphous silica, anhydrite, Fe-rich natroalunite, kieserite, and hematite. Within the limitations of spectroscopic and other measurements, this predicted assemblage is consistent with the mineralogy of many sulfate deposits that have been observed at Mars, including those at Meridiani Planum and Gale Crater and within Valles Marineris.

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Present-Day Continental Sites of Serpentinization as Analogs for Serpentinization on Mars. Penny Morrill¹, Natalie Szponar¹, Heidi Kavanagh¹, Amanda Rietze¹, Lukas Kohl¹, (¹Dept. Earth Sciences, Memorial University of Newfoundland, NL, CAN), William Brazelton², Mathew Schrenk², (²Dept. of Biology, East Carolina University, NC, USA), Susan Lang³ (³Inst. f. Geochemistry and Petrology, ETH, Zurich, SWITZ), J.Gijs Kuenen⁴ (⁴Delft University of Technology, Delft, Netherlands), Barb Sherwood Lollar⁵ (⁵Dept. of Geology, University of Toronto, ON, CAN), Jennifer L. Eigenbrode⁶ (⁶Goddard Space Flight Center, NASA, MD,USA), Dina Bower⁷, Andrew Steele⁷, Marilyn Fogel⁷, (⁷Geophysical Laboratory, Carnegie Institution for Science, DC, USA), Shino Suzuki⁸, and Kenneth H. Nealson⁸ (⁸J. Craig Venter Institute, San Diego, CA, USA).

Introduction: The Tablelands, NL, CAN and The Cedars, CA, USA are Mars analogs for the altered ultramafic rocks with Mg-carbonate and serpentine signatures of the NE Syrtis Acidic-Alkaline transition. The presence of these rock types suggest that serpentinization may have occurred on Mars at this location in the past. Serpentinization creates conditions amenable for both abiogenic and microbial synthesis of CH₄. Subsurface serpentinization may have been the source of the putative CH₄ in the Martian atmosphere. Therefore the Tablelands and The Cedars analog sites are ideal for testing the detection of abio- and biosignatures, and hypothesizing the formation mechanisms of organic molecules at sites of serpentinization.

Mission Description: The Tablelands and The Cedars are analogs of the NE Syrtis Acidic-Alkaline transition, which was one of the proposed landing sites that was not selected for MSL. The NE Syrtis Acidic-Alkaline transition contains altered ultramafic rocks with Mg-carbonate and serpentine signatures. The detection of these rock types suggest that serpentinization may have occurred on Mars, and therefore conditions amenable for both abiogenic synthesis and microbial chemosynthesis of hydrocarbons, such as methane, may have existed at the NE Syrtis Acidic-Alkaline transition proposed landing site. Studying past and present-day serpentinization at continental sites of serpentinization will answer questions about the habitability of sites of serpentinization, the potential of abiogenic production of hydrocarbons, and the preservation of biosignatures; therefore, contribute to the scientific goals of the 2018 ExoMars Rovers Mission, and the Mars Exploration Program Analysis Group (MEPEG).

Scientific Merit: The studies of the Tablelands and The Cedars have the following goals: 1) to determine the carbon source and reaction pathways (biogenic and abiogenic) that produce the organics (e.g. CH₄) found in the ultra-basic groundwater resulting from subsurface serpentinization, 2) to determine microbial communities that thrive in the ultra-basic reducing groundwater at sites of serpentinization; and 3) to determine preservation of abio- and biosignatures in carbonate rocks indigenous to sites of serpentinization. This poster will present data describing the carbon

pools, potential sources of the organics detected, the methods used for sourcing organics, genomic results, and molecular biomarkers detected at the Tablelands and The Cedars.

Logistic and Environmental Constraints of the Field Site: The Tablelands is located in Gros Morne National Park which is a UNESCO world heritage site. Any work at the Tablelands requires permits, and may be restricted due to the world heritage designation. The Cedars is privately owned. Access is difficult (7 river crossings, and only accessible in the summer) and at the purview of the owners.

Spectral Study of Water Tracks as an Analog for Recurring Slope Lineae. L. Ojha^{1*} & M. B. Wilhelm^{2,1*}, J. J. Wray¹. ¹Georgia Institute of Technology, Atlanta, GA; ²NASA Ames Research Center, Moffett Field, CA *(luju@gatech.edu, mbwillhelm@gatech.edu).

Introduction: Liquid water is a key requirement for life on Earth, and serves as an important constraint on present day habitability on Mars. Recurring Slope Lineae (RSL) are a unique phenomenon on Mars that may be formed by brine seeps. Their morphological, seasonal and temporal characteristics support this hypothesis [1-3]; however, spectral evidence has been lacking. Ojha *et al.*, 2013 [4] recently analyzed CRISM images from all confirmed RSL in the southern mid-latitudes and equatorial regions and found no spectroscopic evidence for water. Instead, enhanced abundances or distinct grain sizes of both ferric and ferrous minerals are observed at most sites. The strength of these spectral signatures changes as a function of season, possibly indicating removal of a fine-grained surface component during RSL flow, precipitation of ferric oxides, and/or wetting of the substrate.

Water tracks (WT) have been suggested as a terrestrial analog for RSL by Levy *et al.*, 2011 [5]. WT are defined as dark surface features that extend downslope in a linear or branching fashion, usually oriented along the steepest local gradient, in the Dry Valleys of Antarctica. They can be 1-3 m in width and can have lengths up to 2 km. They share many morphological and seasonal characteristics with RSL including active growth during summer seasons and fading during winter [5]. Snowmelt, ground ice melt and deliquescence by hygroscopic salts have been suggested as possible formation mechanisms for water tracks [5]. No spectral work to date has been reported for water tracks.

Analog Study Description: We propose to perform a three-part spectral investigation to determine both the mineralogical and biologic signature of Antarctic water tracks for comparison to the recent spectral analysis of RSL and to inform future remote sensing and rover exploration of Mars. This will involve the use of Earth-orbiter multispectral images, in-situ spectral measurements of WT at high temporal resolution to understand spectral behavior as a function of volumetric water content (VWC) and season, and Raman analysis of potential organic biomarkers to investigate organic deposition, preservation, and detection potential of RSL analogs with field-rated instrumentation.

(1) Remote Sensing: Panchromatic and multispectral images acquired through high resolution Earth orbiters (e.g. World View-1 with maximum multispectral resolution of 1.65 m) will be used to: **(a)** detect possible water related signatures in WT spectra and **(b)** study putative temporal variations in the spectra of WT as a function of season and VWC. This will help us

understand why water bands are not detected in even the widest of RSL. A possible reason we do not detect H₂O absorptions in RSL is that MRO acquires images of Mars in the late afternoon (~3PM), by which time RSL may have largely dried due to low humidity, while nevertheless retaining their dark appearance [6]. By studying the variation in spectra of WT as a function of time, we will be able to test this hypothesis.

(2) In-Situ Mineralogical Analysis: In-situ infrared measurements of WT with a field-rated spectrometer will also be acquired to establish the relationship between VWC and spectral signatures. This analysis can serve as an important ground truth of remote spectral observations and can be coupled to further micro- and meso-scale geologic observations.

(3) Raman Organic Analysis: Levy and Fountain, 2011 [7] found that organic matter is more abundant (up to 5 times more) in water track soils than in adjacent dry soils. We propose to do a detailed field investigation of biomarkers present over time on and off water track soils and with depth using a field-rated Raman system. Samples will be collected for a later, more detailed analysis with a GC-MS system to compare with Raman field results to determine the viability of using such systems as a primary biomarker detection and characterization tool. Furthermore, Raman and infrared spectroscopic investigations can be coupled, and can inform the use of these systems in tandem to identify sites with the highest organic concentration and preservation potential.

Scientific Merit & Application to Mars: The seasonal, temporal and geomorphic characteristics suggest that RSL are formed by brines. Spectroscopic evidence has previously been lacking, but there now appears to be a diagnostic, consistent spectral signature associated with RSL slopes [4]. The proposed work will aid in the understanding of spectral characteristics observed on RSL slopes and will inform potential future biomarker identification. If RSL are confirmed to be due to brines, it will prove pivotal for the future exploration of Mars, both in terms of astrobiology and resource availability for potential human missions.

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SAHARA AS A CONTINENT-WIDE MARS ANALOGUE AND THE IBN BATTUTA CENTRE AT MARRAKECH. G. G. Ori ^{1,2}, I. Dell’Arciprete ² and K. Taj-Eddine ^{2,3}, ¹IRSPS, Università d’Annunzio (Viale Pindaro 42, 65127 Pescara, Italy, ggori@irsps.unich.it), ² Ibn Battuta Centre, Université Cadi Ayyad, Marrakech, Morocco, unich.it), ³ Faculté de Sciences, Université Cadi Ayyad, Marrakech, Morocco.

Introduction: The Ibn Battuta Centre for exploration and field activities was established in 2006 by the International Research School of Planetary Sciences (Pescara, Italy) to prepare and execute tests of rovers, landing systems, instruments and operations related to the exploration of Mars and Moon. The Centre has a major partner, the Université Cadi Ayyad of Marrakech (Morocco) where it is located. The Centre is named after the famous Moroccan explorer Ibn Battuta (born in Tangier on 24th February 1304 – 703 Hijra) who explored a large part of Northern Africa and Asia. During his travels Ibn Battuta visited almost the entire Muslim world and travelled more than 120,000 kilometres.

The centre take advantage of the Sahara environment that has been shaped by sedimentary processes that are partially similar to the those active on Mars. Moreover, the large geological variability of its history of its past is testified by a number of geological and astrobiological targets of Mars analogue missions.

Sahara and Mars: Sahara has experienced during its long geological history a large number of climatic changes from humid conditions (with savanna-type environments) to dry conditions (with hot desert environments). Therefore since the late Miocene Sahara alternated periods with rivers, lakes, deltas swamps with periods with a strong aeolian activity and the formation of deflation surface and sand seas. The Sahara is also dominated by a cratonic landscape with a marginal mountain chain (the Atlas) and volcanic centres (Hoggar, Tibesti). The landscape is therefore broad with swells and domes resembling the Martian topography.

The continental sedimentary systems that formed during humid period have been reworked by the wind processes during the dry periods. The aeolian erosion has been extremely efficient leaving some remains of the fluvial deposits as meander belts or exhumed (inverted) channels. Deltaic deposits are strongly eroded and large inland lakes and swamp eroded and a few remains are mostly buried below dunes and sand seas. The leftover of the fluvial deposits is basically the coarse-grained component because the finer sediment has been removed by the wind. Sand to silt material accumulated (mostly by saltation) in the sand sheets and seas. The finer portion (able to enter the wind as suspended material) that can be trapped in the large-scale atmospheric circulation and has been redistrib-

uted in Sahara and in other adjacent continents (mostly Europe and South America) and oceans.

The results of these climatic changes are fluvial systems and lacustrine deposits interrelated with deflation surfaces and sand accumulations. This situation is similar to Mars where fluvial deposits and morphologies abund but are largely eroded. When deposits are present are basically coarse-grained (e.g. the meandering channels of the Eberswakde deltaic plain) because the long-lasting aeolian. This has removed the finer portion of the sediment and accumulated the sand to silt grade portion in sand seas and sheets and the fines in a sort of draping dust.



The Kess Kess: Devonian mud mounds formed by hydrothermal activity and methane emissions

The Ibn Battuta Centre: Besides these quaternary environments, several sites of the Centre consist of ancient deposits such as the Devonian Mud Mounds of the Kess Kess or the Precambrian stromatolites near Ouarzazate. The Centre is devoted to both scientific and technical developments and testing from EDL system validation to human exploration activity. The landscape and the surfaces where these tests are performed are similar to Mars.

The Centre organised the 3rd Conference on Mars Analogues and it is part of the Europlanet Research Infrastructure of the European Union. In this frame, it hosted a number of scientists working from the astrobiology of chemosynthetic deposits to the formation of dust devils. The Centre is involved in the ExoMars programme of ESA supporting the analysis of the landing sites, testing EDL procedures and surface operations. Wirt Austrian OWF is involved in testing Martian human operations.

LATE JURASSIC ROCKS OF THE COLORADO PLATEAU AS DEPOSITIONAL AND DIAGENETIC ANALOGS TO GALE CRATER, MARS. S.L. Potter-McIntyre^{1,2}, M. Boraas², and K.DePriest² ¹Department of Geology, Southern Illinois University, Carbondale, IL, slpotter@coloradomesa.edu ²Department of Physical and Environmental Sciences, Colorado Mesa University, Grand Junction, CO.

Introduction: The Morrison Fm (the upper Brushy Basin and the Tidwell Mbrs) and Wanakah Fm are proposed as terrestrial analogs to sedimentary rocks exposed in Gale Crater, Mars, due abundant sedimentological and diagenetic similarities. These late Jurassic units are well exposed in western Colorado and eastern Utah (Colorado Plateau) and the depositional environments are interpreted as hypersaline lake systems with abundant volcanic ash input [1].

Scientific Merit: This investigation addresses the MEPAG goal to understand the geology of Mars surface because these volcanoclastic, clay- and iron-rich shales are similar in terms of lithology, mineralogy and chemistry to the sedimentary rocks at Gale Crater [2, 3, 4]. Therefore, interpretations of depositional environment and diagenetic history can be inferred. Secondly, the goal to understand the potential for life on Mars will be addressed by evaluating preservation potential and documenting diagnostic biogenic features present in these terrestrial units for application to the search for evidence of life possibly preserved in the sediments on Mars.

Lithofacies	Jmb	Jmt	Jw	GC
Silt-/claystone				
Laminated	X	X	X	X
Massive	X	X	X	X
Vuggy	X	X		X
Disrupted	X	X	X	
Sandstone				
Cross-bedded	X	X	X	X
Laminated	X	X	X	X
Cimbing ripples		X	X	
Massive	X	X	X	?
Conglomerate	X	?		X
Gypsum		X	X	X
Limestone		X	X	?
Composition				
Clays	X	X	X	X
Iron (oxyhydr)oxides	X	X	X	X
Gypsum veins		X		X
Volcaniclastic	X	X	X	X
Concretions	X	X	X	X
Carbonates		X	X	X

Table 1. Comparison of features in the Brushy Basin Mbr (Jmb), the Tidwell Mbr (Jmt), the Wanakah Fm (Jw) and rocks at Gale Crater (GC) [3,4, 5].

Five primary lithofacies are present in both the Colorado Plateau and the Mars rocks: silt-/claystone, sandstone, and conglomerate, sulfates and carbonates (Table 1; Figure 1) [2,3,4]. Both terrestrial and martian silt-/claystone lithofacies are interpreted as lacustrine depositional

environments due to features such as parallel laminated, massive, and vuggy sedimentary structures [3,4]. Fluvial sediments are also present in the analog units and the Gale Crater rocks such as cross-bedded sandstones and imbricated conglomerates [3,4, 5].

Both the Tidwell Mbr and the Wanakah Fm contain meters-thick horizons of gypsum analogous to sulfates in the rocks at Gale Crater. Additionally, gypsum veins

are present in the Tidwell Mbr and at Gale Crater. Thin, laminated limestones are common in the Tidwell Mbr and the Wanakah Fm. The Brushy Basin Mbr hosts a 3-4m thick limestone sabkha deposit. Carbonates are also found at Gale Crater [2]. Concretions are present in all the Colorado Plateau units and at Gale Crater.

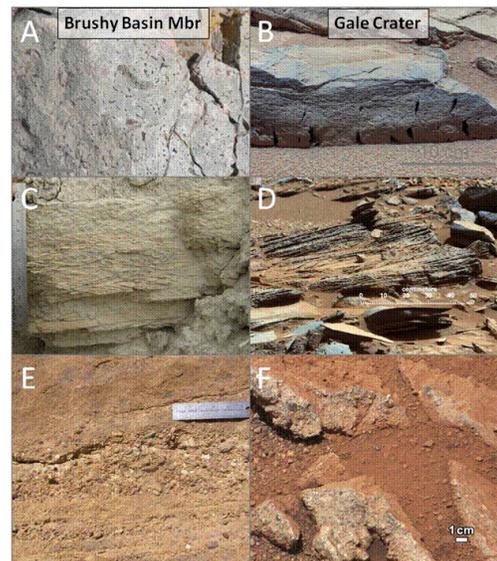


Fig. 1. Lithofacies in the late Jurassic Brushy Basin Mbr of the Morrison Fm (Jmb) and at Gale Crater, Mars (GC). A. and B. Vuggy siltstone in Jmb (A) and GC (B). C and D. Cross-bedded sandstone in Jmb (C) and GC (D). E and F. Imbricated conglomerates in Jmb (E) and GC (F). Mars photos: NASA/JPL-Caltech/MSSS

Mission Description: Research on the Brushy Basin Mbr, the Tidwell Mbr and the Wanakah Fm will inform the Mars Science Laboratory mission on important scientific questions: 1. What is the depositional environment?, 2. What is the history of fluid-rock-(biota?) interactions, 3. What past chemical environments existed (fluid composition during deposition and diagenesis?), and 4. What types of biomarkers can we expect to find? There are no environmental or travel constraints and the exposures of these rocks are easily accessible.

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SMALL LAKES AT THE ICE-FREE MARGIN OF WESTERN GREENLAND AS MARS ANALOGS TO EVALUATE METHANE DYNAMICS. L.M. Pratt¹ (prattl@indiana.edu), Y. Peng¹, S.B. Cadieux¹, S.A. Young¹, and J.R. White¹, ¹Department of Geological Sciences, Indiana University, Bloomington, IN, 47405

Introduction: On Earth, methane emissions are predominantly derived from thermal cracking of ancient organic matter in the deep subsurface or from microbial methanogenic metabolism in low-salinity aquatic environments. Detailed study of methane cycling in lakes and soils on the ice-free margin of Greenland provides an insightful analog for habitable environments on Mars during climatic intervals when seasonally ice covered lakes can be expected to form in craters and thermokarst depressions.

Mission Description: During early pluvial periods in Martian history, isolated crater lakes likely were a common landscape feature. Individual lakes would have evolved distinct chemical signatures due to the seal of underlying permafrost and lack of through-going surface drainage. In the absence of stream inflow, sediment input to crater lakes would have been limited to discharge from gullies on the surrounding crater walls and aeolian dust. Similar geochemical isolation and restricted sediment input can be studied under open-water (summer) and ice-covered (winter) conditions in a series of small Greenlandic lakes located within a steep-walled, fault valley visible as a linear furrow on satellite images (Figure 1). In order to assess the potential for putative microbial processes to be recorded in fine-grained sediments from Martian crater lakes, we are comparing the stable isotopic composition of organic matter and sulfide minerals in sediment cores with the concentration and isotopic composition of sulfate, sulfide, bicarbonate, and methane in the water column under both summer and winter conditions in Greenland.

Scientific Merit: Lakes at the study site are ice-covered from mid-September to mid-June, developing about 2 m of ice overlying an anoxic water body with widely varying methane concentrations. Due to minimal spring and summer precipitation, the study lakes are supplied with water mostly through local contributions from the melting snowpack and develop similar stratified thermal properties despite marked variations in aqueous chemistry. In essence, the small lakes at the study site allow for independent monitoring of seven microbial ecosystems experiencing the same external factors related to climate. Sediment cores from the lakes have equivalent wind-blown siliciclastic input (loess) but with differing biogeochemical inputs from microbial cycling of carbon and sulfur in the water and sediment columns.

Logistic and environmental constraints of the field site: The field area is located within 25 km of a fully-supported international airport and the Kangerlussuaq International Science Support facility (KISS). The US Air National Guard provides heavy-lift support for scientists working in Greenland and flies directly to Kangerlussuaq airport. KISS provides excellent year-round living quarters and lab facilities on the edge of the air field. Access to field sites involves a 25 km drive on gravel road and 2-3 km hike over open terrain. Helicopter support is also available at the airport for transport of heavy equipment into field sites. Logistics are highly favorable for year-round work at the edge of a major ice sheet in the Arctic.

The field area offers a wide range of landscape types: lakes and wetlands, soils underlain by continuous permafrost, polygonal peat soils, recently exposed glacial till and the edge of the active Russell Glacier (Figure 1). Continuous permafrost is present down to 300 m depth with temperatures dropping to -3°C at a depth of about four meters, providing a relatively shallow and pristine setting for an instrumented study of reduced trace gases cycling in super-permafrost soil and groundwater constituting the active layer.

Variations in methane concentrations within lakes reflect redox conditions, however concentrations and stable isotopic signatures of methane fundamentally differ between lakes. The physiochemical diversity observed among the lakes in the study area is likely due to ecological and hydrogeochemical factors such as differences in bedrock and vegetation. Further work is under way to identify factors of the surrounding soils and bedrock that may be influencing differences in methane cycling in each lake.



Figure 1. Greenland study area location map with study lakes: 1) EVV Upper Lake, 2) EVV Lower Lake, 3) Teardrop Lake, 4) Potentilla Lake, 5) Little Long Lake, 6) North Twin Lake, 7) South Twin Lake.

ENDOLITHIC MICROBIAL COMMUNITIES IN MARS ANALOG VOLCANIC FUMARoles, CERRO NEGRO VOLCANO, NICARAGUA. K. L. Rogers^{1,2}, B. M. Hynek^{3,4} and T. M. McCollom⁴, ¹Rensselaer Polytechnic Institute, Troy, NY (kr Rogers@ciw.edu), ²Carnegie Institution of Washington, Washington, DC, ³Department of Geological Sciences and ⁴LASP, University of Colorado, Boulder.

Introduction: Widespread sulfate-bearing deposits have been identified via both orbiter and lander observations across the martian surface [e.g. 1]. Several of these observations, including sulfate and silica deposits near the Home Plate site in Gusev Crater and the layered sulfate deposits at Meridiani Planum, have been attributed to acid-sulfate alteration of martian basalt in volcanic settings [e.g. 2-5]. Together these observations suggest that fumarolic environments may have been widespread on Mars, perhaps continuing to recent times.

In order to evaluate the habitability of such environments, we are investigating the geochemical and biological composition of active fumaroles at Cerro Negro (CN) volcano, Nicaragua, where fresh basaltic cinders similar in composition to martian basalts are altered by acidic, sulfur-bearing gases. Temperatures at active fumaroles can reach as high as 400°C and the pH of the steam ranges from <0 to 5. Adjacent to some fumaroles, silica is being precipitated from condensing steam on the crater walls and endolithic photosynthetic mats are found at 1-2 cm depth within these silica deposits.

Mission Relevance: As part of ongoing research at CN, we have been investigating the potential for microbial communities in acidic, fumarolic environments. In these fumaroles, steep gradients in temperature, volcanic exhalations and water availability seem to limit niches of habitability over very small spatial scales. Understanding the extent of small-scale, habitable niches in these dynamic environments, and how these niches are related to geochemical and mineralogical parameters, will inform target selection in current (Curiosity) and future Mars lander missions aimed at identifying martian biosignatures. Furthermore, endolithic microbial communities found at CN contain individual cells that are encrusted with silica, providing the possibility for biosignature formation and preservation. Documenting the morphology and diversity of such biosignatures on Earth is necessary for interpreting current and future observations of the martian surface.

Scientific Merit: During our investigation of habitable niches at Cerro Negro, we documented a photosynthetic, endolithic microbial community. The silica-coated, green-pigmented layer was found ~1cm below a silica crust. We analyzed one of these mats growing at 65°C and pH ~4.5 for both archaeal and bacterial diversity. Sequencing of PCR-amplified 16S rRNA genes revealed a diverse community of bacteria, domi-

nated by sequences most closely related to the *Ktedonobacteria* and the chloroplast associated with the thermoacidophilic *Cyanidiales* (red algae). *Acidomicrobiales*, *Acidobacteria* and other groups were also identified. The archaeal community was far less diverse, with sequences related to the *Desulfurococcales*, *Caldisphaera* and *Thermofilum*. The *Desulfurococcales* were primarily represented by the *Hyperthermus*. The archaeal sequences were more distant from isolated species than the bacterial sequences. While, some of these lineages have been found in wetter, hot spring environments in Yellowstone National Park, Greenland, Iceland, New Zealand and Costa Rica, this particular microbial assemblage is unique to this relatively dry, acidic, fumarole setting.

An analysis of the metabolic structure of this endolith community suggests that the red algae, together with S- and Fe-reducers, are primary producers that support both aerobic and anaerobic heterotrophic thermoacidophiles. The presence of neutrophilic hyperthermophiles was enigmatic for the *in situ* conditions of the mat. Similar metabolic structures could have existed on Mars, perhaps with S- and Fe-reduction being the dominant primary production pathway, and heterotrophs being dominated by anaerobes.

In putative hydrothermal environments on early Mars similar settings with moderate temperatures and acidic conditions could have supported analogous endolithic communities. Even on a generally cold and dry Mars, volcanic craters likely provided long-lived warm and wet conditions that could have supported diverse assemblages of thermoacidophilic organisms with various metabolic strategies adapted to environmental conditions of the acid-sulfate fumaroles. Further, martian endolithic communities would have been shielded from radiation and the low humidity atmosphere and, given their encasement in rock, represent key targets for biopreservation.

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GYPSIFEROUS SUBTERRANEAN ENVIRONMENTS AS POTENTIAL ANALOG OF MARS. F. Rull¹, F. Gázquez¹, G. Venegas¹, J.M. Calaforra², J. Medina¹, J. Martínez-Frías¹, ¹Associated Unit to the Center of Astrobiology (CSIC) - University of Valladolid, Spain, ²Water Resources and Environmental Geology – University of Almería, Spain.

Introduction: Ca-rich sulfates (probably gypsum, $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$) have been recently identified on the surface of Mars. Gypsiferous sands constitute dense dune fields in the Olympia Planum, around the Martian North Polar Cap [1]. Furthermore, in 2011 the Exploration Rover *Opportunity* found bright veins of a mineral, apparently gypsum that could be of hydrothermal origin. Upon this outstanding discovery, attention has been focused on the terrestrial gypsiferous formations.

In the present work, we propose the hydrothermal mechanisms that generated the giant gypsum crystals of the Cueva de los Cristales (Naica Mine, Chihuahua, Mexico) and the Giant geode of Pulpí (SE, Spain) as potential analogs of hydrated Ca-sulfates precipitation in Mars. On the other hand, the caves of the gypsum karst of Sorbas host gypsum concretions generated by evaporation. In same case, the genesis of these minerals might be linked to microbial activity with consequent relevance for astrobiological research. Gypsum from these sites are been studied by mineralogical and geochemical techniques, in particular by Raman spectroscopy.



Fig 1. Gypsiferous subterranean environments. A. Cueva de los Cristales (Naica Mine, Mexico); B. Giant gypsum geode of Pulpí (SE, Spain); C. Covadura Cave (Sorbas, SE Spain). Photos: La Venta and Speleoresearch & Films, Jabier Les and Laura Sanna, respectively.

Mission Description: Regarding that the ExoMars mission of the ESA, scheduled for launch in 2020 will be equipped with a Raman spectrometer [2], investigations by Raman spectroscopy on Earth's minerals are essential to interpret data coming from this further

mission to Mars. Among the aims of the ExoMars mission, studying the Martian subsoil -up to 2 m below the surface- will be one of the most challenging tasks.

Scientific Merit: The absence of solar radiation, practically constant temperature at daily and seasonal scale and the presence of liquid water are some of the attractions which make Earth's caves interesting for Martian research. On the other hand, there are growing evidences that subsoil and caves in Mars could be place for hosting biological activity or biomarkers [3]. Furthermore, caves [4,5] and lava tubes [5] have been recently detected on the Mars surface, so the interest in caves and cave minerals of the Earth has exponentially increased. In fact, cave minerals have started to be studied as potential Martian analogs [6]. Cave minerals represent an opportunity to better understand the genesis of Martian minerals and the evolution of Mars itself, in particular by studying minerals formed in hydrothermal conditions (Naica Mine and Giant Geode of Pulpí), as well as gypsum precipitated from evaporative mechanisms (Sorbas Caves).

Logistic and environmental constraints of the field site: Caves are extremely stable environments, so anthropic perturbations can irreversibly affect these unique sites. Gypsum crystals and concretions in caves like those shown in this work occur very rarely worldwide. These places must be conserved due to their natural environmental value, and also because their potential use in future research.

Fortunately, Raman spectroscopy is a non-destructive technique that enables in-situ analyses, so it presents great advantages over other techniques for mineralogical studies, both on Earth and Mars.

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POTENTIAL MARTIAN ANALOG SITES IN SOUTHEASTERN SPAIN. F. Rull¹, G. Venegas¹, F. Gázquez¹, J.M. Calaforra², J. Martínez-Frías¹, A. Sansano¹ and J. Medina¹, ¹Associated Unit to the Center of Astrobiology (CSIC) - University of Valladolid, Spain, ²Water Resources and Environmental Geology Group – University of Almería, Spain.

Introduction: Hydrated sulfates have been detected on Mars using spectrometers onboard orbiter, as well as by two rover vehicles that are currently exploring the Martian surface. Thus, investigation on terrestrial sulfate deposits formed in similar conditions than those occurred on Mars in the past, is of considerable interest regarding the current and future exploration missions to Mars (MSL and ExoMars) [1].

The origin of most terrestrial hydrated minerals is bounded to the presence of liquid water, so research on these materials is essential to understand the genesis of the hydrated sulphates found on the Martian surface and their relevance for hosting astrobiological vestiges. In the present work, we propose three field sites in southeastern Spain in which hydrated sulfate minerals generated by hydrothermal and evaporative mechanisms are present.

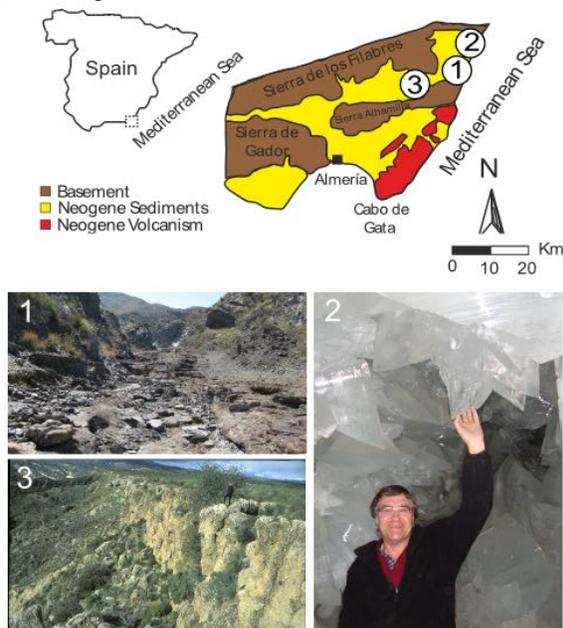


Fig 1. 1) Jaroso ravine; 2) Giant gypsum geode of Pulpí; 3) Gypsum karst of Sorbas.

Mission Description: ExoMars is the first ESA flag-ship mission of the Aurora program that will send a rover to the surface of Mars in 2018. The main goal of this mission is to identify the presence of past or present life on Mars. Characterization of minerals produced by water-related processes and identification of biomarkers linked to these forming mechanisms are of primary interest for this mission [2]. ExoMars is a combined mission of ESA in agreement with

Roscosmos, in which the Martian subsoil -up to 2 m below the surface- will be sampled by means of a drill. Powdered samples will be analyzed by several techniques onboard the rover vehicle, including Raman and IR spectroscopy.

Scientific Merit: Volcanism in SE Spain during Messinian generated a hydrothermal system that produced alteration of earlier metamorphic materials and the precipitation of massive sulfate deposits. Among the minerals found in this area, jarosite and gypsum have become extremely interesting for research on Mars. In fact, jarosite was identified at Meridiani Planum on Mars by the MER Opportunity rover [3]. Jarosite and other hydrated sulfates in SE Spain have been found in the Jaroso Ravine, as well as in the mine that host the Giant geode of Pulpí. The origin of jarosite in this area attends to hydrothermal processes, so its study could help to understand the genesis of jarosite on Mars.

On the other hand, Ca-rich sulfates (probably gypsum) have been recently identified on the Martian surface [4]. Gypsum of hydrothermal origin has been found in the Jaroso Ravine, whereas the Giant geode of Pulpí hosts some of the largest gypsum crystals worldwide. Furthermore, the gypsum karst of Sorbas is one of the highlighted examples over the world of marine gypsum precipitation during the Messinian Salinity Crisis. Besides, the presence of caves turns the Sorbas basin into a suitable site for studying subsurface mechanisms of mineral precipitation, some of them mediated by microorganism which could be Martian analogs.

Logistic and environmental constraints of the field site: Jaroso and Sorbas areas are characterized by a good access to the outcrops. However, note that caves (both Pulpí and Sorbas) are protected sites, so non-destructive analyses and responsible sampling are essential. For this reason, license is required to access these sites.

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Acknowledgments: Financial support for this work was made available through the Project “RLS Exomars Science” (AYA2011-30291-C02-02, Ministry of Science and Innovation, Spain and FEDER funds of EU).

EXPLORING SINGLE STATION SEISMOMETER TECHNIQUES ON EARTH IN PREPARATION FOR THE INSIGHT GEOPHYSICAL MISSION TO MARS. N.C. Schmerr¹, ¹NASA-GSFC Code 698, Greenbelt, MD 20771 USA
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Introduction: Ground based geophysical instrumentation, in particular seismometers, have the potential to provide unprecedented access to details of the unexplored interiors of planets, asteroids, and moons of the solar system. Lessons from Apollo, Viking, and Venera have illustrated the need for robust field-testing of planetary seismometers in analog deployment sites on Earth, to deal with unusual noise fields, surface material properties, and challenging environments.

Mission Description: The Martian interior has constraints from the moment of inertia [1, 2], gravity [3], tidal parameters [4], and bulk composition derived from the SNC meteorites [5]. The Viking Landers were equipped with seismic instruments [6], but substantial wind signal and poor coupling with the Martian surface limited the detectability of seismicity. The upcoming InSight Geophysical Mission to Mars instrument set consists of a single 3-component seismometer (SEIS), a precision tracking X-band radar system (RISE), and a heat flow and physical properties probe (HP3) [7-9]. InSight will launch and deploy this instrumentation package onto the surface of Mars in 2016; landing site selection has already selected a number of potential landing ellipses in western Elysium (Fig. 1). InSight will provide continuous seismic data, tracking of martian nutation and precession, as well as heat flow from up to 5 meters below the surface [9] over a 2 earth-year period (1 martian year).

InSight will land on a consolidated surface consisting of a mixture of lava flows and sedimentary materials. Seismic stations on Earth deployed in similar environments can be used to simulate signals that would be recorded by SEIS for single-station analysis of the seismograms for determining seismicity and structure. Outlined in Figure 1 is a single station approach using synthetic Martian seismograms to locate an impact on the surface of Mars. A similar approach can be used for an analog seismometer on Earth deployed in an as of yet unidentified Martian analog environment. Thus, we seek input in identifying candidate target environments for this type of analysis.

Scientific Merit: The deployment of a single station seismometer on Mars will provide unprecedented access to the deep interior and seismicity of the planet. Regions of active seismicity may harbor energy resources for life (e.g., active volcanic provinces, hot springs, etc.) and inform future landing site selection for other missions. Imaging the thickness of the crust, size of the Martian core, and properties of the mantle

has broad implications for models of Martian formation, evolution, and current dynamics.

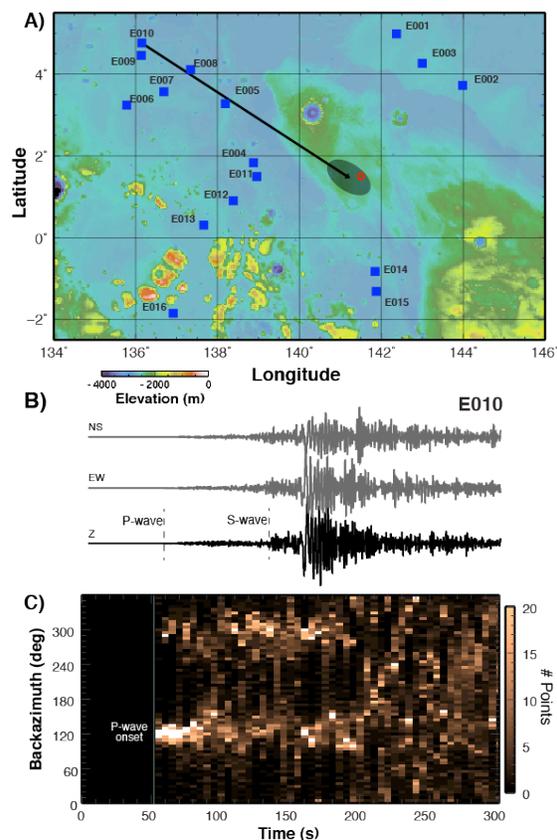


Figure 1. Seismograms and single station source location results. A) MOLA topography and proposed landing sites for the InSight (blue squares). B) Seismograms showing *S* and *P*-wave selected arrival times. C) Histogram of backazimuth solutions for a sliding time window average of 5 seconds. The vector in part A) shows the best-fit backazimuth ($\sim 136 \pm 2.5^\circ$) and epicentral distance from the *P*-*S* times (356 ± 32 km). The red circle is the actual source location.

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BILLION YEAR OLD CRATONS PROVIDE CLUES FOR HABITABILITY OF SUBSURFACE WATERS AND REDUCED GASES ON MARS. B. Sherwood Lollar¹, T. Brisco¹, B. Esen¹ and G. Lacrampe-Couloume¹,
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Introduction:

Deep saline fracture waters have been found in billion year old cratons throughout the Precambrian Shield rocks of Canada, Fennoscandia and the Witwatersrand basin of South Africa [1]. Dissolved gases in these waters are dominated by methane and higher hydrocarbons, some of the most radiogenic noble gas signatures ever reported, and up to mM concentrations of H₂, making these environments as H₂-rich as the hydrothermal vents and spreading centers [2]. While the discovery of microbial ecosystems sustained by H₂-producing water-rock reactions in the deep ocean vents transformed thinking about where life may have originated on Earth and the search for life on other planets such as Mars, the billion year old rocks of the Precambrian cratons have been under-investigated to date as Mars analogs.

Billion-year old waters. Recently Holland et al. (2013) reported that ancient fluid environments capable of supporting life can remain isolated for up to billions of years in the Precambrian crust [3]. This discovery changes our understanding of the extent of the Earth's crust, and by inference Mars' crust, that may be habitable, and the role that such potential buried biomes play in preserving, evolving and propagating life on planetary timescales. Mars, like the Precambrian shields on Earth, is dominated by tectonically quiescent geologic terrains which are billions of years old, some with serpentinized ultramafic rocks capable of sustaining production of reduced gases [4]. If such ancient fluids, with mM concentrations of H₂ and CH₄, are preserved deep in the terrestrial crust on Ga time scales, similar potential buried biomes may be preserved at depth in the subsurface of Mars.

Scientific Merit and Mission Description:

The significant surface area and thickness of Precambrian continental crust with H₂ generating potential from either radiolysis and/or serpentinization is presently under investigated as a habitable biome and Mars analog. H₂ and reduced gas flux estimates to date have been primarily based on investigations of marine systems, creating an important knowledge gap particularly relevant if we are to extrapolate findings on potential for reduced gas production to the ancient geologic terrains of Mars. A thorough assessment of the global H₂ potential for supporting subsurface life cannot continue to neglect the Precambrian continental terrains, the largest exposures of ultramafic rock on the planet. Finally, since Mars, like the terrestrial Precambrian crust,

consists of billions of years old, tectonically quiescent rocks with ultramafic terrains with H₂ producing potential – further investigation of the billion year old cratons is necessary for developing our understanding of the nature and distribution of subsurface fluids and reduced gases on Mars.

The major goals of this analog program include: 1. Subsurface field investigations at Precambrian sites that represent a range of potential hydrogen-generating reactions including both ultramafic sites relevant to serpentinization (e.g. Timmins ON) and more felsic hosted rocks relevant to radiolytic hydrogen generation (e.g. Sudbury, Wits Basin). 2. Investigation of a range of ultramafic geologic formations of different ages to provide a comparison of relatively young, fresh serpentinites on the ocean floor (e.g. Lost City), to continental periodotite bodies such as exposed at Kirkland Lake ON, to ancient Archean era ultramafics in the greenstone belts of Canada [3]. 3. Determination of the degree to which deep-seated reduced gases are discharged to surface via fractures or groundwater discharge. Olivine-rich surface terranes might reveal subsurface ultramafic rocks undergoing serpentinization. Surface springs might indicate where subsurface groundwater discharges from depth to surface. As gases can leak to the atmosphere through fractures in overlying bedrock, episodic release might reflect controls, such as seasonal temperatures, on the permeability of the bedrock and regolith. **Together these goals will provide an important test of the potential for reduced gas flux to the atmosphere from ancient crystalline terrains such as those that characterize the Mars surface.**

References:

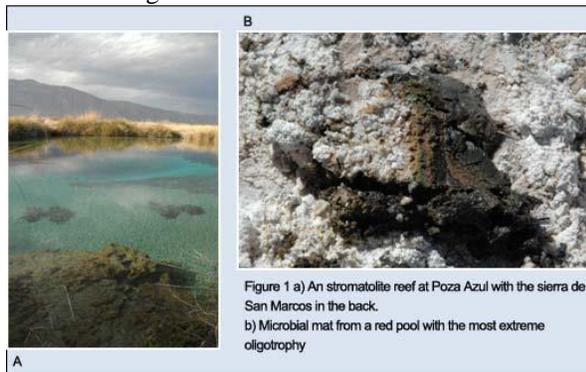
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The Cuatro Ciénegas Basin in Coahuila, Mexico: An Astrobiological Precambrian Park and Mars Analogue

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Introduction:

Gale crater appears to have recorded a diverse stratigraphy in a well defined mound that may likely reflect deposition during dynamic environmental conditions. Additionally, it has been postulated that biosignatures may be preserved in the sulfate bearing strata in the mound. There are parallel ecological that make the environmental phenomenon of Gale crater analogous to Cuatro Ciénegas Basin.



The Cuatro Ciénegas Basin (CCB) is an oasis in the Chihuahuan desert in the state of Coahuila in the North of Mexico (See table 1). Despite the arid climate, the CCB harbors an extensive system of springs, streams, and pools of significant scientific interest. It presents an extreme elemental stoichiometry with regards to phosphorus, (900:150:1-15820:157:1 C:N:P ratio)¹ when compared to similar environments. Its spring-fed ecosystems are dominated by microbial mats and living stromatolitic features (see Figure 1) by an aquatic sulfur cycle and a terrestrial gypsum based ecology in large parts of the valley¹. Our work there indicates that the microbial lineages of the

Table 1	
Site Name	CUATRO CIENEGAS COAHUILA
Center Coordinate	26°59'N 102°03'W
Elevation	740 masl
Areal Extent	40 km by 30 km
Prime Science Questions	How early life on Earth survived, diversified and changed the destiny of the planet?
Distance to road	4 km.
Environmental characteristics	Max temp:55 C Min temp: -2 C Precipitation: 150 mm Vegetation coverage:30% gypsophylic shrubs, and halophyte grass
Previous studies at analogue site	10 years of research and 15 publications

site carry a signature of an ancient marine ancestry in their genomes²⁻⁸ and understanding the link between this signal and the paleoecology of the oasis is a current focus of our research. These unique biosignatures, the abundance of fossil and living microbialites, the geologic history, and the biodiversity make CCB interesting for Astrobiology. Moreover, molecular clock studies on the genomes of *Bacillus* and *Exiguobacteria* as well as *Cyanobacteria* from CCB demonstrate that many species from Cuatro Ciénegas have diverged from related true marine species in the late Proterozoic.^{7,8} It is our inference that CCB represents an extant ecological “time machine” suggestive of earlier times in Earth’s history and by extension, other similar extraterrestrial planet bodies during their paleoecological past. One of the primary research concerns of the CCB team is to understand in broad terms how microbial life colonizes, adapts and diversifies. Our ultimate goal is to use CCB to provide empirically generated rules of microbial evolution that can be extrapolated to alternative ecologies. As results are tallied, we are continually refining our system of rules of ‘coexistence’ in the bacterial communities of CCB. Special attention is given to descriptive and chemical biosignatures that are evidenced by the adaptive response to the geologic environment. The ability to extrapolate, even in first order terms, the adaptive potential of earth based microbial life provides a platform on which to consider the profoundly different evolutionary trajectory from Earth to sister planets such as Mars.

Gale crater as a primary MSL target has been chosen due to the mound and moat preservation and the accompanying stratigraphy that indicates the fluvial system was supplied by underground hydrologic sources. All of these considerations can be informed by the CCB analogue site presented herein.

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PARALLELS BETWEEN STRATOSPHERIC MICROBIOLOGY AND MARS ASTROBIOLOGY MISSIONS. D. J. Smith¹ and A. C. Schuerger², ¹NASA Kennedy Space Center, Surface Systems Office, Mail Code: NE-S, KSC, FL, 32899, david.j.smith-3@nasa.gov, ²University of Florida, 505 Odyssey Way, Exploration Park, N. Merritt Island, FL, 32953, schuerg@ufl.edu.

Introduction: Microbes can reach the stratosphere (about 17 to 50 km above sea level (ASL)) by strong upward winds, violent storms, volcanic eruptions, and aircraft [1]. Aerosol exchange in the tropopause is increasing due to climate change [2], suggesting a greater numbers of microbes will cross between the troposphere and stratosphere in the coming years. The exploration of Earth's upper atmosphere can help constrain the search for potentially habitable environments on other worlds. Like Mars, the stratosphere is extremely dry, frozen, irradiated, and hypobaric [1].

Mission Description: Detecting microbial signatures without false positives is a critical feature shared by stratospheric and solar system exploration. In either context, an unacceptable outcome is the inability to discriminate between *in situ* microorganisms and terrestrial contaminants hitchhiking on flight hardware. Sterility and contamination controls developed by future missions to the stratosphere will likely employ multiple layers of containment, along with unique positive and negative controls or in-flight sterilization measures, which will contribute to development of technologies and procedures for preventing the forward contamination of other worlds by spacecraft. Lessons learned in the stratosphere might also advance methods for life detection experiments on Mars. Not only are scientific requirements comparable (i.e., detecting very low microbial biomass), but the rarified near-space environment of the stratosphere imposes similar operational parameters on flight hardware. Other Mars analogs (e.g., Antarctica) lack key features of the martian environment, including hypobaria and extreme UV irradiation levels.

Access Using Balloons: Large scientific balloons are a reliable and efficient way of reaching the upper atmosphere and can be used up to about 50 km ASL [3]. Balloons are made of a thin polyethylene film, inflated with helium, and expand up to 140 m in diameter during ascent through the increasingly rarefied atmosphere. Two to three hours after launch, balloons reach the target float altitude and travel in the prevailing wind direction, carrying atmospheric sampling instruments on a gondola suspended underneath the balloon. Payloads eventually return to the surface on a parachute. Sampling time aloft depends on payload weight (typically < 3600 kg), target altitude, launch site, and weather conditions. Recent advances in ultra-

long duration ballooning allowed a payload to remain aloft for 55 days at 39 km ASL [4].

Scientific Merit: Both Mars exploration and balloon-based stratospheric microbiology experiments must detect microbial signatures without false positives (i.e., contamination) on flight hardware that operates autonomously in harsh conditions. Balloon-based stratospheric microbiology research can also improve our understanding of UV-resistant microbial species. Taxa capable of surviving the rigors of transport (e.g., desiccation and UV irradiation) have been documented at extreme altitudes [1]. Cell pigmentation, UV repair pathways, and the ability to form spores are a few examples of what might be considered atmospheric specialization. Understanding what microbes survive in the stratosphere might inform the search for life on Mars and also contribute to planetary protection policies for missions, since post-landing UV may not kill all terrestrial microbes on the exterior of spacecraft [5].

Logistic and Environmental Constraints: Before molecular methods in microbiology emerged, stratospheric microbiology studies had to rely upon culturing, which can miss most microbes present from environmental samples [6]. Acquiring molecular-based microbiology data with stratospheric samples has not yet been achieved because bioaerosols are diluted in the voluminous atmosphere and density decreases with altitude [3]. New air sampling technologies must be developed in order to collect sufficient biomass for employing molecular assays. Furthermore, if Mars missions with life detection instrument payloads are first required to demonstrate technology readiness in the upper atmosphere (e.g., instrument sensitivity, in-flight sterilization or contamination containment), access to the stratosphere must become easier. Perhaps a cooperative agreement between NASA Balloon Program Office and Mars Exploration Program would encourage and enable the use of this underexplored, compelling terrestrial analog site.

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AUTOMATED MINERAL IDENTIFICATION IN THREE MARS ANALOGUE SITES USING IN-SITU NIR REFLECTANCE SPECTROSCOPY AND LINEAR SPECTRAL UNMIXING. P. Sobron^{1,2}, G. Lopez-Reyes³, Alian Wang⁴. ¹SETI Institute, Mountain View, CA. ²MalaUva Labs, St. Louis, MO (psobron@malauvalabs.com). ³Unidad Asociada UVA-CSIC-Center of Astrobiology, Valladolid, Spain. ⁴Washington University in St. Louis, St. Louis, MO.

Introduction: We have recorded in-situ NIR reflectance spectra from three Mars analogues: Atacama, Chile, Svalbard, Norway, and Qaidam Basin, China, and used spectral mixture analysis improved algorithms to determine the mineralogical composition of select samples from these three sites.

Mission Description and Scientific Merit:

NIR reflectance spectroscopy: Reflectance spectroscopy is a powerful tool for characterizing the surface mineralogy from Mars orbit, and can provide ground truth during surface exploration with rovers: the European Space Agency ExoMars 2018 Rover instrument suite includes the MicrOmega Infrared Spectroscopic imager. In this work, we deployed an active source miniaturized NIR (1.14-4.76 μm) reflectance spectrometer (WIR) in three Mars analogue sites. The WIR has been developed for lander/rover deployment that enables in-situ identification of water carbonates, sulfates, hydrated silicates, as well as C-H & N-H bonds in organic species [1]. We expect the WIR will be a powerful scientific payload in future NASA/ESA exploration missions to various planetary bodies.

Science enabled through our field sites: (1) Atacama; we investigated a ~2m layered outcrop [2] composed of a consolidated mix of clay, sulfates, and halides. Outcrops comprising individual layers of submeter thickness are present at numerous locations within the MSL landing ellipse, [2, Figure S1] that show various Ca and Mg-sulfates and Fe- and Mg-clay minerals [3]. Our study site in the Atacama and Gale crater have obvious structural and (possible) mineralogical similarities; the site is an analogue that provides a case-study for improving Curiosity's tactical operations. (2) Svalbard; our site, The Troll hot springs, is located

along the Bockfjorden fault zone on Svalbard. There is abundant travertine and silica-rich mineralogy, typically associated to hot springs. The study of this spring system is helping answer questions related to the precipitation of carbonates from non-acidic waters, with clear implications for the understanding of similar systems on Mars such as the ancient hydrothermal springs in Arabia Terra [5]. (3) Qaidam Basin; we investigated a former lake in the Da Langtan playa region. The evaporation of the lake has produced a sequence of light and dark-toned rings that resembles that observed at various locations on Mars, particularly at Gale crater. We have built a lake evaporation model [5] that constrains the physico-chemistry of the DL lake's water, and can help understand the occurrence of water-related mineral deposits and elucidate the geochemistry of putative former aqueous systems on Mars.

Results: We used MESMA [6] to identify minerals in our reflectance spectra (Fig. 1) and to estimate their abundance. Table 1 summarizes some of our results.

Sites/logistics: Table 2 shows the main features of each of the three sites we propose as Mars analogues.

Conclusions: Atacama outcrops, Troll springs, and the evaporated lake in Da Langtan are analogues for sedimentary, mineralogical, morphological, and geochemical processes that have/do operate on Mars. NIR reflectance and MESMA-based automated spectral processing provides an estimation of the abundance of mineral species in samples analyzed in-situ, which is critical for providing ground truth to remote sensing mineralogical investigations.

Acknowledgments: NASA ASTEP, PIDP, MIDP, ASTID, CSA, McDonnell Center for Space Sciences.

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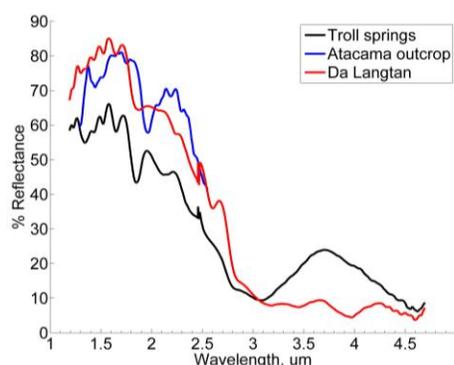


Figure 1. Select spectra from each analogue. Spectra recorded in-situ using the WIR

Sample	ID (% concent)
Ata 1	gypsum (49) limestone (29) glauberite (22)
Ata 2	limestone (80) gypsum (20)
Troll 1	CaCO ₃ (88) NaHCO ₃ (12)
Troll 2	CaCO ₃ (44) NaHCO ₃ (26) aragonite (30)
DL 1	nontronite (63) hectorite (37)
DL 2	gypsum (43) hectorite (57)
DL 3	magnesite (40) lepidolite (55) carbonate (15)

	Atacama	Troll	Da Langtan
Where?	N Chile	Svalbard	NW China
Why?	Sedimentary Aridity Temperature UV Gale crater	Springs Carbonate Hydro-thermal Arabia Terra	Sedimentary Evaporation Gale crater
How?	Commercial flight + truck	Commercial flight + boat/helicopter	Commercial flight + truck
Logistics	Dirt roads No cell	Weather National Park (permit) No cell	Dirt roads Permit re- quired No cell

Meteorites from Mars as Analogues for Mars Missions - The Gifts That Keep On Giving. A. Steele¹ and M. Glamoclija, F McCubbin Author², L. Benning, M Fries. 1 - Geophysical Laboratory, Carnegie Institution of Washington, 5251 Broad Branch Rd, NW Washington DC, 20015 USA. 2 – Institute of Meteoritics, Department of Earth and Planetary Sciences, University of New Mexico, Albuquerque, New Mexico, 87131 USA. 3 – School of Earth and Environment, University of Leeds, Leeds, LS2 9JT, UK. 4-NASA Johnson Space Center, Houston Texas 77058.

Introduction: The fall of the Tissint meteorite has provided a unique opportunity to study a minimally contaminated piece of Mars. Martian organic carbon has been detected previously in igneous basalts and the carbonates of ALH 84001. Analysis of sealed maskelynite inclusions using *in situ* techniques including Raman, NanoSIMS, ToFSIMS, STXM and TEM, coupled with whole rock analysis by stepped combustion, GCMS and evolved gas analysis has revealed an inventory of organic compounds containing –CH, –CN, –CNO, –COOH, –CO, and aromatic complexes. These are spatially resolved to known inorganic catalysts, i.e. magnetite, pyrite, nickel containing pyrrhotite, and clays. Furthermore there is a release of nitrogen containing organics above 600°C, at which temperature $\delta^{15}\text{N}$ is $\sim +40\text{‰}$. These results show that Mars has an inventory of organic carbon and nitrogen containing molecules that are probably produced through abiological hydrothermal activity.

Fourteen martian meteorites were analyzed using stepped-combustion isotope-ratio mass spectrometry, and they were reported to contain between 1 and 50 ppm of “crystalline” carbon that combusted between 600 and 1000°C (1,2). This temperature release range was interpreted by Grady et al. (2) as representing reduced magmatic carbon along grain boundaries or included within silicates. In the present study, we used CRIS to study microphenocrysts of oxides (spinel-group minerals) included in olivine and pyroxene grains (Figure 1) in twelve Martian meteorites including samples of the recent Tissint meteorite fall and NWA7034 (1,3). We identified MMC in ten of these meteorites associated with small (2-20 μm) chromite-rich grains that are ubiquitous as mineral inclusions within olivine and / or pyroxene grains in these meteorites. Any MMC found to be incompletely enclosed within its silicate host (i.e. in cracks, grain boundaries, at the surface of the sample, or associated with weathering or contaminating phases) was treated as contamination and discounted from this study. All of the MMC we report here was located at least several microns below the undisrupted surface of the observed thin section and occurs in association with chromite-rich microphenocrysts. The association of MMC with spinel is consistent in recent falls (Tissint, Zagami) as well as older finds (DaG 476, SAU 019) and is unlikely to be terrestrial contamination. MMC was characterized by the diagnostic disordered and graphitic (or ordered) “D” and “G” Raman peaks at ~ 1350 and 1590 cm^{-1} respectively (1). MMC was initially discovered in Dar al Gani (DaG) 476 associated with an oxide + pyroxene inclusion. DaG 476 is an olivine-phyric sher-

gottite with olivine comprising 15-17% of the mode (1). The oxides are fine-grained spinel-group minerals (hereafter referred to as spinel), which are closest to magnetite or chromite based on the Raman peak positions. They are distributed throughout the olivine with enough grains below the surface to allow study of associated MMC completely enclosed within the host. CRIS and is neither carbonate or terrestrial microbial contamination. In any case, the source of carbon for the associated MMC in these inclusions would therefore, originate from that which was dissolved in the host phase during crystallization or from any trapped melt.

Trapping of this carbon-enriched melt in the mineral host likely led to the early saturation in a C-O-H fluid-phase in the melt inclusion. Importantly, the C:H ratio of the trapped melt would be greater than the parental melt as H-species diffuse much more rapidly through the melt than C-species thus setting the stage for subsequent MMC and PAH production and enrichment in the inclusion as the host olivine cooled and trapped melt crystallized. Furthermore, if the mantle source for these meteorites contained graphite early saturation in a C-bearing fluid phase could occur regardless of the boundary-layer effects at low degrees of partial melting. The amorphous nature of the MMC, and the presence of PAHs in the MMC (1) containing assemblages indicate that the MMC precipitated in contact with the oxides as an insoluble organic carbon phase whose presence was therefore sensitive to the redox state of the magma. It has been hypothesized that the Martian mantle is graphite saturated and that the oxygen fugacities of the mantle sources for the Martian meteorites are buffered by fluids in the C-H-O system. Significant amounts of hydrogen occur in Martian magmatic source regions (27-28), indicating that if the Martian mantle is graphite saturated, mantle fluids would have likely contained significant C-O-H components. The Tissint meteorite shows similar MMC / spinel features as the other meteorites with a $\delta^{13}\text{C}$ of -17.8 ± 1.89 and ~ 14 ppm of reduced carbon. Combining all these studies shows that igneous Martian rocks could contain up to $\sim 20 \pm 6$ ppm of reduced carbon with an average $\delta^{13}\text{C}$ of $\sim -19.8 \pm 4.3\text{‰}$.

Given that these meteorites contain an abiotic background of organic carbon combined with Martian minerals in both igneous and a possible breccia we will argue that these rocks represent the best Martian analogue material on which to test future and present Mars bound instrumentation

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CARBON ISOTOPIC MEASUREMENTS IN MARS ANALOG ENVIRONMENTS BY COMMERCIAL CAVITY RINGDOWN SPECTROMETRY. J.C. Stern¹, A.C. McAdam¹, P.R. Mahaffy¹, A. Steele¹ Planetary Environments Laboratory, Code 699, NASA Goddard Space Flight Center, Greenbelt, MD 20771, 301-614-6062, Jennifer.C.Stern@nasa.gov
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Introduction: Performing measurements in Mars analog settings with instrumentation similar to that deployed during landed Mars missions is vital to assessing data precision and fidelity. Stable isotopic measurements, previously only possible by taking gaseous, liquid, or solid samples and carefully storing them for the return trip home, can now be made either *in situ* or in remote field laboratories with cavity ringdown spectrometry (CRDS). The advent of these instruments allows stable isotopic data to be obtained over the course of the field expedition, informing sampling strategies while in the field.

Instrumentation: Several vendors now offer a range of benchtop and portable trace gas isotope analyzers that can be operated in the field using a generator, or in a remote laboratory setting. Among these, Picarro and Los Gatos Research lead the commercial development of CRDS for carbon isotopes in carbon dioxide and methane, and hydrogen and oxygen isotopes in water. These commercial instruments are analogous to the tunable laser spectrometer (TLS, [1]) component of the Sample Analysis at Mars (SAM) instrument suite on the Mars Science Laboratory (MSL) in their ability to make spectroscopic measurements of individual gas species with precisions appropriate for isotopic measurements.

Field Deployment: Here we give two examples of use of commercial CRDS to make isotope measurements in Mars analog environments.

Solid Sample Analysis. On the 2010 and 2011 Arctic Mars Analog Svalbard Expeditions (AMASE), we simulated SAM's capability to measure the $\delta^{13}\text{C}$ of CO_2 from thermal decomposition of planetary regolith

by using a GSFC-built pyrocell coupled to a Hiden EGA-MS system with a gas collection manifold and a Picarro Cavity Ringdown CO_2 isotope analyzer. Gas was captured during the portion of the pyrolysis ramp in a stainless steel cylinder, backfilled with N_2 , and then transferred to a Teflon gas sampling bag for introduction to the CRDS under the atmospheric pressures for which the instrument was designed. Carbonate-containing rocks from two geologically distinct settings were analyzed. The accuracy and precision of $\delta^{13}\text{C}$ obtained in this manner yielded information regarding the source of carbon and mechanism of formation of these carbonates [2].

Gaseous Sample Analysis.

A Los Gatos CO_2 isotope analyzer was deployed on the Greenland Emission of Trace Gases as an Analogue for Methane on Mars (GETGAMM) expedition in 2012 and 2013. CO_2 isotopic measurements were coupled with $\delta^{13}\text{C}$ measurements of methane in shallow boreholes. A gas stripping technique allowed measurement of dissolved methane and CO_2 in water by LGR CO_2 isotope analyzer and Picarro methane isotope CRDS, indicating that these techniques are versatile for ambient gases and dissolved gases, and have much to offer to Mars analog research.

Conclusion: Commercial CRDS isotope analyzers can be used in Mars Analog Environments to better understand data returned from Mars landed missions, including $\delta^{13}\text{C}$ of CO_2 in Mars atmosphere and solids measured by SAM-TLS on MSL.

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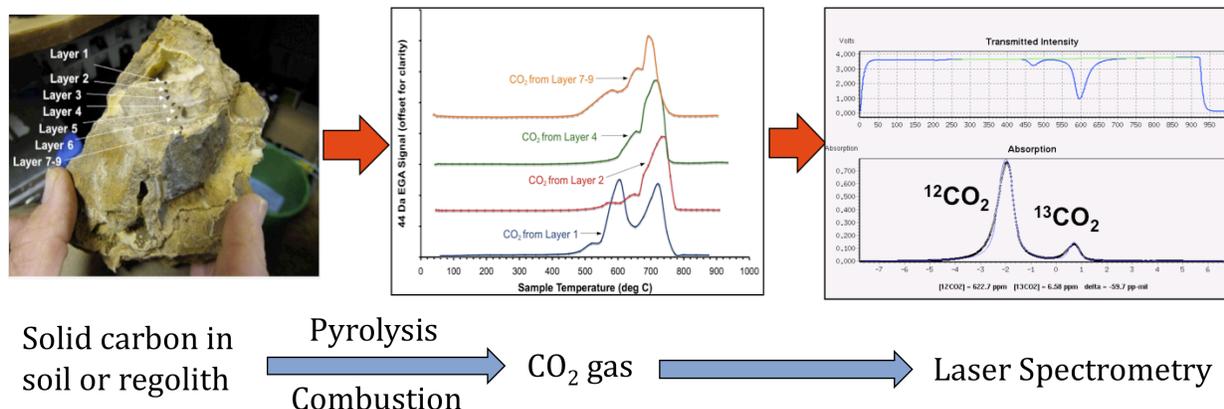


Figure 1. CO_2 evolved from thermal decomposition of solid carbon can be measured using commercial cavity ringdown spectrometry, yielding $\delta^{13}\text{C}$ results in the field or remote laboratory.

TERRESTRIAL EFFLORESCENCES AS ANALOGS FOR THE ORIGIN OF SULFATE MINERALS IN VALLEY SETTINGS ON MARS. A. Szyrkiewicz¹ and D.T. Vaniman², ¹University of Tennessee, 1412 Circle Drive, Knoxville, TN 37996 (aaszynkiewicz@utep.edu), ²Planetary Science Institute, 1700 East Fort Lowell, Tucson, AZ 85719 (dvaniman@psi.edu).

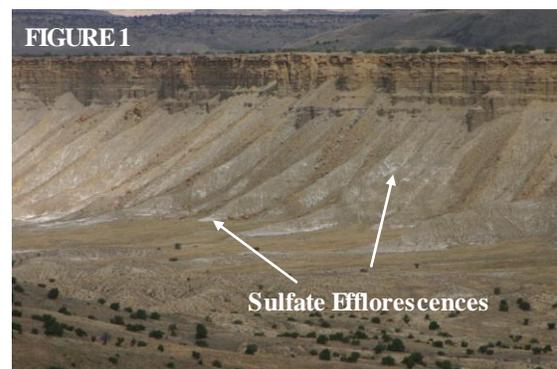
Introduction: A distinctive sulfur (S) cycle dominates many geological processes on Mars. However, many of the key processes controlling the hydrological transport of S, including S sources, climate and the depositional history that led to precipitation of sulfate minerals on Mars remain unclear. In this abstract, we use a model for the formation of sulfate efflorescent salts (Mg-Ca-Na sulfates) in the Rio Puerco watershed of New Mexico, a terrestrial analog site from the semiarid Southwest U.S., to assess the origin and environmental conditions that may have controlled deposition of hydrated sulfates in Valles Marineris on Mars. Consequently, this model also applies to understanding the origin of sulfates in other locations on Mars (e.g., North Polar Region), which show evidence of low-temperature water/ice-rock interaction and chemical weathering.

Similar to hydrated sulfates in Valles Marineris on Mars, the sulfate efflorescences of the Rio Puerco watershed are widespread along canyon walls, slopes, and lower surfaces (Fig. 1). They are found on erosional hill slopes, steep and fractured canyon walls, on mounds and topographic depressions of valley floors, and in pseudo-layers precipitating at shallow groundwater discharge points in the lower slopes of mesas. In addition, efflorescences fill bedrock fractures that conduct shallow groundwater flow and seasonally precipitate on the surface of ephemeral and intermittent streams draining the watershed during spring snowmelt and the summer monsoon. Our XRD analyses of these efflorescences show that they are chiefly composed of hydrated Mg-sulfates (starkeyite, hexahydrite; <84 wt.%), Ca-sulfate (gypsum; <99 wt.%), Na-sulfate (thenardite; <93 wt.%), and Mg-Na-sulfates (blödite, konyaite; <17 wt.%). Additionally, local patches of yellow Fe-K sulfate (jarosite; <93 wt.%) can be found in small topographic depressions at the tops of mesas. The $\delta^{34}\text{S}$ values (-36.0 to +11.1‰) show that an ephemeral arid hydrological cycle that mobilizes S present in the bedrock as sulfides, evaporite minerals, and dry/wet atmospheric deposition contribute to widespread surface accumulations of hydrated sulfate efflorescences. These three S sources contribute 21-61%, 39-79%, and <4%, respectively, to the aqueous sulfate. Repeating cycles of salt dissolution and reprecipitation appear to be major processes that migrate sulfate efflorescences to sites of surface deposition and ultimately increase the aqueous SO_4^{2-} flux along the watershed (average 41,273 metric tons/year). Notably, these processes do

not involve deep groundwater flow. We suggest that similar, shallow aqueous processes may explain the occurrence of hydrated sulfates detected on the scarps and valley floors of Valles Marineris on Mars. Our estimates of salt mass and distribution are in accord with studies suggesting a rather short-lived process of sulfate formation (~100 to 1,000 years) and restriction by prevailing arid conditions on Mars.

Mission Description/Scientific Merit: Major goals of robotic missions to Mars focus on collecting surface data to understand the geological history of the Red Planet related to climate, water activity and nature/distribution of habitable environments. Our terrestrial analog provides a relatively simple explanation of sulfate formation in a shallow, semiarid environment and is consistent with previous assumptions regarding short-lived water activity and prevailing dry conditions on Mars. A large quantity of the studied efflorescences is derived by sulfide oxidation, which in terrestrial systems is often accelerated by microbial metabolism. Because of the widespread surface occurrence of chemical weathering (hundreds of km^2 in the Rio Puerco site), microbial sulfide oxidation might be a much easier target for seeking evidence of past life on Mars, compared with more localized and random volcanic S emissions and hydrothermal activity.

Logistics & Environmental Constraints: The Rio Puerco analog site has easy access by standard SUV and is only 1h away from the Albuquerque airport. The climate is semiarid, controlled by summer monsoon and winter snow fall. The bedrock geology (e.g., Cretaceous sedimentary formations) differs from Mars. Therefore, this analog site is best for studies of the role of arid climate and microbial processes on geochemical S cycles during water-rock interaction and chemical weathering. However, it is more limited for quantifying similar processes in basalt alteration.



THE Khibiny MASSIF AS POSSIBLE ANALOG SITE FOR FUTURE GEOPHYSICAL RESEARCH ON MARS.

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Introduction: Landforms visible on Mars strongly suggest that liquid water has at least at times existed on the planet's surface. Huge linear swathes of scoured ground, known as outflow channels, cut across the surface in around 25 places. These are thought to record erosion which occurred during the catastrophic release of water from subsurface aquifers, though some of these structures have also been hypothesised to result from the action of glaciers or lava [1].

Mission Description: The surface of Mars is primarily composed of tholeiitic basalt [2] although parts are more silica-rich than typical basalt and may be similar to andesitic rocks on Earth or silica glass. Regions of low albedo show concentrations of plagioclase feldspar, with northern low albedo regions displaying higher than normal concentrations of sheet silicates and high-silicon glass. Parts of the southern highlands include detectable amounts of high-calcium pyroxenes. Localized concentrations of hematite and olivine have also been found [3]. The results presented there indicate a predominance of volcanic compositions within Martian dust-free surfaces. Much of the surface is deeply covered by finely grained iron(III) oxide dust [4]. In June, 2008, the Phoenix Lander returned data showing Martian soil to be slightly alkaline and containing vital nutrients such as magnesium, sodium potassium and chloride. On October, 2012, the first X-ray diffraction analysis of Martian soil was performed by MSL Curiosity rover at "Rocknest". The results revealed the presence of several minerals, including feldspar, pyroxene and olivine, which was not unexpected. It was also found that roughly half the soil is non-crystalline material, such as volcanic glass or products from weathering of the glass [5].

Scientific Merit: As concerned geological conditions, martian samples are similar to the weathered basaltic soils of the Khibiny massif belongs to Agpaitic intrusion, Kola Peininsula, Russia. This type of intrusion is also called a alkaline intrusion because the rocks are rich in sodium and potassium. Khibiny mountains were formed about 362 m.y. ago when a blob of alkaline magma intruded the Archean granite-gneiss. The intrusion measures about 30 km in diameter, the entire center section of the intrusion consists of foyaitite. In this foyaitite zone are isles or xenoliths of carbonatite. What generally makes Khibins such interesting site for the analysis of martial surficial layer

is the frost (at winter, -40 C), strong winds (till 50 m/sec) and occurrence of hydrothermal reflux. Hot waters circulated through cracks of the intrusive rocks. On it's way the water dissolved minerals and deposited others. Many of the primary minerals, such as albite, nepheline and eudialyte are easily attacked by these fluids. The majority of Khibins minerals are akaganeite, jarosite, schwertmannite, hematite, pigeonite, lepidocrocite, goethite, smectite clay minerals and others similar to the rocks found on Mars.

All of the above reasons make the Khibiny massif very perspective candidate for terrestrial research of the regolith layer on Mars. For instance, the thickness of the regolith in the place of landing station InSight, 2016, and the absence of a close layer of solid rock are crucial for the success of the experiment on the measurement of heat flow. Also, estimates of the physical structure (particle size, cohesion, angle of internal friction, porosity and presence of outcrop or rocks) of the upper 5 m of prospective landing sites is one of the important tasks.

Logistic and environmental constraints of the field site: Our group at GEOKHI RAS has access to the Khibins mines and can arrange for a study by the layout of the sands mineralogical similar to Martian soils, experimental study of their properties in the similar environmental conditions and details of impact craters formation. Also, we have experience with the modern analytical methods (Raman spectroscopy, scanning electron microscopy and energy dispersive X-Ray microanalyses) and support mineralogical analysis of meteorites. For instance, samples from the famous last fall – Chelyabinsk, 15 March, 2013 – have also been analysed in our group [6].

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MINERALOGICAL ENVIRONMENTS WITHIN SALT-RICH SUBSURFACE AT ATACAMA AND TIBET PLATEAU Alian Wang¹, James L. Lambert², Jie Wei¹, ¹Dept of Earth and Planetary Sciences and McDonnell Center for Space Sciences, Washington University in St. Louis, St. Louis, MO, 63130, USA, ²Jet Propulsion Laboratory, 4800 Oak Grove Drive, CA, 91109 (alianw@levee.wustl.edu)

Introduction: The environmental conditions on Mars that are easier to simulate in terrestrial analogs are those within salt-rich subsurface. Because the environment there would be controlled mainly by the surrounding hydrous salts (sulfates, chlorides, perchlorates), their hydration degrees, their amounts, and their burying depths, and would be less influenced by surface atmospheric conditions which are quite different between Mars and Earth.

Until now, we know very little about Mars subsurface mineralogy, the hydration degrees of subsurface salts, and the environments that they maintained. Spectrometers on Mars orbit sense surface mineralogy down to mm only. Rovers and landers dug into tens' cm. On the other hand, thermal models predict the change of temperature profile (which relates directly to relative humidity) in deeper depth when salt-rich layer exist in subsurface. Combining model calculations with the results from laboratory experiments on hydrous salts, the survival probability of the hydrous salts with mid-high degrees of hydration *does exist*, thus the environments for potential habitability.

For next mission to Mars, the questions include how deep we can dig into and how fast we can check the form of hydrous minerals before dehydration happens (thus to evaluate the habitability) link directly to the technical capabilities of next generation of rover and its payload, and to the cost of a mission. This is the reason for study the mineralogical environments within salt-rich subsurface in hyper arid terrestrial analog sites on high plateaus, such as Atacama and Tibet, by rover deployed drill, or by human made trenches. These investigations can help us understand the salt-rich subsurface environment on Mars.

Field expeditions: We have joined two field expeditions to Atacama Desert in 2012-2013 and a field expedition to Da Langtan (DLT) playa on Tibet plateau. The investigations include orbital remote sensing, *in situ* sensing of surface and subsurface materials, and laboratory measurements of collected samples.

Laser Raman spectroscopy (LRS) is our major tool to characterize the inorganic and organic species. The Mars Microbeam Raman Spectrometer (MMRS) was tested at 13 sites in Atacama as a stand-alone system in 2012. It was installed on Zoe rover (Carnegie-Mellon University) in 2013, and making *in situ* measurements of subsurface materials brought up by a drill (Honey-Bee Robotics) right now along the traverse route of

Zoe in southeast portion of Atacama. A near IR reflectance spectrometer (WIR) and a UV-fluorescence imager (BUF) were also used for *in situ* measurements during these expeditions. They provided complimentary data to MMRS. WIR was used for *in situ* measurement during our first field expedition to Da Langtan Playa on Tibet plateau.

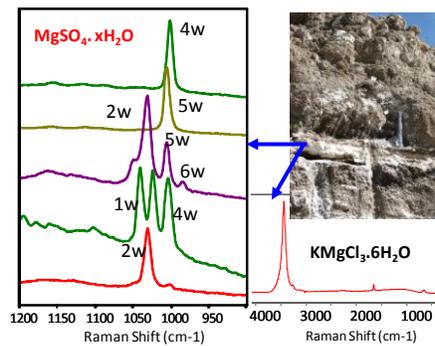
Laboratory measurements for ground truth: All samples that we measured during expeditions were/are collected, sealed in plastic bags for laboratory mineralogy characterization. LRS, XRD, NIR, MIR, and in some cases LIBS, measurements were (and will be) made on them.

The analyses on the collected samples from Tibet were finished. As predicted by a combined analysis based on lab-experiments and model calculation, large amount of highly hydrated Mg-sulfate ($\text{MgSO}_4 \cdot 7\text{H}_2\text{O}$, $\text{MgSO}_4 \cdot 6\text{H}_2\text{O}$, $\text{MgSO}_4 \cdot 4\text{H}_2\text{O}$) and chloride hydrate ($\text{KMgCl}_3 \cdot 6\text{H}_2\text{O}$) were identified in the subsurface salt-rich layers of DLT (Figure 1).

Conclusion: It is critical through the terrestrial analog site investigation to understand the nature of geological processes, especially those related to the formation and preservation of high hydrated salts at Mars subsurface, and the maintained environmental conditions by them. In addition, the field campaign helps the understanding of the power of a multi-instrument payload and the synergistic applications of a particular instrument in it.

Acknowledgement: NASA supports from PIDDP, MIDP, ASTID, MFRP, and ASTEP program for the development of MMRS, WIR, BUF and for field tests at Atacama. A special support from McDonnell Center for Space Science at Washington University in St. Louis is for the field expedition to DLT on Tibet Plateau.

Figure 1. Laser Raman Spectra of highly hydrated salts preserved in the subsurface of a hyperarid region, DLT in Qidam basin on Tibet Plateau.



ORGANIC ENTRAINMENT AND PRESERVATION IN VOLCANIC GLASSES. M. B. Wilhelm^{1,2*} & L. Ojha^{1*}, A. E. Brunner³, J. Dufek¹, J. J. Wray¹. ¹Georgia Institute of Technology, Atlanta, GA; ²NASA Ames Research Center, Moffett Field, CA; ³CRESST and NASA Goddard Space Flight Center, Greenbelt, MD *(mbwilhelm@gatech.edu, luju@gatech.edu).

Introduction: Unaltered pyroclastic deposits have previously been deemed to have “low” potential for the formation, concentration and preservation of organic material on the Martian surface¹. Yet volcanic glasses that have solidified very quickly after an eruption may be good candidates for containment and preservation of refractory organic material that existed in a biologic system pre-eruption due to their impermeability and ability to attenuate UV radiation². Analysis using NanoSIMS of volcanic glass³ could then be performed to both deduce carbon isotope ratios that indicate biologic origin and confirm entrainment during eruption.

Terrestrial contamination is one of the biggest barriers to definitive Martian organic identification in soil and rock samples. While there is a greater potential to concentrate organics in sedimentary strata, volcanic glasses may better encapsulate and preserve organics over long time scales, and are widespread on Mars. If volcanic glass from many sites on Earth could be shown to contain biologically derived organics from the original environment, there could be significant implications for the search for biomarkers in ancient Martian environments.

Background: Previously, organics (hydrocarbons, aromatics, aldehydes, ketones, alcohols) have been detected in gas samples from active fumaroles and hydrothermal fluids⁴⁻⁷. This hot material may have either been supporting active biological systems or have volatilized pre-existing biological material. Carbonaceous material has been detected surrounding cracks or grain boundaries of mantle xenoliths, namely olivine, and is thought to be derived from a biogenic source after cooling⁸. ToF-SIMS analysis of the grain boundaries of amphibolites from depths of ~5-9 km have revealed that hydrocarbons are produced during retrograde metamorphism⁹. Also, isotopic biomarkers have been discovered in micron-size tubules thought to be created by microbes boring into Archean-aged basalt glass¹⁰⁻¹³. Abiotic macromolecular carbon has been determined to be ubiquitous in martian basalts in meteorite samples¹⁴ and bound in maskelynite inclusions in the minimally contaminated Tissint meteorite¹⁵.

Application & Merit in Martian Environments:

(1) Minimizing terrestrial contamination: With the right detection techniques, organics found preserved in volcanic glass would imply entrainment shortly after solidification, thereby ruling out later contamination by subsequent environments or sampling.

(2) Original setting/dating: Volcanic deposits can be dated, and organics found in volcanic glasses could be linked to not only the timing of the event, but also the approximate location and setting during their entrainment.

(3) Containment and preservation: Most organic material degrades or disappears over long time scales of exposure to radiative environments and/or later aqueous alteration,

making detection in ancient Martian sedimentary units difficult. During an eruption, magma temperatures would likely exceed 500°C, causing volatiles to be released and transforming preexisting organic material into a potentially more stable form as well as leaving behind refractory organics. If this residual organic material was encapsulated in a cooling glass, it would essentially be trapped and partitioned off from the external environment. Glass also offers protection from incident radiation.

Proposed Analog Sites: Earth has three dominant types of volcanic sites that contain large sections of volcanic glass that may have incorporated organics: pyroclastic density current (PDC) vitrophyres, glass from lava domes, and silicic lava flows that have low volatile content. Vitrophyres can be found near the base of many large PDCs in the western United States. They are typically formed through the rapid quenching at the base and top of PDCs, and might be more likely to entrain organics, although the slower moving lava flows may also entrain and interact with their substrate and existing organics.

The following examples are a subset of proposed field locations. This initial study will include glass-rich sites that are diverse in age, type, and pre-eruption environment.

Site Name	Eruption Type	Age (Ma)	Pre-eruption Environment
Eocene Ione Formation, CA	Rhyolitic	28-31	Auriferous gravel, sand, & minor clay)
Obsidian Cliffs, Three Sisters, OR	Rhyodacitic	0.1	Flank of a mafic composite volcano
Newberry Volcano obsidian flows, OR	Shield: basaltic-rhyolitic	1-10	

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Lonar Crater, India: An analog for Mars in the field and in the laboratory S.P. Wright¹ and H.E. Newsom²,
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Introduction: The primary geologic processes on Mars are basaltic volcanism, sedimentation, impact cratering, and alteration. The 1.8 km diameter Lonar Crater (Figure 1 and Table 1) in the state of Maharashtra, India includes morphological features of cratering and impactite deposits. The pre-impact strata consisted of fresh basalt overlying aqueously-altered basalt.

Geologic History/Stratigraphy/Samples: Lonar Crater is a young (~570 ka) [1] impact site emplaced in ~65 Ma Deccan basalt, which is an excellent analog material for Mars with ~45-50% labradorite and ~35% augite/pigeonite before lower flows were altered and then shocked. In ejecta, both fresh and aqueously-altered basalt are found as impact breccia clasts in a ~8 m thick lithic (relatively unshocked; “throw out”) and ~1 m suevite (all ranges of shock pressure; “fall out”) ejecta. Two geologic histories are possible at Lonar after the initial basaltic volcanism: 1.) the alteration of impactites/glasses of a range of shock pressures (“post-impact alteration”), which likely increase the rate of alteration where compared to pristine, igneous minerals, and 2.) the existence of altered basalt protoliths (“pre-impact alteration”) now vitrified as in-situ breccia clasts or float. Both geologic histories have implications for the discoveries of alteration minerals found solely in Martian ejecta blankets with remote VNIR data. Alteration minerals are briefly listed here, and these mirror those suggested for Mars: chlorite, serpentine, zeolites, hematite, palagonite, calcite. Two aspects of studies of Lonar Crater can be described: fieldwork and sample analyses. Fieldwork demonstrates that underlying, altered basalt (by groundwater) is only exposed in the ejecta due to impact. Otherwise it would be at depth and not available to the field geologist (or rover). There are two goals of sample analyses performed for Lonar Crater samples: 1) those that characterize the mineralogy and geochemistry (petrography, XRF, XRD, SEM) for detailed descriptions of what the samples were and are, *i.e.* the determination of the state of alteration of the protolith and constraints on the amount of shock pressure received, and 2) those that mirror spectral and instrumental analyses sent to Mars via rovers, such as TIR, VNIR, Mossbauer, LIBS, APXS, and, again, XRD.

Merit: Lonar includes mineralogical signatures of alteration in basaltic ejecta and crater-floor breccia deposit: phyllosilicates and aqueous alteration. Impactites are found as shocked and melted rocks in a layered ejecta blanket. On Mars, we must be able to unravel the geologic histories of sedimentary rocks, al-

tered rocks, and soils. Evidence for the climate history is reflected in the alteration of materials in the ejecta blanket. The erosion processes producing gullies on crater walls can also be studied on the rim and interior walls at the site. The basaltic lava flows of the target and interflow deposits are analogous to the Martian crust. The engineering merit of the Lonar site includes the preservation of ejecta topography of a simple impact crater. The site can support tests of drilling into ejecta blankets and exploration tests on the surface and excavated cross sections of ejecta.



Figure 1. Aerial view of Lonar from the southwest. The town of Lonar on NE rim developed ~1 ka near largest gully (due to a pre-impact spring and fault).

Table 1: Characteristics of proposed analog site

Site Name	Lonar Crater, India
Coordinates	19°58' N, 76°31' E (central India)
Elevation	~500 m (rim is ~30 m above plains)
Areal Extent	ejecta blanket + crater = ~5 km by ~5 km
Prime Science Questions	Mineralogical signatures of aqueous alteration; post-impact climate history from ejecta (lapilli, <i>etc.</i>), alteration of impact melts/ glasses, nature of erosion processes
Accessibility of Science Targets	Lithic breccias – everywhere. Suevite ejecta – several outcrops are ~100 m from road. Gully on east ejecta – 50 m from road. Drilling required for lake & melt sheet deposits.
Environmental characteristics	Temperatures ~80° F in winter. Summers: ~2 months of monsoon & high humidity. Vegetation: seasonal.
Previous studies at site	Fredriksson et al., 1973; Kieffer et al., 1976; Fudali et al., 1980; Hagerty & Newsom, 2003; Maloof et al., 2010; Wright & Newsom, 2011; Wright et al., 2011; Wright, 2013
Mars Landing Site Targets	<i>e.g.</i> , sites with exposed proximal or distal ejecta layers, impact breccias, and craters exposing buried lithologies.

Funding: Whereas XRF geochemistry and XRD mineralogy represent the most basic characterization of geologic materials, NASA nspires programs have not funded the analyses of Lonar shocked-altered and altered-shocked basalt that must precede spectroscopy.

References: [1] Jourdan et al., 2011 + see Table 1.

TESTING OF DRILL SYSTEMS IN ANALOG ENVIRONMENTS. K. Zacny¹, G. Paulsen¹, and J. Craft²¹Honeybee Robotics, 398 W Washington Blvd, Suite 200, Pasadena, CA 91103, zacny@honeybeerobotics.com.²Honeybee Robotics, 460 W 34th Street, New York, NY 10001

Introduction: Testing of sample acquisition systems such as drills, grinders, and excavators in various relevant planetary analogs is of paramount importance. Unlike laboratory testing, analog environments offer true geological uncertainty, and environmental challenges such as extreme air and formation temperatures, wind, dust, and day-night cycles.

Since the 2000s, Honeybee Robotics has been extensively testing its sampling systems across various analog field sites. These include the Arctic, Antarctic, Atacama, Greenland, Mauna Kea, and the Mojave. See Table 1.

Table 1. Analog sites used for testing Honeybee drills

Analog Site	Drill Name	Year
Miller LS quarry, Santa Cruz	MARTE	2005
Rio Tinto, Spain	MARTE	2005
Devon Island	Dame	2004-2007
Devon Island	CRUX	2007-2009
Devon Island	Icebreaker	2010-13
Antarctica	Icebreaker	2010-13
Mauna Kea, Hawaii	CCR Anchor, Heat Flow, 5 m drill	2010
Mojave	SASSI	2011
Greenland	Sniffer	2012-13
Atacama	LITA	2012-13
Borrego Springs	AutoGopher	2012

Lessons Learned from Field Campaigns: We learned that there are a number of factors that must be taken into account to make the field campaign useful and successful.

First, the site must be selected based on the capability to answer specific science or exploratory questions. For example, drilling in Dry Valleys of Antarctica allowed sampling ice and ice cemented ground underneath the desert pavement at air and formation temperature always below freezing – an ideal analog for the Northern Regions of Mars. At this site we learned for example that as long as ice chips are kept cold and are kept away from the direct sunlight, they flow well and do not stick. We also found the drilling system does not warm up formations much. The ΔT is approximately 15 °C. Simulating such conditions in the lab would had been very difficult because of lack of proper boundary conditions.

Once the site has been selected, the success or failure of the field campaign will depend on proper prepara-

tion. This not only includes logistics (e.g. how to ship cargo, clearing customs, when to go) but also preparing for the weather, challenges imposed by the environment (e.g. we had to carry drill boxes because large bolder field prevent us from using vehicles – hence boxes have to weigh <100 lbs for 2 people to carry them). It is important to note that if a person is comfortable, well rested, and properly fed, that person will perform much better in the field, make fewer mistakes, and take better notes.

The test equipment has to be prepared for the harshness of the field environment and lack of easily available replacement parts. The team must be self-sufficient and pack many spare parts and tools. These parts and tools must be easy to locate in various boxes, hence good documentation is of paramount importance. Good documentation is also useful for customs purposes. Sometimes a comprimie has to be made what parts to take because there is often a mass limit on the cargo.

It is extremely important to document each and every test with personal notes, photographs, and movies. Very often it is difficult to write good notes (person is cold, tired, dizzy etc.) but it is relatively easy to snap a few shots (with GPS enabled camera) and movies. These can prove instrumental in post-test data processing. It is important to take a few pictures of the test location from further away to get a sense of geological context, and not just close ups.

We also found that it is more useful to end the day earlier and download all the results, write notes, discuss and note all the findings rather than try to run more tests in a day. The time spent processing the data at the end of the day very often gave us clues about how to improve for next day and identified what mistakes we made. We find it is important to perform a few good tests, rather than rush to do as many as you can only to realize that they are not very good or were not very well documented.

After the field campaign, it is also important to write a report or paper as soon as possible. Even simple things such as the order of the test or the name of the site could be easily forgotten or confused, even if notes are good.

In summary, for the field campaign to be useful and worthwhile all the factors, ranging from science-related to logistics, have to be considered. Months of preparation can be wasted because of simple mistake or oversight.

The poster will present a number of field campaigns, their science value and required logistics.

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