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Analogue Sites for Mars Missions: MSL and Beyond

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Preface

This volume contains abstracts that have been accepted for presentation at the workshop on Analogue Sites for Mars Missions: MSL and Beyond, March 5–6, 2011, The Woodlands, Texas.

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ROVER SCIENCE OPERATIONS: LESSONS FROM ROCKY 7 AND FIDO FIELD EXPERIMENTS AND MARS EXPLORATION ROVER FLIGHT OPERATIONS.
R. E. Arvidson, Washington University in St. Louis, arvidson@wunder.wustl.edu.

Introduction: Field trials using progressively more realistic prototypes of the Mars Exploration Rovers and its scientific payload have been implemented in the Southwestern United States at sites that are geologically interesting. These experiments helped train the science teams on the capabilities and limitations of doing field work and in-situ observations remotely and paved the way for the transition into operations for both Spirit and Opportunity.

Rocky 7: Rocky 7 is a prototype flight rover based on the Sojourner chassis, augmented with a mast-based, stereo imaging system and hazard avoidance cameras that allowed the vehicle to avoid obstacles while driving. A hand-deployed Moessbauer Spectrometer and an XRD unit were employed to simulate actions associated with robotic arm-based in-situ measurements. Rocky 7 was deployed to Lavic Lake in the Mojave Desert and made measurements on varnish-coated basaltic flow surfaces and playa materials. This joint engineering-science experiment proved to be important mainly in understanding automated driving across real terrains [1]. For example, the first drive led to high-centering of the rover on a pointy basaltic boulder that was deemed by the machine-vision system to be innocuous. It was also the first joint engineering-science experiment for JPL with what became part of the core of the Mars Exploration Rover Athena Science Team.

FIDO: FIDO is a MER-class rover mobility system, and several were built at JPL. The most advanced version of payloads on the rover included a mast-based stereo imaging system and point reflectance spectrometer, and a deployable arm with a Moessbauer Spectrometer and close-up imager. Further, the vehicle was equipped with a body-mounted Mini-Corer capable of acquiring and caching rock cores [2], [3]. To test driving across complex terrains and making measurements, FIDO was deployed at Silver Lake and its northern boundary in beach deposits and alluvial material, in the Lunar Crater Volcanic Field, Nevada (with a NASA Ames version of a FIDO), in the Soda Mountain area in a fluvial deposit, and east of Flagstaff Arizona in alluvial and fluvial deposits. For the Nevada experiments the vehicle was equipped with a mast-based prototype of the Laser Induced Breakdown Spectrometer (LIBS) that is now in a flight version on the Mars Science Laboratory's Curiosity. An additional mobility experiment was conducted with FIDO on dissected alluvial fans at Edwards Air Force Base to test driving capabilities and limitations over rolling terrain with variably soft soils [4].

Implications for Spirit and Opportunity: Spirit and Opportunity have far exceeded their "warranties," surviving on Mars for much longer than expected and making many more measurements that predicted by anyone (e.g., [5], [6]). Consider that Opportunity has driven over 26 km and made hundreds of in-situ measurements of rocks and soils. The prototypical work done using Rocky 7 and FIDO helped the Athena Science Team demonstrate that rover-based science can be done and that important discoveries about past aqueous environments can be made. The Rocky 7 and FIDO field experiences also helped focus the MER Athena Science Payload to include mast-based imaging and point spectroscopy, and arm-based APXS, Moessbauer, and close-up imaging experiments. The Earth-based experiments also, and perhaps most importantly, trained both the science and engineering teams on how to efficiently use the limited temporal, power, and data volume resources and how to trade-off driving and reconnaissance observations with detailed in-situ studies. An additional bonus was prototyping involvement of high school student teams to help with science and operations, leading to the Athena Student Intern Program [7]. Mobility tests helped the engineering and science teams understand the interplay of slopes and deformable soils in causing wheel sinkage and slippage, with dynamical models developed from these data and updated with flight information [4], [8]. Finally, the field experiments provided key material for prototyping The PDS Geosciences Node's Analyst's Notebooks, on-line and web-based pages that allow one to "play back" mission operations to see what was done during a particular time interval and to display and download data collected (http://wufs.wustl.edu/fido/; http://an.rsl.wustl.edu/).

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THE COLD SEEP EMPLACED GOLDEN DEPOSIT AS AN ANALOGUE FOR SULFATE DEPOSITS ON MARS. M.M. Battler[1], G.R. Osinski[1,2], D.S.S. Lim[3], A.F. Davila[3], F.A. Michel[4], G.F. Slater[5], A.G. Fairén[3], N.R. Banerjee[1], [1]Dept. of Earth Sci., Univ. Western Ontario, London, ON, Canada, mbattle@uwo.ca, [2]Dept. of Physics and Astronomy, Univ. Western Ontario, [3]SETI Institute and NASA Ames Research Center, Moffett Field, CA, USA, [4]Institute of Environ. Sci., Carleton Univ., Ottawa, ON, Canada, [5]School of Geography and Earth Sci., McMaster Univ., Hamilton, ON, Canada.

Introduction: Surficial deposits of the iron sulfate mineral jarosite have been observed in several places on Mars, such as Meridiani Planum [1, 2] and Mawrth Vallis [3]. Jarosite is thermodynamically stable under a majority of temperature and pressure conditions on present-day Mars and, as such, jarosite may contain chemical or textural indicators of Mars' history, perhaps including evidence of biological activity [4]. Martian jarosite deposition mechanisms are not known, but by comparing Martian sites to analogous sites on the Earth, conditions of formation, and thus paleoenvironments on Mars during the time of deposition may be postulated. Mawrth Vallis has been identified as one of four potential landing sites for the Mars Science Laboratory (MSL) mission. Mawrth Vallis features a thick sequence of ancient, layered, phyllosilicate bearing rocks, overlain locally by presumably younger sulfate bearing material. A 3 x 5 km patch of jarosite has been identified 105 km from the proposed landing ellipse [3], and more recently other jarosite patches have been identified by Michalski and Niles [5]. Smaller patches of a scale undetectable by CRISM may exist even closer to the landing ellipse.

We propose the jarositic, cold seep emplaced Golden Deposit (GD), in Northwest Territories, Canada, (65º11'58" N, 124º38'15" W; Fig. 1) as an excellent analogue to the jarositic patches identified at Mawrth Vallis, and perhaps elsewhere on Mars [6, 7]. Located in a semi-arid desert, the GD is visible from the air as a brilliant golden-yellow patch of unvegetated soil, approximately 140 m x 50 m. The GD is underlain by permafrost and consists of yellow ochre, which is precipitating from seeps of acidic, iron-bearing groundwater [8]. The GD represents an intriguing analogue to past aqueous processes and habitability at Mawrth Vallis, as chemical environment, permafrost conditions, and arid conditions at the time of deposition are comparable. The GD would be a suitable place to test rovers and instruments, although the area of operations is limited.

Mission Description: MSL will aim to determine whether a particular region of Mars' surface has ever featured environments that were or are able to support microbial life, and to quantitatively assess potential habitats. Major goals relevant to GD include: 1. assessing the habitability of a target area by determining the nature and inventory of organic carbon and carbon compounds, in addition to H, N, O, P, and S, and by looking for textural biosignatures; 2. geological and geochemical characterization of the landing region and paleoenvironmental reconstruction using chemical, isotopic, and mineralogical techniques; and 3. investigation of planetary processes relevant to past habitability through looking at atmospheric processes and water cycling.

Science Merit Related to Mission Objectives: The GD is similar in scale, mineralogy, and appearance to the jarosite deposits at Mawrth Vallis. Mineralogy of the GD is predominantly natrojarosite and jarosite, with hydronium jarosite, goethite, quartz, clays, and hematite in some areas [6]. Water pH varies significantly over short distances, from

2.3 directly above seeps, to 5.7 several metres downstream from seeps [6]. Visual observations of microbial filament communities, phospholipid fatty acid analyses, and identification of sulfate reduction bacteria by Leoni et al. [9] confirm that the GD is capable of supporting life for at least part of the year. The suspected recharge area for the flow system is located 12 km to the west and features outcrops of, and sinkholes in, Lower to Middle Devonian and Ordovician limestones and dolomites along a 300 m high ridge. The GD is directly underlain by a thick sequence of Cretaceous pyritiferous marine shales. The acid seep waters form through reactions of ground water first with dolomite, and then with a pyritiferous shale bed at depth [8]. Biochemical oxidation of pyrite is thought to play a role, and may be enhanced by iron-oxidizing bacteria [10].

The basic ingredients needed to create a surficial jarosite patch on Mars similar to the GD are: 1. Fe-sulfides at depth, (possibly in sedimentary bedrock), 2. ground-water circulation and upwelling, and 3. arid, oxidizing surface conditions. There is evidence for all three ingredients on Mars at a planetary scale, as well as locally at Mawrth Vallis. If the Mawrth Vallis jarosite patches were formed by upwelling of acidic groundwater and subsequent precipitation of sulfates, additional smaller scale patches could be present throughout the Mawrth Vallis site below the scale required for detection by CRISM data, and this region could offer more potential evidence of more recent aqueous paleoenvironments and potential habitability than previously thought.

Mawrth Vallis is an ideal place to search for organics preserved in phyllosilicates during Mars' earlier alkaline aqueous period [11], and sulfate deposits could provide information about a later acidic saline aqueous period on Mars [12]. Moreover, we suggest that sulfate deposits at Mawrth Vallis should be an even higher priority target in the search for preserved organics. The GD jarosite is similar in many ways to jarosite at Rio Tinto, and thus analogies can be drawn between these two terrestrial jarosite deposits, and those reported at Mawrth Vallis. Jarosite, goethite, and hematite samples from Rio Tinto, from present day to 2 Ma, have been shown by Preston et al. [13] to preserve biomolecules and morphological evidence of cells. Therefore, environments on Mars such as Mawrth Vallis, which are similar to the GD and Rio Tinto, could have supported and preserved evidence of life. These sites should be targeted by rover missions equipped with instruments capable of detecting organics, such as MSL, or future missions with IR spectroscopy instruments.

In addition, the GD demonstrates that geochemical heterogeneity at sub-metre scales can exist at a seemingly homogeneous deposit (as observed by orbital spectroscopy), and indicates that there is likely much yet to be discovered at Mawrth Vallis. We do not have satellite datasets analogous to CRISM, but these could be obtained. Satellite data has been approximated by producing a representative spectrum via a linear mixture of the spectra of 21 of the surficial samples collected [6]. The GD is important as an analogous test bed for hypotheses, and for ground truthing data which may be returned by MSL from sulfate deposits at Mawrth Vallis. Hypotheses related to habitability and depositional environment can, and have been addressed at the GD by several studies referenced throughout this paper [6, 7, 8, 9, 10, 14].

Most Important Question: Can organics be preserved and detected by MSL instruments in jarosite and other Fe-sulfates in a cold, arid, acidic surface environment?

Logistic and Environmental Constraints: The GD is accessible by float plane (land on a lake 1 km from the site), or by helicopter (land directly on the site). Weather data from Norman Wells (100 km west of the GD) over the past 30 years indicate that the mean annual air temperature is -5.52 °C, and maximum and minimum air temperatures are 35 °C and -52 °C [15]. Mean annual precipitation is 290 mm [15]. The GD is unvegetated, but is surrounded by muskeg-rich boreal forest, and snow-covered from approximately October to April each year. A research permit from the Aurora Research Institute is required, which may take several months to obtain and involves translations.

Table 1: Golden Deposit (GD) overview.

Site Name	Golden Deposit
Center Coordinates	65º11'58" N, 124º38'15" W
Elevation	~0.2 km
Areal Extent	140 m x 50 m
Prime Science Questions	How were sulfates deposited at Mawrth Vallis? Can organics be preserved in sulfates in a cold, arid, acidic surface environment? Can a sulfate deposit of this nature be identified spectrally from orbit, and how do orbital spectra compare to in situ data?
Distance from airstrip	1 km from lake (float plane landing area); 0 km from helicopter landing site.
Environmental characteristics	Max temp: 35 °C; min temp: -52 °C; precipitation: 290 mm (mean annual); vegetation coverage: none
Previous studies at analogue site	Michel, 1977; van Everdingen et al., 1985; Michel and van Everdingen, 1987; Battler et al., 2011a; Battler et al., 2011b; Leoni et al., 2011
Primary Landing Site	Mawrth Vallis

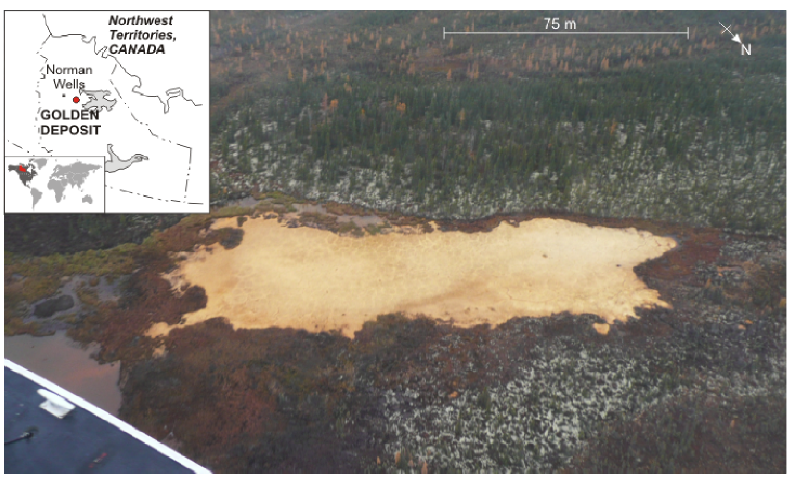

Fig. 1. Aerial photograph of the Golden Deposit (65º11'58" N, 124º38'15" W), Sept 2009. Inset maps show GD location. Prime science targets are Fe-sulfate minerals deposited by cold, acidic seeps.

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The Stable Isotopic Composition of Biogenic Methane in Mars Analogue Hypersaline Environments. B. M. Bebout[1], A. M. Tazaz[2], C. A. Kelley[3], J. Poole[3], A. F. Davila[4], and J. P. Chanton[2]. [1]Exobiology Branch, NASA Ames Research Center, Mail Stop 239-4, Moffett Field, CA 94035, Brad.M.Bebout@nasa.gov, [2]Department of Earth, Ocean and Atmospheric Science, Florida State University, 117 N. Woodward Avenue, Tallahassee, Fl 32306-4320, [3]Department of Geological Sciences, 101 Geological Sciences Building University of Missouri- Columbia, Columbia, MO 65211, [4]SETI Institute, 189 Bernardo Ave., Suite 100, Mountain View, CA 94043.

Introduction: Detecting and interpreting the detection of biogenic methane is at the core of NASA's strategies for the recognition of life both within our own solar system, and on extrasolar planets. Instruments for the analysis of both the concentration and carbon isotopic composition of methane are already loaded on board the Mars Science Laboratory for a launch next year, and have just been selected for inclusion in the 2016 ExoMars Trace Gas Orbiter. Additionally, the spectral absorbance bands for methane are a high priority, if not the highest priority, targets for instruments being considered for the identification of gases in the atmospheres of extrasolar planets.

We report here the results of investigations of biological methane production (methanogenesis) in hypersaline environments. Hypersaline environments are proposed as analogues for past, as well as present, habitable environments on Mars based on the following considerations. Spectrometers orbiting Mars have detected widespread chloride bearing deposits resembling salt flats in the cratered highlands [1]. Many of these deposits appear to have formed in large sedimentary basins, both within and between impact craters [2, 3], at a time when conditions on the surface of the planet were seemingly benign for life. Other evaporitic minerals, e.g., sulfates, are also abundant in several regions, including those studied by the Mars Exploration Rovers. The widespread presence of evaporites on Mars is consistent with the known evolution of the Martian climate, from warmer and wetter to cold and hyper-arid, and suggests that evaporitic and hypersaline environments were even more common on Mars in the past. Salt is also exceedingly important for determining presently habitable environments on Mars. Any subsurface water on Mars is likely to be brine. In addition, deliquescence, the property by which minerals at a certain relative humidity level spontaneously absorb water molecules forming a liquid solution on the surface of their crystals, is common in evaporitic minerals (including perchlorates, which have been found on Mars) and could be a source of water even under present conditions [4]. Mineral deliquescence has, in fact, been shown to be an important process supporting life in the driest and oldest desert on Earth, the Atacama Desert, in Chile [5]. In summary, salt has important consequences for energy production and metabolism in all biological systems, including systems in which methane is produced.

Mars analogue hypersaline environments on Earth provide an important opportunity to develop the strategies necessary to determine biogenicity of methane. Measurements of methanogenesis in hypersaline environments will provide a conceptual framework within which the data to be returned from Mars may be evaluated. Upcoming missions, most notably MSL and ESA/NASA ExoMars Trace Gas Orbiter, will be assessing the biogenicity of methane on Mars based on isotopic criteria as well as the $C_1/(C_2 + C_3)$ ratio. It is of critical importance to make these measurements in as many relevant analogue environments as possible in order to interpret the data returning from Mars missions. Hypersaline environments examined to date by our team include salt ponds located in Baja California, the San Francisco Bay, and the Atacama Desert. Many more hypersaline environments exist which deserve consideration as analogue environments, especially environments which are both cold and hypersaline.

Mission Description: Measurements of concentration and stable carbon isotopic composition of methane will be performed by the Sample Analysis at Mars (SAM) suite of instruments on MSL. A prime science objective for the 2016 ESA/NASA ExoMars Trace Gas Orbiter (EMTGO) is to characterize the chemical composition of the Mars atmosphere down to a pptv sensitivity level. In particular, much more detail about the temporal and spatial variability of methane will be acquired by elements of the payload on this mission.

Because methane can be produced abiotically as well as biologically, it is important to generate criteria to unambiguously assess biogenicity. The stable carbon and hydrogen isotopic signature of methane, as well as its ratio to other low molecular weight hydrocarbons (the methane/(ethane + propane) ratio: $C_1/(C_2 + C_3)$), has been suggested to be diagnostic for biogenic methane. In hypersaline Mars analogue environments on Earth, it is possible to study the factors determining the stable isotopic composition as well as the $C_1/(C_2 + C_3)$ ratio in unquestionably biogenic methane.

Science Merit Related to Mission Objectives: Measurements of the concentrations and stable isotopic signature of methane from a range of hypersaline environments are reported here. Work to date has shown that methane can be found in gas produced both in the sediments, and in gypsum- and halite-hosted (endolithic) microbial communities. Maximum methane concentrations in gas bubbles were as high as 40% by volume. The methane carbon isotopic ($\delta^{13}C$) composition showed a wide range of values, from about -60 ‰ to -30 ‰, while the hydrogen isotopic composition (δ^2H) ranged from about -350 to -150 ‰. These isotopic values are outside the range generally considered to be biogenic, however incubations of the sediments and salt crusts revealed that the methane is indeed being produced there. The highest rate of methane production was 20 nmol/g/d, in a gypsum crust with endolithic microbial communities.

Many of the highly ^{13}C enriched methane samples (up to -30 ‰) were obtained in evaporitic environments characterized by extremely low organic carbon concentrations. Experimental manipulations suggest that the highly ^{13}C enriched methane results from reduced fractionation of substrate by methanogens operating under conditions of extremely low organic carbon concentrations. These environments would seem to be extremely relevant analogues for low organic matter environments on Mars (both present day and past).

Most Important Question Answered by Site: Measurements of methane in various hypersaline analogue environments provide important information about rates of methane production, concentrations of methane within and above the sediments, and the stable isotopic composition of the methane produced. Therefore, the measurements performed in these analogue environments provide important constraints on the range of possible carbon and hydrogen stable isotopic compositions in unquestionably biogenic methane. Additionally, the pathways leading to methane production, as well as environmental controls on methane stable isotopic composition may be investigated and understood.

Logistic and Environmental Constraints: Many hypersaline environments, e.g., Baja California, Mexico, the Atacama Desert, Chile are relatively accessible. The hypersaline environments at the southern end of the San Francisco Bay are exceedingly easy to access, and are in close proximity to NASA's Ames Research Center.

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Calcium-Magnesium Carbonate Cements in the Del Puerto Ophiolite, CA: Microbial Biosignatures Associated with Alkaline Springs in Phyllosilicate-rich Ultramafic Rocks

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Introduction: This analog site is located in the vicinity of the alkaline Adobe Springs, which emanate from the hydrothermally altered mafic and ultramafic rocks of the Del Puerto Canyon Ophiolite in the California Coast Range. Here, a community of novel bacteria is associated with the precipitation of Mg–Ca carbonate cements in the creek beds that line the drainage basins of the ophiolite terrain. The carbonates are a biosignature that could guide the search for past life on Mars.

Mission Description: A Mars candidate landing site related to the Del Puerto Canyon analog would contain hydrothermally altered ultramafic rocks with associated phylllosilicates (such as serpentine minerals antigorite, chrysotile, and lizardite) and carbonates. Brown et al. [1] described a site with similar mineralogical characteristics in the Nili Fossae region using CRISM data.

Science Merit Related to Mission Objectives: The process of serpentinization of mafic and ultramafic rocks produces Mg-rich alkaline water, which in this analog site are associated with Mg-Ca carbonate cements and unusual microbial communities at the surface. Serpentinization generates methane and hydrogen, two potential sources of energy for chemosynthetic organisms that could exist in a subsurface environment (e.g., [2]). This setting (where water is in contact with mafic and ultramafic rocks) may serve as a good analog for similar environments on Mars that may have supported life in the past or be hosting life today.

Figure 1 Ca-Mg carbonate cement lining the Del Puerto Creek at Adobe Springs. Photo from sampling station DP6 in Fig. 2.

Initial investigations at Adobe Springs [3] have focused on three critical components: (1) the chemistry of the alkaline waters emanating from serpentinized mafic and ultramafic rocks, (2) the types and compositions of actively precipitating carbonate cements found lining the adjacent creek drainages (Fig. 1), and (3) the novel microbial communities associated with the alkaline waters and carbonate cements. On the basis of thermodynamic constraints, low-temperature deposition of Ca-Mg carbonate cements in the creeks requires microbial mediation. Future work at the site will focus on further characterizing the link between biological activity and carbonate cement precipitation.

Most Important Question Answered by Site: Could the presence of calcium-magnesium carbonates associated with phyllosilicates and ultramafic rocks on the Martian surface be indicators of past life there?

Logistical and Environmental Constraints: The Del Puerto Ophiolite is located approximately 100 km SE of San Francisco and is accessible by car along the paved Del Puerto Canyon Road. The area is rugged, sparsely vegetated and populated, and marked by steep hillsides that flank the local creeks. Flow in the creeks is seasonal, and summertime temperatures in the canyon can exceed 46°C. The land is private property and permission for access must be obtained from the landowners. Access to the Adobe Springs area can be obtained from Mr. Paul Mason, who maintains a spigot for public consumption of the high-Mg spring water.

Table 1: Site Information for Adobe Springs analog site in the Del Puerto Ophiolite, CA.

Site Name	Adobe Springs
Coordinates	37°24'31.09"N, 121°24'32.94"W (Public-access Adobe Springs spigot, DP Canyon Rd)
Elevation	403 masl at lat/long specified above
Areal Extent	~3 km x 2 km DP Ophiolite exposure; cement-lined creek beds up to ~25 m wide & several km long
Prime Science Questions	Which organisms catalyze carbonate cement formation? How do the environmental conditions promote biomineralization?
Distance of Science Targets from nearest road or airstrip	Accessible by paved Del Puerto Canyon Road or by dirt Adobe Canyon Road or within walking distance of roadside
Environmental characteristics	Max. temperature: > 46°C (115°F) Min. temperature: < -12°C (10°F) Ave. precipitation: < 40 cm/year Vegetation coverage: sparse Mg-rich alkaline water; see mgwater.com
Previous studies at site	[3, 4]
Primary Landing Site Target	TBD; e.g., Nili Fossae
Regional and Local Geology – CA Coast Range Ophiolites	Ophiolite age ~ 65 Ma [5]; Del Puerto Geology [6,7]

Figure 2: Location of Adobe Springs analog site in the Del Puerto Ophiolite CA. Easy access is from the Del Puerto Canyon Road, which runs approximately EW along Del Puerto Creek. Push-pin symbols denote sampling locations described in Blank et al. [3].

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THE UBEHEBE VOLCANIC FIELD (DEATH VALLEY, CA): A HIGH-FIDELITY ANALOG SITE SUPPORTING MSL11 INTEGRATED SCIENCE MISSION GOALS. CLAY CYCLE AND HABITABILITY POTENTIAL UNDER ARID HYDROCLIMATIC CONDITIONS.

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Introduction: The Mars Science Laboratory (MSL) mission will primarily search for potentially habitable, ancient geological environments, as a preliminary step to future life detection e.g., the ESA/US 2018 Pasteur ExoMars, and sample return missions. All MSL site candidates include hydrated clay minerals, or phyllosilicates, and have been evaluated by *context, diversity, habitability, and preservation potential of organics***.** Phyllosilicates are unambiguous indicators of past aqueous activity on Mars, and of particular interest due to their high preservation potential.

MSL science goals will require a highly-integrated science approach simultaneously involving: a) the understanding of role of (liquid) water/climate, and time scales involved in weathering processes and conducive to life (as we know it); and b) the identification of geological targets enabling concentration as well as preservation of biological and nonbiological organics.

In the above context, we have identified high-fidelity analog sites at the Ubehebe Volcanic Field (UVF) (Death Valley National Park, California, USA), Figure 1. Overall, the UVF combines multiple analogies (geological, geomorphologic, mineralogical, and hydro-climatic) of setting and processes argued for MSL sites and other Martian sites.

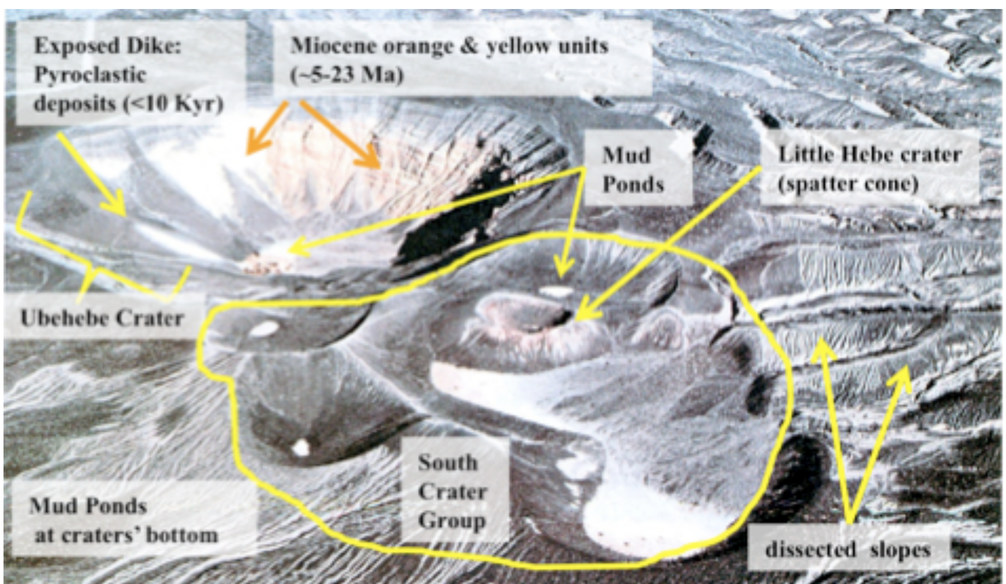

Figure 1. Aerial view (~2 km by ~2 km) out of 25 km^2 including target features of the UVF at a spatial scale (few hundreds of meters to 4-5 km traverse) reachable by a rover. The Ubehebe Crater is centered at 37°0'35"N, 117°27'01"W at an elevation of ~655-meters. Road access is on the left-upper corner.

The UVF comprises three main subsystems, or areas of prime science interest, each one with a specific, and/or general feature relevant to MSL sites (underlined).

1. The ***Ubehebe Crater (UC)***, the largest in the area, is ~0.8 km-wide, 150 to 237 m-deep, and ~2 to 4-7 thousand years old. The exposed wall lithology consists of hundreds meters-thick heterogeneous fluvial deposit (e.g., reddish mudstone), and a rhyolitic tuff outcrop uniquely localized. They are overlain by thinly bedded/laminated pyroclastic deposits (pumice and basaltic ash) of Recent age. Wall deposits supply weatherable material to intra-crater fill deposit rich in Al-smectites (**Mawrth/ Eberswalde**) and of unknown thickness.

2) The ***Southern Craters Group (SCG)*** has a shallow drainage and more extended alluvial features **(Holden Crater)** with respect to the other sites; and 3) the **Little Hebe *(LH)*** *is* a small spatter cone, which rim consists of molten scoriaceous lava, partially oxidized (hematite), layered sulfates unique at this site, and clays (mineralogical variability**/ Gale Crater).**

A comprehensive set of integrated investigations can be conducted at each location to address general and specific mission goals and to test science-driven hypotheses (multiple Science Merit Related to Mission Objective)**.**

- The **UVF** is a cratered terrain (caldera) formed by subsequent phreatomagmatic eruptions 2-7 thousands years ago and presents a well-distinct drainage system. This enables direct measurement and quantification of sedimentary processes, moisture conditions and clay formation from a unique source, or a few well-identifiable ones.
- The **UVF** geology is relatively young – oldest formations are of Miocene age - with respect to that argued for the MSL sites (e.g., Noachian-Hesperian). As such, the analogy refers to a ***past*** wetter/ warmer Mars rather than to the present dry and cold Mars, or to geological age.
- UVF developed under desert conditions and timescale (~10^3 to 10^4 years to present), which are **analog of hydro-climatic conditions** and timescale inferred by some for the Noachian–Hesperian transition i.e., characterized by episodic (maybe seasonal) long-term arid-semiarid rainfall (~10^4 years) [1]. **Mission Elements:** Understanding time scales of sediment weathering in function of liquid water exposure and subsequent formation of clays from geologically different parent materials. **Hypotheses:** Are Al-smectites produced in situ, or are they (wash-out) from elsewhere?
- UVF includes a diversified set of **sedimentary analog environments (**fluvial, alluvial, lacustrine, and pyroclastic) at landing sites. **Mission Element:** Identification of the best target for concentration/ preservation of organics. **Main question:** How do different depositional setting will influence habitability and preservation potential?
- UVF subsystems account for a **high mineralogical variability:** Within 1 km^2 presence of different types of phyllosilicates (Marwth) **and/ or** more mineral types (clays, Fe-oxides, detrital silicates, sulfates, and carbonates). **Mission Element:** Prioritizing search for organics/habitable environments by the CheMin-SAM suite based on non-contact, remote information from ChemCam. **Hypotheses:** Evaluation of habitability and preservation potential in clay-rich vs. nonclay background materials (follow the minerals and the water!).

Current Investigations. To address **prime science questions** we have been focusing on the Ubehebe Crater fill deposit (mud pond). Here we can test hypotheses centered on recycling vs. neo-formation of clay minerals as analog processes of forming smectites on Mars. Preliminary Q&A, based on a still limited set of observations, follows below.

1. Are currently arid hydro-climatic conditions sufficient to form smectites from recycled sedimentary components?

Yes: up to hundreds meters of fine-grained sediment can rapidly accumulate and weather to Al-phyllosilicates under arid conditions (118 ± 42 mm/y Rainfall over year 2004 to date) similar to those argued for the Noachian–Hesperian transition [1].

The bulk mineralogical composition (XRD data) of red mudstones (N=6) from wall materials (fluvial) is typically detrital (major amounts of quartz, carbonates, plagioclase, k-feldspar), and minor inherited clays (chlorite, muscovite/illite, and possible smectites). In contrast, the intra-crater fill (mud ~99wt.% avg., N=5) contains higher amounts of primary products from weathering of glass and feldspars to Ca-montmorillonite (Al-smectite). Al-smectite-bearing horizons at Mawrth Vallis [2-4] may represent a late sedimentary, or altered pyroclastic deposit [5] draping the topography [6-7], which appears to be the case for the Ubehebe Crater.

In Water Year (WY) 2010 two extreme rainfall events delivered 75 mm rain in about 7 days (January and February 2010). We assume that from the two events combined, the crater bottom received up to 3 - 5 mm average (N=7) silty-clay from direct erosion of the rhyolitic tuff outcrop (surface area of 4,263 m^2). A major contribution ~11.6 ± 1.7 mm (N=38) was from wall (surface ~55,062 m^2). By assuming a constant average sediment rate of ~1 cm/y since the crater formed (2-10 thousands years) we can estimate a present-day thickness of about 33 to 167 m-depth.

2. How long does water have to be in contact with surface minerals in these sediments to form smectites?

In WY 2010 the two rainfall events formed a 20 cm-deep pond (volume 286 m^3), conditions not reproduced in WY 2011, yet. Pond moisture varies from 2-3 wt.% water content in summer/dry conditions to ~50-55 wt.% (saturated conditions).

Other Investigations: We have been focusing [8-10] on distinguishing preservation from habitability potential. Particularly in testing (microbial) hypotheses in clay-rich vs. nonclay (background) materials: 1) Clays are environments relatively low in living microbial content. 2) Clays can well preserve organic remains of microbe. Detailed explanation is behind the scope of this abstract and will be provided as the opportunity arises.

Table 1: Scientific merit of the analogue site to MSL/ExoMars missions

Site Name	Ubehebe Crater and Ubehebe Volcanic Field
Prime Science Questions 1	See main text above (this page).
Distance of Science Targets from nearest road or airstrip	Ubehebe Crater Bottom – 10-15 min walk 0.3 km to park lot Little Hebe – 20 min-walk 1.5 km to park lot Southern Crater Group – 2 km to park lot
Environmental features	Max temp: Air 52ºC, Min temp: -10ºC Precipitation: see main text. Vegetation coverage: 0 to 20-50% bush, depending on season and location.
Previous studies at analogue site	[8-10]
Primary Landing Site Target	MSL: e.g., Mawrth, Eberswalde. Any smectite-rich area of Mars.

Airborne imaging spectrometer and AVIRIS data are available for this site. We have developed a good knowledge of sites and logistics from several years of working at the UVF. The UVF is located within one hour's walk from the service area/parking lot. Safety considerations may arise particularly during the rainfall season, owing to extreme weather (flash flood and storms). The site is easily accessible (paved road) via CA Hwy 190, ~5 miles from the Grapevine Ranger Station (radio station and closest shelter) and it is ~10 miles from the main Station at Scotty's Castle (emergency medical services/shelter, radio station). Maintenance assistance for federal vehicles is available during emergencies. Research permits enabling sampling and placement of data loggers have been cleared with the NPS (DEVA-2010-SCI-0027). They fulfill tribal requirements/limitations for activity at the most sacred area to the Timbisha-Shoshone Tribe. At DEVA E/PO activities outlining relevance of the UVF to MSL are planned from March 2011 to prior launch.

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LAVA TUBES AS ANALOGUE REPOSITORIES FOR LIFE, GEOCHEMISTRY, AND CLIMATE RECORDS ON MARS. P.J. Boston[1], J.G Blank[2], D.E. Northup[3], M. Deans[4].

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Introduction: Lava tubes are a terrestrial analogue for a key prospective astrobiological target on Mars, namely, the cave, subsurface, and rock fracture environment. Caves exhibit stable physical and geochemical conditions, are sheltered from physical weathering and especially ultraviolet and cosmic ray bombardment, and may be one of the best ways to access the relatively near to mid-range subsurface of the Martian landscape. Lava tube caves have been identified on the Moon and Mars using satellite imagery [1,2]. They may be present on other Solar System bodies [3]. The restricted connection of many lava tubes to the atmosphere could increase the possibility for the retention of water [4], a requirement for living systems. These subterranean settings could serve as a protected habitat for lifeforms, enhance the preservation of recognizable biosignatures from past life and preserve evidence of past climates [5-8].

Although premature for consideration for very near-term missions (e.g. MSL or MSR/Mars 2018), Mars lava tubes offer much scientific value for future robotic and eventually human missions [9]. Identifying such features on the Martian surface or elsewhere in the Solar System and developing methodologies for studying their numerous analogues on Earth will set the stage for future capabilities to actually access such potential treasure troves of unusually well preserved materials on future missions.

Mission Description: A mission that aims to access a lava tube could be framed in one of two ways, either a direct entry into a natural opening, or a shallow drilling effort into a sealed tube. To enter a lava tube directly, a mission must be capable of advanced robotic entry, possibly by small independent and numerous units that use a variety of novel techniques not currently employed on conventional large-scale robotic rovers [10, 11, 12] or to access an open lava tube with a smooth floor (Figure 1) a rover like the current K-10 could be employed [13, 14]. The second alternative is to employ drilling technology to bore down through the parent rock into the lava tube chamber below. Ground penetrating radar (GPR) is being used on Earth to find subsurface cavities [15] and has been suggested for use on Mars [16, 17].

Science Merit Related to Mission Objectives: Science objectives of future landed missions will include broad aspects of the potential presence of extant life and traces of past life. We note that microbial/mineral materials on lava tube walls produce distinguishable and distinctive textures that persist after the organisms themselves no longer inhabit the surfaces [18]. In terrestrial lava tubes, allochthonous deposits of sediments are frequently preserved unaltered for geologically significant periods of time, thus enabling a glimpse of past climate and hydrology [18]. These lava tubes often have collapsed segments that could be excellent time capsules for trapped volatiles, particles, possibly organics, and build up of high concentrations of gases from deeper geological sources [19, 20]. On Earth, tectonic and weathering processes limit the lifetime of lava tubes to perhaps a few million years (e.g., Saudi tubes are considered to be very old, at ~3-4 Ma). On a more geologically quiescent body such as Mars, the duration of a lava tube feature is likely to be much longer.

Most Important Question Answered by Site: Lava tubes provide a window into the subsurface that allows access to major void space that may contain: 1) volatiles (frozen or gaseous; 2) mineral and geochemical biosignatures and climate signals, 3) live or dead Martian life. As in many Earth lava tubes, we anticipate similar exquisite preservation of mineral, sedimentary, and geochemical materials.

Logistic and Environmental Constraints: The dozens of lava tube sites around the world that our team is studying range from a few feet off a parking lot to many km hiking over rough terrain. The temperatures within the caves vary greatly with latitude, altitude, and whether a particular tube is acting as a cold trap.

Figure 1: Hibashi Cave, Saudi Arabia. This lava tube has a smooth floor courtesy of blown in sand. Frequent dust storms on Mars probably have deposited a similar blanket of material on the floors of open lava tubes. Such a flat floor would be accessible even to some wheeled or legged robots. Microbial/mineral white coating is visible on the walls. Image courtesy of J. Pint.

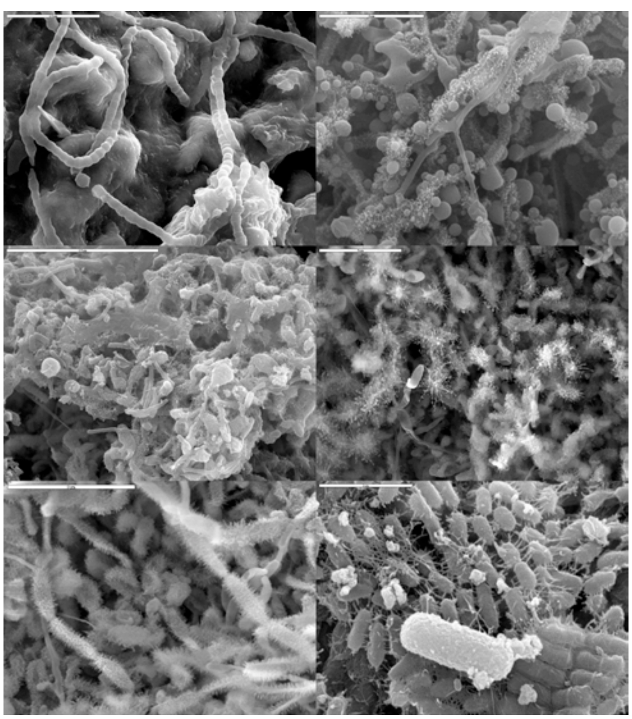

Figure 2: Selection of SEM images of microbial colonies on lava tube surfaces around the world. In some cases microbial colonies are visible to the naked eye, in many cases the rock appears to be bear, but at microscopic resolution numerous organisms, biofilm, and associated minerals appear.

Table 1: Lava Tube Analog Overview

Feature	Description
Lava tubes on Earth are liberally distributed around the planet	Lava tubes studied by our team: New Mexico, Arizona, Oregon, California, Hawaii, Azorean Islands, Saudi Arabia, Oman, Chile (Atacama)
Elevation	Sea level to 4 km
Areal Extent	Lava tube containing flows of 1 – 100 km^2
Prime Science Questions	e.g., What textural, microscopic, and geochemical signals of biology, climate, and sedimentological histories are contained within the lava tubes?
Distance of Science Targets from nearest road or airstrip	From 20 m to 10 km
Environmental characteristics	Max temp: 45°C Min temp: -10°C Precipitation: <1 mm/decade to 4 m/year Vegetation coverage: Bare (new Hawaiian lava tubes <50 yrs old; old Saudi sand desert lava tubes) to heavily vegetated temperate or tropical forest.
Previous studies at analogue site	Complete bibliography at http://www.caveslime.org/ & http://www.ees.nmt.edu/boston/pubs.html
Primary Landing Site Target	e.g., Mars lava tubes have been identified so far at: Arsia Mons, Olympus Mons, Pavonis Mons, East of Jovus Tholus, & Elysium Mons

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Mass Spectrometry on Future Mars Landers. W. B. Brinckerhoff[1], P. R. Mahaffy[1], and the MSL/SAM and ExoMars/MOMA Investigation Teams, [1]Code 699 Planetary Environments Laboratory, NASA Goddard Space Flight Center, Greenbelt, MD 20771, william.b.brinckerhoff@nasa.gov, paul.r.mahaffy@nasa.gov.

Introduction: Mass spectrometry investigations on the 2011 Mars Science Laboratory (MSL) and the 2018 ExoMars missions will address core science objectives related to the potential habitability of their landing site environments and more generally the near-surface organic inventory of Mars. The analysis of complex solid samples by mass spectrometry is a well-known approach that can provide a broad and sensitive survey of organic and inorganic compounds as well as supportive data for mineralogical analysis. The science value of such compositional information is maximized when one appreciates the particular opportunities and limitations of *in situ* analysis with resource-constrained instrumentation in the context of a complete science payload and applied to materials found in a particular environment. The Sample Analysis at Mars (SAM) investigation on MSL and the Mars Organic Molecule Analyzer (MOMA) investigation on ExoMars will thus benefit from and inform broad-based analog field site work linked to the Mars environments where such analysis will occur.

Mission Description: The SAM investigation [1] merges the capabilities of a quadrupole mass spectrometer (QMS) with those of a gas chromatograph (GC) and a tunable laser spectrometer (TLS), supported by a seventy-four cup solid sample manipulation system (SMS) and an extensive chemical separation and processing laboratory (CSPL). SAM analyzes the chemical and isotopic composition of both the martian atmosphere and particulate samples introduced from the MSL sample acquisition-sample analysis and handling (SA-SPaH) system through solid sample inlet tubes and into the quartz sample cups. Gas is extracted from solid samples via pyrolysis (with selectable options for derivatization, thermochemolysis, and combustion). Gas may be sampled directly by the 2-550 Da mass-to-charge (m/z) range QMS or preprocessed in the CSPL to concentrate organics or noble gases. It may additionally be routed into the GC or the TLS. The six column GC not only has its own detectors, but also can operate together with the QMS as a gas chromatograph mass spectrometer (GCMS). The GCMS detection limit surpasses the part per billion mission requirement for organic detection. The TLS is a two-channel Herriott cell design spectrometer that provides detection of CH_4, H_2O, and CO_2 and the isotope ratios $^{13}C/^{12}C$, $^{18}O/^{16}O$, and $^{17}O/^{16}O$ in carbon dioxide, D/H in water, and $^{13}C/^{12}C$ in methane. The TLS sensitivity for atmospheric gas is < 1 ppb and the detection limit can be substantially reduced by methane enrichment in SAM's CSPL. SAM thus provides a broad investigation of organic and inorganic species and their isotopes in solid and atmospheric samples. In the context of the full MSL payload including chemical and mineralogical analysis tools such as CheMin, ChemCam, and APXS, the SAM investigation will directly support the assessment of potential habitability of an environment characterized by evidence of ancient hydrologic, depositional, and preservational features, to be selected later this year. SAM has participated in analog field campaigns such as the Antarctic Mars Analog Svalbard Expedition (AMASE) supported by the Astrobiology Science and Technology for Exploring Planets (ASTEP) program as well as MSL-sponsored field tests, and is involved in an intensive ongoing development of mass spectral libraries using standard and analog materials representative of potential landing site composition.

The MOMA investigation led by the Max Planck Institute for Solar System Explortaion (MPS) merges the capabilities of a GCMS and a laser desorption MS into a single miniaturized instrument incorporated into the Analytical Laboratory Drawer (ALD) of the ExoMars rover. The rover is significantly smaller than MSL and as such provides a more focused set of measurements, aligned to support the top science objective of the search for signs of life on Mars. A significant advancement offered by ExoMars is a drill that obtains samples from depths of up to two meters below the surface, which in some cases may be substantially better for survival of complex organics than the highly degradational surface environment. Crushed samples are delivered to instruments including MOMA via rover-provided sample manipulation facilities within the ALD. In MOMA particulate samples are loaded into small oven cups and pyrolyzed analogous to SAM. Evolved gas is transported to the (multiplexed) four-column MOMA GC provided by the same French team that provided the SAM GC, incorporating some advancements such as a high density valve assembly. Both derivatization and thermochemolysis are baselined for a fraction of the oven cups to permit volatilization and survival of organics that are more readily fragmented or oxidized under the pyrolysis protocol. GC effluent is directed into a highly-miniaturized ion trap mass spectrometer (ITMS) with electron ionization that supports an m/z range of 2 kDa and which can be operated in tandem mass spectrometry (MS/MS) mode to provide additional information on molecular structure. In addition, MOMA incorporates the ability to analyze solid samples provided on a tray at Mars ambient pressure using pulsed laser desorption/ionization (LDI) and an ion optical scheme that brings prompt laser ions into the ITMS. The LDI mode offers complementary information on the more nonvolatile organic and elemental composition of the sample, with the possibility of directly detecting higher molecular weight species that may be indicative of the survival of complex organics in the near surface of Mars. MOMA has begun to participate in analog field campaigns such as AMASE and the team is particularly interested in opportunities for collaborative field work in support of ExoMars objectives. Analog sites and materials representing potentially Mars-like microenvironments (phyllosilicate-rich deposits, cryptoendolithic communities, varnishes, brines/ices, etc.) for preservation of both extinct and extant or dormant habitats are a strong need going forward to optimize the application of the complementary MOMA mass spectrometry techniques on ExoMars.

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MSL AND BEYOND – ANALOG SITES FOR THE EXPLORATION OF MARS HABITABILITY AND LIFE POTENTIAL IN THE ATACAMA, ALTIPLANO, AND ANDES (AAA). N. A. Cabrol[1] and D. S. Wettergreen[2], [1]NASA Ames/SETI CSC. Space Science Division, MS 245-3, Moffett Field, CA 94035-1000. Email: Nathalie.A.Cabrol@nasa.gov; [2]The Robotics Institute, Carnegie Mellon University, 5000 Forbes Avenue, Pittsburgh, PA 15213-3890. Email: dsw@ri.cmu.edu.

Introduction – The Mars Exploration Rover (MER) mission has shown how critical it is for planetary surface missions to rely on ground-truth obtained from terrestrial analog environments. This was especially significant when time came to distinguish between the plausible hypotheses explaining the distinct types of environments forming the blueberries at Meridiani and the silica spherules at Gusev or the origin of the various soils and sedimentary sequences in outcrops. As the Mars Exploration Program (MEP) transitions from *following the water* with MER and examining habitable environments with the Mars Science Laboratory mission (MSL) towards *seeking signs of life*, the Mars Exploration Program Analysis Group (MEPAG) Mid-Range Rover Science Advisory Group (MRR-SAG) has formulated the Mars Astrobioloy Explorer-Cacher (MAX-C) mission concept that responds to this new direction of exploration [1].

Beyond MSL, a new class of missions will, thus, evaluate life's potential on Mars in the coming decade. Such investigations will require new technology, instruments, science payloads, exploration strategies, and new operational templates that will involve testing in realistic analog environments so that datasets can be compared with in situ data on Mars during missions. The selection of realistic Mars analog sites also benefits now from a deeper knowledge of the martian morphological, geological, mineralogical, and past and present climatic environment accumulated from orbit and ground missions.

Over the past 15 years, the Chilean Atacama desert, Altiplano, and Andes (AAA) have provided robust sites for Mars mission simulations and analog studies for NASA-funded investigations. Robotic exploration missions, geological and environmental studies, and astrobiological projects have been carried out in the AAA and funded by the agency through various programs (e.g., ASTEP, NAI, PGG). The depth of a multifold analogy is continuously reinforced by new data coming from Mars, making the AAA critical assets in the pool of NASA's analog sites for the coming decade of Mars exploration. Although Table 1 is pointing to the potential of a few sites in particular, our goal is to draw the attention on the relevance of the AAA as a whole to all types of missions described in MAX-C.

The Atacama desert: Exceptionally favorable analog conditions are present in the Atacama to evaluate the validity of exploration strategies of missions that will be investigating habitability and life potential in an environment that provides many parallels to Mars. Environmental conditions include extreme aridity, high solar irradiance, salinity, and oxidation over the past 10-15 million years, which makes the Atacama one of the oldest terrestrial deserts. Further, desert pavement, volcanic, hydrothermal, playa, channel, alluvial fan, lag, aeolian, heterogeneous aquifer distribution, and impact deposits, as well as soils of varied cohesiveness, textural, mineralogical compositions, and trafficability characteristics will allow to accumulate critical science, technology, and operational datasets in preparation for Mars exploration. As a result, the Atacama has already been the focus of several large NASA-funded science and technology deployments simulating Mars missions, including rover field experiments such as Nomad in 1997 and Life in the Atacama (LiTA) in 2003-2006 [e.g., 2-7]. These projects were supported by Letters of Agreements between NASA and Chilean institutions, some still in effect. There is a long history of successull collaboration between US research teams and local governmental agencies and logistical companies providing access to the field.

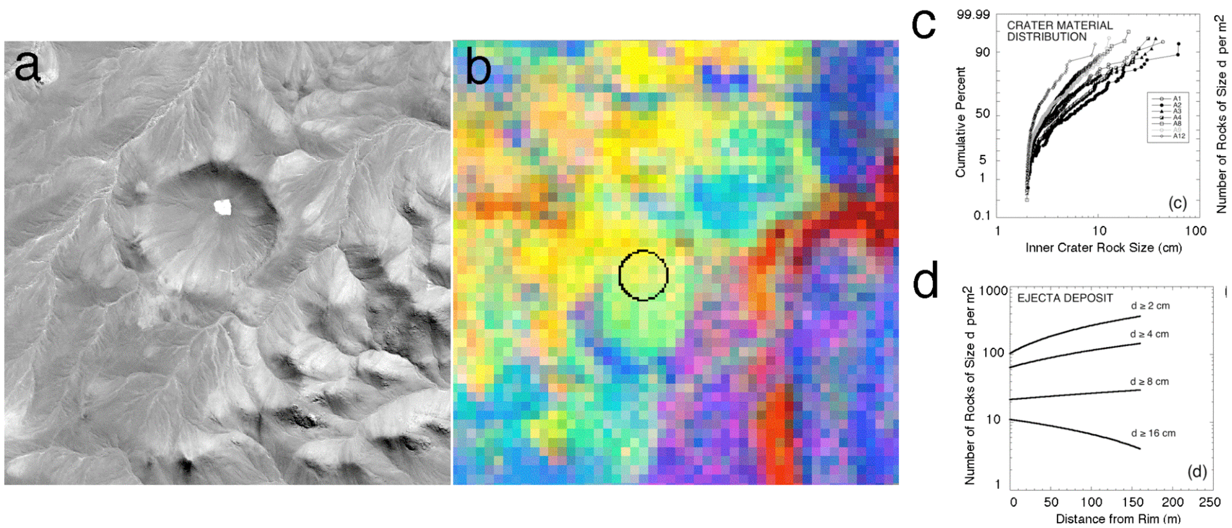
Exploring for rare extant life heterogeneously distributed in a hyperarid habitat provides another layer of analogy with Mars. The search for culturable bacteria from 24-28°S indicates that the quantity and diversity of heterotrophic bacteria increase as a function of scarce water availability [e.g., 9-15]. In the driest regions (24S), no bacteria could be isolated in carbon-depleted soils. Atmosphere/ surface interaction (condensation, fog) favors the formation of soil crusts and cements [e.g., 6, 10 16-17] through processes reminiscent of those forming the ubiquitous soil salty crust and particle cements observed on Mars, particularly at Gusev crater. Both oxidized soils and crust host microbial communities at low detection levels varying according to available moisture [*e.g.,* 6, 14, 15]. This scarcity of life challenged the LiTA project, fostering the development of new exploration strategies that ultimately resulted in the first automated discovery of microbial life by a rover [6, 18].

Extinct microbial life is present under the form of biomarkers and bioconstructs, some of the bioconstructs dating back from the Jurassic and Cretaceous times, e.g., stromatolites. Their investigation will lead to the accumulation of critical datasets for future imagers (visible, multispectral, and microscopic) and help the identification of similar signatures on Mars.

The Altiplano and High Andes: The Atacama transitions into the Altiplano, a high plateau between 3,500-4,200 m asl and into the volcanic Andes, which culminate at ~6,900 m asl. In its arid core (18-28S), the Andean landscape is composed of a volcanic, sulfur-rich environment, hydrothermal springs and deposits, lakes, dunes field, and aeolian deposits. Dry lakes and declining lake habitats provide a rare opportunity to measure, as it happens, the impact of rapid climate change on microbial life and on the morphology and mineralogy of its habitats. This rapid change is currently occurring in a physical and unstable atmospheric environment presenting many analogies to early Mars at the Noachian/Hesperian transition [19], including: a thin atmosphere (600-470 mb) with daily occurrence of dust devils between 10:30 am and 3:00 pm; enhanced evaporation (-1,500 mm/yr); one of the highest solar radiation environments on Earth including the presence of short UVB and a UV index up to 28 [20]; strong daily and yearly temperature fluctuation; sudden and sharp daily temperature variations generating high UV:T ratios that impacts life's ability to repair its DNA; seasonal ice-cover; and sulfur-rich, volcanic and hydrothermal environment [21]. In the Central Andes (30-38S) and at high elevation in the arid Andes, permafrost and debris-covered glaciers are present [22]. The AAA is overall highly relevant to the next generations of missions to Mars. Table 1 shows selected examples of sites.

- Table 1 -

Sites 1-4	1. Monturaqui Impact Crater (400 m diameter) **(Figs a-d)**; 2. Salar Grande; 3. El Tatio; 4. Dry lakebed deposits throughout the Atacama, Altiplano, and Andes
Lat/ long	1. 23.56S/68.17'W 2. 70.00'W/20.45'S; 3. 22.35S/68.2W; 4. Overall area from the western border of Chile to Andes. Landscape diversity extends to Bolivia and Peru.
Elevation (asl)	1. 3000 m; 2. 1500 m; 3. 4500 m; 4. From 1000-6000 m.
Prime Science Questions	1. Stratigraphy, morphology, and mineralogy of small impact structures. 2. Planetary spherules formation, silica deposits 3. Geothermal, hydrothermal spring deposits
Environmental characteristics	Hyperaridity, < 10 mm/yr precipitation in the Atacama, 30-120 mm/yr in the altiplano and arid Andes (18-28S), and up to 400 mm/yr in the Central Andes where debris-covered glaciers are. T extremes are 0-+23C in the Atacama, -10/+15 in the Altiplano, and -40 to +10C in the Altiplano. Mostly no vegetation in the Atacama except oases. Barren land-scape in the Altiplano and Andes.
Previous studies at analogue site	Abundant. Some cited in the reference list.



Monturaqui Impact Crater – a. Ikonos image (1m/pxl) of Monturaqui. Highest albedo deposits correspond to the central playa; **b.** Subset of a minimum noise transformof ASTER SWIR data (crater outlined). Color variations are related to spectral variations; **c.** Size distribution of inner crater material graded as a function of distance from ground zero; **d.** Abundance of rock classes as a function of distance from northern rim (after Cabrol et al., 2010).

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ARCTIC-WEATHERING PROFILES OVERLYING SULFIDE ORE BODIES (GOSSANS) AS ANALOGS FOR PARTIALLY OXIDIZED FE-S MINERALS ON MARS. S. B. Cadieux[1] and L. M. Pratt[1], Department of Geological Sciences, Indiana University, Bloomington Indiana (sbcadieu@indiana.edu).

Introduction: Iron sulfates are common on the surface of Mars therefore, understanding the formation of these minerals is crucial for interpretation of geological processes on the surface and in the shallow subsurface. Jarosite ($K_2Fe_6(SO_4)_4(OH)_{12}$), gypsum ($CaSO_4{\cdot}2H_2O$), and schwertmannite ($Fe_8O_8(OH)_6(SO_4){\cdot}nH_2O$) are repeatedly identified by orbiting and landed instruments. It has been reported recently that Juvenate Chasma, a deep depression approximately 3km deep and 150 km wide near 4°S and 298°W, contains four light-toned sulfate-bearing mounds, composed of both monohydrated and polyhydrated sulfates [1]. Most of the spectrally identified monohydrated sulfates in the mounds resemble either szomolnokite ($FeSO_4{\cdot}H_2O$) or kieserite ($MgSO_4{\cdot}H_2O$) [1]. Terrestrial hydrothermal processes produce an acidic environment where hydroxidated ferric sulfate minerals precipitated. Acidic environments on Earth associated with formation of iron sulfate minerals are primarily located at sites of natural acid mine drainage (gossans) or near volcanic craters and vents.

Gossans provide an understudied and important analog for low-temperature hydrogeochemical formation of ferric and ferrous sulfate minerals on Mars. Gossans are defined as intensely oxidized, weathered, or decomposed rock, usually in the upper part of an ore deposit or mineral vein [2]. Previous studies of terrestrial acidic environments have focused on iron oxide/oxyhdroxide and sulfate minerals in mined regions such as Rio Tinto in Spain [3] and Iron Mountain in California [4]. Although useful as analogues for aqueous processes on a warm and wet Mars, both sites are highly impacted by mining activities, and natural sites of acid weathering in polar regions are needed to inferred processes influencing formation of ferric and ferrous sulfate minerals on Mars under relatively cold and dry conditions.

Arctic weathering of sulfide-ore deposits in settings with limited flowing or standing water, generates an acid-leached residue that contains diverse hydrated Fe-oxides and sulfates bearing textural and mineralogical similarities with martian regolith [5], [6] (Fig. 1). A substantial portion of the present-day water inventory on Mars is sequestered in subsurface permafrost, however distinctive geomorphological features suggest intermittent melting of permafrost [7]. Conspicuous terrestrial gossans develop in water-limited settings where weathering products build-up in a vertical profile overlying a descending front of oxidation mimicking water-limited conditions on a cold and dry Mars.

Sulfide-rich rocks at Citronen Fjord, Northern Greenland, provide a unique environment to study sulfide oxidation and microbial involvement in the High Arctic. Exploration of the Fjord has demonstrated the existence of a zinc and lead-bearing semimassive to massive pyrite deposit [9]. Fresh sulfide-rich rock contains over 30% S total sulfur, primarily as pyrite (FeS_2) and sphalerite (ZnS). Secondary sulfate minerals, such jarosite, have been identified with depth [8]. Porewater analyses yielded pH values between 1 and 2, with surface runoff from reactive areas having a pH below 3 [9]. Both autotrophic and heterotrophic microbial activity has been observed in gossan matieral from Citronen Fjord [8]. Further exploration of partially oxidized Fe-S minerals in this Arctic environment may provide evidence of if these minerals record a necessary evidence of biological involvement.

Mission Description: The primary strategy of Mars 2018 is to evaluate the likelihood of habitability of high-potential Martian environments. The proposed 2018 Landed Mission concept includes near sub-surface access and acquisition of sample cores, with sample return being essential in the search for past microbial life. Further understanding the formation of partially oxidized Fe-S minerals on Earth which are similar to those identified on Mars is key in deciding a site that has a potential for past habitability and the preservation of ancient biosignatures.

Geologic Framework: The Citronen Fjord zinc-lead deposit is located in the eastern end of the Lower Paleozoic Franklinian Basin that extends through the Arctic Islands of Canada and across northern Greenland [10]. The stratiform mineralization is hosted in dark argillaceous rocks of the Amundensen Land Group of latest Ordovician to Early Silurian age that comprises a starved basin sequence of cherts and shales with siltstones and mudstones. The Lower Paleozoic strata at Citronen Fjord are part of the southern margin of the North Greenland Fold Belt characterized by southerly facing folds and thrust faults [10]. The ore deposit comprises at least five major, massive sulfide mounds that form a 10 km long NW-SE trending lineament, with total tonnage of sulfides estimated to exceed 350 million tons. Due to the absence of vegetation, sulfide ore deposits of the gossan at Citronen Fjord can be recognized with satellite imagery, such as Google Earth.

Most Important Question Answered by Site: Does the occurrence of partially oxidized iron-sulfate minerals record evidence of biological involvement? The presence of microorganisms is know at Citron Fjord [8], however are they necessary in the development of partially oxidized iron-sulfate minerals such as szomolnokite? Is there a biological signature left in the iron-sulfate minerals that may be used to identify potential life on Mars? Through further analysis of the iron-sulfate minerals we hope to constrain their use as indicators of previous or current habitable environments on Mars.

Logistic and Environmental Constraints: Environmental conditions (cold temperatures, ice coverage) and limited accessibility makes fieldwork in Northern Greenland difficult. However, Ironbark Zinc Limited (“Ironbark”) is currently proposing a process plant to mine the zinc ore at Citronen Fjord. As of January 2011, Ironbark has concluded the resource estimate, process design, and key project engineering aspects. Their results confirm the relevance of the Citronen project as a large scale and long life mining operation. Therefore, with the aid of a mining company, access to the gossans in Citronen Fjord will improve, and mining will allow for the collection of fresh samples and cores with ease.

Site Name	Citronen Fjord, North Greenland
Center Coordinates Latitude, longitude	83°05'N, 28°15'W
Elevation	700-1000 m
Areal Extent	500 m width
Prime Science Question	Does the occurrence of partially oxidized iron-sulfate minerals record evidence of biological involvement?
Distance of Science Targets from nearest road or airstrip	250 km NW of Danish military support base Station Nord; 100 km SE of Kap Morris Jesup, the northern cape of Greenland.
Environmental Characteristics	Max temp: 10°C; Min Temp: -30°C; Precipitation: 100-200 mm yr[1] (mostly as snow); Vegetation coverage: <5% plant cover (primarily lichen)
Previous studies at analogue site	Elbring and Langdahl, 1997; Langdahl and Ingvorsen, 1998; van der Stiljl and Mosher, 1998.
Primary Landing Site Target	Sulfate mounds in Juventae Chasma (4°S and 298°W)[1]

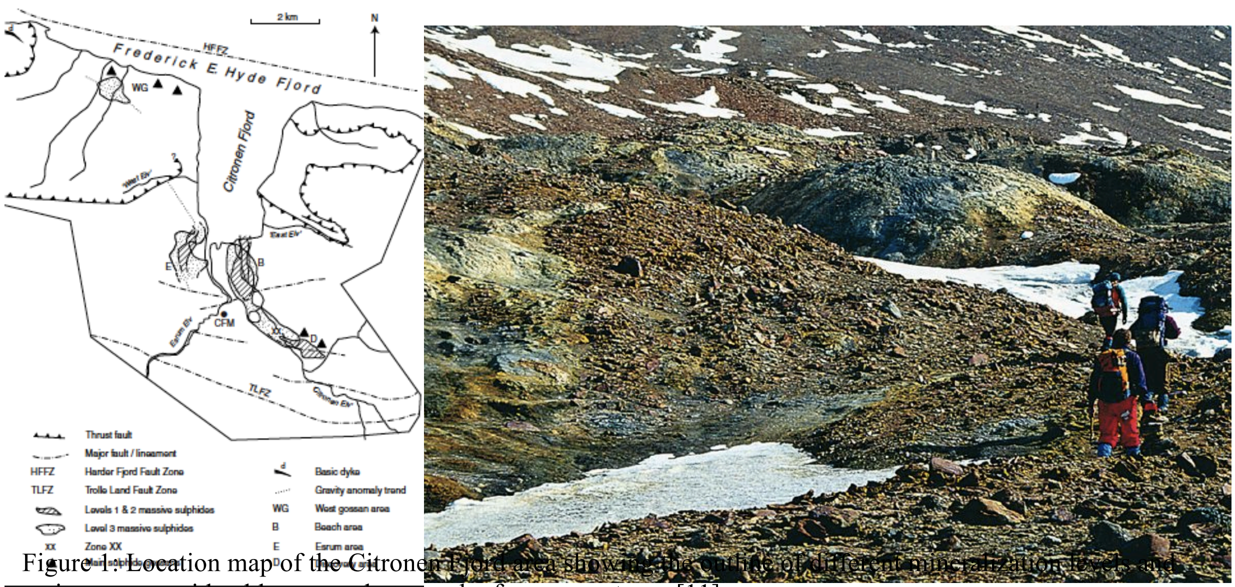

Figure 1: Location map of the Citronen Fjord area showing the outline of different mineralization levels and main gossans with a blown up photograph of gossan outcrop [11].

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THE EAST GERMAN CREEK, MANITOBA HYPERSALINE SPRINGS: ANALOGUE FOR "LAST REFUGE" OF LIFE ON MARS. E. Cloutis[1], P. Badiou[2], D. Bailey[1], G. Berard[1], R. Bezys[3], M. Craig[4], G. Goldsborough[5], S. Grasby[6], W. Last[7], F. Last[7], K. Londry[8], P. Mann[1], and J. Stromberg[1]. [1]Dept. of Geography, Univ. of Winnipeg, 515 Portage Ave., Winnipeg, MB, Canada R3B 2E9; e.cloutis@uwinnipeg.ca; [2]Ducks Unlimited Canada, p_badiou@ducks.ca; [3]Wildwood Geological Services, 627 Manchester Blvd N., Winnipeg, MB, Canada R3T 1N9 rbezys@shaw.ca; [4]Dept. of Geology, Univ. of Western Ontario, 1151 Richmond St., London, ON, Canada N6A 3K7, [5]Dept. of Biological Sciences, Univ. of Manitoba, Winnipeg, MB, Canada R3T 2N2, ggoldsb@cc.umanitoba.ca; [6]Geological Survey of Canada, 3303-3rd St. NW, Calgary, AB, Canada T2L 2A7, sgrasby@nrcan.gc.ca; [7]Dept. of Geological Sciences, Univ. of Manitoba, Winnipeg, MB, Canada R3T 2N2, wm_last@umanitoba.ca; [8]Dept. of Biological Sciences, Univ. of Alberta, Edmonton, AB, Canada T6G 2E9, londry@ualberta.ca.

Introduction: The East German Creek (EGC) site in west-central Manitoba is part of a series of springs that are present in Devonian age carbonates on the eastern side of the Williston basin. These hypersaline springs originate from a reflux of glacial meltwater that intrudes into underlying bedrock and buried salt beds [1, 2, 3]. These perennial springs host a unique marine ecosystem [4].

The site consists of both active and fossil springs and spring activity can vary on yearly to decadal time scales. The active springs flow year-round with only small temperature variations (<~5°C) and are characterized by hypersaline composition, a variety of flow rates, and variable coverage by microbial mats. The surficial geology of the site is dominated by extensive dissolution/ reprecipitation of the carbonates, and ubiquitous gypsum, halite, and iron oxides [2, 5]. The EGC springs outcrop in a Devonian limestone reef. West of the site, putative fossil springs are exposed in the walls of a limestone quarry (Mafeking quarry), providing a view of the third dimension of these features [6].

The presence of carbonate bedrock on Mars [7] makes this site of interest for future Mars landing sites in such terrains. In addition, similar putative spring deposits have been identified in Arabia Terra on Mars that share many similarities to EGC in terms of scale, morphology, and tonal variations in surface expression [8].

Mission Description: The current four MSL landing sites are not targeting carbonate-bearing bedrock, thus the EGC site is more applicable to future lander/rover missions. Extensive spectroscopic studies of materials from EGC show that the deposited gypsum, halite, and iron oxides can effectively mask the spectral signatures of the underlying carbonates and/or microbial mats in the 0.35-2.5 µm region [9].

The EGC site provides a good analogue of Mars carbonate bedrock exposures which may have been affected by surficial evaporites, as well as for understanding how fossil spring sites are expressed. The precipitated minerals show variations in type and abundance with distance from the springs, potentially providing a method for recognizing fossil springs and constraining water chemistry. Field investigations conducted to date suggest that geochemical signatures may allow sites populated by microbial communities to be recognized [1].

The EGC site has also been proposed as an analogue for similar terrains on Mars [1]. In addition to the putative fossil springs in Arabia Terra [8], the EGC site is relevant to understanding features related to possible cold-trapped martian water during a transition from open water bodies to ice caps [10].

The EGC site can be used to test what spectroscopic and geochemical techniques can be applied to recognizing such sites, reconstructing water chemistry, and recognizing the presence of past microbial activity.

Science Merit Related to Mission Objectives: The current four MSL landing sites are not targeting carbonate-bearing bedrock, thus the EGC site is more applicable to future lander/rover missions. As mentioned, it is relevant to understanding putative spring deposits on Mars [8] and terrains affected by cold-trapped martian water [10]. Given the presence of microbial activity at the site and the different ways in which such springs may evolve, it is relevant to the exploration goals of determining if life ever arose on Mars (MEPAG Goal I; Objectives A and B), the history of climate on Mars (Goal II; Objectives B and C), and evolution of the surface (Goal III, Objective A) [http://marsoweb.nas.nasa.gov/landingsites/].

The EGC site geology is dominated by fractured carbonate (calcite + dolomite) bedrock (reef structure) whose upper surface has been heavily modified by carbonate dissolution/reprecipitation, and evaporite deposits. The intensity of these effects declines gradually with depth, and evaporite mineralogy shows lateral variations. Investigations to depth (possible at the Mafeking quarry) indicate that the springs are fed by extensive groundwater networks that culminate in solution chimneys that fill with clay minerals and silica [5]. The EGC site contains both active and fossil springs. Imagery of the site is limited (Landsat TM and aerial photography), and has been augmented by extensive laboratory spectra of surficial materials [e.g., 9].

Most Important Question Answered by Site: The EGC site can help us address what sorts of investigations would allow us to identify carbonate bedrock and geochemical signatures associated with spring deposits on Mars.

Logistic and Environmental Constraints: The EGC site is located ~5 hours by road from Winnipeg, MB, and ~45 minutes by all-weather roads (paved and gravel) from Swan River, MB (the nearest substantial community; population: ~5000). The site is located ~100 m from the road and is easily accessible on foot and by quads. It is on Crown land and no permits are required for site access. Due to the groundwater salinity (~30-60 g/L TDS, 95% Na-Cl), the site is essentially free of vegetation (Fig. 1).

Standard Information Required for Analogue Sites: The main spring and downstream outflow channel is shown in Fig. 1.

Table 1: Table of characteristics of East German Creek analogue site.

Site Name	East German Creek
Center Coordinates	52°45’ 07”N 100°52’ 58” W
Elevation	262 m
Areal Extent	400 m by 400 m
Prime Science Questions	How do evaporites affect carbonate detectability? How do evaporites vary with distance from springs? What are the geochemical signatures of microbialites?
Distance from nearest road	100 m
Environmental characteristics	Max temp: 18℃. Min temp: -18℃. Precipitation: 53 cm. Vegetation coverage: None
Previous studies at site	References 1-6, 9 (see below)
Primary Landing Site Target	Arabia Terra putative springs

Figure 1: View of main spring at EGC site looking downstream.

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THE GYPSUMVILLE – LAKE ST. MARTIN IMPACT STRUCTURE: SHOCKED CARBONATES, INTRACRATER EVAPORITES, AND CRYPTOENDOLITHS. E. A. Cloutis[1], G. Berard[1], P. Mann[1], and J. Stromberg[1]. [1]Department of Geography, University of Winnipeg, 515 Portage Ave., Winnipeg, MB, Canada R3B 2E9, e.cloutis@uwinnipeg.ca.

Introduction: The Lake St. Martin (LSM) impact structure is an ~40 km impact structure approximately 200 Ma in age located in central Manitoba, Canada [1-4]. The impact occurred in ~200-400 m of Ordovician and Devonian sandstones, shales, and carbonates overlying Archaean-aged granite [1]. Outcrops are sparse in the area, but include uplifted, unshocked granites, shocked granites and pseudotachylites of the central uplift, and intracrater red beds and gypsum/anhydrite deposits exposed by open pit mining operations.

The red beds include a wide variety of poorly sorted clasts including impact melts and shocked granites, and shock-melted carbonates. An open pit gypsum mine in the area (Gypsumville) has exposed a continuous ~5 km long section of gypsum/anhydrite deposits, of up to 15 m vertical exposure (Fig. 1). Exploratory drilling in the area indicates that these beds range in thickness up to at least 30 m [3, 5].

The Ca-sulfates in the area consist largely of gypsum and anhydrite, with minor glauberite [3, 5], and occasional interbedded clays. Grain sizes and bed morphologies are highly variable, ranging from multi-cm selenite crystals to cryptocrystalline, saccharoid-textured dense layers. The gypsum beds grade laterally and abruptly into poorly sorted red beds that contain a variety of clasts, including gypsum, impact melt, shocked granite, and impact-melted carbonates (Fig. 2).

This site provides an accessible example of intracrater evaporites. Exposed gypsum faces exhibit a variety of weathering textures (Fig. 3), drag folds due to the movement of glacial ice [6], and cryptoendoliths located at depth (>1-2 cm) in gypsum boulders (Fig. 4) [7]. This site has some similarities to Columbus crater on Mars, which exhibits interbedded gypsum-phyllosilicates with complex folding [8].

Mission Description: Gypsum-bearing terrains are not included in the four candidate MSL landing sites. However, Eberswalde, Gale, and Holden craters will all sample presumed intracrater sediments. Gypsum-bearing terrains may be targets for future (Mars 2018) campaigns. The LSM site can be used to:

1. determine how well mineralogically-unique clasts in red bed (poorly sorted clastic sediments) deposits can be distinguished;
2. determine whether shocked and unshocked carbonates are spectrally distinguishable;
3. determine how and whether cryptoendoliths can be detected in sulfate-rich environments.

Science Merit Related to Mission Objectives: The LSM site provides access to intracrater sediments and evaporites, impact melts, different shocked and unshocked lithologies (carbonates, granites), and gypsum-hosted cryptoendoliths. Exposures of these materials are all located within 20 km of each other at LSM. The age of the impact is ~200 Ma; the age of the intracrater deposits is less well known, but likely immediately post-dates the impact [1-5]. Results from previous and ongoing work are helping to better define its various Mars-relevant characteristics. Available imagery for the site is limited to Landsat and aerial photographs.

Given the presence of microbial activity at the site and the diversity of rock types and terrains, it is relevant to the exploration goals of determining if life ever arose on Mars (MEPAG Goal I; Objectives A and B), the history of climate on Mars (Goal II; Objectives B and C), and evolution of the surface (Goal III, Objective A) [http://marsoweb.nas.nasa.gov/landingsites/].

Most Important Question Answered by Site: This analogue site can help us address the conditions necessary for cryptoendoliths survival in Ca-sulfate deposits and how their detection can best be undertaken.

Logistic and Environmental Constraints: The LSM site is located ~2 hours by road from Winnipeg, MB by paved road. Access to various sites within the area is largely by an all-weather gravel road. The majority of the sites are located on Crown land and no permits are required for site access. Mined areas and bedrock exposures are free of vegetation.

Standard Information Required for Analogue Sites: A regional map, and images from the gypsum and red bed quarries, and cryptoendolith-bearing gypsum boulders are shown below.

Table 1: Table of characteristics of Lake St. Martin analogue site.

Site Name	Lake St. Martin Impact Structure
Center Coordinates	51°46' 13"N 98°38' 06" W
Elevation	258 m
Areal Extent	~40 km by 40 km
Prime Science Questions	Detection of cryptoendoliths Characteristics of intracrater evaporite deposits, shocked/unshocked carbonates
Distance from nearest road	0 – 2 km
Environmental characteristics	Max temp: 18℃. Min temp: -18℃. Precipitation: 53 cm. Vegetation coverage: None in areas of interest
Previous studies at site	References 1-7 (see below)
Primary Landing Site Target	Columbus crater

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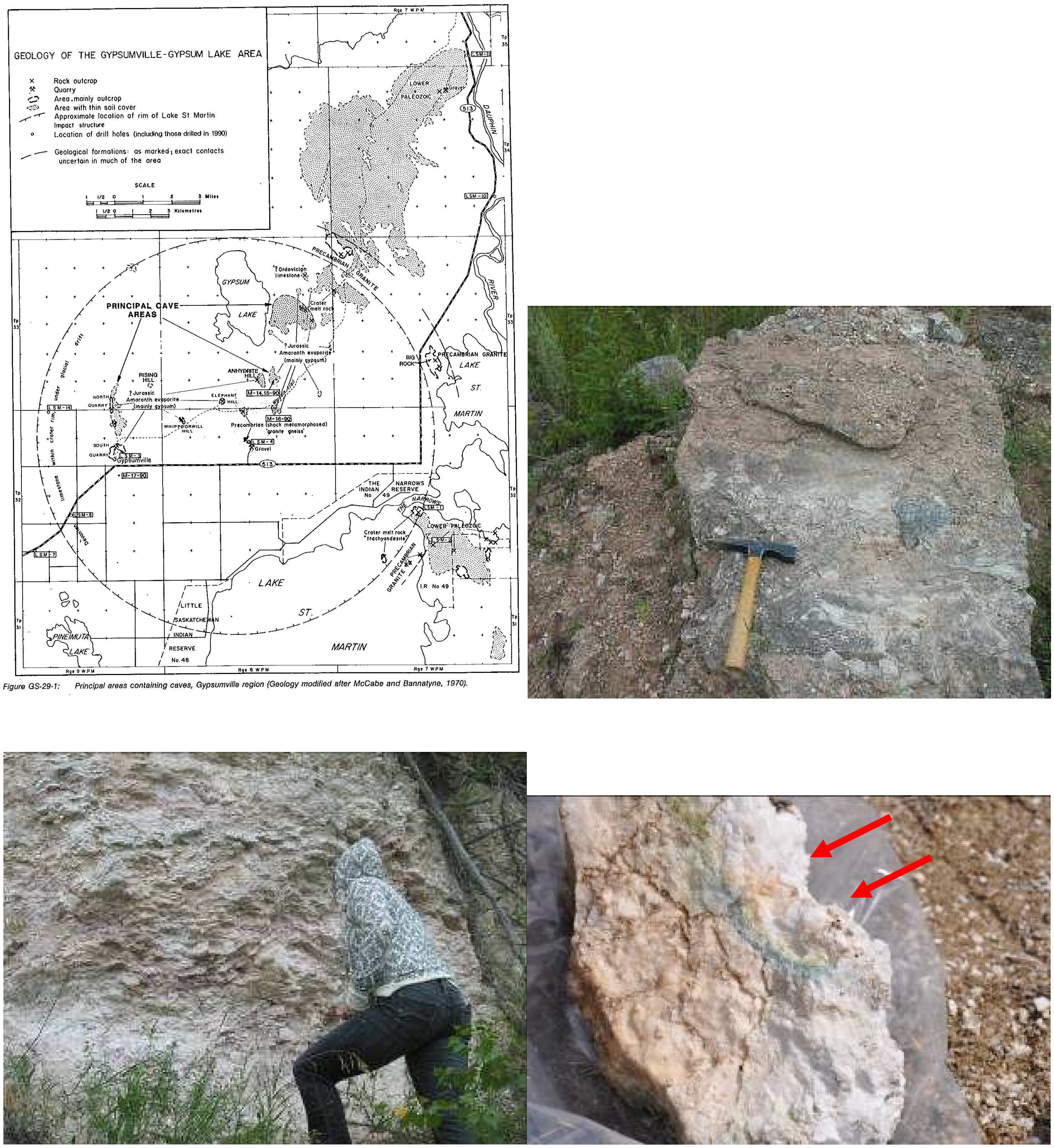

Figure 1. *Upper left:* geological map of Lake St. Martin impact structure (from ref. 5). *Upper right:* slab of red bed deposit. *Lower left:* wall of gypsum quarry with minor iron oxide staining. *Lower right:* broken surface of gypsum boulder showing cryptodendolith layers (blue-green). Rock is ~20 cm across and original exposed surface is to the upper right (arrows).

JEFFREY MINE, ASBESTOS, QUEBEC, CANADA: ANALOGUE SITE FOR A MARS METHANE MISSION. E. A. Cloutis[1], H. Vrionis[2], A. Qadi[3], L. Whyte[2], C. Samson[4], A. Tremblay[5], B. Wing[6], K. Strong[7], A. Ellery[3], R. Kruzelecky[8], J.F. Bell III[9], A. Boivin[4], J. Stromberg[1], P. Mann[1], and G. Berard[1], [1]Department of Geography, University of Winnipeg, 515 Portage Ave., Winnipeg, MB, Canada R3B 2E9, e.cloutis@uwinnipeg.ca, [2]Dept. of Natural Resource Sciences, McGill University, Ste. Anne de Bellevue, QC, Canada, Helen.vrionis@mcgill.ca; [3]Dept. of Mechanical and Aerospace Engineering, Carleton University, Ottawa, ON, Canada, alaqadi@mae.carleton.ca; [4]Dept. of Earth Sciences, Carleton University, Ottawa, ON, Canada, csamson@earthsci.carleton.ca; [5]Sciences de la Terre et de l'Atmosphére, Université du Quebec á Montréal, Montreal, QC, Canada, tremblay.a@uqam.ca; [6]Dept. of Earth and Planetary Sciences, McGill University, Montreal, QC, Canada, boswell.wing@mcgill.ca; [7]Dept. of Physics, University of Toronto, Toronto, ON, Canada, strong@atmos.physics.utoronto.ca; [8]MPBC Inc., Pointe Claire, QC, Canada, roman.kruzelecky@mpbc.ca; [9]School of Earth and Space Exploration, Arizona State University, Tempe, AZ, USA, jim.bell@asu.edu.

Introduction: As part of a CSA-funded program to investigate planetary analogues sites and their use for testing of technologies destined for future planetary missions, we have been investigating the Jeffrey Mine in Quebec. The Jeffrey Mine is an active open pit serpentinite deposit that we are investigating as a suitable analogue for future Mars landers/rovers that may target similar terrains on Mars. Field campaigns which include rover trials and testing of an array of investigative technologies (tunable spectrometers, imaging spectrometers, Raman) are planned for the summer of 2011 and 2012.

The Jeffrey Mine hosts an extensive body of serpentinite which contains a wide variety of minerals, many of which are also found on Mars. Of most significance, it hosts abundant serpentinite, magnesium carbonates, and iron oxides/hydroxides, all of which have been detected on Mars [1, 2]. One of the areas on Mars that hosts these deposits is the Nili Fossae region: one of four candidate MSL sites.

Mission Description: The Jeffrey Mine site, because of its mineralogical similarities to serpentinite- and Mg-carbonate-bearing terrains in Nili Fossae (and other regions on Mars) can be used to assess the performance of various MSL instruments in mapping geological diversity at such sites, as well as for methane detection and characterization. Future applications could include assessing the performance of geophysical tools in mapping subsurface structures at such sites as well as possible relationships between surface mineralogy, the presence of subsurface fractures (as pathways for subsurface methane release), and any mineral alteration that may be induced by methane release.

Planned activities at the analogue site include mapping areal patterns of any methane release and determining relationships to fractures, C isotope analysis of any evolved methane, and microbiological assessment of surface and subsurface environments.

Scientific hypotheses that can be tested at the site include determining whether methane is actively produced in non-hydrothermal serpentinites, the types of microbial communities that exist at such sites, and the nature of any evolved methane.

Science Merit Related to Mission Objectives: The investigations planned at the analogue site include testing the performance of stable isotope analysers similar to that being used by MSL, as well as assessing the XRD/XRF and spectroscopic signatures of minerals at the site (Fig. 1). The Jeffrey Mine site includes both freshly exposed as well as previously exposed serpentinites, as well as surrounding country rocks (non-serpentinitic) that have been excavated to enable open pit mining of the ore body. It also contains an extensive network of NE-SW trending fractures likely associated with emplacement of the serpentinite body (Fig. 2). The site includes a wide range of terrain types suitable for testing rover performance, ranging from intact bedrock to surface fines, and a wide range of slopes. Available imagery for the site includes archival SPOT and Landsat imagery as well as a series of historic and recent aerial photographs.

Most Important Question Answered by Site: This analogue site can help us address the quality and quantity of information that MSL (and future missions) could derive concerning the geology, (structure), microbiology, and presence and nature of methane that may be present at non-hydrothermal serpentinite- and Mg carbonate-bearing sites.

Logistic and Environmental Constraints: The Jeffrey Mine is located immediately adjacent to the town of Asbestos, Quebec, Canada (population ~7000), and approximately 2 hours by road from Montreal. The site itself has a series of access roads that cross the mine site (~4 x 3 km in areal extent). Site managers have been extremely generous in providing access to the site for initial reconnaissance and for future activities at the site. Weather in the area averages -15C in January to +18C in July, with average precipitation of 90 cm/year. The mine site is free of vegetation.

Standard Information Required for Analogue Sites: See below.

Table 1: Jeffrey Mine site, Asbestos, Quebec, Canada.

Site Name	Jeffrey Mine
Center Coordinates (lat., long.)	45° 46' 20" N 71° 57' 00" W
Elevation	~220 m
Areal Extent	~4 km by ~3 km
Prime Science Questions	What is the mineralogical diversity of a serpentinite-bearing terrain? Do non-hydrothermal serpentinite-bearing terrains produce methane?Of what composition? What microbial communities are hosted in such terrains? What is the relationship between surface geology, structure (e.g., fractures) and methane production?
Distance of Science Targets from nearest road or airstrip	~1 km for all targets
Environmental characteristics	Max temp: ~18 C; Min temp: ~-15 C Precipitation: ~90 cm/year Vegetation coverage: None

Previous studies at analogue site	Refs 3-5
Primary Landing Site Target	Nili Fossae serpentinite-bearing terrains

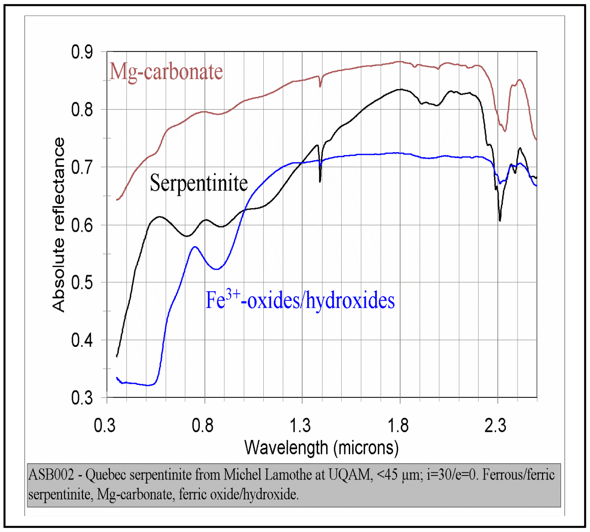

Figure 1. Reflectance spectra of phases present in Asbestos-region serpentinites (measured at University of Winnipeg laboratory).

Figure 2: Satellite view of Jeffrey Mine site. Asbestos townsite can be seen E and SE of mine. Regional tectonic fabric (NE-SW) can be seen in N part of mine. Tentative locations of rover traverse starting points for 2011 and 2012 field campaigns are shown.

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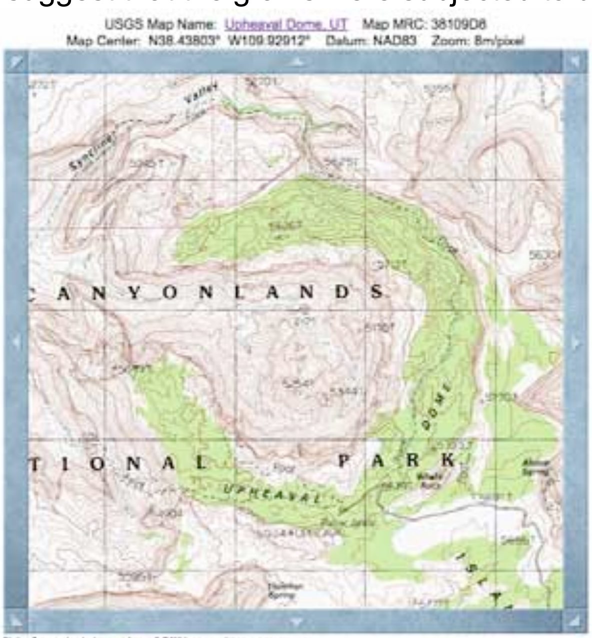
UPHEAVAL DOME, AN ANALOGUE SITE FOR GALE CRATER. P. G. Conrad[1], J. L. Eigenbrode[1] [1]NASA Goddard Space Flight Center, Code 699, Greenbelt, MD 20771 Pamela.G.Conrad@nasa.gov

Introduction: We propose Upheaval Dome in southeastern Utah as an impact analogue site on Earth to Mars Science Laboratory candidate landing site Gale Crater. The genesis of Upheaval Dome was a mystery for some time—originally thought to be a salt dome. The 5 km crater was discovered to possess shocked quartz and other shock metamorphic features just a few years ago, compelling evidence that the crater was formed by impact [1], although the structural geology caused Shoemaker and Herkenhoff to speculate an impact origin some 25 years earlier [2]. The lithology of the crater is sedimentary. The oldest rocks are exposed in the center of the dome, upper Permian sandstones, and progressively younger units are well exposed moving outward from the center. These are Triassic sandstones, siltstones and shales, which are intruded by clastic dikes. There are also other clay-rich strata down section, as is the case with Gale Crater. There is significant deformation in the center of the crater, with folding and steeply tilted beds, unlike the surrounding Canyonlands area, which is relatively undeformed. The rock units are well exposed at Upheaval Dome, and there are shatter cones, impactite fragments, shocked quartz grains and melt rocks present [3]. The mineral shock features suggest that the grains were subjected to dynamic pressures > 10 GPa.



The site, because of its location in a National Park, requires a permit, which typically takes about a month to obtain. The overall crater morphology has good fidelity to Gale Crater and the thick sedimentary strata are analogous to the sedimentary structure. The mineralogy is not an exact match, however there are clays (kaolinite), micas (muscovite), hematite, quartz and calcite observations from AVARIS flyovers [4], which provide an opportunity to correlate morphology and remotely sensed mineral data with on-the-ground measurements.

Mission Description: For Mars Science Laboratory, one of the advantages of the Gale Crater site is its thick stratigraphic section of diverse minerals that may appear cyclically [5]. The landing ellipse for Gale is such that it is a “go to” site, so an analogue investigation of the extent of the footprint of the eroded central mound at its base would be informative with respect to what can be learned immediately after traverse at the most approachable targets.

Science Merit Related to Mission Objectives: Upheaval Dome has been extensively studied because it is one of the best-exposed large impact craters in the world [3]. It provides an opportunity to discover how well the chemical and physical evidence of a habitable environment survives a large impact event. As such, it could help us model the stability fields of various habitability signatures with respect to high-pressure shock

(> 10 GPa). The deeply eroded crater also provides access to evaporites, though not the putative sulfate diversity thought to be representative of Gale Crater strata.

As already stated, there is remote sensing data, structural data, stratigraphic and mineralogical data from Upheaval Dome (see references) and it is an easily accessible site that does not require special support.

Most Important Question Answered by Site: What does the mineralogical, textural and geochemical character of the central mound feature tell us about the processes and the gradient of these attributes from edge to center? How well are the indicators of habitability preserved over 300 million years? Chemical signatures of habitability may be more subject to attack on Earth from aqueous processes, though these may be less harsh than the ionizing radiation and putative chemical oxidant of the martian surface.

Logistic and Environmental Constraints: This is an accessible site although it is in a National Park and permits are required. There is limited camping available within the park, although camping and motels are available in nearby Moab, Utah, which is the nearest city served by air (Great Lakes Aviation). One can connect from Salt Lake City, Denver or Grand Junction, CO. Alternatively; one can drive (4 hrs from Salt Lake City, 1.5 hrs from Grand Junction). The drive to the site from Moab is about 40 minutes (according to the park web site). It is cold in the winter and hot in the summer (see Table 1), but because of the low annual precipitation, temperature is the defining comfort and safety factor. Very little vegetation obscures the excellent exposure of this analogue site.

Standard Information Required for Analogue Sites:

Table 1: Summary of Upheaval Dome Facts

Site Name	Upheaval Dome, Utah
Center Coordinates Latitude, longitude	Latitude: 38.4247054 Longitude: -109.9309568
Elevation	1.8 km
Areal Extent	Crater is about 5 km diameter and central uplift feature is about 2.5 km diameter
Prime Science Questions	How is the geochemical, mineralogical and textural character distributed through the crater from the edge through the central dome? How far do you have to go in a “go to” site to get a look at (a) primary rock (b) impact generated products and (c) sedimentary in-filling?
Distance of Science Targets from nearest road or airstrip	Autos and 4WD are available in MOAB You can drive to a trailhead at the edge of the crater and hike in.
Environmental characteristics	Max temp: 43 °C (mid summer noon) Min temp: -18 °C (midwinter night) Precipitation: quite arid (US southwest) Vegetation coverage: bedrock is more than 75% exposed
Previous studies at analogue site	see references below
Primary Landing Site Target	Gale Crater
Other	National Park Service permit required

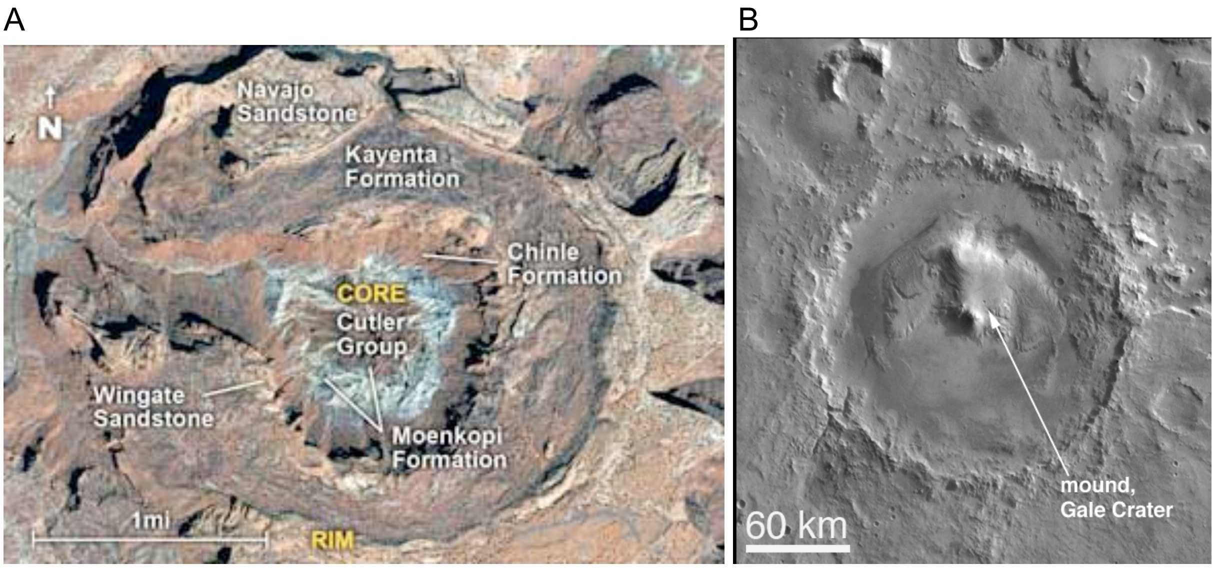


Figure 1: Panel A is Upheaval Dome in Canyonlands National Park in Utah, USA. Panel B is Gale Crater, one of the four candidate landing sites for Mars Science Laboratory.

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Salt Flats in Terra Syrenum-A site to search for extant and extinct life on Mars.

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Mission Description: We propose a mission to search for life in salt flats on Mars. The main hypothesis are:
1.-The landing site is a sedimentary basin that was habitable during the Noachian.
2.-Salt flats in the basin are habitable under current conditions.
3.-Organic compounds (signs of life) and complex biomolecules (proof of life) are preserved inside the salt.

Target landing site and proposed analogue site: The target landing site is a sedimentary basin containing salt flats in Terra Sirenum [1,2] (Figure 1). Chloride-bearing deposits in the basin are interpreted as salt-flats based on (1) shape and morphology of the deposits, (2) presence of normal and inverted fluvial channels with fans at their termini, (3) occurrence of the deposits in the lowest topographic reaches, and (4) presence of hydrated minerals (Fe/Mg-smectites) in the ejecta and rims of craters that impacted the salt flats, suggesting that phyllosilicates are abundant beneath the deposits, a sequence consistent with terrestrial cycles of siliciclastic deposition followed by evaporation [2]. The estimated area of individual salt flats range between 10 and 50 km^{2}. All salt flats and phyllosilicate-bearing deposits occur within a broad basin defined by the 1280 m topographic contour (Figure 1). Taking the topographically lowest hydrated deposit inside the basin, we estimate a depth and an areal extent of at least 200 m and 30,000 km^2, respectively. Aqueous activity was likely more extensive, but evidence has been obscured by geologic processes, such as impact and large north-northwest-trending faults that deformed the Terra Sirenum province [3]. Crater count statistics indicate an average surface age of the basin to be 3.95±0.1 Ga.

The proposed analogue sites are salt flats (*salares*) in the Atacama Desert (Figure 2a). We specifically proposed Salar Grande as an ideal analog (Table 1). Salar Grande is similar to salt flats on Mars both with respect to origin, physiographical setting, composition (NaCl), and geomorphology. Salar Grande formed c.a. 5 Myr ago after the evaporation of surface waters [4]. The slat flat is tens of meters thick, and on the surface the salts have a knobby morphology, with salt knobs approx. 10-30 cm size (Figure 2b). This morphology is due to the evolution of salt polygons in extremely dry conditions, and are unique to the Atacama Desert. As a result, salt knobs are composed of almost pure halite (NaCl) and have a porous fabric. We expect the same evolution and morphology of salt flats on Mars. Salar Grande and other salt flats in Atacama are the only niche so far were life is possible under the extremely dry conditions. The salt knobs are colonized by a diversity of microorganisms [5,6] (Figure 2c), who take advantage of the deliquescence properties of the salt [7]. When RH reaches a critical value, the salt flats form small liquid brines in their interior which are stable for periods of several months. This explains the presence of organisms inside the salts and suggests that similar deposits on Mars could also be a place where liquid water forms episodically, even under current conditions [8].

Science Merit Related to Mission Objectives: Searching for life on Mars is the ultimate question of the Mars exploration program. As such, the proposed mission deserves the highest science merits. Salt flats on Mars are extremely relevant for astrobiology due to their similarity to terrestrial environments where life is abundant [9, 5]. Depending on their composition, these salt flats would interact with atmospheric water vapor in a manner similar to those in the Atacama Desert, and could spontaneously form saturated solutions even under the current climate [8]. As we retreat in time, the martian atmosphere was thicker and moister, and the habitability potential of salt flats would be higher. Evaporitic deposits are also excellent to preserve biomarkers [9], making these deposits an ideal target for a life detection mission.

Most Important Question Answered by Site: The proposed analogue site will help us establish the habitability of salt flats on Mars, the preservation of organic compounds and complex biomolecules in extremely dry environments, and the potential for the occurrence of small briny solutions on Mars under present conditions.

Logistic and Environmental Constraints: Salar Grande has minimum logistical constrains. Main transport roads guarantee accessibility close to the site and well paved dirt roads grant access directly to the salt flats. There are no requirements for permits, nor any seasonal transport restrictions. Maximum and minimum daily temperatures in the Atacama are c.a. 35ºC and -2ºC respectively. Temperatures are similar throughout the year. The Atacama has a mean annual precipitation of 1mm/yr [10] and soils are completely free of vegetation.

Table 1: Standard Information

Site Name	Salar Grande
Center Coordinates (Latitude, longitude)	Between 20-21°S
Elevation	1 km
Areal Extent	5 km by 15 km
Prime Science Questions	e.g., Dry limit of life. Preservation of organics in extremely dry environments.
Distance of Science Targets from nearest road or airstrip	Salt flats – tens of meters
Environmental characteristics	Max temp: 40ºC Min temp: -2ºC Precipitation: 1mm/yr Vegetation coverage: none
Previous studies at analogue site	[4,5,6,7]
Primary Landing Site Target	Chloride-bearing deposits on Mars
Other	

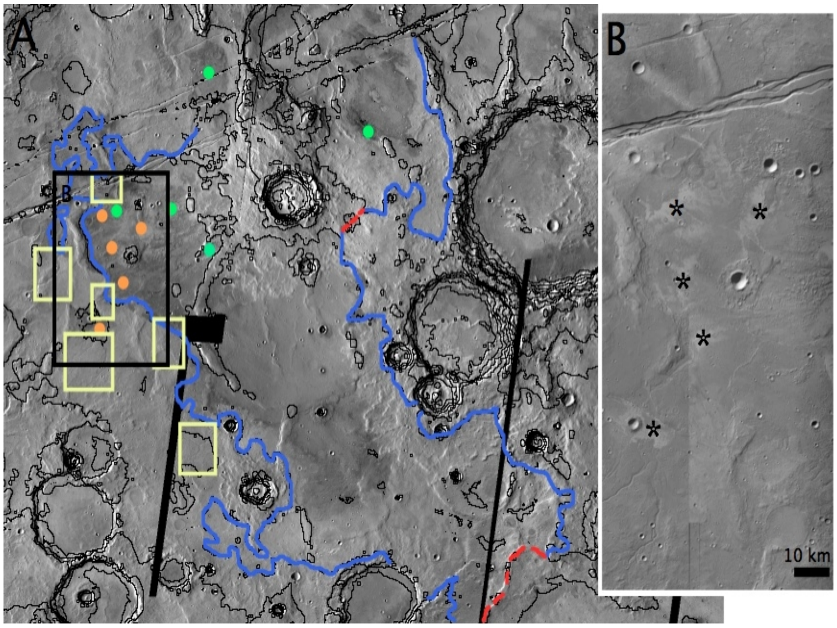

Figure 1: Landing site. **A**: Blue line = shoreline of the proposed basin. Orange dots = chloride-bearing deposits interpreted as salt-flats. Green dots = Mg/Fe-smectite-bearing deposits. Yellow squares = fluvial features. **B**: detailed view of the salt-flats (stars). Image centered at 23.8°S, 326.7°E. Elevation = 1.2 km. Prime science targets are salt and phyllosilicates within the basin.

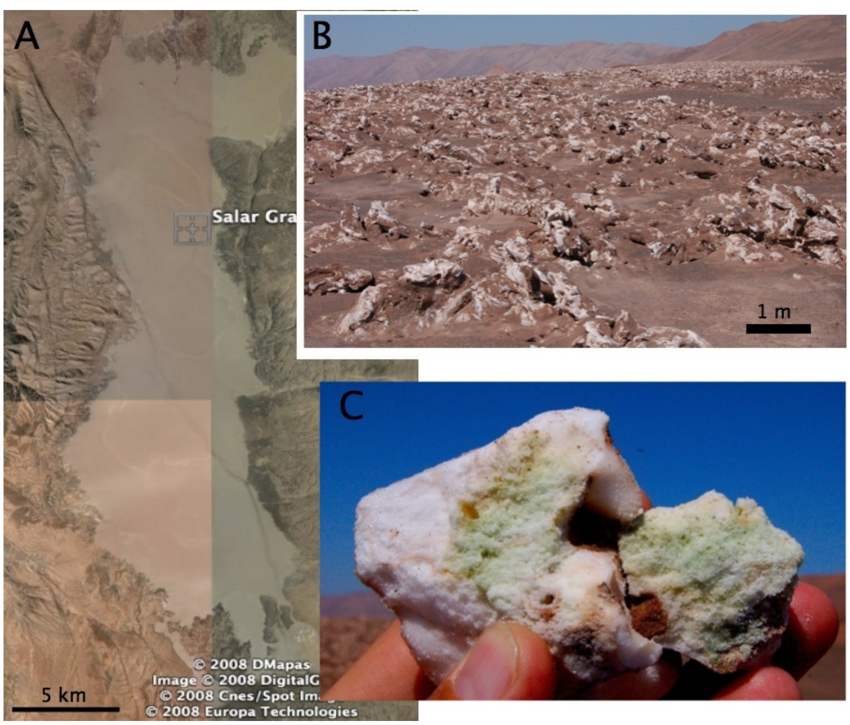

Figure 2: Analogue site. **A**: Salar Grande in the Atacama Desert. **B**: Surface of salt flats with knobby morphologies. **C**: Interior of salt knob with colonies of photosynthetic organisms (green)

References:

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TERRESTRIAL SERPENTINIZING SYSTEMS AS MINERALOGICAL, GEOCHEMICAL (AND BIOLOGICAL?) ANALOGUES FOR MARS. B.L. Ehlmann[1], D. Cardace[2], T. Hoehler[3], D. Blake[3], P. Kelemen[4]
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Introduction: Serpentinization, the aqueous alteration of ultramafic rocks, is of interest for Mars both because it leaves lasting (mineralogical) indicators of prior physicochemical environment and has the potential to support chemosynthetic life [1,2]. Mineral detections from orbit indicate that serpentinization has occurred on Mars in the past, and liquid-water bearing horizons within the Martian crust could support the process even into the present day. Serpentinization has been proposed to account for the present-day generation of methane [3] and magnetic signatures in ancient crust [4,5]. A research framework that interrelates mineralogy, geochemistry, and biological potential in serpentinizing systems would support a range of future Mars missions – including both orbital and landed missions – for which habitability is a point of focus. Many actively serpentinzing systems are accessible on Earth, but characterization thereof is only now beginning to include biology and aspects of aqueous geochemistry most relevant for assessing biological potential.

The Serpentinization Process: The reaction of ultramafic rocks (olivine and pyroxene) with water is often presented as an idealized reaction such as:

$$\underset{\text{Olivine}}{(Mg,Fe)_2SiO_4} + H_2O_{(l)} \rightarrow \underset{\text{Serpentine}}{(Mg,Fe)_3Si_2O_5(OH)_4} + \underset{\text{Brucite}}{(Mg,Fe)(OH)_2} + \underset{\text{Magnetite}}{Fe_3O_4} + H_{2(g)}$$

This reaction represents a diverse set of processes and the true stoichiometry is strongly dependent on parent rock composition, fluid composition, water-rock ratio, and physical conditions, especially temperature [6,7]. Mineralogy, geochemistry, habitability, and possibly preservation potential vary widely within the general class of "serpentinizing systems". Relative to understanding the aqueous history and habitability of Mars, the key aspects of this reaction are

(i) Hydrogen – which, on Earth, is utilized as a source of energy and reductant by a wide range of microorganisms – is produced when ferrous iron in the parent rock is oxidized to ferric iron in magnetite. The ferrous iron content of the host rock and the abundance of magnetite in the alteration products provide mineral indicators of H_2-generating potential or H_2 generation, respectively [e.g. 6].

(ii) Alkalinity – As indicated by the formation of brucite, the serpentinization process can yield highly alkaline conditions. High pH can pose a challenge for biology both by necessitating a large energy expenditure on regulation of clement (circumneutral) intracellular pH and by partitioning inorganic carbon into biologically inaccessible or less accessible phases.

(iii) Mineralogy – The secondary minerals formed and specific serpentine composition are sensitive to temperature and other physicochemical variables, thus providing a resilient mineralogical indicator of prior (aqueous) environmental conditions [e.g. 7].

Serpentine on Mars: Near-infrared data recently acquired from the orbiting imaging spectrometer MRO-CRISM indicate the presence of magnesian serpentine in a dozen rock outcrops at tens- to hundreds-of-meter-scale. The exposures can be grouped in three geologic settings: (1) crater ejecta, (2) "mélange" terrains in association with other minerals (kaolinite, Fe/Mg smectites, chlorite, olivine, low-calcium pyroxene) but lacking in coherent stratigraphy, and (3) in association with a fractured, olivine-rich bedrock unit that is variably weathered to magnesium carbonate [8]. These serpentine-bearing rocks date from Mars' Noachian period, providing evidence that serpentinization processes were at least locally active >3.7 Gyr ago.

Terrestrial Analogues: On Earth, serpentinization principally occurs under and along mid-ocean ridge crests and off-axis hydrothermal zones [9,10] that are unlikely to be apt process analogs for Mars. However, present-day serpentinization has also been reported at convergent plate boundaries where oceanic lithosphere has been tectonically emplaced on land (e.g., "ophiolite suites"), leading to serpentinization in groundwater systems (Table) [e.g. 11, 12]. Each presents an opportunity to investigate the geochemical processes surrounding the serpentinization process, its relevance as a habitable environment and its potential for organic preservation. Serpentinization reactions are kinetically hindered at low temperatures, with the result that both reactant and product minerals (as well as alteration "fabrics") persist as evidence of their paragenesis [2]. Examination of such a petrologic assemblage allows the development of models of geochemical cycling, thermal and H_2 evolution over time, habitability potential, and potential for organic preservation. A few ongoing projects by us explore different aspects of such systems:

Figure 1. (Clockwise) Locations of analogue sites; serpentinites in NZ and Oman altered by surface weathering; sampling waters from surface seeps in Turkey.

Analogue Site	*Location*	*Key Questions and Approach*
Coast Range Ophiolite, McLaughlin Reserve, California, USA	39 N, 122 W	What is the relationship between geochemistry, mineralization, and microbial communities at an active, subsurface serpentinization site? Sampling process in-situ from deep well groundwaters and rock cores.
Northern Anatolian Fault Zone & Izmir-Ankara Suture, Turkey	41 N, 31 E	How does the geochemistry of springs sourced from serpentinizing rocks influence microbial diversity and community structure? Sampling from surface spring waters and gas seeps. Microbial bioenergetics modeling and direct sampling of environmental genome.
Bay of Islands Ophiolite, Newfoundland, Canada	58 W, 50 N	
Dun Mountain Ophiolite Belt & Anita Shear Zone, New Zealand	41 S, 173 E	
Samail Ophiolite, Oman	23 N, 57 E	How does mineralogy indicate serpentinization process? To what extent does weathering alter the record of physiochemical parameters? Airborne and ground-based n spectrocopy. Rock sampling and lab analysis.

Coast Range Ophiolite, California: Low-temperature serpentinization reactions are ongoing in the Coast Range ophiolite [13]. Fluids taking part in serpentinization reactions at depth are accessible via groundwater wells at the McLaughlin Reserve as are core cuttings from subsurface serpentinite strata. These provide raw materials for investigation of how mineralogy, geochemistry and habitabiltiy are linked at an active serpentinizing site, examined *in situ*. The presence of deep biosphere communities in a serpentinizing system is supported by field and analytical results, and permit study of subsurface microbial community structure and diversity and relation to distinctive aqueous geochemistry reported at multiple well sites [14]).

Northern Anatolian Fault Zone, Turkey; Bay of Islands Ophiolite, Canada; Dun Mountain Ophiolite, New Zealand: Fluids and solids (biofilms and sediment) with variable fractions of ultramafic-sourced and serpentinizing reaction fluids and mineral fragments have been collected from surface seeps and springs. Sample locations vary in temperature 15-90ºC and pH 6.5-11.5. Study of the aqeuous geochemistry allows prediction of available sources of energy in these nutrient-limited ecosystems and consideration of mafic/ultramafic rocks as habitable formations [15]. Nucleic acid-based analysis of sediments and biofilms has revealed wide variation in diversity of 16S rRNA and nitrogen cycle related genes in each system. Integrating geobiological data from these sites is revealing how microbial systems respond to subtle shifts in geochemistry of the water-rock system [16].

Samail ophiolite, Oman: Peridotite rocks of the Samail ophiolite exhibit variable degrees of serpentinization, which mostly occurred at the sea floor prior to uplift. However, presently, a groundwater cycle involving surface aquifer recharge, transport then serpentinization at depth, and release in down-gradient springs results in precipitation of additional serpentine plus abundant carbonate minerals of diverse composition within the serpentinite. Mg carbonates form as veins in near-surface, open systems. High pH, Ca-rich waters, which are discharged following serpentinization at depth, precipitate calcite and dolomite [17]. The spectral signatures of these rocks are similar to those detected from Mars orbit [18] and may represent a similar formation process. An ongoing investigation (Ehlmann, Kelemen, Mustard, Pinet, Lanneau) uses remotely sensed compositional data as well as laboratory analysis of samples to investigate how mineralogy of serpentinites changes with arid-zone weathering and the extent to which original mineralogic signatures of physiochemical conditions are preserved.

Analogue Relevance to Future Missions: Future rover missions (e.g. ExoMars, MAX-C) will seek sites with clear geologic context, evidence for past or present habitability, and potential for the preservation of organic matter. Future orbital missions, e.g. the 2016 Trace Gas Orbiter, will seek to understand the provenance of trace species like methane, including possible localization in specific geologic terrains (e.g. from reaction of CO_2 with H_2 released by serpentinization). A candidate landing site, Northeastern Syrtis [19], has been identified that would allow the exploration of a Martian olivine-carbonate-serpentine unit in stratigraphic section above Middle Noachian clay bearing units and beneath the Early Hesperian Syrtis Major lavas. The regionally widespread olivine unit is variably altered to carbonate [18] and highly fractured at a few-tens-of-meter scale. At NE Syrtis, a geologic record of process exists where both the reactants and products of serpentinization are found, potentially permitting calculations of aqueous geochemistry and free energy of serpentinization reactions relevant to biological potential and comparison to well-studied terrestrial sites.

Key Measurements & Questions on Earth & Mars

Relating physiochemical parameters to biology: To best support future Mars missions, analogue studies of serpentinizing systems should (i) include parallel characterization of mineralogy, aqueous geochemistry, and biology; (ii) compare these features across as broad a range of physicochemical parameters as possible; and (iii) include a component that examines the process *in situ*, rather than at surface expressions that are in more oxidizing environments and spatially distinct from the region of active serpentinization (as has been exclusively the case to date). Rigorous relation of the physiochemical parameters at active sites to biological potential and the nature of microbial life in terrestrial serpentinizing systems is essential for habitability assessment because the precise conditions that led to the generation of serpentine on Mars remain to be discovered.

Relating past to present: A second aspect of analog studies is understanding the relationship of active serpentinization sites that are current habitats for life to relict sites. Key measurements to be made of terrestrial (or Martian) serpentinizing systems include: (i) host rock bulk geochemistry and, in particular, ferrous iron content, (ii) the abundance of magnetite and any associated magnetic signatures, (iii) rock modal mineralogy, including precise characterization of the serpentine phase, and (iv) evidence for organic molecules or other biomarkers. Items (i)-(iii) are essential for characterizing aspects of biological potential: hydrogen production, alkalinity, and other physiochemical parameters. A key component of this effort should also be to understand how later processes, e.g. surface weathering, change or obscure mineralogic indicators of the original system physiochemical parameters.

Understanding Biological Potential and Signatures. Recent work has established the presence of active biological communities and abundant, abiotic hydrocarbons where fluids react with serpentinizing peridotite, thus providing support to the notion that such systems could generate and/or support life on Mars [7, 10, 20-22]. Work on serpentinization will become more directly applicable to Mars when conducted on a broader (including more moderate) range of conditions, with an emphasis on *in situ* characterization. Whether and how much biomass can be supported in serpentinizing systems depends principally on the availability of H_2 or organic electron donors, electron acceptors (e.g., CO_2, SO_4^{2-}, etc.), carbon and nutrients, and physicochemical conditions – especially temperature and pH. A model developed to constrain the potential for serpentinizing systems to support methanogenic communities predicts that methanogen biomass may vary by 4-5 orders of magnitude across a range of environmentally realistic variations in pH, temperature, and concentrations of H_2 and CO_2 [23]. The model also predicts that some serpentinzing systems may yield conditions that are completely uninhabitable with respect to methanogenesis. A critical next step will be to evaluate such predictions by parallel characterization of mineralogy, geochemistry, and biology across a range of serpentinizing systems representing the broadest possible variation in physicochemical conditions. A future step will be the assessment of whether any unique biosignatures exist that might indicate the past presence of life.

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AQUEOUS ALTERATION OF BASALTIC LAVAS IN ICELAND: AN ANALOGUE FOR NOACHIAN MARS. B.L. Ehlmann[1], J.F. Mustard[2], D.L. Bish[3], [1]IAS U. Paris-Sud XI [2]Geological Sciences, Brown Univ. [3]Geological Sciences, Indiana Univ. (bethany.ehlmann@ias.u-psud.fr)

Introduction: Orbital investigations of the basaltic terrains comprising Mars' earliest Noachian crust have revealed diverse assemblages of hydrated silicate mineral phases formed during aqueous alteration [1]. Most commonly detected are smectite clays, chlorites, prehnite, silica, and zeolite; hence, the rock record fron early Mars preserves mostly evidence for neutral to alkaline pH environments. These include near-surface pedogenic and low-temperature/pressure hydrothermal systems [2-4]. In recent investigations of terrestrial Mars-analog sites, neutral to alkaline pH alteration of basalt has been neglected in favor of sulfur-rich, acidic systems. We began study of the near-neutral pH, near-surface alteration of basalt lava flows in Iceland as a geochemical and mineralogic analog for Noachian Mars [5]. This setting has provided a testbed for understanding synergies between different instrumental measurements used to infer past paleoenvironmental conditions and also provides an opportunity to study the habitability and organic preservation potential of crustal groundwater systems.

Appropriateness as an Analogue: Because the basaltic bedrock of Iceland is recently formed (<16Ma), with few localities of more highly evolved composition, and has poorly formed soils and sparse vegetation, ground and surface waters may be similar to those that might have existed on Noachian Mars. Iceland has a variety of geothermal spring systems of different temperatures and sulfur contents, each of which creates distinctive mineralogic assemblages. Here we have examined rocks collected from basalt flows that were in some places altered at the surface by pedogenesis and in other locations were hydrothermally altered by non-sulfurous groundwater circulation (low T, low S) as most analogous to Noachian Mars (Figure 1).

Site Name	Icelandic Basalts (Hvalfjordur, Berufjordur)
Location	61.3°N, 21.7°W and 64.8°N, 14.5°W
Areal Extent	Outcrops at tens to hundreds of meters-scale, with stratigraphy best-exposed in channels carved by fluvial erosion
Prime Science Questions	Do VNIR spectra accurately capture mineralogy, permitting paleoenvironmental determination? What are the synergies between XRD and IR techniques? Can these environments host and preserve evidence for life?
Analogous to	Most smectite-bearing terrains on Mars, especially as exposed by craters of the S. Highlands

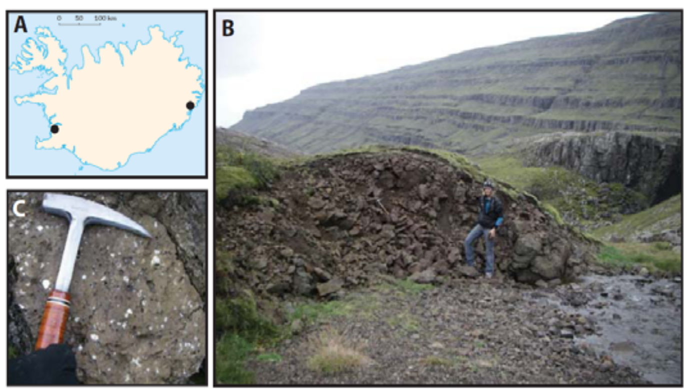

Figure 1. Sampling sites and study samples. (a) Rocks were sampled near Hvalfjordur (west) and Berufjordur (east). At both sites, massive basaltic flows exhibited evidence of alteration minerals filling veins and fractures. (b) Successive basalt flows eroded by glacial activity and a stream at Berufjordur, site of sample wtrfall016. (c) Outcropping of zeolitized basalt at Hvalfjordur.

Linking remote spectroscopic and in-situ mineral detections: Our sample characterization methods emulated orbital data from CRISM, OMEGA, and TES, which detect the infrared active components, linked to *in-situ* data such as will be measured by MSL's ChemMin instrument. Rock samples were surveyed in the field using a portable VNIR spectrometer. Altered and unaltered rocks that were typical for the locality were collected, as were altered rocks whose spectra were most similar to those measured by CRISM from Mars orbit (similar to the Al- and Fe/Mg clays at Mawrth Vallis as well as the smectite-zeolite-silica assemblages associated with Noachian cratered terrains). In RELAB, reflectance spectra from 0.4-25µm were acquired of dried particle-size separates (<150µm) derived from the bulk rock and from precipitated minerals extracted from vesicles and veins (Figure 2). X-ray diffraction (XRD) data were measured on the <25µm size fraction from 2º to 70º 2θ with 0.02º 2θ steps. Areas of the most intense peaks from component minerals were measured, and the relative percentage of each constituent was determined using the reference intensity ratio (RIR) method [6]. Rietveld refinement was also applied, using the Topas Rietveld program, to determine the relative abundance of the well-ordered (i.e., non-clay mineral) components. Final mineral abundances (Table) represent wt. % obtained from the Rietveld method scaled to include the RIR-determined smectite abundances. To verify the presence of smectite and check for interstratified or non-expanding clays (e.g., chlorite, kaolinite), untreated samples with a (001) diffraction peak near 15Å were prepared as oriented mounts, dried, saturated with ethylene glycol, and then measured from 2-20º 2θ. Bulk chemistry of samples was measured with flux fusion/OES.

Sample	description	VNIR mineralogy	XRD mineralogy
hvalfj011	gray, friable rock	HCP + Fe/Mg smectite + (chlorite?)	smectite 17% pyroxene 34% plagioclase 40% ilmenite 5% clinoptilolite 5%
hvalfj025	host rock from rock with vesicles with blue-green precipitate	HCP + hydrated phase (FeOH-bearing?)	smectite 11% pyroxene 38% plagioclase 49%
hvalfj054	host rock from rock with vesicles with whitish precipitates	HCP + Mg smectite	smectite 17% pyroxene 63% plagioclase 5% hematite 5% levyne 9%
icel009	massive brown rock with greasy feel	HCP + Fe/Mg smectite	smectite 23% pyroxene 26% plagioclase 49%
icel010	massive black rock with greasy feel	HCP + Fe/Mg smectite	smectite 20% pyroxene 28% plagioclase 49% ilmenite 3%
hvalfj017	reddish friable rock	montmorillonite + hematite	montmorillonite 79% hematite 10% plagioclase 10%
hvalfj023	blue-green precipitate in vesicle	celadonite	celadonite 38% silica 35% smectite 20% plagioclase 6%
hvalfj055	opaque white to cream precipitate in vesicle	thomsonite (+ other zeolite?)	scolecite/mesolite 36% thomsonite 30% stilbite/stellerite 26% smectite 8%
hvalfj057	transparent, white xlls precipitated in vesicle	analcime	analcime 55% smectite 33% stilbite/stellerite 11%
wtrfall016	white precipitate from vein	hydrated silica	quartz 91% cristobalite 3% plagioclase 2% clinoptilolite 4%

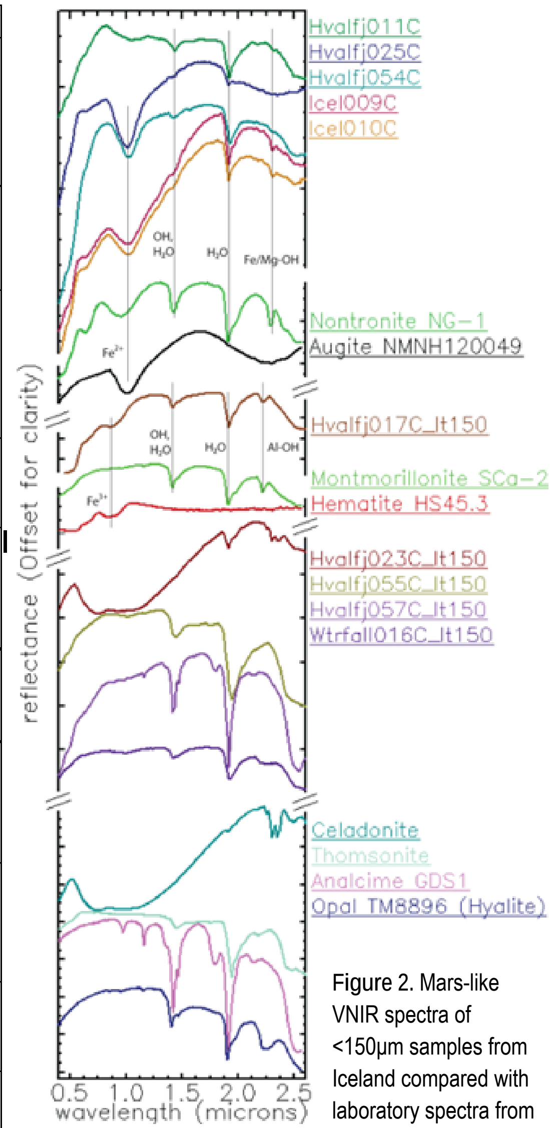

Figure 2. Mars-like VNIR spectra of <150μm samples from Iceland compared with laboratory spectra from USGS and CRISM spectral libraries

VNIR spectra of all samples show evidence for aqueous alteration, including the 1.9μm combination tone from the stretch and bend of the H_2O molecule (Fig. 2). OH and metal-OH overtones and combination tones are also visible near 1.4μm and over the 2.0-2.6μm region. Some minerals composing the sample, usually two or less, can be identified using the VNIR data (Table). Five samples have spectra consistent with high-calcium pyroxene and Fe/Mg smectite. One sample appears to be a mixture of hematite and montmorillonite, indicated by an Al-OH 2.2μm band. The four samples from rock veins and vesicles appear to be celadonite-, thomsonite-, analcime-, and hydrated silica-bearing. XRD analyses confirm all of these identifications. In the bulk rock samples smectite is the most abundant alteration mineral. As little as ~10% smectite is observable in VNIR spectra of altered mafic rocks measured here. Zeolites in <10% abundance also occur in the host rock, although their presence cannot be determined from VNIR data. In samples extracted from veins and vesicles, alteration minerals other than smectite are most abundant phase. In these precipitates, some alteration minerals, e.g., analcime and celadonite in hvalfj057 and hvalfj023, respectively, mask in VNIR data the signature of substantial quantities of smectite.

Nature of Alteration: Interestingly, bulk rock samples plot similarly in chemical diagrams in spite of different proportions of alteration minerals and, presumably, different amounts of removal and addition of ions by interaction with fluids. The most-altered bulk-rock sample in terms of mineralogy, hvalfj017, does not appreciably differ from less altered samples, suggesting the alteration may have been nearly isochemical (Figure 3). There is little progression along the typical terrestrial weathering trend towards the Al vertex. Most of the variation lies along the feldspar-olivine join with precipitates becoming either Fe-enriched or Fe-depleted. Variation along this line was also typical for low water:rock ratio acidic alteration on Mars (Hurowitz & McLennan, 2007). For these Icelandic environments of alteration, whole-rock elemental analyses only would lead to underestimation of the extent of alteration relative to the higher degree apparent from VNIR or XRD techniques, demonstrating the importance of knowledge of mineralogy in addition to chemistry in the exploration of Mars.

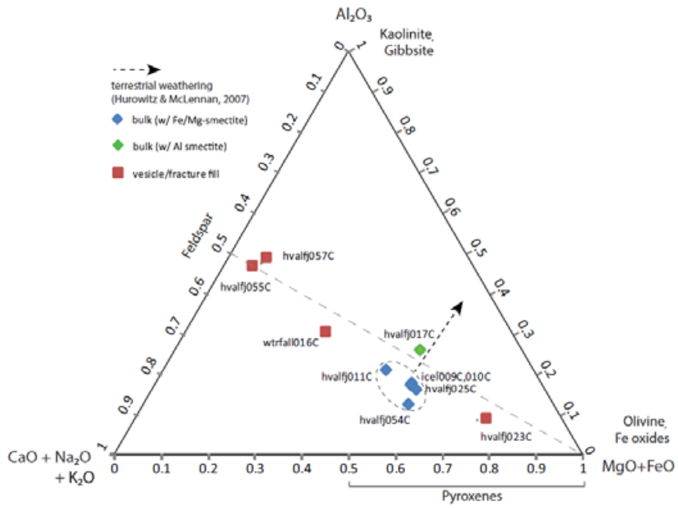

Figure 3. Ternary Al_2O_3, $(CaO+Na_2O+K_2O)$, (FeO_T+MgO) diagrams, data plotted in mole percent. The bold black arrow indicates the direction of terrestrial weathering (after Hurowitz & McLennan, 2007). Light gray arrows indicate relationships between bulk rocks (blue diamonds for Fe/Mg smectite-bearing, green diamonds for Al smectite-bearing) and vesicle/fracture fill (orange squares) found within those bulk rocks.

Key Measurements and Questions on Earth and Mars: In icealnd, full sample mineralogy is not completely captured by spectroscopic data because of textural effects and masking of some minerals' signatures by others. Nevertheless, VNIR spectra capture the principal mineralogic diversity, and provide a means of rapidly assessing the nature of past alteration. Examination of whole rocks from Mars orbit, even at large scales, should yield similarly effective information on the mineral assemblages present on the surface. Presently, XRD is the only *in-situ* technique with which it is possible to characterize sample mineralogy quantitatively. But of all the mineralogic techniques, VNIR spectroscopy provides the most definitive information on the nature of the altered, smectite component due to its sensitivity to shifts in absorption band position that provide information on the octahedral cations even when smectites are at small abundances in bulk samples. Use of a combination of measurements to characterize the mineralogy of alteration on Mars lends confidence to inferences of past environmental processes.

As research proceeds on alteration in groundwater systems in basalt, a key future direction is biological: do these environments of aqueous alteration provide a habitat for microbial life? If so, for what quantities of biomass and via what metabolic mechanisms? Finally, are signatures of biological processes preserved through time? Synergistic study of the geochemistry, mineralogy, and biology of alteration of Icelandic lavas may help to reveal the nature and habitability of the first aqueous environments on early Mars.

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LONG-TERM PRESERVATION OF BIOLOGICAL INFORMATION IN THE RÍO TINTO MARS ANALOG: IMPORTANCE FOR SITE SELECTION IN THE ASTROBIOLOGICAL EXPLORATION OF MARS. D. C. Fernández-Remolar[1], [1]Centro de Astrobiología (INTA-CSIC), INTA Campus, Ctra Ajalvir km 4, Torrejón de Ardoz, 28850 Spain, fernandezrd@inta.es

The planetary community has widely accepted that the presence of extensive deposits of Mars phyllosilicates is the best mineral matrix to search for early life on Mars [1]. This has been supported by different paradigmatic assumptions that can be resumed in the four following commandments: 1) phyllosilicates are the result of an hydrosphere interacting to the Mars under neutral chemistry and wet conditions, 2) prebiotic chemistry will only lead to the emergence of life if this occurs under a neutral to alkaline chemistry that, in theory, agrees with moderate and wet clay-producing environments, 3) life prefers high water activity and moderate pH environments to be active and diversify, and 4) preservation of molecules sourced on biological activity is much higher under a moderate-pH diagenesis.

These arguments are based on some experimental and theoretical data but have not been contrasted to results from harsh conditions. Indeed, research on different extreme environments, including their geohistoric counterparts, is providing some unexpected results that go against of some of these paradigmatic assumptions. For example, mineralogical and geobiological research in the Rio Tinto extreme environment is providing interesting information regarding to the formation of specific sedimentary record that associates fine-grained deposits, including clays, with acidic sulfates [2]. As a consequence, phyllosilicates can occur in extremely low pH environments depending on the hydrological regimen of the basin, which is unknown for early Mars. Moreover, studies focused on preservation potential in the acidic by-products of the Río Tinto acidic system hare resulted surprising because are observed not only structures of biological origin [3], but also preservation of large molecules in the oldest sediments of Rio Tinto [4]. These results go against assumptions 3 and 4, from which preservation and record of biological information of molecular origin (see Figure 1) would not be expected. Moreover, studies on geobiology of the acidic and non-acidic sediments strongly support that intact salts are the best candidates to found traces of life in the sedimentary record of Earth [5, 6] and probably on Mars.

By the application of the information supported by geobiological data it is possible to reassess an explorative strategy for searching traces of ancient life on Mars. In this sense, studying the molecular preservation in a diagenesis of salty and acidic deposits over time suggests that preservation in then is as good as the preservation in the phyllosilicate-rich deposits. Moreover, whereas most of salts are very soluble, clayey deposits are generally resistant to aqueous alteration that can eventually destroy any evidence of life. This scenario is highly plausible on Mars and should be considered before of planning the ground missions to the red planet.

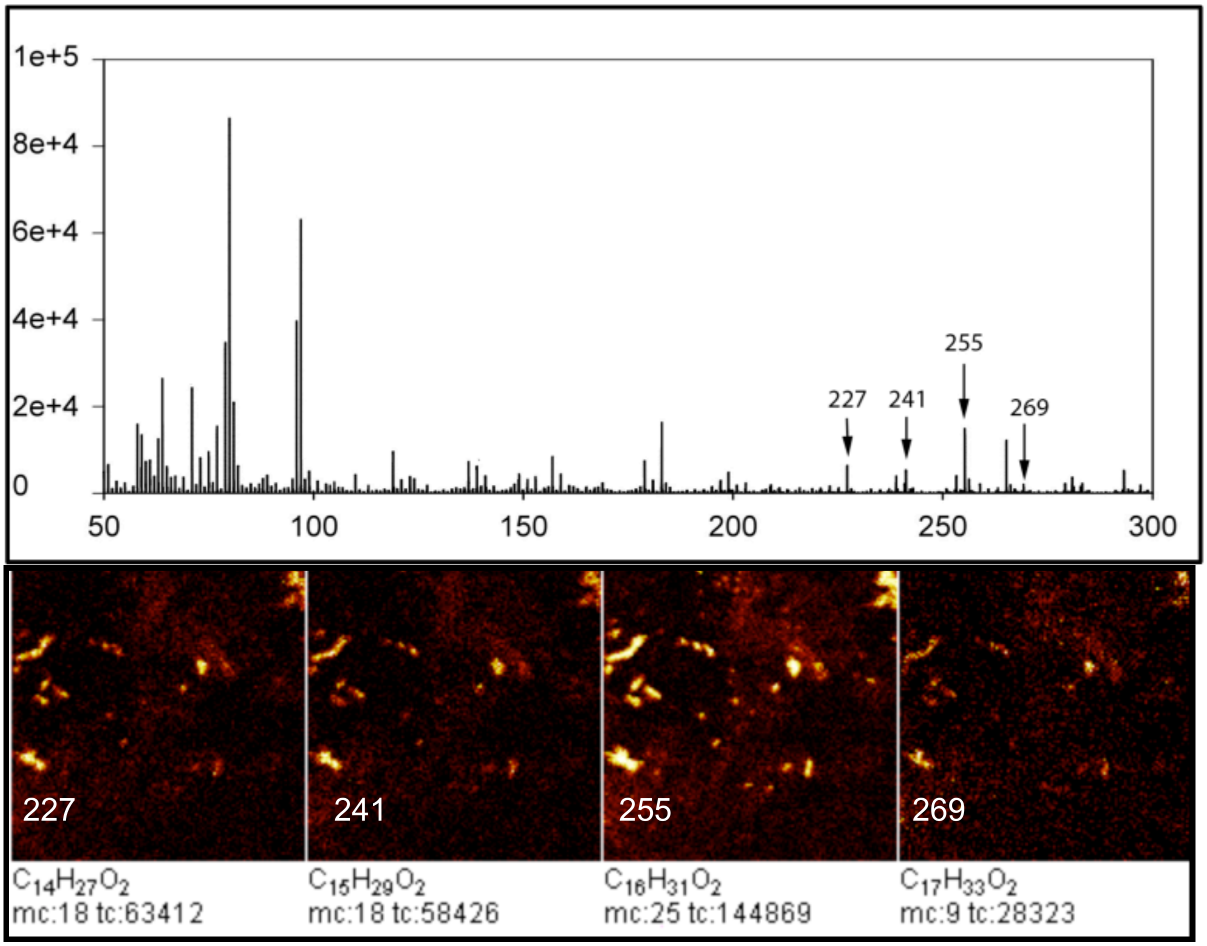

Figure 1: ToF-SIMS analysis for negative ions of the 2.1 Ma old terrace in Río Tinto. Mapping of molecular mass in sample interpreted as organic compounds trace some filamentous shapes supporting their biological origin as primary.

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UTAH DESERT ANALOGUE SITES FOR MARS RESEARCH AND MISSIONS.

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Introduction: The geological site near Hanksville, Utah, contains a range of Mars analogue features relevant for geology and astrobiology studies. It contains a series of sediments derived from weathering and erosion from marine to fluvial and lacustrine deposits containing also volcanic ashes. The landscape consists of mesas and scarp-bounded surfaces, with alternating layers of clay-rich units more eroded than sandstones units [1]. The landscape also includes segmented and inverted paleochannels exhumed from the Morrison formation that hosts small concretions, morphologically similar to meridiani "blueberries" [2]. This analogue site can help to test instruments, and perform scientific investigations [1-9], as well as operational traverses relevant for the MSL rover or the ExoMars rover, or for the acquisition and context characterization of samples in preparation for Max-C and Mars sample return.

Mission Description: The analogue scenarios will simulate planned activities after landing [1, 9].

1. Definition of campaign objectives and trade-off from science, technical or operational constraints
2. Analysis of remote sensing data and existing maps
3. Imaging reconnaissance
4. Monitoring of the local environment and meteorology
5. Geology and geophysical context
6. Field geology and geomorphology investigations
7. Field geochemistry characterization
8. Field subsurface studies
9. Sample handling (extraction and collection) methods
10. Analysis of soils and rocks in-situ (physical, mineral, chemical, organic, biological measurements)
11. A posteriori sample analysis using advanced facilities in international institutes.

Science Merit Related to Mission Objectives: The MDRS analogue site can address the science objectives of different planning scenarios for MSL, ExoMars rovers and for the acquisition of samples in a documented geological, geochemical and astrobiological context. We have demonstrated some of these scenarios during precursor generic campaigns EuroGeoMars2009 [1-8], and DOMEX-EuroMoonMars2010 [2,9]. Dedicated campaigns more representative of consolidated Mars missions objectives and constraints can be organized as discussed at the 2011 Woodlands workshop.

Precursor investigations following that methodology were performed during EuroGeoMars campaign (Foing et al 2011). The field traverses included an in-situ inspection and recognition of the characteristic petrology. A camera system with images at various embedded scales (panoramic, high resolution, close-up camera) was used in order to document the location, protocol and samples. The soil mechanical properties could be measured in situ using penetrometry, or by studying the tracks left by rovers. The mineralogy and mineral assemblages of rocks was mostly determined in situ by close up visual inspection. The various minerals identified include quartz, gypsum, clays, calcite and sulfates. The Xterra (by InXitu) Field XRay Diffractometer for mineralogy and XRay Fluorescence for elemental chemistry, and the Raman spectrometer (InPhotonics) were tested in outdoor conditions as the instruments could be transported. Drilling equipment included a Milwaukee hand-operated electrical drill that could reach depths down to 1 m. Another manual rotary drill was used to sample soft clays areas. The drill cores provided information on the vertical structure of soils and the distribution of minerals within rocks. These observations were compared to the lateral variations in rock layers observed from the edges of cliffs to determine the scale of heterogeneity of individual strata. A comparison was also made with data obtained from Ground Penetrating Radar (GPR) subsurface test measurements. the samples were catalogued and curated. The samples were analysed using a Raman Spectrometer (InPhotonics), a Visible/NIR Spectrometer (OceanOptics), an integrated X-Ray diffractometer/X-Ray fluorescence meter (Terra 158), as well as an optical microscope.The samples were divided and sent to Earth-based laboratories for sophisticated analysis of PAHs (Orzechowska et al 2011), of mineral matrix composition (Kotler et al 2011) or of amino-acids (Martins et al 2011). Post-analysis studies determined the total carbon content

(Orzechowska et al. 2011). A study of solid phase microextraction (SPME) method for fast screening and determination of PAHs in soil samples was performed, minimizing sample handling and preserving chemical integrity of the sample. Complementary liquid extraction was used to obtain information on five and six-ring PAH compounds. The measured concentrations of PAHs are, in general, very low, ranging from 1 ng/g to 60 ng/g (Orzechowska et al 2011).
In the different formations near MDRS there are multiple soil and rock units of diverse morphology and mineralogy that display systematic trends and clear stratigraphy and cross-cutting relations (diversity).
Regarding the geologic framework and chronology of the site (geologic context), the MDRS is surrounded by a series of early Jurassic to late Cretaceous sediments derived by weathering and erosion from Paleozoic sedimentary rocks to the west, with mineralogical or geomorphic evidence that can be used to test mission hypotheses. There is some high resolution aerial imagery of the analogue site on scales relevant to HiRISE, CTX, and hyperspectral measurements can be acquired relevant to CRISM.

Most Important Question Answered by Site:
How to optimize the reconnaissance and selection of samples to be analysed in situ?
What is the interaction of minerals with organics and biomarkers?

Logistic and Environmental Constraints: The site is quite accessible (near Hanksville or from Grand Junction). MDRS is used for research and simulation campaigns. The region around Hanksville is characterised as arid desert, cold in winter and hot in summer with an average annual temperature of 12 °C. The diurnal range is given as 16-37 °C in July, and -7 to +7 ° C on 1 Feb. The area is subjected to wind erosion and was shaped by fluvial erosion. The availability of the Mars Desert Research station for logistic support and habitat is a great asset, also for telecontrol of rovers, and as laboratory for engineering preparation, scientific evaluation and preliminary screening and analysis of samples.

Standard Information Required for Analogue Sites:

Table 1: MDRS analogue site proposed.

Site Name	Mars Desert Research Site, MDRS Utah
Center Coordinates Latitude, longitude	Between 38.40 and 38.44 N, W110.78 to W110.90
Elevation	1.3 to 1.5 km
Areal Extent	Core 4x 25 km (extendable)
Prime Science Questions	How to optimize reconnaissance and selection of samples & analysis in situ? What is the interaction of minerals with organics and biomarkers?
Distance of Science Targets from nearest road	Clay layers & concretions – near MDRS Inverted channel at 2 km
Environmental characteristics	Max temp: 37 C in summer day Min temp: -7 C in winter night Precipitation: 140 mm annual Vegetation coverage: arid
Previous studies at analogue site/refs	Special Issue: “Astrobiology field research in Moon/Mars analog environments”: International Journal of Astrobiology 2011, in press [1-9] (Foing, Stoker, Ehrenfreund, editors)
Primary Landing Site Target	Mawrth, Eberswalde, Holden, Gale, Meridiani
Other	Logistics experience & support MDRS

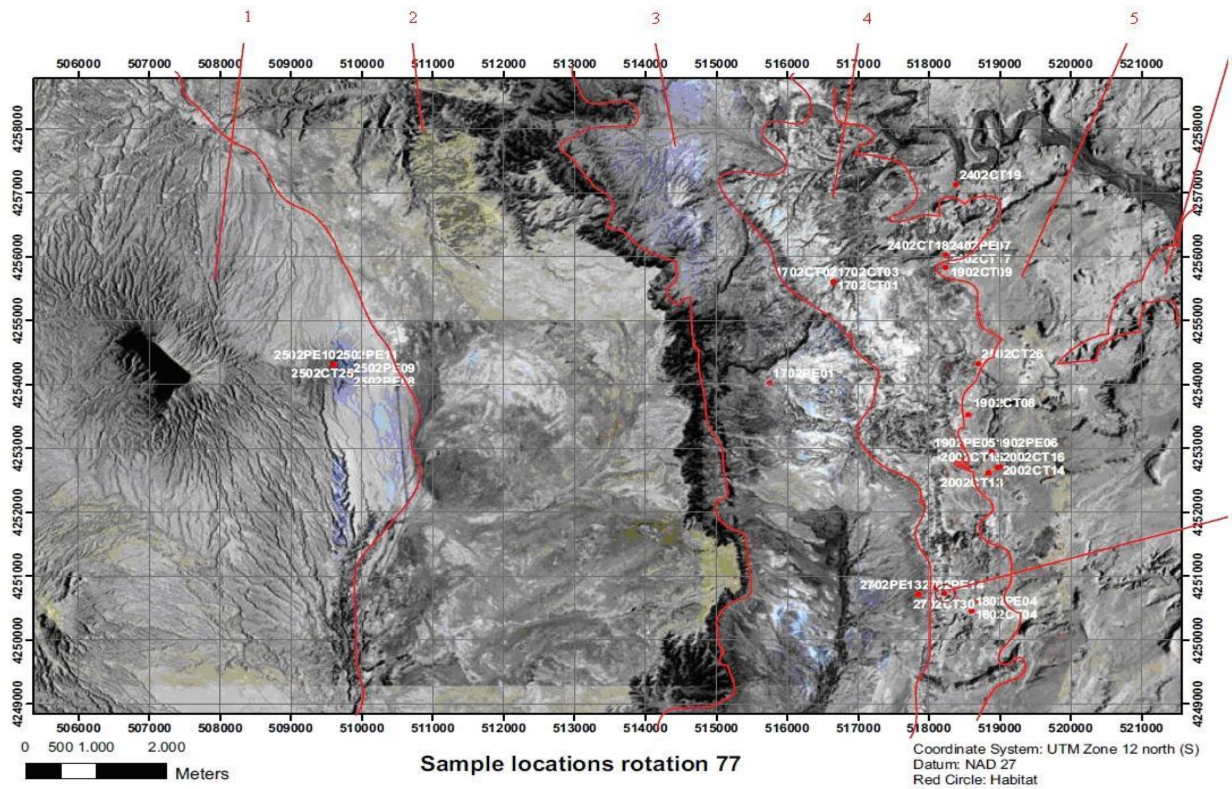

Fig. 1 Geology units around MDRS for EuroGeoMars2009 campaign, and positions of sampling areas (Foing et al 2011). The red lines (1-7) in Fig 1b indicate some of the geological formations and their member Mb (in clockwise numbered order from top):

Mancos Shale Formation (Cretaceous): Emery sandstone Mb.; Blue Gate Shale Mb (1); Ferron Sandstone Mb (2) formed as fluvial to marginally marine units; Tununk Mb containing bluish carbonaceous pyritic marine shales.

Dakota Sandstone Formation (Early Cretaceous) (3)

Morrison Formation (Late Jurassic): Brushy Basin Mb (4) consists of lacustrine and fluvial red brown clays/ mudstones, green-bluish-purple beds and sandstone lenses. Interbedded ash layers are weathered to smectite. This formation represents an analogue for some Martian terrains; Salt Wash Mb (5) from semiarid alluvial plain with cross bedded or conglomerate sandstones and local patchy halite and sulfate efflorescence.

Summerville formation (Middle Jurassic) intercalated siltstone and mudstone (6) locally containing gypsum beds and mud cracks that formed in a tidal flat environment.

Location of MDRS habitat is indicated in (7) within the Brushy basin Mb.

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Periglacial landscapes on Svalbard: terrestrial analogues for cold-climate landforms on Mars.
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Introduction: The surface of Mars shows many landforms that resemble cold-climate features on Earth [e.g., 1,2]. The potential use of these landforms as indicators of the past and present Martian environment makes them prime targets for paleoclimatic investigations [3-5]. Since permafrost on Earth is known to host rich habitats containing cold-adapted microbial communities [e.g., 6,7], its exploration on Mars is important for exobiologic studies. Life might even have originated in cold environments (e.g., see the studies of Trinks et al. [8], which was inspired by field experiments in Svalbard), and cryophilic (i.e. cold-tolerating) organisms may be analogues for possible psychrophiles (extremophilic organisms capable of growing and reproducing in cold temperatures, ranging from -15°C to +10°C) that exist or might have existed on, or deep inside, the surface of Mars [9 and references therein]. Another point of interest related to these landforms is the possible occurrence of liquid water over short timescales, e.g., as a result of ice or frost melting (water ice is known to form seasonally on pole-facing scarps at mid-latitudes [10]). The *in situ* study of these sites would reveal important insights into the current climate and hydrology of Mars, and it would offer the unique opportunity to search for extant life at places where liquid water might exist today.

Mission Description: The proposed analogue site on Svalbard would be best suited to identify a landing site and support the data interpretation for a future mission beyond ExoMars/MAX-C. This mission would go to a so-called "Special Region" [4,11,12], i.e. where present-day liquid water is expected. The mission would therefore have to qualify for planetary protection category IV. One of the main goals would be the search for extant life on Mars [13], although it has to be emphasized that such a mission would also have very important secondary goals (see above), such as the search for near-surface liquid water, the understanding of the Martian climatic evolution, or the assessment of ice as a resource for future human exploration.

Science Merit Related to Mission Objectives: The importance of this analogue site lies in the close spatial proximity of many diverse morphologies related to permafrost and periglacial processes. The combined existence of landforms typical for lowland permafrost (polygons, pingos) alpine permafrost (rock glaciers), and cold-climate slope processes (gullies, debris flow fans) is rarely encountered elsewhere. The analysis of these landforms helps to understand the mutual relationships of Martian mid-latitude landforms, their stratigraphy, and their chronological evolution. The bedrock in the study area consists of Jurassic and Cretaceous sediments. The lithology is characterized by sandstones, siltstones, shales, and some thin coal seams. The rocks are thinly layered (cm to tens of centimeters), and the layering is generally subhorizontal. The strata are heavily fractured by frost-shattering and – in particular near the coast –salt weathering. Valley marginal terraces in lower Adventdalen are thought to be proximal loess deposits that were likely derived by deflation and local deposition of fluvial sediments. Most of the periglacial landforms in Adventdalen (e.g., pingos, ice-wedge polygons) were formed in the late Holocene and are only about 3,000 years old, but some ice wedges at high elevations might have survived the Weichselian ice age under cold-based ice.

Another unique aspect of this analogue site is the availability of extremely high-resolution color images and topographic data. The German Aerospace Center (DLR) operates the HRSC-AX instrument, which is an airborne version of the High Resolution Stereo Camera (HRSC) on Mars Express. HRSC-AX obtains stereo and color images in nine different channels, enabling the derivation of Digital Elevation Models (DEM) with a grid spacing of 50 cm and a vertical resolution of 10 cm. Corresponding true- and false-color orthoimages have a ground pixel resolution of 20 cm/pixel. As such, these data are almost identical in resolution to the HiRISE images of the Martian surface (~20 cm/pixel), which will be the basis for any landing site selection for a Martian landed mission. A HRSC-AX flight campaign in July/August 2008 covered a total of seven regions in Svalbard, including Longyearbyen and the surroundings of

Adventfjorden as well as large parts of Adventdalen. Further details and first results of the flight campaign and accompanying field work in 2008 and 2009 are in press [14-16].

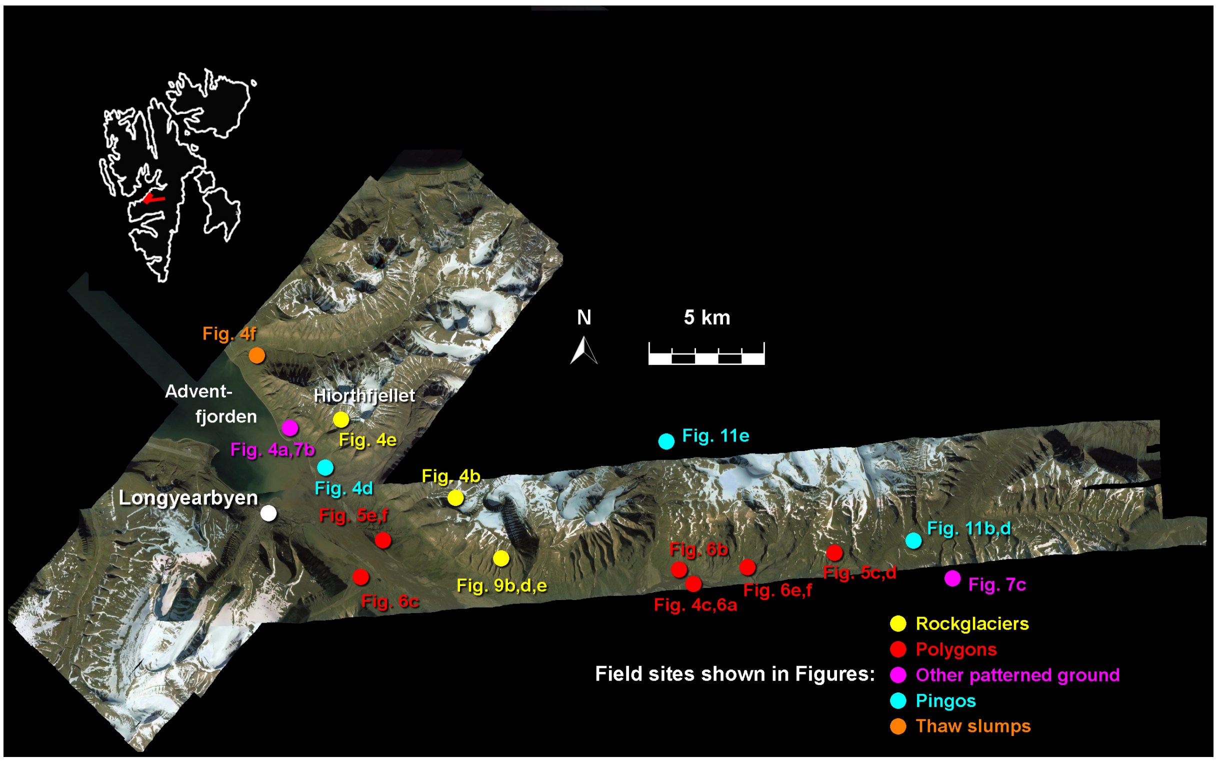
Most Important Question Answered by Site: Was liquid water required to form the cold-climate landforms at Martian mid-latitudes?

Logistic and Environmental Constraints: Access to Svalbard is logistically easy with daily flights from Norway to Longyearbyen (the capital of Svalbard). The study site covers the Adventdalen, a major valley that transitions into the Adventfjorden at approximately the location of Longyearbyen (Fig. 1). Adventdalen (as basically the rest of Svalbard) is free of any human population and infrastructure. There is one road serving an active coal mine, which extends a few km into Adventdalen. No bridge exists over the river in Adventdalen, so any research activity on the northern side of Adventdalen requires a river crossing by foot (which can be impossible at meltwater season), a crossing of the fjord by boat, or the use of a helicopter (which can be rented). Research in Svalbard, including the use of a field camp, requires previous permission by the Governor of Svalbard, and a registration at the data base "Research in Svalbard" (RIS; http://www.ssf.npolar.no/pages/database.htm). Due to the polar night and the associated environmental conditions, the recommended field season for the type of studies at this analogue site is typically between June and September (ideally July and August). Temperatures at this season are typically ~5-10°C during "day" and 0-5°C during "night" (there is 24 hours daylight, allowing long field days). More extreme (subzero) temperatures can not be excluded. Precipitation is very low and can occur as rain or snow even in summer (Tab. 1). Any person or group on Svalbard leaving one of the three settlements is expected to carry a rifle to protect themselves against polar bears. A safety training including rifle handling is advised.

Table 1: General information about the proposed analogue site on Svalbard.

Site Name	**Adventdalen**
Center Coordinates	~78.2°N, ~16.5°E (see Fig. 1)
Elevation	0 to ~900 m a.s.l.
Areal Extent	~40 km by 10 km
Prime Science Questions	Does the assemblage of very young permafrost-like landforms in Martian mid-latitude regions imply the involvement of liquid water?
Distance of selected Science Targets from nearest road or airstrip	**Polygons –** 0 m (next to road) **Rock glaciers –** 0.5 km to SSE **Gullies –** 0 m (next to road) **Pingos –** ~3 km (but beyond river/fjord, without bridge)
Environmental characteristics	**Max temp:** ~8°C **Min temp:** ~ -30°C **Precipitation:** 180 mm/yr **Vegetation coverage:** very sparse (bare ground, moss, grasses)
Previous studies at analogue site	Hauber et al. (2011a,b) [14,15]; Reiss et al. (2011) [16]
Primary Landing Site Target	Cold-climate landforms at Martian mid-latitudes with a chance of present-day occurrence of liquid water
Other	Compared to other possible analogue sites in terrestrial polar deserts, access is logistically easy and cost effective.

Figure 1. *(left)* Overview of Svalbard and the study area (box). Svalbard is a zone of continuous permafrost. It is warmer and wetter than other areas in the High Arctic (e.g., the Canadian High Arctic), but the interior is still relatively dry and considered to be a polar desert. *(below)* HRSC-AX true-color image mosaic with locations of selected landforms of interest. Adventdalen continues southeastward (then eastwards) from Adventfjorden (only the northern half is covered by HRSC-AX). Colored points indicate different surface features, all of which have close morphological analogues on Mars (from [14]). The combination of remote sensing data such as these with field work is a promising way in the study of terrestrial analogues to increase our knowledge of Martian landforms.



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A BALLOON-BORNE MARS ANALOG PLATFORM FOR 'FIELD' TESTS OF IN SITU INSTRUMENTS.
T. L. Hudson[1], E. Neidholdt[1], D. Banfield[2]. [1]Jet Propulsion Laboratory, California Institute of Technology, (4800 Oak Grove Dr. Pasadena, CA 91109, tlhudson@jpl.nasa.gov), [2]Department of Astronomy, Cornell University (banfield@astro.cornell.edu).

Introduction: In September 2011 JPL will launch the Analog Site Testbed for Readiness Advancement (ASTRA) – a stratospheric balloon carrying three TRL 4 instruments designed to perform in situ investigations on Mars' surface. The instruments (described below) are a mass spectrometer (RAMS), and two anemometers (SASA and HWA). A successful flight will demonstrate the instruments' capabilities and autonomy, advancing their TRL to 5 and taking significant steps toward TRL 6. It will also support reuse of the balloon platform for advancement of other instruments.

Mission Description: Conditions in the terrestrial stratosphere are similar in many respects to the environments encountered on Mars' surface at equatorial latitudes. Candidate instruments, sampling mechanisms, and sensors that are part of any landed mission, whether static or rover-based, must demonstrate their ability to operate within this environment. Some key characteristics of the stratosphere vis-à-vis the martian surface are as follows:

- Low Pressure: Potential for outgassing; pressures near the Paschen curve minimum, increasing risk for electrostatic dischange.
- Low Temperature: -50C to -70C may be below the operating temperature of specific electronic components, lubricants may cease to function.
- Radiation-dominated thermal environment: Convection is absent, requiring active or passive components (e.g., heaters, radiators, heat pipes, insulation) to maintain appropriate operating temperatures.
- Chemistry: A significant difference between the Mars surface and the terrestrial stratosphere is the atmospheric composition, including reactive species. However, oxidizing molecules like ozone are present, and could serve as a proxy for detecting oxidants in the martian atmosphere
- Wind: the stratosphere is an idea natural analog for testing the operation of anemometers, or devices that measure rapidly changing fluxes of mass or energy.

Science Merit Related to Mission Objectives: The merits of this analog site lie more in the technological advancement and demonstration of instrument maturity for seletiction as part of a landed payload.

The current compliment of instruments for the ASTRA mission include two anemometers (hot-wire and sonic), which would provide medium and high-frequency wind vectors in the boundary layer and could contribute to the understanding of mass fluxes of tracer species (e.g., water, methane) and momentum / energy exchange during diurnal cycles. The third ASTRA instrument is a mass spectrometer capable of rapid full-spectrum acquisition. This instrument colud be combined with an anemometer to complete the mass flux measurements described above, or could be part of a rock analysis suite ultimately capable of remote geochronological measurements.

The stratospheric analog site itself could be used to advance the TRL of any landed instrument or mechanism by demonstrating autonomous operation in a relevant environment. Field testing of instruments in Mars analogs can demonstrate their robustness and autonomy. Analog sites such as deserts or Antarctic Dry Valleys may approximate temperature and humidity conditions, but are wetter, warmer and (always) at higher pressure than Mars' surface. The terrestrial stratosphere possesses several superior Mars analog characteristics, listed above, that make it suitable for rigorous engineering demonstrations.

Most Important Question Answered by Site: This analog site allows candidate instruments to demonstrate their level of readiness by operating autonomously in an environment simalr to that of Mars' surface.

Logistic and Environmental Constraints: Balloon flights to the stratosphere are frequent and well-practiced endeavors. The Columbia Scientific Balloon Facility, operated by the Wallops Flight Facility, provides full-service balloon flights (including telecommunications, launch and recovery, tracking, and testing/staging environs) starting around $100k. Time 'at-float' may be limited by stratospheric winds, the balloon's flight path, battery life, ballast availability, robustness to overnight operation, and necessity of instrument / equipment recovery. These considerations inform the choice of launch sites and balloon sizes.

Standard Information Required for Analogue Sites:

Table 1: Terrestrial Stratosphere

Site Name	Earth's Stratosphere
Center Coordinates Latitude, longitude	N/A
Elevation	34.5 km
Areal Extent	~510 x 10^6 km^2 (practically 100 km^2)
Prime Science (Technology) Questions	How do instruments behave in a natural Mars-like environment? Can they operate autonomously?
Distance of Science Targets from nearest road or airstrip	34.5 km – straight up. (CSBF Launchsites: Ft. Sumner, NM; Palestine, TX)
Environmental characteristics	Max temp: -40C Min temp: -70C Precipitation: None Vegetation coverage: None Pressure: 4 – 10 mbar
Previous studies at analogue site	None known
Primary Landing Site Target	Non-polar surface of Mars.

Other	Any other items of interest

Figure 1: The Terrestrial Stratosphere. Below the edge of space, the pressure and temperature at 34.5 km is the most-like "on" Earth. Other characteristics are also quite Mars-like: the presence of natural wind, the presence of oxidizing molecules, and a radiation-dominated thermal environment.

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

[1] Author A. B. and Author C. D. (1997) *JGR, 90,* 1151–1154. [2] Author E. F. et al. (1997) *Meteoritics & Planet. Sci., 32,* A74. [3] Author G. H. (1996) *LPS XXVII,* 1344–1345. [4] Author I. J. (2002) *LPS XXXIII,* Abstract #1402.

THE BASQUE LAKES, BRITISH COLUMBIA, CANADA – AN ANALOGUE SITE FOR EVALUATING HABITABILITY, GEOLOGY & SAMPLE RETURN AT MG-SULFATE AND CLAY-RICH AREAS ON MARS, LIKE GALE CRATER. P. L. King[1,2] & G. Southam[2] [1]Institute for Meteoritics, Univ. New Mexico, Albuquerque NM 87109 USA, [2]Department of Earth Sciences, Univ. Western Ontario, London ON N6A 5B7 Canada.

Introduction: Sulfur is one of the most important elements on Mars, and some authors have suggested that Mars has a "sulfur cycle", rather than the hydrologic cycle found on Earth [1, 2]. Therefore, to better interpret future missions – like Mars Science Laboratory (MSL), Exo-Mars and Mars 2018 – it is essential to understand how sulfur is precipitated as sulfates and to understand the habitability of sulfate systems. Here, we focus on magnesium-rich sulfates with various hydration states (termed 'Mg-sulfates') because these are found at some of the proposed MSL landing sites (e.g., Gale Crater (Fig. 1) and possibly Mawrth Valles [3]), they are widespread on Mars [e.g., 1, 2, 4], and are predicted based on experiments [5] and theoretical models [4]. Because Mg-sulfates are so abundant on Mars it is critical to collect information on the habitability, geochemistry/mineralogy and sample return issues through analogue site studies.

Logistic & Environmental Conditions: The Basque Lakes (Fig. 2) include eight closed basin sulfate-clay playas that are fed by a volcanic ash aquifer. The lakes have different compositions ($Mg\text{-}SO_4$, $Na\text{-}SO_4$, $Mg\text{-}CO_3$ and fresh water; Fig. 3, [6-9]) and the sites of most relevance to the MSL and Mars 2018/Exo-Mars opportunities are the $Mg\text{-}SO_4$-rich lakes. The area is located in British Columbia, less than 45 min drive from Cache Creek and 1.5 hrs from Kamloops airport (Fig. 2). Some of the lakes are adjacent to the road, but more pristine lakes are located a <30 min walk from the road on Canadian Crown Land (i.e., they are accessible). Further logistic and environmental conditions are given in Table 1 and available remote sensing data are given in Table 2.

Relevance to Missions: The *Mars Science Laboratory (MSL) mission's* primary scientific goal is to "explore & quantitatively assess a local region on Mars' surface as a potential habitat for life, past or present". This goal requires understanding preservation potential and geologic context of Mars rocks. The *Mars 2018 mission* will include the European ExoMars Rover and the NASA MAX-C rover, with complementary objectives to search for evidence of past or present life, demonstrate key technologies, and to prepare to return samples with known geologic context on Mars to Earth. Below we outline how research at the Basque Lakes will help with these goals.

Habitability & Preservation of Biomarkers: The Basque Lakes provide a realistic analogue site to quantitatively assess the potential habitability of Mars' surface. Investigations of organic and inorganic compounds and the processes that might preserve them have commenced [7, 8] and show that microbial life is not only viable, but abundant, in this extreme environment. Non-photosynthetic micro-organisms are halophilic (salt-loving) and include Archaea and sulfate-reducing bacteria (SRB) [7]. Halophiles are excellent possibilities for past or extant life on Mars because they are known to survive variations in desiccation-freezing, water contents, pH, solution composition, $P(O_2)$, and may be shielded from radiation if they contain dark pigmentation (like Archea and SRBs). The halophiles may be trapped and preserved in fluid inclusions and along grain boundaries [7]. Key habitability questions to answer at the Basque Lakes, and relevant for Mars missions, include:

- What limits habitability in sulfate environments (temperature, chemistry, pH etc.)?
- What are diagnostic organics & isotopes for microbes in sulfate environments?
- How do inorganic versus organic processes affect salt precipitation?
- What are environmental controls on biomarker preservation - in other words, salt precipitation/dissolution & microbe entrapment/release?
- Which MSL/Exo-Mars/MAX-C instruments provide the necessary information to interpret habitability & biomarkers?

Geologic Context: The multiple playas present diverse morphology and mineralogy that display systematic trends within each lake as evaporation proceeds [6-9]. Laterally, the playas contain Mg-sulfate rich brine pools and gypsum-clay banks. Vertical stratigraphy requires motorized coring methods. Chemical and mineralogical studies show that the minerals include epsomite, hexahydrite, kieserite, meridianiite, bloedite, gypsum, thenardite, Ca-protodolomite, bischofite and clays [6-9]. Geochemical modeling is in progress [like 4, 10]. The site offers the possibilities to evaluate:

- What geologic, hydrologic & organic processes cause sulfate salts to form & can we infer the context based on textures, mineralogy/chemistry & geologic mapping?
- How do isotopes (e.g., Mg, S, O and H) respond to changing groundwater, surface water, aquifer composition, biology and environmental conditions?
- Which MSL/Exo-Mars/MAX-C instruments provide the necessary information to interpret the geologic context and preservation?

Mars *Salt* Return Sampling Strategies: Sulfates are known to change phase as a function of relative humidity, temperature and radiation environment [7, 11]. The Basque Lakes site will provide a means to test methods to preserve phases or track phase changes during sampling (e.g., coring with Exo-Mars), caching (in a separate, closed container with MAX-C) or during transport to Earth. Since Mg-sulfates may de-water under certain conditions these sulfates may cross-contaminate other phases. We need to devise methods to understand such processes and the Basque Lakes provides the materials for studies where temperature-pressure-relative humidity conditions and textural/phase changes may be monitored. Questions include:

- What are the kinetics of phase changes under different environmental conditions?
- How do mixed phases respond to changes in environmental conditions and is it possible to reconstruct the original mineralogy?

Final Comments: A consortium of international researchers is interested in obtaining funds to examine the Basque Lakes site because it represents a unique analogue site for Mars. Approaches that can be taken to better understand Mars through studies at the Basque Lakes are given in Table 2.

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Table 1: Details of the Basque Lakes (playas) Mars analogue site.

Location & elevation	*Latitude:* 50.59326, *Longitude:* -121.34880, *Elevation:* 1050 – 1250 m
Areal extent	11 playas. 7 Mg-SO_4 playas that are each ≤400 m^2. Depth of salt unknown.
Prime science questions	What is the habitability & preservation potential of Mg-sulfate? How do Mg-sulfates, Ca-sulfates & clays form? How do we interpret samples from Mars *Salt* Return?
Proximity of targets	Sulfates & clays, meters to <800m from the road, <5km from highway.
Environmental characteristics	*Average temperature:* -9 to 28 °C. *Precipitation:* <4 cm / yr including snow. *Best time to sample:* September-October. *Vegetation:* pine trees adjacent to playas
Previous analyses & studies	Inductively-coupled plasma optical emission spectrometry, ion chromotography, protein assays, infrared spectroscopy, scanning emission & confocal microscopy, in situ X-ray diffraction, X-ray diffraction (XRD), & microbiology cultures [6-9]
Landing site target	Gale Crater and sulfate or clay-rich areas of Mars

Table 2: Advantages of examining the Basque Lakes in the context of upcoming missions to Mars.

Science objective	**Basque Lakes possible approach**	**Instruments to be used on Mars***
Habitability & biosignature preservation	Examine the limits of life through culturing materials under various conditions (temp, chemistry, pH etc.). Evaluate biosignatures with instruments that complement ChemCam & SAM.	MSL ChemCam & Sample Analysis at Mars (SAM). MAX-C science payload including scanner. Exo-Mars Mars Organic Molecule Analyzer and infrared scanner.
Geologic setting	Characterize lithologic variations- both lateral & vertical (subsurface drill). Constrain roles of groundwater, inorganic & organic processes.	MSL imagers (MastCam & Mars Hand-Lens Imager - MAHLI) and chemistry (Alpha-Particle X-ray Spectrometer, APXS). MAX-C science payload. Exo-Mars drill with science payload.
Mineral ID, textures & bulk composition	Previous analysis methods, APXS, Raman, near-IR, gas geochemistry, ToF-SIMS# & visible light photography	MSL CheMin, APXS, ChemCam & MAHLI, MAX-C spectroscopic imager/scanner & APXS. Exo-Mars Raman, multispectral imager, MicrOmega & XRD
Isotopic composition	Determine isotopic changes during inorganic processes (e.g. evaporation & groundwater infiltration) & organic processes (e.g. via dissimilatory sulfate reduction by SRBs)	MSL SAM & Exo-Mars Mars Organic Molecule Analyzer.
Remote sensing	Iknonos, Quickbird, Worldview-1, GeoEye-1; LandSat 5, Advanced Spaceborne Thermal Emission and Reflection Radiometer, Moderate Resolution Imaging Spectroradiometer	Mars Reconnaissance Orbiter Context Camera, High Resolution Stereo Camera, High Resolution Imaging Science Experiment; Observatoire pour la Minéralogie, l'Eau, les Glaces et l'Activité, Compact Reconnaissance Imaging Spectrometer for Mars

* Mars 2018 will ultimately include analysis of samples in laboratories on Earth. #Time of Flight Secondary Ion Mass Spectrometry.

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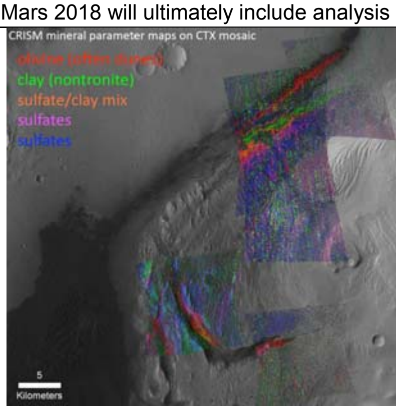

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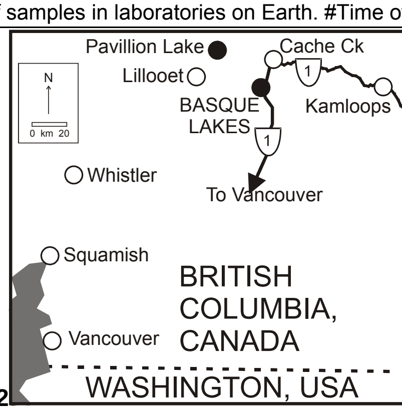

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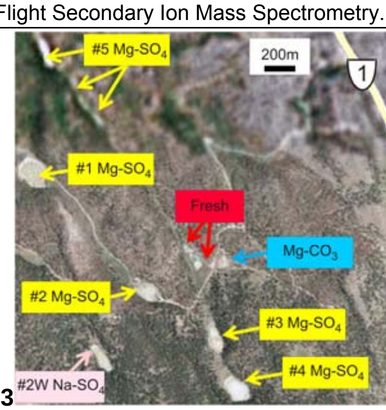


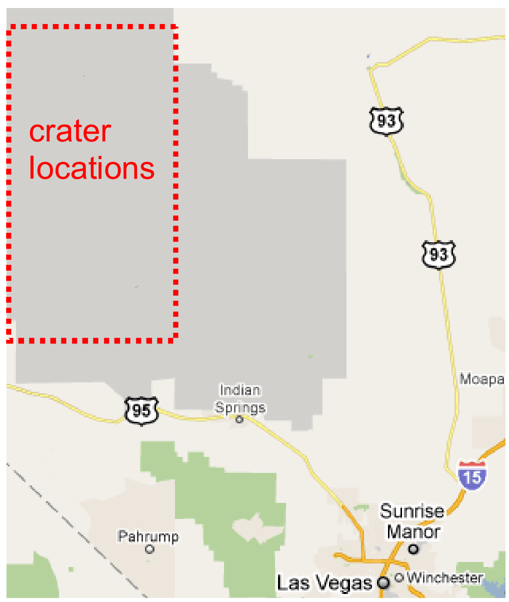
Fig. 1: Compact Reconnaissance Imaging Spectrometer for Mars (CRISM) overlay of Gale Crater, a proposed MSL site [from 3]. The prime science targets are sulfates (e.g., the Mg-sulfate, kieserite) and phyllosilicates (clays).
Fig. 2: Map of the Basque Lakes. **Fig. 3:** GoogleEarth image of the Basque Lakes with different lake compositions.

SMALL, FRESH CRATERS AT THE NEVADA TEST SITE. L. E. Kirkland[1,2] and K. C. Herr[2], [1]Lunar and Planetary Institute, [2]The Aerospace Corporation.

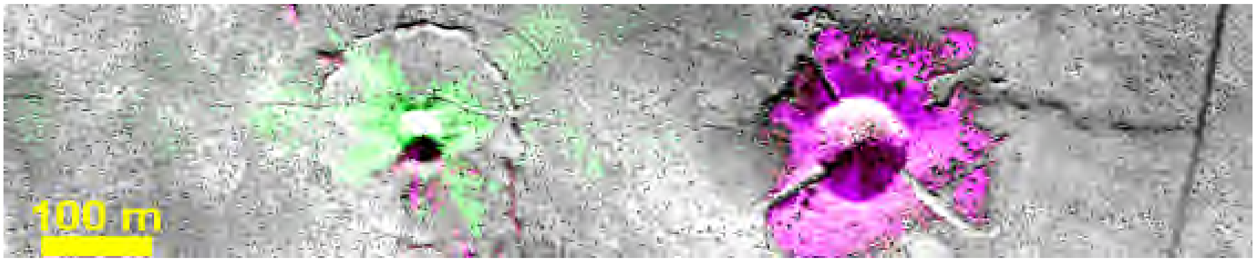
Introduction: Small (~5-400 m diameter), well-preserved explosion craters at the Nevada Test Site provide analog sites to develop lessons-learned for exploration by rovers on Mars. Craters made using explosives are good analogs to impact craters because they form by broadly similar methods and with similar resulting morphology [1, 2,3,4,5,6]. Impact craters form when the impactor is compressed into a nearly hemispherical shock wave as it punches into the ground, then is decompressed by a tensile wave and ejected [7]. Explosion craters form by a similar method of a hemispherical shock from the explosion followed by decompression [7].

The Nevada Test Site has manmade craters that range from ~5 to 400 m diameter. However, since ~1980, only very limited airborne (satellite analog) and ground-based (rover analog) studies exist of the NTS craters [e.g., 8,9,10]. Thus the craters remain important and unique assets for study, particularly using more modern instrumentation. For example, near-surface rocks exposed by some of the craters have opal coatings [8,9,10], which would be critical to detect on Mars, if present [11]. Exploration of these unique sites can support the operational foundation for routes to discovery for Mars.

The analog site is NW of Las Vegas, NV (map at right). Craters at the NTS range from fairly smooth (easily walked) to very rough. All the craters are accessible for science research. In addition, high quality airborne hyperspectral data sets already exist of many of the sites to support research. These data sets include AVIRIS and SpecTIR (0.4–2.5 μm) and SEBASS (2.5–6 μm and 7.5–13.5 μm).



Right: Oblique picture of Buckboard-12 (lower) and Danny Boy (upper) craters, taken Sep 2009. The light toned linear features are roads. Details of crater locations are in the table below.



Example of existing hyperspectral imagery of the Buckboard-12 (left) and Danny Boy (right). The image illustrates that fresh ejecta makes a window into sub-surface material. SEBASS image color coding: Gray=8.6 µm (1163 cm^{-1}) brightness temperature; purple=match to basalt signature from Danny Boy; green= match to laboratory signature measured of a sample of opal from this location [8,9,10].

This picture of Schooner Crater was taken September 2009, looking ~northwest. The light toned linear features are roads. The linear feature running to the crater lip is a trench dug in May-June 1969 for ejecta studies [12].

Google image of example chemical (non-nuclear), small craters at the “Pre-Buggy” NTS site (location in the table below). The smaller craters are ~10 m diameter, and the linear features are dirt roads. The elongated craters were from excavation experiments.

Table 1. Example explosion craters at the NTS

Crater name	Size (dia, m)	Yield (kt)	Type	Year made	Coordinates	Geographic location	Substrate
Pre-Buggy[a]	14		chemical		36.832 / 115.971	Frenchman	alluvium
Watusi	25	0.02	chemical	2002	37.099 / 116.092	Yucca	alluvium
Stagecoach[b]	30		chemical		37.165 / 116.035	Yucca	alluvium
Scooter	91	0.5	chemical	1960	37.171 / 116.038	Yucca	alluvium
Uncle	79	1.2	nuclear	1951	37.168 / 116.043	Yucca	alluvium
ESS	91	1	nuclear	1955	37.170 / 116.045	Yucca	alluvium
Sedan	390	104	nuclear	1962	37.177 / 116.046	Yucca	alluvium
Johnnie Boy	?	0.5	nuclear	1962	37.122 / 116.334	E of Buckboard	alluvium
Buckboard-5	5	0.0005	chemical	1960	near Buckboard-12	Buckboard Mesa	basalt
Buckboard-12	37	0.02	chemical	1960	37.111 / 116.370	Buckboard Mesa	basalt
Danny Boy	81	0.4	nuclear	1962	37.111 / 116.366	Buckboard Mesa	basalt
Dugout[c]	41x87	0.1	chemical		37.094 / 116.345	Buckboard Mesa	basalt
Buggy[d]	76x259	5.4	nuclear	1968	37.008 / 116.372	Area 30	basalt
Cabriolet	55	2.3	nuclear	1968	37.281 / 116.515	Pahute Mesa	rhyolite
Palanquin	73	4.3	nuclear	1965	37.280 / 116.524	Pahute Mesa	rhyolite
Schooner	280	30	nuclear	1968	37.343 / 116.567	N Pahute Mesa	layered tuff

[a]Pre-Buggy has 10 craters in the same region and the sizes vary. [b]There are 3 Stagecoach craters, all similar size and location. [c]Dugout is 5 separate charges made along a row; each charge was 0.02 kt. [d]Buggy is 5 separate charges made along a row; each charge was 1.08 kt

Most of the craters are readily accessible. This fresh crater (2002) shows an example of steep walls. Other craters are gently sloped, providing a range for testing.

Logistic and Environmental Constraints: The Department of Energy (DOE) grants access to the NTS for science research. Our research group has found DOE to be very accommodating. Most of the craters are readily accessible via paved or good quality dirt roads. Weather is typical for SW desert, with low vegetation coverage. Most studies base out of Las Vegas, or on-site at the Mercury dorms. In comparison to many planetary analog sites, travel costs are low.

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GARWOOD VALLEY, ANTARCTICA: AN ANALOG SITE FOR EXPLORING COLD DESERT FLUVIAL DELTAS AND CHANNELS, BIOGEOCHEMICAL STRATIGRAPHY, AND PERMAFROST-MODIFIED MANTLES. J. S. Levy[1], Fountain, A. G.[1], O'Connor, J. E.[2] [1]Portland State University, Department of Geology, Portland, OR, 97201. [2]USGS Oregon Water Science Center, Portland, OR, 9721. jlevy@pdx.edu

Introduction: Mars is a permafrost planet. Mean annual surface temperatures on Mars are well below 273 K at all latitudes, and likely have been, on average, since the Noachian [1, 2]. Exploration of the geomorphic, geochemical, and astrobiological processes at the MSL and MAX-C/ExoMars landing sites is exploration of processes occurring at the warm and wet fringe of these cold desert conditions, when surface and shallow groundwater were more abundant.

Terrestrial landforms analogous to those present at MSL candidate-landing sites are found in Garwood Valley, Antarctica (Fig. 1, Table. 1). **Closed-basin lacustrine deltas** formed during the last glacial maximum (~10 ky BP) dominate Garwood Valley [3, 4] (analogous to fluvio-deltaic sediments present at Eberswalde, Hale, and possibly lower parts of Gale crater). These deltaic sediments preserve abundant algal, diatomaceous, and carbonate horizons that contain both **physical and chemical biomarkers**. The lower portion of Garwood Valley supports ice-cored, glacial-drift **permafrost** and **cryogenic sulfates** analogous to martian Latitude Dependent Mantle (LDM) [5, 6] ice-rich permafrost—the equator-wards fringe of which is present at Eberswalde, Holden, and Mawrth Valles. The upper reaches of Garwood Valley contain glacial **outburst flood channels** that incised through frozen regolith, strongly analogous to Mawrth Valles outflow channel surfaces. *Accordingly, Garwood Valley represents an ideal site for testing flight instrumentation under near-Mars-like (cold and hyper-arid) conditions and for refining geological, geochemical, and biological models of processes typical of all the MSL candidate landing sites.*

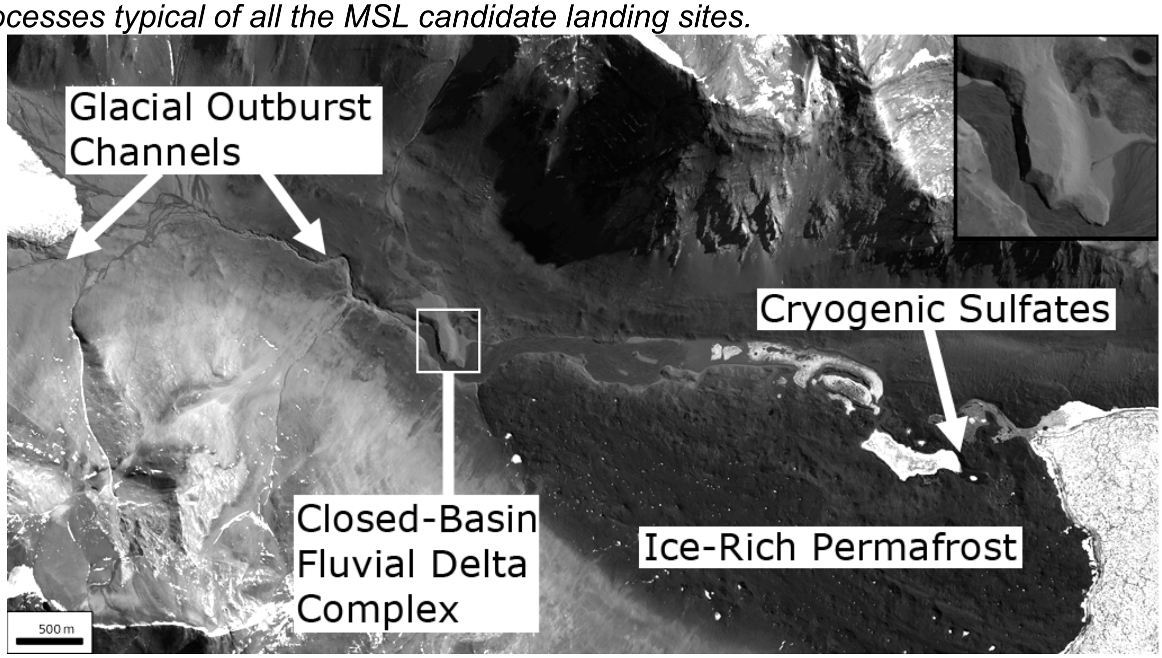

Fig. 1. Garwood Valley, Antarctica. Mars-analog landforms are highlighted: outflow channels, frozen deltas (larger view in inset), ice-rich permafrost, cryogenic sulfate.

Mission Description: Garwood Valley analog investigations can address three major MSL science objectives related to Mars habitability [7]. Investigations will use ground methods, as well as Ikonos (60 cm/pix) and ASTER (15 m/pix) remote sensing.

Objective 1) "Assess the biological potential of at least one target environment... identifying features that may record the actions of biologically relevant processes." Analysis of **multiple, 5 to >10 ky old, fossil algal mats exposed in cross section** will permit estimation of **taphonometric decay rates** of physical biomarkers (e.g., intact cells, biofilms, biofilaments) under ultra-cold, ultra-dry conditions that may extend expectations of biomarker preservation under ice/permafrost conditions [8] (Fig. 2). Chemical and morphological analysis of **biogenic carbonate deposits interbedded with thick phyllosilicate deposits** will permit estimates of carbon and nutrient flux into cold (ice-covered) closed basin lakes (Fig. 2).

Fig. 2. (Left) 1-2 cm thick, continuous algal mat (arrow) bed preserved above Garwood delta sands (pebble-gravel at image bottom). (Right) Finely bedded carbonate and clays (~1 mm lamellae, grouped in ~1 cm packages). Note permafrost disruption by ice lenses (arrow).

Objective 2) "Characterize the geology of the landing region..." **Well-constrained Holocene and Pleistocene chronology** in Garwood deposits will permit calculation of fluvial delta aggradation rates under freezing surface conditions (e.g., seasonal water flow into ice-covered lakes) (Holden, Eberswalde). Likewise, ^{14}C age control on modern glacial outburst floods will constrain **rates of outflow channel incision** through frozen ground (e.g., Mawrth). Finally, comparison of depositional environments for contemporaneous, but spatially-segregated **phyllosilicates and glaciogenic sulfates** will provide insight into cold-climate geochemical divides (Hale) [9].

Objective 3) "Investigate planetary processes of relevance to past habitability (including the role of water)..." Garwood deltas can be used to identify unique geomorphic climate signatures of cold-climate delta formation (e.g., glacial/ice-cover interactions, permafrost modification, etc.). Ice lenses disrupting sedimentary deposits (Fig. 2) can be used to calculate a spatio-temporal **rate of sediment disruption by cryoturbation**.

Most Important Question Answered by Site: 1) What is the **degradation rate and magnitude** of algal and microbial, physical and chemical biomarkers in perennially frozen deltas? 2) What are the **unique geomorphic characteristics** of cold/frozen fluvial and lacustrine systems? 3) How does **permafrost mediate geochemical divides** between contemporaneous sulfate and phyllosilicate systems?

Logistic and Environmental Constraints: Access to Garwood Valley is limited to US Antarctic Program or international Antarctic program partner participants. Garwood Valley is accessible from McMurdo Station via helicopter. Levy et al. have established a helicopter landing site and camp with access to all analog landforms. Activities in Garwood Valley are subject to environmental review under the provisions of the Antarctic Treaty Environmental Protocols. High winds (in excess of 110 km/h) and low temperatures (-30˚C) are not uncommon during early and late summer. No vegetation other than sparse algal mats is present.

Table 1: Summary of Garwood Valley MSL/Mars Analog Site.

Site Name	Garwood Valley
Center Coordinates	Site center: 78.03˚S, 164.14˚E
Elevation	0-0.2 km ASL
Areal Extent	7 km by 3 km
Prime Science Questions	1) What is the degradation rate and magnitude of algal and microbial, physical and chemical biomarkers in perennially frozen deltas? 2) What are the unique geomorphic characteristics of cold/frozen fluvial and lacustrine systems? 3) How does permafrost mediate geochemical divides between contemporaneous sulfate/phyllosilicate systems?
Distance of Science Targets from helicopter landing site.	Deltas: 100 m to N. Permafrost: 50 m to E. Cryogenic sulfates: 3 km to E.
Environmental characteristics	Max temp: 6˚C, Min temp: -35˚C, Mean temp. -18˚C Precipitation: <50 mm w.eq./year. Vegetation: 0%
Previous studies	[3, 4, 10]
Primary Landing Site Target	Primary Analog: Eberswalde and Holden Craters. Secondary Analog: Mawrth Valles. Tertiary Analog: Gale Crater, LDM deposits, phyllosilicate/sulfate contacts.

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CHARACTERISTIC INVESTIGATION BY ROBOTIC LANDINGS ON MARS. Y. Miura, Earth System Sci., Yamaguchi University (Yoshida 1677-1, Yamaguchi, 753-8512, Japan. yasmiura@yamaguchi-u.ac.jp) .

Introduction: Robotic investigation on Martian landing sites are significant for collection site data of outcrops and sample observation sites which are impossible to obtain sample original collection sites of the meteoroids and cosmic dusts [1-5]. However, it is significant to collect various information to discuss origin and formation process of Mars which are main purposes of the present paper.

Characterization factors in Martian materials: The origin and the formation process of Mars are multiple information data from Martian materials shown by total formation factor (F) of main six characterized factors (f) as shown in Equation (1).

F (total) = f (physics) + f (chemistry) + f (biology) + f (time) + f (location) + f (growth)…(1)

Standard formation factor (F) shown on the Earth are composed of physics (crystalline or amorphous), chemistry (chemical composition), biology (inorganic mineral and fossil as shown in carbonates or organic compounds), time (various isotope ages), location (collection sites with outcrop) and growth (slow to rapid cooling reaction), as shown in Equation(1) and Table 1, which can be applied to extraterrestrial materials of Mars, the Moon, Asteroids and cosmic dusts.

Table 1. Characterization of terrestrial and extraterrestrial materials as multiple data.

Factor (f)	Contents
1) Physics	Crystalline (in mineral) or amorphous (glassy, in rocks).
2) Chemistry	Major or volatile elements (C, O, S, H, N and Cl).
3) Biology	Organic compounds or inorganic remnant of fossil (mainly Earth).
4) Time	Various isotope ages after re-melting (many ages after melting).
5) Location	Various collection sites (outcrop data as geological data).
6) Growth	Slow or rapid cooling reaction (Tiny fine grains by impacts) .

Robotic data to any Martian surfaces: Terrestrial material can be obtained all factors due to in-situ or laboratory analyses and detailed outcrop with collection sites and ages as geological information. On the Moon far from the Earth all formation factors can be obtained due to the Apollo returned samples by U.S. astronauts with detailed outcrop information by photo and conversation with Houston people published field notes, though the lunar collection sites are mainly lunar equator areas on the near side. The followed lunar robotic explosions are covers whole lunar surface (i.e. all location data) by remote-sensing data without ant lunar materials (i.e. no data of ages and growth), which cannot be obtained the total formation factor (F) in the Moon in details. Almost all meteoroids and cosmic dusts have no data of the location (due to broken and floated materials). On the other hands, robotic data of Martian surfaces show the location data of outcrops obtained by remote-camera (with geologic data of topography and glassy mixtures) and composition of remote-analyzing instruments (without detailed data of in-situ ages and microscopic nano-growth with volatile elements of carbon and chlorine), though more developed instruments by robotic expedition are expected as shown in Figure 1 and Table 1.

$$F\,(\text{total}) = f\,(\text{physics}) + f\,(\text{chemistry}) + f\,(\text{location}) + f\,(\text{time}) + f\,(\text{reaction})$$

Robotic samples for In-situ analytical outcrops

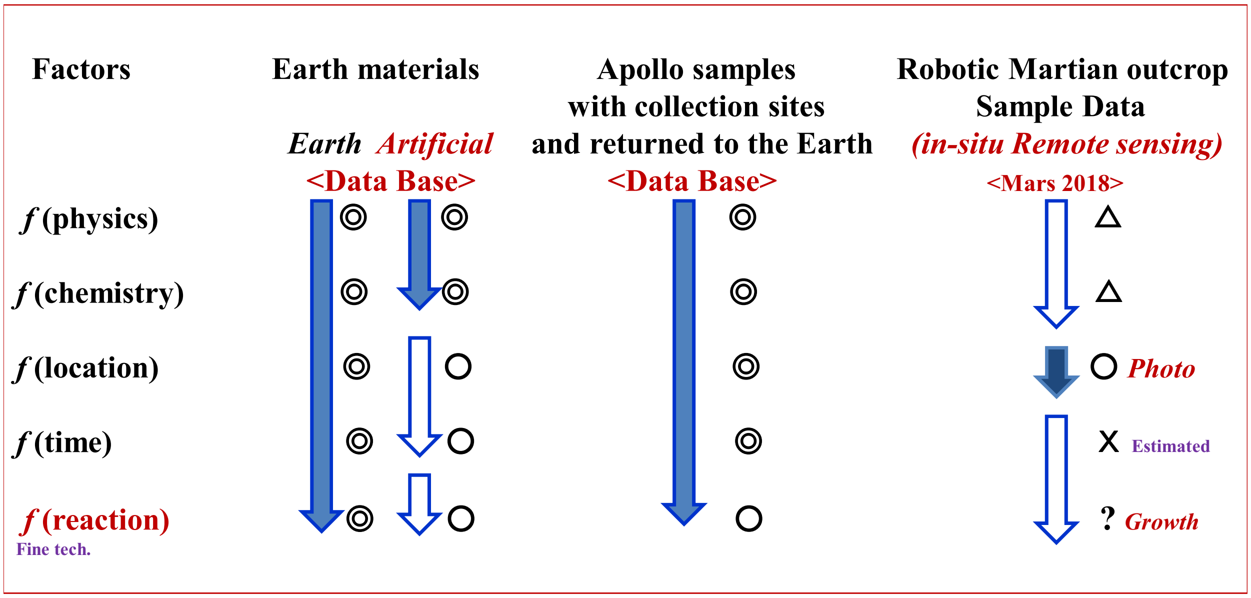

Figure 1: Material characterization by total factor (F) and five factors (f's) as in Table 1, where robotic analyses of biology factor (f) which is included to chemistry factor (f) are mainly inactive organic compound in this figure. The returned Martian sample with location data can be discussed as separated biology factor (f). In future the biology factor (f) will be main target of the Martian robotic analyses. ◎:Complete data. ○: Obtained data. △: Estimated data or limited analyzed data. X:Estimated data (mainly by comparison in Mars; Known present data in artificial materials). ?: Unknown data (by microscopic analyses) .Arrows with filled color : Data base. Arrows without color: Estimated data (mainly by comparison).

Problems for biologic factor of Martian robotic analyses: Present biological analyses of extraterrestrial materials as in meteorites on the Earth are mainly "monomer organic molecules" (i.e. dead or inactive organic compounds to life materials in carbon cycle) due to small quantities. In this sense, Martian robotic analyses of biology factor (f) should be included to chemistry factor (f) in Equation (1) and Figure 1. In this sense, future returned Martian sample with location data can be discussed as separated biology factor (f). In future the biology factor (f) will be main target of the Martian robotic analyses due to carbon states in air and rocks.

Next candidates for Martian landing sites: Although there are previous Martian landing sites of interesting low and higher lands including impact craters with some sedimentary layers, the next interesting landing sites are considered to be 1) any steep cliffs of canyons with deeper sedimentary layers where there are various carbon-bearing materials, and 2) steep slope and cliffs of Martian volcanoes with various volcanic rocks with carbon cycle. Both landing sites are required to be flying-instruments along deeper cliff outcrops with new instrumental developments.

Summary: The present study can be summarized as followed:
1) Origin and detailed formation of Earth can be discussed by multiple formation factors of physics, chemistry, biology, time, location and growth reaction, as shown in Equation (1), which can be applied for extraterrestrial materials of Mars, the Moon, Asteroids and cosmic dusts as some of characterized factors (f's).
2) Landing sites on Martian sites are very important to collect the location data of outcrops obtained by remote-camera and composition of remote-analyzing instruments (including volatile elements of carbon and chlorine).
3) Martian biology factor (f) including to chemistry factor (f) in the present development of analyzing instruments will be main target of the Martian robotic analyses due to carbon states in air and rocks, though future returned Martian sample with location data can be discussed as separated biology factor (f).
4) Candidates of Martian landing sites are any steep cliffs of canyons and/or volcanoes with deeper sedimentary and/or volcanic layers where there are various carbon-bearing materials. New instrumental developments are required to be flying-instruments along deeper cliff outcrops.

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The Tablelands Ophiolite of Newfoundland: A Mars analogue site of present-day serpentinization

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Introduction: The Tablelands Ophiolite (N49° 27' 58.9", W 57° 57' 29.0") is a Mars analogue for the altered ultramafic rocks with Mg-carbonate and serpentine signatures of the MSL proposed landing site, NE Syrtis Acidic-Alkaline transition. The presence of these rock types suggest that serpentinization may have occurred on Mars at this location. The Tablelands Ophiolite is a location of past and present-day continental serpentinization. Present-day continental occurrences of serpentinization are rare. On the West coast of Newfoundland in Gros Morne National Park, uplifting of an ancient sea bed during the collision of the continents ca. 470 million years ago revealed underlying ultramafic rocks of Earth's mantle creating the Tablelands Ophiolite. Weathering due to recent glaciations has left large areas of unaltered ultramafic rock at the surface and created fissures for fluid flow. As a result serpentinization is occurring as fresh water penetrates the rock. Multiple ultrabasic reducing springs bubbling with gases characteristic of present-day serpentinization have been identified in the Tablelands Ophiolite (1;2). Serpentinization creates conditions amendable for both abiogenic and microbial synthesis of organic compounds. Therefore this analogue site is ideal for testing the detection of abio- and biosignatures. This project has a series of long-term goals: 1) to develop and test methods under high pH and low microbial biomass conditions characteristic of sites of serpentinization that are being prepared for space flight and contribute to the scientific goals of the Mars Sample Laboratory (MSL), the 2018 ExoMars Rovers Mission, and the Mars Exploration Program Analysis Group (MEPEG); 2) to put in situ measurements in context of carbon source and reaction pathways (biogenic and abiogenic) and to determine microbial communities that thrive in the ultrabasic reducing groundwater at sites of serpentinization; and 3) to determine preservation of abio- and biosignatures in carbonate rocks indigenous to sites of serpentinization.

Mission Description: The Tablelands Ophiolite is an analogue of the MSL NE Syrtis Acidic-Alkaline transition proposed landing site where there are 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 amendable 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 the Tablelands 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 Mars Sample Laboratory (MSL), the 2018 ExoMars Rovers Mission, and the Mars Exploration Program Analysis Group (MEPEG).

Science Merit Related to Mission Objectives: In the Tablelands Ophiolite there are ultrabasic reducing groundwater springs emerging from highly altered ultramafic rocks containing serpentine minerals. Mg- and Ca- carbonate fluff, and travertines are precipitating where the groundwater emerges. Older travertines have also been identified in association with less more oxic springs, suggesting that these are sites of past serpentinization. Both types of springs are being studied to determine the habitability of sites of serpentinization, the potential of abiogenic production of hydrocarbons, and the preservation of biosignatures.

Most Important Question Answered by Site: Studying past and present-day serpentinization at the Tablelands will answer questions about the habitability of sites of serpentinization, the potential of abiogenic production of hydrocarbons, and the preservation of biosignatures.

Logistic and Environmental Constraints: The Tablelands Ophiolite is located in Gros Morne National Park, which is a United Nations Educational, Scientific and Cultural Organization (UNESCO) World Heritage Site. A permit is required to perform research there. The closest airport is in Deer Lake, NL, which is about an hour's drive from the Tablelands. There are roads through Gros Morne. The springs located thus far are at most a 45 min walk from the road. The terrain can be unsafe; it is sometimes steep and consists of unstable talus slopes. Very little vegetation can grow on the ultramafic rock of the Tablelands. The Tablelands can be snow covered until early summer.

Standard Information Required for Analogue Sites:

Table 1: Tablelands Ophiolite, Gros Morne National Park, NL, Canada

Site Name	Tablelands Ophiolite, Gros Morne National Park, NL, Canada
Center Coordinates Latitude, longitude	N49° 27' 58.9", W 57° 57' 29.0"
Elevation	0.25 - 0.7 km
Areal Extent	83.2 Km^2 – Oval shape, see Figure 1
Prime Science Questions	Habitability of sites of serpentinization, the potential of abiogenic production of hydrocarbons, and the preservation of biosignatures
Distance of Science Targets from nearest road or airstrip	All springs are located within 45 min hike from the nearest road
Environmental characteristics	Max temp: 22°C (average high) Min temp: -11°C (average low) Precipitation: 1300 mm/yr Vegetation coverage: sparse
Previous studies at analogue site	See 1 and 2 in reference list
Primary Landing Site Target	MSL NE Syrtis Acidic-Alkaline transition.

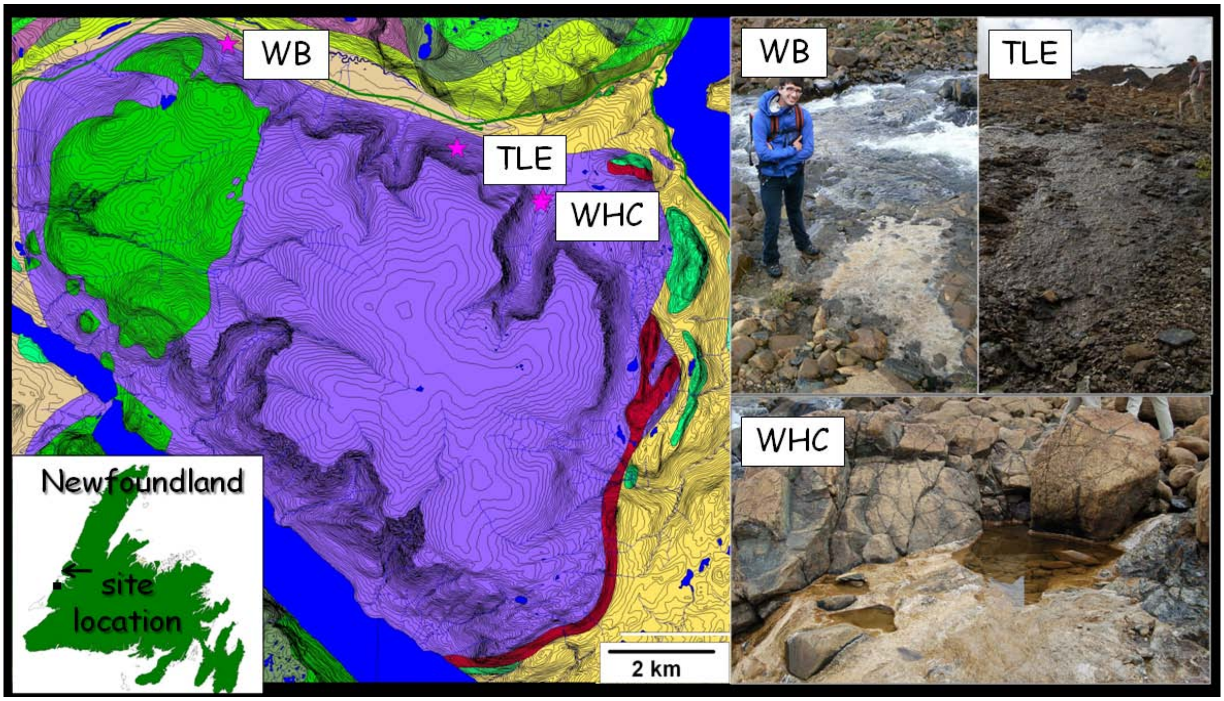

Figure 1: Geologic and topographic map of the Tablelands Ophiolite in Gros Morne National Park, Newfoundland, Canada (N49° 27' 58.9", W 57° 57' 29.0"). The prime science targets are ultra-basic reducing groundwater springs emerging from the ultramafic rock. These groundwaters have been modified by the water-rock reaction known as serpentinization. Three complexes of ultra-basic reducing springs have been located and are labeled as Winter House Creek (WHC), Tablelands East (TLE), and Wallace Brook (WB). WHC has the most ultrabasic reducing conditions, and it is the primary site of interest.

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MARS-LIKE SOILS IN THE DRIEST CORE OF THE ATACAMA DESERT IN NORTHEN CHILE: THE YUNGAY AREA. R. Navarro-González[1] and C.P. McKay[2], [1]Laboratorio de Laboratorio de Química de Plasmas y Estudios Planetarios, Instituto de Ciencias Nucleares, Universidad Nacional Autónoma de México, Circuito Exterior, Ciudad Universitaria, Apartado Postal 70-543, México D.F. 04510, MEXICO (navarro@nucleares.unam.mx), [2]Space Science Division, NASA Ames Research Center, Moffett Field, CA 94035 (chris.mckay@nasa.gov).

Introduction: The next set of missions (MSL 2011, Mars 2018 and ExoMars 2018) seeks to understand whether life ever arose on Mars by detecting the chemical building blocks of life (e.g., organic compounds containing the elements CHONSP) in the soil. Because organic compounds are thermally labile, a simple tool for their analysis is the thermal volatilization (TV) method, which consists of heating the soil in an oven to temperatures ranging from 200ºC to 500 ºC or greater up to 1000ºC in order to vaporize small molecules and break down larger ones into smaller organic molecules, and the resultant organic fragments are then detected by mass spectrometry (MS) [1, 2]. This thermal volatilization process has been the method of choice in past space missions starting with Viking [3], the two ill-fated missions (Mars Polar Lander [4] and Beagle 2 [5]), and Phoenix [6], as well as in future missions: MSL 2011 [7] and ExoMars 2018 [8]. The Viking mission detected water at 0.1–1.0 wt% with traces of chloromethane at 15 ppb, at Viking landing site 1, and water at 0.05–1.0 wt% and carbon dioxide at 50–700 ppm, with traces of dichloromethane at 0.04–40 ppb at Viking landing site 2 [3]. However, these chlorohydrocarbons were considered to be terrestrial contaminants, although they were not detected in the blank runs [3]. The Phoenix Lander did not find organics in the soil [6]. Surprisingly, magnesium perchlorate, a thermodynamically unstable but kinetically stable chemical salt was discovered in the Martian Arctic soil by the Phoenix Lander [9]. With the use of terrestrial Mars analogs, it has been possible to realize important limitations in the search of organics on Mars using the TV method. The successful detection of organics depends not only on the sensitivity of the MS, as generally alleged [10], but also that organics are not refractory (e.g., thermally stable) at the temperature regime investigated [1, 11] or that are not combusted to carbon dioxide in the oven by oxidants (e.g., peroxides, superoxides, perchlorates) present in the soil matrix [1, 2, 12-14]. The arid core region of the Atacama Desert in Yungay has played a key role in understanding the Viking and Phoenix results. Yungay contains Mars-like soils in the surface that have no culturable bacteria ($<10^2$ colony-forming units per gram), low levels of extractable DNA, and low organic concentrations (20–40 ppm C) that become detectable at temperature regimes greater than investigated by the Viking mission, and the presence of a non-chirally specific oxidant that consumes organics in aqueous solution [11]. The valley of Yungay contained among the largest deposits of nitrates and perchlorates on Earth, which were mined at the start of last century [15]. However, if Yungay soils are spiked with magnesium perchlorate and treated using the Viking protocol, the low level organics are combusted in the oven but surprisingly a trace amount is quenched in the form of chlorohydrocarbons, namely chloro and dichloromethane [14]. Reinterpretation of the Viking results suggests, therefore, the presence of perchlorates at ≤0.1% and organics at ppm levels at mid-latitudes on Mars [14].

Mission Description: The next set of missions will try to answer the question of whether life ever rose on Mars by searching for the building blocks of life in the soil using the TV method. The Atacama Desert is probably the driest place on Earth, where hyperaridity has persisted for more than 10-15 Myrs [15]. Mars likely became hyperarid after 3.5 Gyr ago [16]. Therefore, if the instruments to be sent to Mars are not able to detect organics in the Yungay soil from past life, it implies that they are not ready for exploring Mars.

Science Merit Related to Mission Objectives: The Yungay soil in the Atacama Desert contains the lowest levels of organics in the form of refractory molecules, no culturable bacteria, low levels of extractable DNA, and the presence of non-chirally specific oxidants. Consequently, this is the most barren site on Earth resembling Mars. Satellite imagery datasets of this site are available commercially or non-commercially.

Most Important Question Answered by Site: Did life ever arise on Mars?

Logistic and Environmental Constraints: Our main work location is the University of Antofagasta Desert Research Station and is located about 1 hour out of Antofagasta, south on Route 5. GPS coordinates of the station are 24º 04' 50.5" S and 69º 55' 11.1" W. The site is readily accessible by car: from Antofogasta, take route 26 east until it merges into highway 5; turn right on Route 5 and go South for about 30 km. There will be a small shack on the left side of the road and a dirt road off to the left. The sign for this road is Socompo. Turn left off Route 5 and continue for 25 km until just past a water pumping plant. There will be a fork in the road with the main road turning right and an old paved road continuing straight. The station is at this junction on the right. The location is a temperate desert that is easily accessible at any time of the year (see Table 1 and Figure1).

Table 1: Characteristics of the Mars Analog Site.

Site Name	Yungay, Atacama Desert
Center Coordinates	24°S, 69.9°W
Elevation	1.1 km
Areal Extent	10 km by 10 km
Prime Science Questions	What is the chemical nature of refractory organics and oxidants in the soil?; What is the age of organics? What is the mechanism of destruction of organics in the soil?
Distance of Science Targets from nearest road or airstrip	Less than 25 km
Environmental characteristics	Average temp: 16.5ºC; Max temp: 37.5ºC; Min temp: -5.7ºC; Precipitation: <1 mm Vegetation coverage: None
Previous studies at analogue site	[1, 11, 14]
Primary Landing Site Target	e.g., Any site on Mars

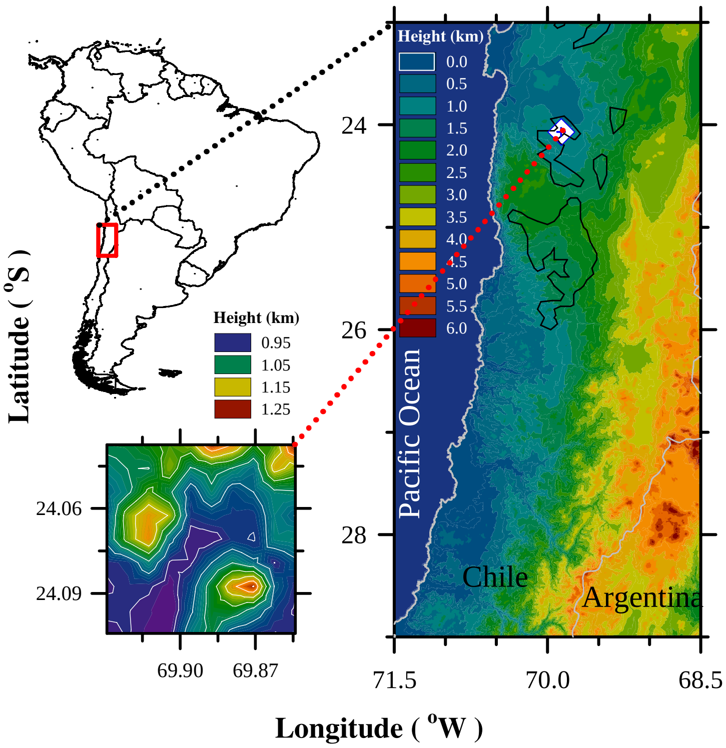

Figure 1. Digital elevation map of the Atacama Desert in Northern Chile at 30 minute resolution showing the historic nitrate mining sites (black counter lines) and a zoom in of the Yungay Area [16].

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LONAR CRATER, INDIA: A NATURAL ANALOG FOR MSL LANDING SITES H.E. Newsom and S.P. Wright, Institute of Meteoritics, University of New Mexico, Albuquerque, NM 87131, newsom@unm.edu, spwright@unm.edu

Introduction: The 1.8 km diameter Lonar Crater in the state of Maharashtra, India includes morphological features of impacts and impactite deposits, including habitable environments, characteristic of features that are present in the four candidate sites for the Mars Science Laboratory (MSL) mission, and which are likely to be present in the MAX-C and Mars Sample Return landing sites.

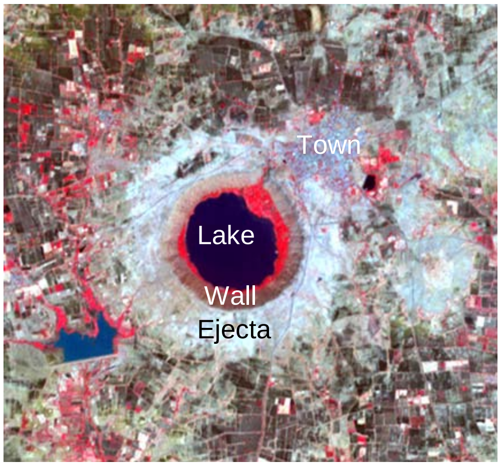

Figure 1. Least-vegetated ASTER VNIR image (14 m resolution) of Lonar, with red signifying high NIR reflectance typical of chlorophyll. With a 1.8 km rim-to-rim diameter, and ~1.5 km of lithic breccias ejecta circum the crater rim, a roughly 5 km x 5 km square provides ~20-25 km^2 of rim, inner-crater, and ejecta outcrops to explore. The extent of the ~1.4 km ejecta blanket is another 0.5 – 1.0 km of patchy lobes beyond the ~0.7 km "halo" caused by pulverized fines making up the breccia matrix.

The science merit of the Lonar site includes mineralogical signatures of habitable environments in proximal and distal ejecta, and crater-floor breccia deposits that may occur on Mars, such as phyllosilicates and chemical precipitates. Features of impactites, such as shocked and melted rocks in a layered ejecta blanket, are also characteristic of the distal ejecta of moderate to large craters. Evidence for the recent 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 inter-flow deposits are also analogous to the Martian crust. The engineering merit of the Lonar site includes the preservation of the topography of a simple impact crater, and the presence of the ejecta blanket with material properties expected for the ejecta blankets of craters in basalt on Mars. The site can support tests of drilling into ejecta blankets and exploration tests on the surface and numerous excavated cross sections of the ejecta (e.g. near Kalapani Dam) for many types of analytical instrumentation including contact and non-contact devices.

Mission Description: The MSL mission will investigate habitable environments associated with sediments and impact crater deposits, and the geologic and climate history of Mars. Each of the four MSL landing sites contains impact craters of different sizes. The sites also contain sedimentary deposits, some of which could represent distal impact crater deposits. Possible impact breccias identified in many of the sites may include basaltic Martian crustal rocks affected by impact.

Testable hypotheses at MSL landing sites with relevance to Lonar Crater, India:

- Are deposits from aqueous and hydrothermal habitable environments generated by impact processes with identifiable mineralogical signatures (e.g., phyllosilicates, evaporitic minerals, lake sediments, etc.) present in the landing sites? This can include the distal ejecta of large impacts.

- Can ejected samples with evidence of a pre-impact habitable environment, such as the porous inter-flow baked-zone deposits in the target rock basalts, retain mineral-chemical signatures representative of this environment?
- Can the nature of the atmosphere at the time of the impact be determined from the types of materials present at the surface (e.g. evidence of airburst due to atmospheric breakup of the impactor) and in the ejecta (e.g. lapilli).
- Can the post-impact climate be determined from the chemistry and mineralogy of surficial weathering including soil vs. paleosol chemistry, and the nature of the erosion of the crater, for example fluvial versus debris flow formation of gullies?

Science Merit of Lonar Related to Mission Objectives: Geological context and chronology - the Lonar Crater is a simple, bowl-shaped, impact crater ~ 1.8 km in diameter with a continuous rim raised ~30 m above the adjacent plains [1-4]. The depth of the crater from its rim crest is ~222 m, whereas the crater floor lies ~90 m below the pre-impact surface [1, 2]. The continuous ejecta deposit extends outward to an average distance of ~1350 m from the crater rim. Beneath the shallow saline lake, a sequence of unconsolidated sediments up to 100 m thick was reported to overlie the impactite breccia lens on the floor of the crater, which has been sampled in drill cores [1, 2]. The crater was excavated on several flows of the Deccan Trap flood basalt, which erupted at or close to the Cretaceous-Tertiary boundary at ~65 Ma. Jourdan et al. [5] find an age from ^{40}Ar/^{39}Ar dating of ~ 650,000 years for glass bombs from the crater ejecta.

Diversity of materials - The iron-rich target basalts at Lonar are similar in composition to Martian basalts [6]. The materials produced by the impact include the impact breccias and the presence of basement rocks shocked to all levels up to the formation of impact melts. The uppermost layer of the ejecta contains impact melts and accretionary lapilli due to processes in the atmosphere above the crater [7 - 9]. The ejecta blanket at Lonar is layered as many Martian craters, and the different size-frequency distribution of rocks and matrix in the proximal and distal exposures reflect the emplacement mechanisms. The ejecta contain evidence of the amount of dust and fines produced in an impact in basalt, including possible condensates from the impact plume. Studies of the size-frequency of the materials produced could help constrain the fraction of Martian surficial soils or dust produced by impacts compared to aeolian erosion.

Aqueous environments - Evidence of aqueous and hydrothermal processes include alteration of the ejecta blanket under ambient conditions [10] and possible hydrothermal alteration of the crater floor breccias. The alteration processes may be representative of processes early in Martian history. Further investigations can determine the level of microscopic magnification and surface preparation, brushing, ratting, and even drill cuttings of impactite deposits is necessary to allow diagnostic features of habitable environments to be identified and characterized. Investigations of the formation of gullies on the impact crater walls may provide signatures of the processes such as fluvial versus mass-wasting or debris flow be distinguished in orbital or rover-based images and help determine the role of water in the modification of the landscape in the MSL landing sites.

Remote sensing data sets relevant to HiRISE, CTX, and CRISM – Remote sensing data are available from ASTER, Landsat, etc. A high-resolution Quickbird image of the area was acquired with NASA funds [3]. Further work is needed to determine if materials at the surface at Lonar, such as phyllosilicates, shocked rocks, etc. can be distinguished techniques similar to remote sensing data available for the MSL landing sites, especially data from THEMIS, and CRISM.

Most Important Question Answered by Site: Can the presence of phyllosilicates and other aqueous minerals in different impact craters and layered target environments provide evidence of habitable environments, and be used to identify such environments in the proposed landing sites on Mars using orbital and rover instrumentation?

Table 1: Characteristics of proposed analog site

Site Name	Lonar Crater, India
Center Coordinates	19°58´ N, 76°31´ E (central India)
Elevation	~500 m
Areal Extent	ejecta blanket: ~5 km by ~5 km
Prime Science Questions	Mineralogical signatures of habitable aqueous and hydrothermal environments Evidence for atmosphere and post-impact climate history from ejecta (lapilli, etc.), 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. Gulley on east ejecta – 50 m from road
Environmental characteristics	Temperatures generally 80° F in winter. Precipitation: ~2 months of monsoon in northern summer. Vegetation coverage: seasonal.
Previous studies at analogue site	[1] Fredriksson et al., 1973 [2] Fudali et al., 1980 [3] Maloof et al. 2010 [6] Hagerty & Newsom, 2003 [8] Wright & Newsom, 2011 [9] Wright et al., 2011 [10] Kieffer et al., 1976 [11] Newsom et al., 2011 [12] Wright & Newsom 2011b.
Primary Landing Site Target	*e.g.*, MSL sites with exposed proximal or distal ejecta layers, impact breccias, and craters exposing buried lithologies.

Travel: Domestic flights from Mumbai or Delhi to Aurangabad (population: ~1.5 million), ~200 km SE of Lonar. The town of Lonar on the NE rim/ejecta of crater (population of 32,000) can provide many services, such as off-road vehicle rental. Hotels in Lonar include the tourist hotel at the crater rim, run by the state of Maharashtra.

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THE IBN BATTUTA CENTRE (MARRAKECH, MOROCCO) FOR TESTING LANDER SCIENCE, OPERATIONS AND LANDING SYSTEMS. G. G. Ori[1] and K. Taj-Eddine[2], I. Dell'Arciprete[1] [1]IRSPS (Universita d'Annunzio Viale Pindaro 42, 65127 Pescara Italy and Ibn Battuta Centre, Universite Cadi Ayyad Maraleck Morocco, ggori@irsps.unich.it), [2] Faculte des Sciences, Universite Cadi Ayyad (Semlelia, Marrakech, Morocco).

Introduction: The Ibn Battuta Centre for Exploration and Field Activity has been set by the International Research School of Planetary Sciences (IRSPS) at Pescara (Italy) to test the hardware and operations for the ESA mission to Mars. Currently, ESA is planning within the frame of the ESA/NASA Joint Exploration Programme to mission in 2016 and 2018. The ExoMars 2016 consists of a simple landing demonstrator while the ExoMars 2018 will consists of a complex rovers that, under the current scenario, will operate along with Max-C. ExoMars 2016 will carry on a small lander, without solar panel, that will "live" on the surface for just a few days. The science payload will be small. An orbiter is completing the mission. ExoMars 2018 is a complex operation and the rover payload represent the state-of-the-art of the geological and astrobiological exploration of the planet. The landing site of ExoMars is currently under study and IRSPS is involved in the engineering characterization. ESA and NASA will select ExoMars 2018 in the future with joint procedures. Of course the facilities of the Ibn Battuta Centre can be used for any other Martian and Lunar mission.

Figure 1. Southern Morocco and approximate location of the field test areas

The Ibn Battuta Centre is identifying several sites in the Moroccan desert to be used as testing site for science and operations. This site span from reg-like deflation surfaces, ancient microbical communities, evaporitic dry lakes, deflated alluvial fans, ergs and sand dunes, ancient stromatolitic surfaces, and all the kind of environments, geological facies and astrobiological targets that the geological diversity of Southern Morocco coupled with the desert environment may offer.

Mission Description: ExoMars 2016 is a landing demonstrator that ESA is planning to put on the Martian surface. The landing gears of the DEM must be tested both in laboratory and in the field. Several tests are already in preparation. ExoMars 2018 will need of extensive testing of the operation and also of the scientific planning and outputs. The broad barren landscape of the Moroccan Sahara mimic quite well the large low-relief “panoramas” of Mars. The Rover Operation Centre will be able, with satellite link to Morocco, to simulate the rover operations and, in case of cooperation with Max-C, to experiment the complex activities of managing to rovers in over large areas with small or negligible landmarks.

Science Merit Related to Mission Objectives: Morocco exhibit an amazing geological diversity. The geological history preserved is temporally huge spanning from Pre-Cambrian to Quaternary. The sedimentary record contains a large number of geological units with microbiological content including the oldest published chemosynthetic microbial mound Silurian in age. Moreover the desert environment offer a large array of different sedimentary environments. Dry lakes with deltaic bodies are also present.

Most Important Question Answered by Site: The Ibn Battuta Centre offer several sites with different purposes from operation testing to science analysis. Most of the questions hat can be answered involve operations. In the Ibn Battuta test sites it will be possible to test the operations and understand if the operations are correctly planned, if the scientific planning is performed satisfactorily and if the scientific return approach ro is the one expected. Moreover, it will be possible to test and understand the best operational approach to scientific activities.

Logistic and Environmental Constraints: Morocco is a tourist Country and full of tourist facilities. The road system is extensive, but of course most of the operations needing large open spaces and pristine environments will be carried on far from cities and village in the desert. *Pistes* (off-road tracks) will be used to approach the test sites. Hotels are basically available in every city. Four wheels cars, pick-up trucks, trucks, choppers, etc are available in the Country. Ourzazate and Erfoud (two areas where most of the sites are located) are sites with a long history of filming movies and colossal, therefore, there is quite an experience of outdoor large-scale operations. Summer temperatures are the major constrains to outdoor activities because from June to August temperatures range from 35 C to 50 C. Usually, operative crew spend night and dinner in Hotels in cities nearby the test site. Then they move every morning to the site to perform their activities. It usually takes half an hour to reach the site, but longer transfer can take into account. There is also the possibility to camp in the site area with comfortable beduin-style tents. K-9 guards from private companies protect the hardware left in the filed. Apart from the very busy airport of Marrakech with a number of cheap flight to Europe there are airports in Ourzazare and Errachidia. Rainfall are of desrtic type (heavy showers) concentrated in December to February).

Table 1: Tests and activities.

Type of test and activity	**Object of test**	**Logistic**
Descent systems	Parachutes, retrorockets, airbags	Chopper, UAV
Rover operations	Visual systems, autonomy, transverse	Large field areas, communications, Martian-like environments
Scientific operations	Payload instruments	Sites with scientific value
Drilling operations and science	Driller	Martian-like environments and stratigraphy
Geophysics	GPR, shallow seismic, etc	Martian-like environments and stratigraphy

HYDRATED SILICATES ON MARS: LESSONS LEARNED FROM TERRESTRIAL IMPACT CRATERS. G. R. Osinski[1] and L. L. Tornabene, [1]Centre for Planetary Science and Exploration, Depts. of Earth Sciences/Physics and Astronomy, University of Western Ontario, London, ON, N6A 5B7, Canada (gosinski@uwo.ca), [2]Center for Earth and Planetary Studies, National Air and Space Museum, Smithsonian Institution, Washington, DC 20560-0315, USA

Introduction: Hydrous silicates, in particular phyllosilicate clays and hydrous glasses, have been detected from orbit in the heavily cratered and ancient highlands of Mars [1-3]. Because these phases typically form from the prolonged exposure of rock in contact with large amounts of water on Earth, a similar mechanism has been proposed on Mars and their discovery within the oldest Noachian surfaces has been interpreted as possible evidence for a warmer and wetter climate on Early Mars [1-3]. It has been pointed out that these hydrous silicate phases on Mars are often associated with surface materials that are interpreted as being of impact origin [4, 5]; however, few studies have been conducted as to the spatial, temporal, and genetic relationship between phyllosilicates and impact craters. Most previous studies have typically explained the proximity of hydrated silicates to impact craters and basins in one of two ways: via impact re-sampling (i.e., the exposure and excavation of preexisting hydrated materials), and/or impact-generated hydrothermal alteration [3, 6, 7].

What can terrestrial impact structures tell us about the origin of hydrous silicates on Mars? Studies of terrestrial craters show that these phases can be produced through 1) impact-induced hydrothermal alteration, 2) devitrification or autometamorphism, and 3) post-impact diagenetic alteration. These mechanisms are not completely understood. As such, terrestrial impact sites should be considered high priority “analogue” sites for preparing for, and understanding the results of, MSL and the Mars 2018 missions:

- MSL: This is a rover mission that will aim to determine whether a particular region of Mars’ surface has ever featured environments that were or are able to support microbial life, and to quantitatively assess any potential habitats.
- Mars 2018: ExoMars science objectives are to search for signs of past and present life, and to characterize the subsurface in terms of physical structure, presence of water/ice, and its geochemistry. The goals of MAX-C are to cache suitable samples from characterized sites that might contain evidence of past life and/or prebiotic chemistry in preparation for a possible future MSR mission.

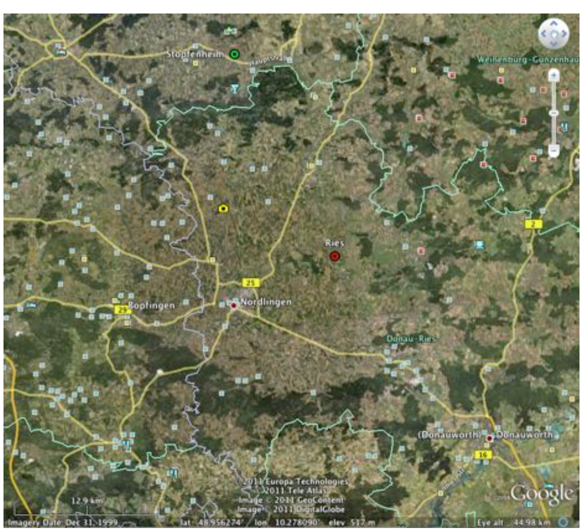

Fig. 1. The Ries impact structure, Germany.

There are approximately 180 impact craters on Earth. Impact-generated hydrothermal deposits have been documented from approximately 60 of these [8]. There are, thus, potentially many sites available for study. However, many sites are buried, under water, too eroded, too heavily vegetated, or in politically unstable regions of the world. Furthermore, the alteration phases produced reflect, in part, the composition of the host rocks. For example, at the 23 km diameter, 39 Ma Haughton structure, which formed in a carbonate-dominated target sequence, the alteration phases are typically carbonates and sulfides and clays are notably lacking [9, 10]. Here, we showcase three sites. The 24 km diameter, 14 Ma Ries structure, Germany (48°53' N, 10°37 E) (Table 1) (Fig. 1) has had much research done; the other two, the twin Clearwater Lakes structures, have not been studied since the 1970's, but phyllosilicates have been documented [11]. At all of these sites, there are multiple (>20) sites of prime science interest.

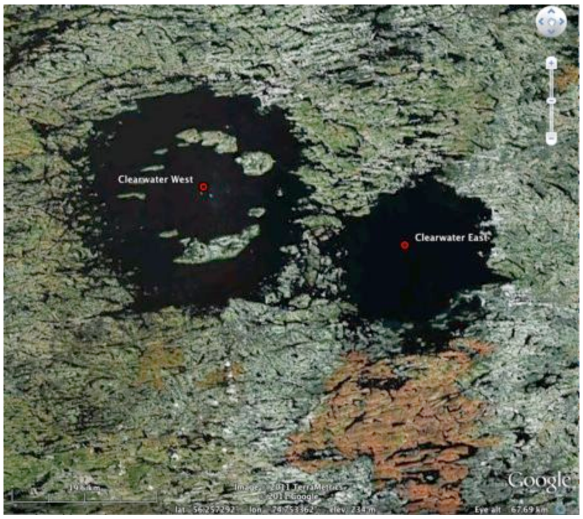

Fig. 2. The East and West Clearwater Lake impact structures.

Mission Description: Four potential MSL landing sites have been selected: Gale Crater (4.5S, 137.4E), Mawrth Vallis (24°N, 341°E), Holden Crater (26°S, 325°E), and Eberswalde Crater (23.9°S, 327°E). Future efforts and remaining questions surrounding the origin of hydrous silicates have been identified for all of these sites and many of these can be addressed by carrying out analogue activities at the terrestrial impact structures.

Science Merit Related to Mission Objectives: One of the primary goals of MSL is to quantitatively assess any potential habitats for life. As noted above, 4 candidate landing sites have been selected, 3 of which are impact craters, and the 4th (Mawrth Vallis) will likely contain a high percentage of impact-generated material, exposing as it does some of the oldest Noachian terrains. It is well known that hydrothermal systems will develop anywhere in the Earth's crust where water coexists with a heat source [12]. Recent work suggests that hydrothermal systems will form following the majority of impacts into any H_2O-bearing solid planetary body [10, 13]. Numerical models of these hydrothermal systems suggest that they may last several Ma for large 100 km-size impact structures [14]. Despite the potential economic and astrobiological importance of hydrothermal deposits, there remains no clear understanding of the nature and distribution of such deposits within impact craters; the only detailed map showing the distribution of impact hydrothermal deposits is available for the Haughton impact structure, Arctic Canada [10, 15] (Fig. 1). It is clear, however, that the generation of clays is commonplace during impact-generated hydrothermal activity [8, 13].

Depending on the target composition, some impact melts or glasses can incorporate a range of crustal components sometimes including significant amounts of H_2O (up to ~20% by weight) [16]. Glasses are more susceptible to alteration than crystalline materials, particularly hydrated varieties. At the Ries impact structure, Germany, clay-rich surficial suevites are present in the ejecta deposits. Textural and compositional analyses indicate that a large proportion of these clays may be the product of devitrification or autometamorphism [17, 18], with a minor diagenetic component. Devitrification is the solid-state transformation of metastable glass into phyllosilicates and other alteration products. Detailed field and laboratory studies of altered impact melt-bearing breccias indicate that devitrification may be a significant phyllosilicate-forming process, especially in craters formed in volatile-rich targets [17]. Devitrification is similar to autometamorphism, (metamorphism of igneous rocks by the action of their own volatile fluids), and occurs in both surficial and crater-fill suevites. This mechanism should be considered as a possible mechanism for forming phyllosilicates on Mars. Importantly, the heat and volatiles for devitrification and autometamorphic transformations originate from the melt-bearing deposits themselves and, thus, large amounts of surface water are not required. This has obvious implications for assessing the past climate on Mars.

Most Important Question Answered by Sites: Important questions remain as to the relative role and importance impact-induced hydrothermal alteration, devitrification or autometamorphism, and post-impact diagenetic alteration, in the formation of hydrous silicates in terrestrial impact craters. Before we can begin to understand the formation of these phases on Mars, we must investigate more fully their formation on Earth.

Logistic and Environmental Constraints. The Ries impact structure, Germany, lies in Bavaria and is easily accessible from Munich international airport (approx. 2 hour drive). Several towns lie within the crater and a network of roads cross the crater. The crater is heavily vegetated but a series of old and active quarries provide access to the variety of impact units. The twin Clearwater Lake impact structures lie in tundra environment (Table 1). They are only accessible only by Twin Otter aircraft and then boat, or helicopter from Kuujjuarapik (approx. 200 km), during June to August each year.

Table 1: Summary of the Ries and Clearwater impact structures.

Site Name	Ries impact structure	Clearwater impact structures
Center Coordinates	48°53' N, 10°37 E	66° 5' N, 74° 7' W & 66° 13' N, 74° 30' W
Elevation	0.5 km	0.4 km
Areal Extent	20 km by 20 km	60 km by 30 km
Prime Science Questions	See text.	See text.
Distance of targets from nearest road or airstrip	100’s m	Up to 30 km (dirt airstrip
Environmental characteristics	Max temp (30 °C), min temp (-15 °C), precipitation (~900 mm), vegetation coverage (~99%)	Max temp (30 °C), min temp (-40 °C), precipitation (~700 mm), vegetation coverage (unknown)
Previous analogue studies	[17, 19]	None.
Primary Landing Site Target	Gale Crater, Holden Crater, Eberswalde Crater	Gale Crater, Holden Crater, Eberswalde Crater

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THE SEARCH FOR LIFE ON MARS: IMPACT CRATERS AS PRIME HABITATS AND EXPLORATION TARGETS. G. R. Osinski[1], C. S. Cockell[2], J. Parnell[3], N. Banerjee[1], H. Henry[1], A. Pontefract[1], H. Sapers[1], and G. Southam[1], [1]Centre for Planetary Science and Exploration, Depts. of Earth Sciences/Physics and Astronomy, University of Western Ontario, London, ON, N6A 5B7, Canada (gosinski@uwo.ca), [2]Planetary and Space Sciences Research Institute, Open University, Milton Keynes, MK7 6AA, UK, [3]Dept. of Geology, University of Aberdeen, Aberdeen AB24 3UE, UK

Introduction: Impact cratering is, arguably, the most important and fundamental geological process in the Solar System. The Martian impact cratering record is notably diverse [1]. The common perception of impact events is that they are agents of destruction. Hence, the deleterious effects of impact events have received a great deal of attention, prompted in a large part by the discovery of the Chicxulub impact structure, Mexico, and its link to the K-T mass extinction event [2]. However, a growing body of evidence suggests that impact events also have beneficial effects, particularly in terms of microbial life [3-7]. Based on our multi-year studies of the Haughton impact structure, Arctic Canada, the Ries impact structure, Germany, and several other terrestrial impact sites, we propose that the potential habitats associated with impact craters may have substantial implications for the search for life on Mars and should be considered high priority exploration targets. Because of the ubiquity of impact craters on the surface of Mars, terrestrial impact sites should be considered high priority "analogue" sites for the MSL/Mars 2018 missions. Considering impact craters as habitats for life has direct relevance to these missions:

- MSL: This is a rover mission that will aim to determine whether a particular region of Mars' surface has ever featured environments that were or are able to support microbial life, and to quantitatively assess any potential habitats.
- Mars 2018: ExoMars science objectives are to search for signs of past and present life, and to characterize the subsurface in terms of physical structure, presence of water/ice, and its geochemistry. The currently proposed objectives of MAX-C are to cache suitable samples from characterized sites that might contain evidence of past life and/or prebiotic chemistry in preparation for a possible future MSR mission.

Fig 1. Aerial view of the Haughton structure.

There are approximately 180 impact craters on Earth. We have commenced a detailed review of the terrestrial impact cratering record to determine all impact sites that may have potential as analogues for future Mars missions. Many sites are automatically disqualified as they are buried, under water, too eroded, so heavily vegetated that access is difficult and/or outcrops are very limited, or in politically unstable regions of the world. Here, we showcase two sites where access is possible and where work has been conducted, or is ongoing, in terms of impact craters being potential habitats for life: these two sites are the 23 km diameter, 39 Ma

Haughton impact structure, Devon Island, Arctic Canada (75° 22' N, 89° 41' W), and the 24 km diameter, 14 Ma Ries impact structure, southern Germany (48°53' N, 10°37 E) (Table 1). At both of these sites, there are multiple (>20) sites of prime science interest.

Fig. 2. The Ries impact structure, Germany. Image: G. Pösges.

Mission Description: Four potential MSL landing sites have been selected: Gale Crater (4.5S, 137.4E), Mawrth Vallis (24°N, 341°E), Holden Crater (26°S, 325°E), and Eberswalde Crater (23.9°S, 327°E). Future efforts and remaining questions have been identified for all of these sites and many of these can be addressed by carrying out analogue activities at the Haughton and Ries impact structures.

Science Merit Related to Mission Objectives: One of the primary goals of MSL is to quantitatively assess any potential habitats for life. As noted above, 4 candidate landing sites have been selected, 3 of which are impact craters, and the 4th (Mawrth Vallis) will likely contain a high percentage of impact-generated material, exposing as it does some of the oldest Noachian terrains. However, despite the selection of these impact sites, they have generally been considered as repositories of sedimentary material. Little attention seems to have been paid to the possibility that these impact craters themselves may have originally represented prime habitats for life following their formation; evidence, if it exists, that will still likely be preserved today.

Based on ongoing and/or completed work at the Haughton, Ries, and other terrestrial impact structures, we propose that impact craters produce many beneficial effects and that they represent ideal habitats for life. Several aspects are highlighted below:

- *Impact-generated hydrothermal systems* – It has been shown from studies of terrestrial craters that most impact events generate heat sources capable of sustaining hydrothermal systems [8], which could provide habitats for thermophilic and hyperthermophilic micro-organisms [9]. The search for biosignatures in fossil terrestrial impact hydrothermal systems is ongoing, but preliminary evidence is provided by S-isotope studies at Haughton [10] and from impact glasses at the Ries structure [11]. The hydrothermal systems have been well characterized [6, 9, 12].
- *Endolithic habitats* – Following this initial phase of hydrothermal succession, several other habitats will become important. At Haughton, it has been shown that impact-processed crystalline rocks have increased porosity and translucence compared to unshocked materials, improving microbial colonization [5, 13, 14]. Shocked sedimentary rocks also preserve this capability [15].
- *Impact crater lakes* – Intra-crater lakes form protected sedimentary basins that can provide improved environments for sustaining communities of primitive phototrophs and increase the preservation potential of fossils and organic material. Both Haughton and Ries preserve crater lake sediments [16, 17].

Both the Haughton and Ries structures contain diverse rock types and geological settings, including impact-generated clays and carbonates at the Ries structure and carbonates, sulfates (gypsum, jarosite, etc.), and sulfides at Haughton. Both structures are well preserved and high resolution satellite imagery is available.

Most Important Question Answered by Sites: There are several fundamental science questions that can be addressed at these sites: (1) Have impact-generated hydrothermal systems been colonized by life? (2) Are endolithic habitats produced in shock processed crystalline rocks on Mars? (3) Do impact crater lakes preserve a record of the potential biological succession of a crater? (4) Where are the prime sites within an impact crater where one should look for life? In terms of the latter, it is notable that work on the hydrothermal system at Haughton has highlighted paleohydrothermal vents that are located only around the crater rim region [6].

Logistic and Environmental Constraints: The Haughton structure lies in a polar desert environment that is largely unvegetated (Table 1). It is accessible only by Twin Otter aircraft or helicopter from Resolute Bay, Nunavut (approx. 1 hour flight), during late June to early August each year. Commercial flights are available to Resolute Bay. Four main permits are required: a research permit from the Nunavut Research Institute, a land use permit from the Dept. of Indian and Northern Affairs Canada, a Water License from the Nunavut Water Board, and access permit from the Qikiqtani Inuit Association to access the parts of the crater that are designated Inuit Own Land. The Ries impact structure, Germany, lies in Bavaria and is easily accessible from Munich international airport (approx. 2 hour drive). Several towns lie within the crater and a network of roads cross the crater. The crater is heavily vegetated but a series of old and active quarries provide access to the variety of impact units.

Table 1: Summary of the Haughton and Ries impact structures.

Site Name	Haughton impact structure	Ries impact structure
Center Coordinates	75° 22' N, 89° 41' W	48°53' N, 10°37 E
Elevation	0.2 km	0.5 km
Areal Extent	30 km by 30 km	20 km by 20 km
Prime Science Questions	See text.	See text.
Distance of targets from nearest road or airstrip	Up to 15 km (dirt airstrip	100's m
Environmental characteristics	Max temp (15 °C), min temp (-40 °C), precipitation (<13 mm), vegetation coverage (<1%)	Max temp (30 °C), min temp (-15 °C), precipitation (~900 mm), vegetation coverage (~99%)
Previous analogue studies	[5, 6, 9, 10, 13-16, 18-23]	[11, 12]
Primary Landing Site Target	Gale Crater, Holden Crater, Eberswalde Crater	Gale Crater, Holden Crater, Eberswalde Crater

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Microbial Habitability in Periglacial Soils of Kilimanjaro

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Introduction: The Kilimanjaro stratovolcano lies on the tectonically active Rift Valley of Africa, and is relatively young (geologically) with volcanic activity starting a million years ago and evidence of recent activity several hundred years ago in the central ash pit. The summit of Kilimanjaro hosts high-elevation, periglacial soils that are among the most extreme soils on Earth. Microbes eking out a living in these near-sterile, volcanic Fe, Al-silicate soils face extreme diurnal freeze-thaw cycles, high UV flux, half an atmosphere of pressure, and extreme low nutrient content and water activity. This environment is being investigated as a possible Mars analog for putative microbial habitability in Martian oligotrophic mineral soils and ices in support of MSL and a planned Mars 2018 mission (either sample caching or astrobiology field lab, AFL, rover missions). Since organic carbon measurements are expected to serve as a first tier screen for life detection [1], the low organic carbon soils of Kilimanjaro will enable us to better understand how organic carbon measurements can serve as an indicator for soil sterility, or conversely, for possible life or prebiotic chemistry. Moreover, the melting glaciers and fumaroles afford the possibility of investigating microbial habitability across temperature and water gradients, which will allow studies of microbial viability, diversity and abundance in a continuum of microenvironments. The summit of Kilimanjaro is an excellent Mars analog that will help define the boundary conditions for microbial habitability, and establish guidelines for Mars sample selection.

Mission Description: Mars scientists operating rovers with organics detection instruments will need to decide whether or not to cache a sample for return analyses, or perform further *in-situ* life detection analyses. On Earth, the presence of organics in desert soils is strongly correlated to viable microbial content. In general, desert soils with total organic carbon (TOC) >5000 µg/g contain at least 10^6 CFU/g of aerobic bacteria [2]. The Kilimanjaro

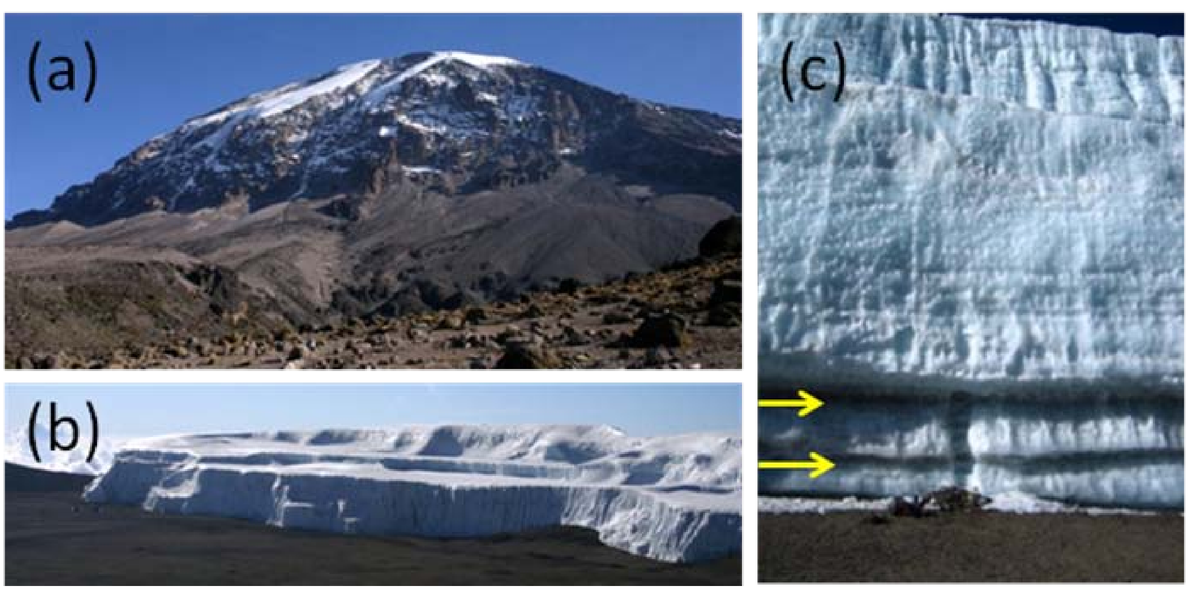

Figure 1. (a) Kilimanjaro **(b)** Summit soils juxtaposed to Northern Ice Field, **(c)** 2008 sampling site with dust rich layers indicated by yellow arrows.

analog site will enable organic carbon and microbial viability measurements across gradients of water, temperature in transects away from the melting glacier and fumaroles. Notably, the endmember soils on Kilimanjaro contain TOC <1000 μg/g and are near sterile. Investigations of microbial viability, organic carbon content, and water activity in these soils will determine growth thresholds that will indicate viable microbial content.

Science Merit Related to Mission Objectives: Kilimanjaro is an excellent analog for Mars and displays a variety of stratigraphic units that present a diverse morphology, mineralogy, and display distinct mappable cross-cutting relationships. The primary rock units associated with the volcano consists of alternating lavas, ashes, and glacial deposits. During recent geologic time, the summit of Kilimanjaro was covered by an ice cap, and the remnants of the ice cap can be seen as the spectacular ice cliffs of the Northern and Eastern Icefields (figure 1). During the advancing and retreating of these glaciers across the summit, a series of concentric ring-like terraces were created near the top of this volcanic massif. The site contains fissure vents and fumaroles, melting/subliming glaciers with stratigraphic layering, including embedded atmospheric dust, and supraglacial meltwater ponds with mud each of which present microbial habitats for investigation [3].

Most Important Question Answered by Site: How does surface oxidation impact organic carbon content, what are the organic carbon thresholds for microbial activity and survival, and how can these thresholds help establish sample collection criteria for sample return or life detection on Mars?

Logistic and Environmental Constraints: Scientific research on Kilimanjaro requires permits, issued at the national and local level, which are (1) a Research Permit from the Tanzania Commission for Science and Technology, (2) a Residence Permit from the Immigration Services, and (3) a TANAPA Research Permit from Tanzania National Parks. These requirements were met when Ponce organized an expedition to Kilimanjaro in October 2008 and 2010 to return samples for microbial diversity, viability, and radiocarbon analyses [3]. In addition, the University of Massachusetts operates a fully permitted weather station atop the Kilimanjaro glacier (since 2000), and Thompson et al. drilled and returned several cores from Kilimanjaro glaciers. Although Kilimanjaro is not a technical climb, there are risks associated with operations in extreme high altitude, including pulmonary and cerebral edema. Guide companies supply oxygen for emergency use, hyperbaric chamber Gamow bag, AED heart saving device, automated external defibrillator, and pulse-oximeter.

Table 1: Kilimanjaro analog site.

Site Name	Kibo
Latitude, longitude	Latitude: -3.06667, Longitude: 37.35
Elevation, Areal Extent	5.9 km, 2 km by 2 km
Prime Science Questions	What is the organic carbon threshold in Fe-, Al-silicate soils for microbial viability?
Distance of Science Targets from nearest road or airstrip	From nearest road, it is a 6 days hike to reach Kilimanjaro summit.
Environmental characteristics	Max temp: 5 °C, Min temp: -26 °C Precipitation: 100 mm, Vegetation coverage: None
Previous studies	Manuscript in preparation.
Primary Landing Site Target	Phylosilicate rich landing sites.

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WEATHERING OF MAFIC DIKES IN SOUTHWESTERN GREENLAND AS AN ANALOGUE FOR LOCAL SOURCES OF METABOLIC ENERGY ON MARS. L. M. Pratt[1], S. A. Young[1], T. C. Onstott[2]
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Introduction: Planetary exploration of Mars has advanced rapidly in the past decade with high-resolution data from orbiting and landed instruments upending the image of a monotonously arid red planet and raising interest in a search for evidence of past or present Martian life. Cratered landscapes dissected by abandoned channels and active gullies, sedimentary sequences containing phyllosilicate and evaporite minerals, and traces of atmospheric methane are tantalizing clues about the habitability potential for dynamic Mars [1–6]. Immense volcanic structures on Mars [7] are likely associated with fracture networks and with disruption of the cryosphere/hydrosphere in ways that could provide nutrients and water for past or present microorganisms [8–12]. Volcanic dike emplacement could initiate melting of ground ice/permafrost, drive hydrothermal mineralization near the margins of the dikes, and trigger large-scale releases of groundwater to the Martian surface [9,10,11]. Both ancient and recent dykes are of interest from the perspective of looking for evidence of life in potentially habitable niches on Mars. A mafic dike swarm near Kangerlussauq in southwest Greenland (Fig. 1) is well suited as a field site to study alternation of mafic rocks in a relatively cold and dry climate. The oxidation/reduction potential for microbial metabolism or carbonate-reduction serpentinization can be assessed by X-ray study of mineral content inward from the weathered rind to fresh mafic rock units in the study area (Fig. 2). In addition to discrete dikes, mineralized veins and zones underlying rusty weathering zones (gossans) can be assessed for the presence of localized sulfide mineralization. Concentration and isotopic composition of reduced sulfur species (monosulfide minerals), elemental sulfur, and fully oxidized sulfur species (sulfate minerals) can be measured in bedrock boreholes (0.5 to 2 m depth) intersecting permafrost environments across a study site of about 1 km^2. Once drilled, shallow boreholes can be sealed and used for repeat sampling of subsurface emission of methane and hydrogen sulfide without atmospheric dilution. Results of the proposed study in Greenland are fundamental to engineering and scientific preparation for a proposed dual landing in 2018 of a NASA rover designed to explore and cache samples and a European Space Agency rover designed to drill down to depths of 2 m [13,14] because planetary protection and life detection require development, testing and refinement of new instrumental methods for directly determining the concentration and isotopic composition of reduced trace gases in Martian samples collected from the lower atmosphere and in shallow boreholes.

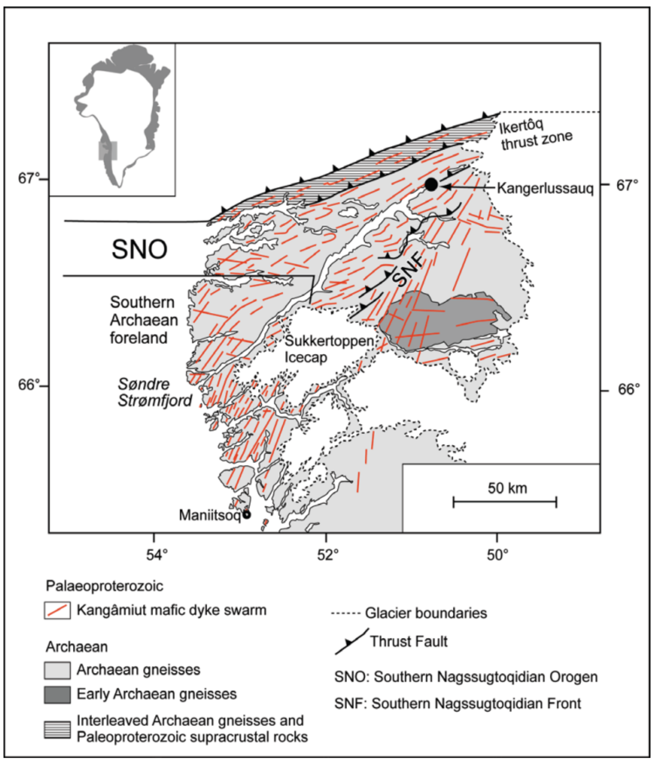

Figure 1. *Regional geological map of southwestern Greenland showing Proterozoic and Archean rock units and boundaries of orogenic provinces. Red lines indicate mapped mafic intrusions in the Kangâmiut dyke swarm. Map modified from vanGool et al. [ref 17].*

Geologic Framework and Relevance to Mars: The ice-free margin of Greenland exposes several deeply eroded Paleoproterozoic tectonic terranes separated by strongly deformed orogenic belts such as the bedrock in the Kangerlussuaq region (Fig. 1) which is part of the Nagssugtoqidian Orogeny [15].

The Nagssugtoqidian belt is divided into three tectonic segments [16,17,18] with the Kangerlussuaq region lying within the southern Nagssugtoqidian orogen (SNO) segment consisting predominantly of reworked gneisses of Achaean age [18,19]. Structural fabrics trend east-northeast in the SNO region with folds trending east-west on a kilometer scale and metamorphic grade reaching amphibolite facies [18]. Critical for the proposed Mars-analogue shallow drilling is the presence of the Kangâmiut mafic alkaline dyke swarms with varying amounts of pyroxene, olivine, hornblede, and carbonate minerals [20,21]. The Kangâmiut dyke swarm (Figure 1) was emplaced into the SNO gneisses at ~ 2.04 Ga ago apparently intruding along pre-existing fracture zones that were present ~ 200 million years prior to the Nagssugtoqidian Orogeny and were subsequently deformed during collisional folding [19, 22]. The mafic dikes are steeply dipping and north-northeast trending in southern Greenland but are folded, foliated, and boudinaged along with their host gneisses in the SNO segment near Kangerlussuaq [17]. Although more alkaline than the tholeiitic basalts on Mars [23,24,25], the dikes contain abundant olivine and pyroxene indicating a mineralogically useful analogue for rocks on Mars. Fracture features associated with brittle deformation are common in the Kangerlussuaq region, including joints, fissures, cracks and linear veins at scales larger than grain size of the host rocks units. The combination of mafic units and diverse fracture features allow drilling of shallow boreholes with good potential to intersect porous fracture zones harboring microbial communities linked to redox cycling of iron and sulfur.

Figure 2. *Bedrock exposures on the western margin of the Greenland Ice Sheet near Kangerlussuaq. The dark-gray unit, about 1 meter in thickness and on the left of the geologist is a mafic dike. Photograph taken by Bruce Douglas from Indiana University during summer 2008 field season.*

Similar microbial communities might have been harbored in hydrothermal systems associated with the emplacement and subsequent cooling of giant dike swarms in the Tharsis and Elysium Regions on Mars [26]. Hydrothermal minerals and deposits have been predicted to be present in the vicinity of dike swarms and associated graben and fracture features on Mars [e.g., 9,11]. V-shaped cracks, fractures, pit-crater chains, grabens, and out-flow channels all associated with Martian dikes and hydrothermal waters [10,11, 12, 27] would have provided entries for microbes into subsurface systems that contained ferrous sulfide minerals available for microbial oxidation. Additionally, regions of past hydrothermal activity provide ideal locations to search for morphological and geochemical evidence of past microbial life potentially preserved in these mineral rich deposits [28, 29].

Sulfur isotopic compositions of ions in the water column, minerals, and organic matter in the sediment column are sensitive indicators of sulfur utilization by microbes. Results from a recent investigation (summer 2009) of groundwater from a deep borehole underneath a thermokarst lake that intersects a bedrock fracture zone in the Kangerlussuaq region, show that sulfate was the dominant ion in the fracture water with the concentration at the time of drilling in the range of 200-250 mg/l. Dissolved sulfate from the borehole has a $\delta^{34}S$ value near zero indicating oxidation of sulfide minerals rather than incursion of seawater. Preliminary investigation of the weathered margin on a mafic dike extending under an acidic lake (pH, 3.46) near Kangerlussuag revealed a diverse suite of sulfur species including pyrite, elemental sulfur, and sulfate minerals.

Logistics and Environmental Constraints: Access to the proposed study site is possible year-round at reasonable cost due to the presence of a former U.S. military airbase with re-purposed buildings serving as the Kangerlussuaq International Scientific Support (KISS) Facility. Using small trucks and all-terrain vehicles, researchers can reach the study site on the southwest margin of the Greenland ice sheet in about 1.5 hours after leaving KISS. Greenland requires travel permits to work in National Parks, on the Greenland ice cap, and in many parts of the ice-free regions. As of February 10, 2010, the Executive Order on Access to and Conditions for Travelling in Certain Parts of Greenland is handled by Greenlandic Ministry of Domestic Affairs, Nature and Environment.

Table 1. *Standard information required for Mars Analogue Site.*

Site Name	Kangerlussuaq, southwest Greenland
Coordinates: Latitude, Longitude	Between 67°N–68°N and 51°W–50°W
Areal Extent	200 km by 100 km
Prime Science Question	Can sulfide minerals associated with dike swarms be local sources of metabolic energy for microbes in extreme environments?
Distance of science targets from nearest road/airstrip	~ 1.5 hours by truck/all-terrain vehicle from airstrip at Kangerlussuaq International Scientific Support (KISS) Facility
Environmental Characteristics	Max temp: 17°C; Min temp: -27°C; Precipitation: average is 149 mm; Vegetation coverage: varies from bedrock exposures with no vegetation to grass covered areas with developed soil horizons
Previous Studies at analoge site	Geological Studies [refs: 15, 16, 17, 18, 19, 20, 21, 22]
Primary Landing Site Target	Dike swarms in Tharsis & Elysium Rise regions of Mars

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THE MOJAVE DESERT: A MARTIAN ANALOG SITE FOR FUTURE ASTROBIOLOGY THEMED MISSIONS. E. Salas[1], W. Abbey[1], R. Bhartia[1], and L. W. Beegle[1], [1]Jet Propulsion Laboratory, California Institute of Technology, 4800 Oak Grove Dr., Pasadena CA, 91109-8099.

Introduction: Astrobiological interest in Mars is highlighted by evidence that Mars was once warm enough to have liquid water present on its surface long enough to create geologic formations that could only exist in the presense of extended fluvial periods. These periods existed at the same time life on Earth arose. If life began on Mars as well during this period, it is reasonable to assume it may have adapted to the *sub*surface as environments at the surface changed into the inhospitable state we find today. If the next series of Mars missions (Mars Science Laboratory, ExoMars Trace Gas Orbiter, and near surface sample return) fail to discover either extinct or extant life on Mars, a subsurface mission will be necessary to attempt to "close the book" on the existence of martian life.

Mars is much colder and drier than Earth, with a very low pressure CO_2 environment and no obvious habitats. Terrestrial regions with limited precipitation, and hence reduced active biota, are some of the best martian low to mid latitude analogs to be found on Earth, be they the Antarctic dry valleys, the Atacama or Mojave Deserts. The Mojave Desert/Death Valley region is considered a Mars analog site by the Terrestrial Analogs Panel of the NSF-sponsored decadal survey; a field guide was even developed and a workshop was held on its applicability as a Mars analog (see Table 1). This region has received a great deal of attention due to its accessibility and the variety of landforms and processes observed relevant to martian studies (Figure 1).

Mission Description: Until recently the only exploration of Mars has been confined to scratching the surface. Viking, Phoenix and MER have studied the surface and near surface, and both appear to be very inhospitable to life. If the surface *was* once habitable and life originated there, it is reasonable to assume that, to survive, life had to adapt to the more hospitable environments in the subsurface. These habitable niches would have to have access to liquid water and an energy source for extant life to still be viable. However, as the migration into the subsurface occurred, evidence would be preserved through chemical and mineralogic signatures that could be explored with a drilling mission. This drilling mission would have to be able to access sufficiently deep into the subsurface, 10's to 100's of meters.

Science Merit: In nature, microorganisms occur as communities where diverse types of microbes co-exist as cohesive colonies, especially when they exist in extreme conditions [1]. The number of habitats known to support microbial communities has steadily increased in recent years and now includes environments once thought anathema to life. Microbes have been discovered inhabiting uranium mines [2], rocks up to 3 km below the surface [3], and oceanic crust 150 m below the sea floor [4]. However, the subsurface microbiology of arid regions has yet to be fully characterized.

In terrestrial ecosystems, within the vadose zone, microbial biomass is found to correlate with factors such as carbon availability [5], terminal electron acceptor availability [6], nutrient availability [7], pH [8] and temperature [6]. The composition of terrestrial subsurface communities has also been found to be strongly depth dependent; communities tend to lose cell

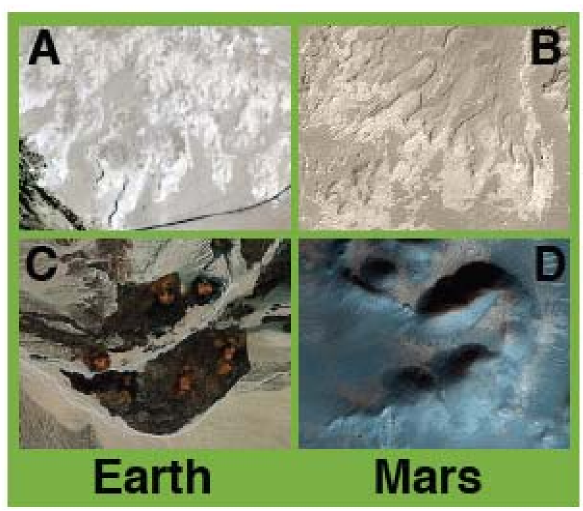

Figure 1. A) Alluvial fan deposit near Shoshone, CA; B) MOC image of a dried river delta in Eberswalde Crater, Mars; C) Lava formation at Cima, CA; and D) A HiRISE IRB color image of the Nili Fossae Trough, an MSL candidate landing site.

numbers, as well as phylogenetic and metabolic diversity, with depth [7, 9, 10]. Studying the variability of organisms in vadose zones within the same climate but in different geological contexts, constrains drilling scenarios on future missions. This includes understanding the variability of within a potential landing site (i.e. understanding the differences, if any between here and 100 meters ways), and depth required to fully understand microbial potential.

Most Important Questions Answered by Site: The Mojave region is an ideal place to perform subsurface investigations as there is an incredible amount of terrain, landform and geologic diversity within a very limited geographic area. There are multiple sites with a fluvial history and orbital geologic features that would make it a likely target site if the same features existed on Mars. Additionally, these sites have experienced the same general climate since the last glacial maximum [11]. At that time, the area was much different, with an ample supply of fresh water from a cooler, wetter climate and from ice melting off the nearby Sierra Nevada. Age dating of subsurface pore waters near this region indicate that the last major wetting of deep soils (>5 m) was at ~14 ka [12]. When the region began to dry the chemistry of the subsurface invariably changed; any organisms that could not adapt to the changing environment would have died off, leaving nutrients and a supply of organic matter for those able to adapt. Any subsequent variation in these subsurface habitats can reasonably be attributed to intermittent hydro-geologic events or local mineral and chemical differences in these environments.

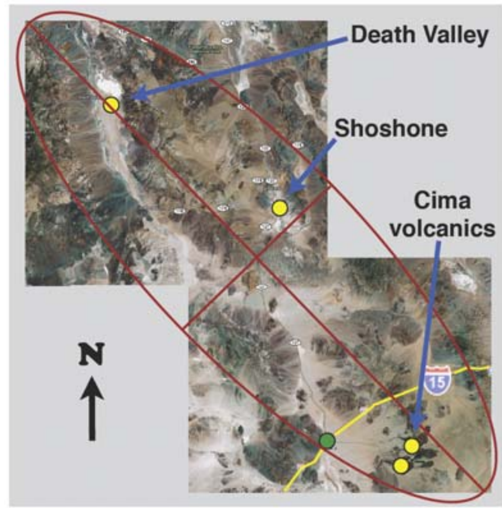

Figure 2. Sites within the Mojave Desert National Preserve & Death Valley National Park. Pale gold dots are proposed drill sites (northern site is DV; southern sites are Cima volcanics; middle site is near Shoshone, CA). Green dot is Baker, CA. Major axis of hypothetical landing elipse is 100 km.

Figure 2 has called out three distinct sites. The Death Valley site was chosen as a field site because its geology has been well characterized, providing a strong foundation for our study [13]. Also, a wide variety of mineralogically distinct evaporite deposits are present within a small area, including gypsum which was recently observed on Mars [14]. At this site we are primarily interested in drilling into an areally extensive gypsum deposit of varying depth and stratigraphic composition.

The second site is an extensive delta deposit located near Shoshone, CA, just outside the boundaries of Death Valley NP. In the Mojave these exposed pediments can vary widely in age, some dating back to well before the region became arid [15], with the older deposits naturally exhibiting a marked increase in well developed soil profiles, which likely has a dramatic effect on the ability of microbes to uptake vital nutrients.

The third field site is the Cima Volcanic Field located 20 km south of Baker, CA , and consists of a lava flow over desert paleosol. This location was chosen because it has experienced multiple volcanic events over the last several million years [16] making it an ideal location to investigate the ability of near subsurface microorganisms to survive extreme catastrophic events. It is expected that the thermal wave penetrated several meters into the soil, approximately the depth of the root zone, at a time when there was abundant vegetation present [17]. These events yielded one of three possible outcomes for the microbial communities present at the time of the eruptions: 1) greatly reduced metabolism in an effort to survive; 2) death of the microbial community due to heat from the lava flow or the newly created energy/nutrient limiting environment; or 3) alteration of the community structure to take advantage of previously less than desirable energy sources.

Understanding the variety in this region enables us understand what might have occurred on Mars during its own 'drying out' period.

Logistics and Environmental Constraints: There is excellent accessibility to the Mojave/Death Valley region. It is within easy (<4 hours) driving distance from several major airports, and is connected via a series of roads to the I-10, which runs right through the region. Most of the land is Bureau of Land Management, with minor areas in the Mojave National Preserve, Death Valley National Park, as well as private hands. Temperatures during the height of summer (Aug-Sep) can limit access. The average rain fall is on the order of 250 mm, with most of it occurring in the winter. During these rain storms there are sites that become dangerous due to flash flooding.

Table 1: Example table required for any analog site proposed.

Site Name	Mojave Desert/Death Valley
Coordinates Latitude, Longitude	Between ~35.18° & 36.30°N and -115.76° & -116.86°W
Elevation	0 to 2 km above sea level
Areal Extent	100 km by 20 km
Prime Science Question	How do microorganisms evolve as the climate changes from high aqueous to dry, and what evidence do they leave behind as they evolve?.
Accessability	Most sites accessible by 1-2 km of driving from major roads. Major airports ~100 km drive, from both Las Vegas, NV and Ontario, CA.
Environmental Characteristics	Max temp: ~49°C Min temp:<-15°C Precipitation: <254 mm/yr Vegetation coverage: Desert with minimal vegetation
Previous Studies at Analog Site	Farr, T.G., (2004); Greeley, R., et al., (1978); Howard et al. (2001) [18-20].
Primary Landing Site	Eberswalde Crater and Nili Fossae Trough
Other	Evaporite lake beds suggested at both Gusev Crater and Meridiani Planum.

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OPHIOLITES AS SOURCE OF ABIOTIC METHANE ON EARTH: ANALOGUE MISSION POTENTIAL SITES FOR METHANE FLUX MEASUREMENTS ON MARS.

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Introduction:

We propose to conduct direct measurements on the methane flux at the hydrated silicate area of Nili Fossae between 302W and 320W Longitude and 0 to 15 Latitude (Figure 1). The measurement could be conducted with a simple fluxmeter as is used to measure methane flux on Earth (3,4,5,6). Such measurements would definitely answer the controversy on the existence of Methane on Mars (1,2).

In support of the design of the fluxmeter for the lander, we propose measurements at various ophiolite sites in California and, if necessary Greece and Turkey with equipment similar to what we used at other ophiolite sites (Fig. 2)

Mission Description:

The mission proposal is to equip the new Mars Lander with a device for direct methane flux measurements possibly similar to instruments used and tested on Earth.

Science Merit Related to Mission Objectives:

The exhalation of abiotic gas from terrestrial ophiolites represents a fundamental reference for understanding the degassing pathways of methane on Mars, whose origin might be related to serpentinization of ultra-mafic rocks. Faulted ophiolites on Earth have shown to release gas into the atmosphere both through visible manifestations (macro-seeps) and diffuse, invisible exhalation (microseepage) [3]. The existence of abiotic gas microseepage on Earth opens a new perspective for assessing CH4 sources on Mars: microseepage would be the easiest degassing pathway of Martian CH4, as it does not require the special focused gas flows and pressure gradients necessary for sustaining large seeps and mud volcanoes. It can occur on Mars even if macro-seeps or mud volcanoes are lacking or are not active. Thus, the search for the origin of Martian CH4, whether biotic or abiotic, should not be necessarily focused on “point” sources, because weak and diffuse microseepage throughout relatively large areas can also be the primary degassing pathway.

Ophiolites, or hydrated mineral-bearing rocks in general, are studied on Earth as a key analogue for Mars, exclusively in relation to their mineralogical and microbiological implication for life. But ophiolites can also be a source of methane due to abiotic synthesis. Exhalation of abiotic gas from ophiolites exists on Earth and it can represent a fundamental reference to understand the degassing pathways of methane on Mars. Yet, aanalogy studies dealing with the fluctuations of ophiolite methane fluxes over time are missing. Also, minimum values for methane fluxes have to be determined as guidance for the design of the fluxmeter on Mars.

The project outcomes can be:

- A reference model for gas exhalation on Mars that can be considered for the detection strategy (choice of sensors, sampling systems, and target distances) of seepage signals on Mars in future missions

- A reference for the variations of methane fluxes in terrestrial ophiolite in support of the design of the flux meter for Mars

- a model of abiotic gas generation to verify whether ophiolite gas exhalation rates, measured on Earth and assumed on Mars, can be sustained by in-situ gas production rates (kinetics of gas synthesis) or if subsurface gas accumulations, eventually pressurized, are necessary.

Most Important Question Answered by Site:

Is there a discernable active methane flux at the hydrated silica terrains on Mars

Logistic and Environmental Constraints: no restrictions

Standard Information Required for Analogue Sites: In order to communicate the scientific merit of the analogue site to the missions and other scientists, the following information is required:

Table 1: Proposed Methane Flux Site.

Site Name	Various Ophiolite Outcrops in California
Center Coordinates Latitude, longitude	Several sites near Mount Diablo in N. California
Elevation	1000 to 5,000 ft
Areal Extent	Few km^2
Prime Science Questions	Variations of the methane flux in ophiolitic terrains
Distance of Science Targets from nearest road or airstrip	N/A
Environmental characteristics	California in summer
Previous studies at analogue site	Refs 3,4,5,6
Primary Landing Site Target	
Other	

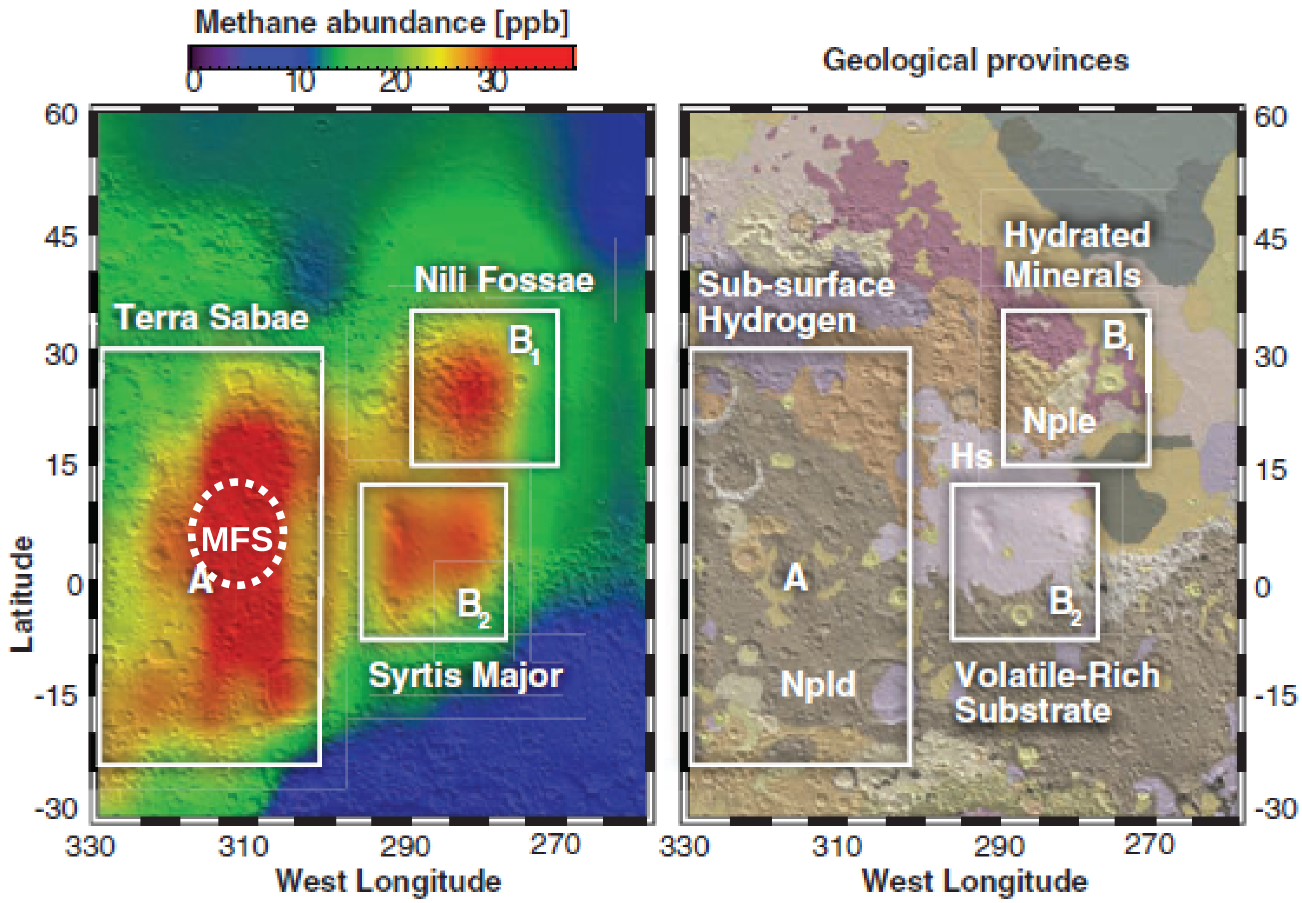

Figure 1: Proposed landing site on Mars for methane flux measurements “MFS” (from Ref.1)

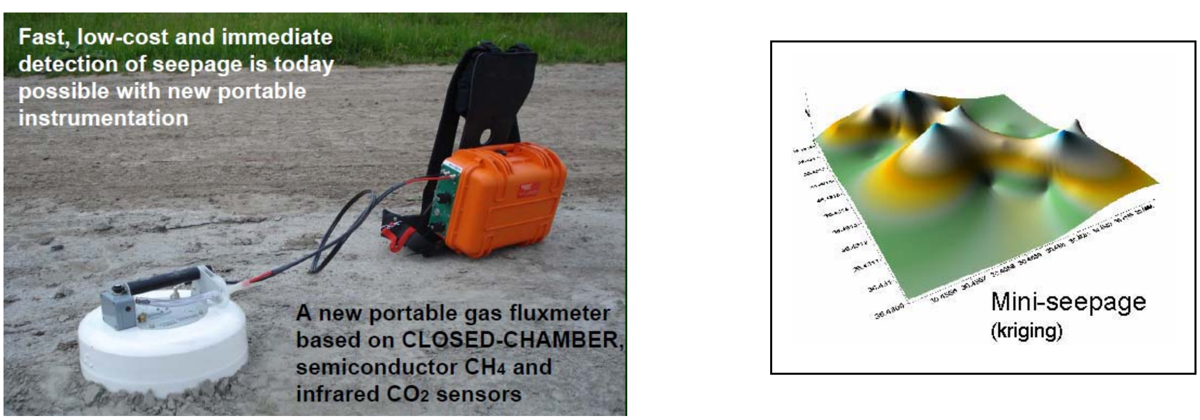

Figure 2:
Left: Methane flux meter for measuring micro seepage in the Nili Fossae area
Right: Microseepage measured at areas of buried ophiolite near Chimera

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NETWORK OF INNER SPACE OBSERVATORIES (NISO) AS TERRESTRIAL ANALOGS FOR THE SUBSURFACE OF MARS (AND OTHER PLANETARY BODIES). Barbara Sherwood Lollar[1], T.L. Kieft[2], and T.C. Onstott[3], [1]University of Toronto (**bslollar@chem.utoronto.ca**), [2]New Mexico Tech (Socorro, NM, tkieft@nmt.edu), [3]Princeton University (tullis@princeton.edu).

Introduction: The proposed target landing site that offers the greatest potential for revealing secrets of the Mars subsurface is Athabasca Valles(*1, 2*), which is a catastrophic flood channel where water and possibly lava are thought to have emerged from the subsurface in multiple events during the late Amazonian epoch. As such, its in-channel deposits have been proposed to be a rich source of recent subsurface material and even to contain biosignatures of subsurface life(*3, 4*). Nili Fossae is also an attractive target for subsurface-related studies due to its large methane plume(*5*). It is an ancient, highly fractured terrain with widely exposed olivine-bearing units(*6*) and abundant serpentinization(*7*). Thus, it allows for both the follow-the-water and follow-the-methane strategies. The source of methane could be subsurface Fischer-Tropsch type reduction of CO_2 by H_2 or even direct biogenic methanogenesis(*8*); either of these scenarios has direct bearing on subsurface life and each has analog habitats/ecosystems in the subsurface on Earth, e.g., in the Canadian Shield, in the Fennoscandian Shield, and in the Kalahari Shield in South Africa. We propose a network of these and other sites as analogues for a subsurface biosphere on Mars as well as other planetary bodies. Our approach thus extends to any and all missions and target landing sites that will generate data from which we can infer habitability of the subsurface (even though currently planned missions, such as ExoMars, will drill no more than ~2 m into the Mars regolith).

Similarly, rather than proposing a single subsurface analog site, we highlight the merits of considering the wide and diverse array of subsurface (so-called inner space) access points worldwide, originally developed for other purposes – including mines, deep geologic repositories and excavations, and existing subsurface laboratories internationally.

Based on research programs spanning the last two decades a substantial body of information and interpretational frameworks exist – ensuring that a new program will be able to build on that rich heritage and make the most rapid progress. Prior information is perhaps most widely available for two settings, the deep gold, base metal and diamond mines of Canada and of South Africa. These might be important targets for the proposed subsurface exploration and census program.

a. The deepest microbial communities yet identified in the planet were investigated and described by a series of papers published on the deep mines of the Witwatersrand Basin including most recently, Lin et al.(*9*) and Chivian et al.(*10*). These papers described a low biomass, low biodiversity ecosystem subsisting by H_2-utilizing sulfate reduction. The origin of the abundant H_2 and sulfate was shown to be radiolytic decomposition of water. The same deep fractures contain high concentrations of abiogenic hydrocarbons. The distribution of these ecosystems may be related to fractures and hydrothermal fluids formed during the 2 Ga Vredefort impact. Completely unexplored are the Pt mines in the 2.1 Ga Bushveld mafic/ultramafic complex north of the Witwatersrand Basin.

b. In a related geologic setting (2.7 billion year old Precambrian Shield rocks) on the other side of the world, significant work has been done to characterize the geologic and geochemical setting in the deep mines of Canada. Abiogenic hydrocarbon and abundant H_2 that may serve as substrates for the deep microbial communities. Due to its ultramafic rock settings, serpentinization is the likely source of H_2 in this setting. Like the hydrothermal vents at Lost City and Rainbow, this is one of the most H_2 rich environments on Earth, with dissolved H_2 up to the mM level.
c. Also located in the Canadian Shield and equally H_2-rich are the fracture waters of the ultramafic/mafic formations in which the Sudbury Neutrino Laboratory resides. Extending to 3 km from surface, the site is both a major scientific research facility and working mine site. Methanogenic communities have been investigated and geochemical evidence suggest the presence of both biologically dominated zones where methanogens and H_2-utilizing SRBs co-exist, with other, typically deeper parts of the system that straddle the biotic-abiotic transition zone and enter a region where the effects of microbiological cycling are minimal and the system is dominated by abiotic water-rock reactions. The SNO facility provides not only extensive access to the deep subsurface but state-of-the-art laboratory facilities on surface making it an ideal setting for real-time sample processing under the highest level of clean conditions and anaerobic handling capabilities. SNO's Director is supportive, indeed eager, to welcome scientific teams beyond the physics community to this unparalleled and easily accessible facility (located just 4.5 hour drive north of Toronto).

Mission Description: Using the follow the methane strategy a rover mission which contains trace gas detectors for H_2, He, hydrocarbons and H_2S, including a CRDS for measuring the C and H isotopic composition of CH_4, would be used to identify sites of active venting or subsurface respiration. These specific locations would be examined outcropping rock units that represent impact ejecta, outwash channel breccia or, if an actual gas vent is detected, particulate ejecta from the vent, in detail with a suite of instruments designed to determine macroscopic features at the mm scale and measure organic carbon species from surface materials. Based upon the analyses samples could be archived for an MSR mission.

Science Merit Related to Mission Objectives: Analyses at the proposed sites provide clues to the type of isotopic, biomass abundance, organic and mineral biosignatures presented by life as we know it in the subsurface of earth versus the isotopic signatures and gas compositions presented by abiogenic systems. The analyses of both water and rock fracture surfaces from these sites informs any rover mission of the type of instruments and sensitivities of those instruments required for life detection.

Most Important Question Answered by Site: Scientific advantages. Much of the above emphasizes the practical advantages of this Network of Observation Points. There are equally compelling scientific arguments for focusing a complementary DCO effort on this resource. In the interest of time I will highlight just a few that are specifically relevant to the sites in Precambrian Shield terrain. While specific to the sites briefly described in Canada and South Africa, the same points would hold for sites in Precambrian exposures throughout the world, including Fennsocandia, the Russian Federation, Australia and South America.

a) As noted, like the Lost City Hydrothermal Vents or Rainbow field, the above settings are some of the most H_2 –rich on the planet and hence an equally critical setting to investigate the planet's habitability – but significantly under investigated compared to the higher temperature hydrothermal systems. They represent a critical environment in which to determine whether the types of chemolithotrophic life recognized at the vents continue to be supported in the much larger segments of the Earth's crust where lower temperatures and hence slower rates of water-rock reaction prevail. This need to investigate lower temperature analogs to the hydrothermal systems has been clearly articulated by those working on the hydrothermal systems(*11*).

b) Tectonically quiescent, ancient fractured rock setting is similarly a critical but to date under investigated element of the Earths' deep subsurface and one which is directly relevant to the Martian environment. Unlike high temperature seafloor systems like Lost City, where rapid fluid circulation and mixing means that the products of water-rock reaction such as H_2 rapidly diffuse away, the hydrogeologically isolated fracture waters in Precambrian Shield rock provide virtual "time capsules" in which, despite the slower rates of reaction, the products of water rock reaction and potential substrates for microbial life can accumulate and build up high concentration gradients over geological long time scales. The deepest and oldest fracture networks have residence time estimates derived from noble gas studies on the order of tens of millions of years. In this sense these systems preserve a geochemical and microbial environment less impacted by mixing with younger more recent systems. They will certainly provide a window into a different aspect of the Earth's biodiversity, but most significantly may preserve a more deeply branched and potentially evolutionarily older component of the Earth's life history with important implications for the origin and radiation of life on Earth.

c) Located in the Sudbury Impact structure, the SNO Observatory Facility has one further aspect worthy of mention. It provides an ideal complement to international research already underway at the impact basins in marine settings. If both sites were studied in a complementary approach, they would provide a superb comparison and contrast of microbial colonization of the subsurface along impact-related fractures and structural controls – under both sub-aqueous and non-aqueous conditions. The Witwatersrand Basin provides a similar impact related setting but in a terrestrial environment.

d) Finally these settings are important analog sites for astrobiological research as well as they will provide an understanding of habitability in single plate planets such as Mars, where surface expressions of volcanism such as hydrothermal vents are unlikely. Similarly, as many sites can be selected in northern regions, the Network also provides important sites for understanding psychrophilic life and hence as analogs for potential extinct or extant life on the icy planets and moons.

Logistic and Environmental Constraints: Logistical constraints are minimal. Each of the NISO sites is a focus of considerable activity, either scientific and/or commercial mining, and so each is served by substantial infrastructure,e.g., roads, electrical power, water, etc. We have built long-term relationships with commercial mines that are included here (e.g., in Canada and South Africa) and these sites are currently being used for scientific study. Environmental conditions cover a wide range of microbial habitability and approach the limits of human habitability; however, scientists and miners routinely work for hours at a time in these sites, and so the infrastructure for access, health, and safety are all well established.

Information on Analogue Sites:

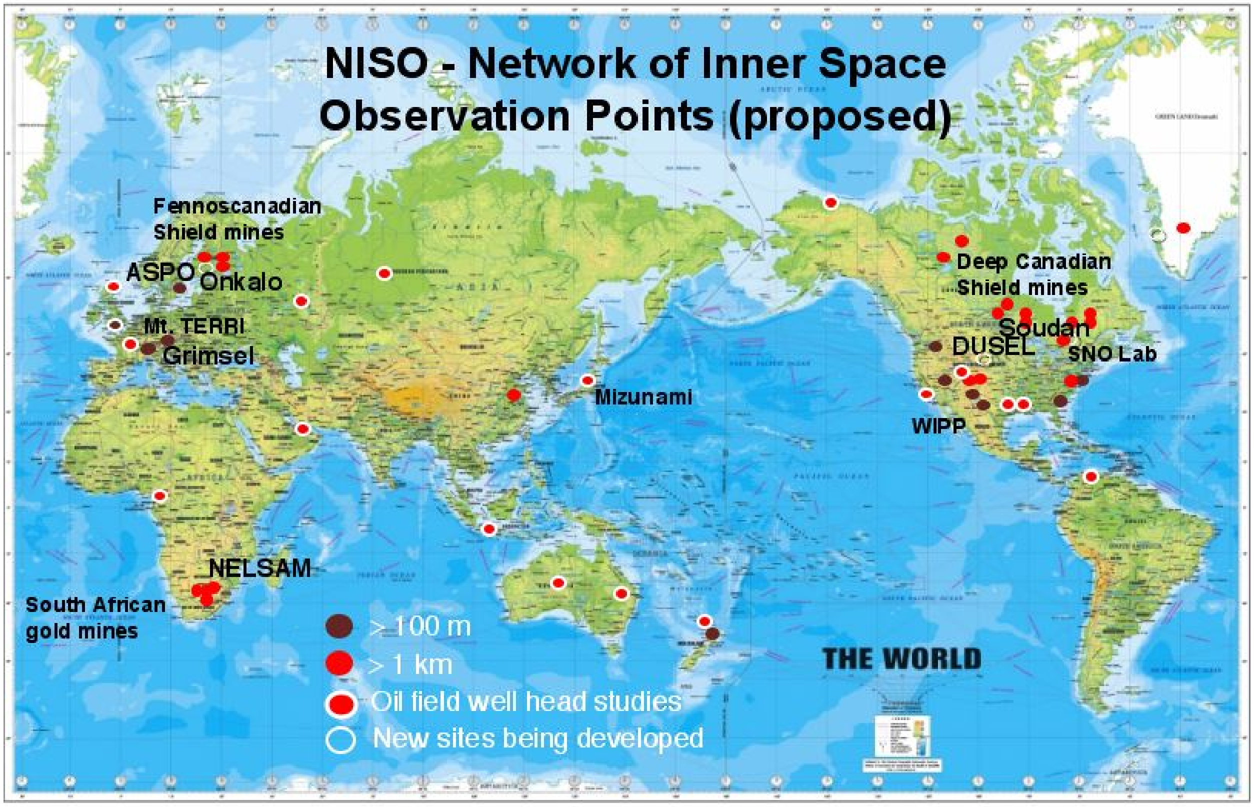

Table 1: Example table required for any analogue site proposed.

Site Name	
Center Coordinates Latitude, longitude	60°N to 30°S Longitudes: varied, see map
Elevation	Surface facillities : 0- 2.5 km
Depths	0 to 3.7 km below land surface
Areal Extent	XX km by XX km
Prime Science Questions	
Distance of Science Targets	0 km from roads or airstrip for all sites

from nearest road or airstrip	
Environmental characteristics	Max temp: 40°C in deep gold mines, but access to water ≥75°C Min temp: <0 in high latitude mines Precipitation: NA for subsurface Vegetation: NA for subsurface
Previous studies at analogue site	
Primary Landing Site Target	Athabasca Valles, Nili Fossae
Other	Any other items of interest

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

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Introduction: The candidate mission MSL 2018 has targeted four landing sites.One of them, 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. Herein we describe the parallel ecological parameters and the astrobiological research at our site that make the environmental phenomenon of Gale crater the most analogous MLS target to Cuatro Cienegas Basin.

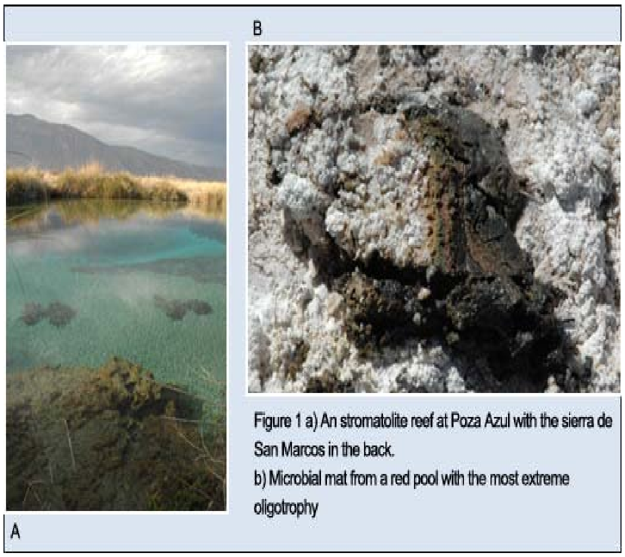

Figure 1 a) An stromatolite reef at Poza Azul with the sierra de San Marcos in the back.
b) Microbial mat from a red pool with the most extreme oligotrophy

The Cuatro Cienegas Basin (CCB) is an oasis in the Chihuahuan desert in the state of Coahuila in the North of Mexico. 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, 9] when compared to similar environments. Its spring-fed ecosystems are dominated by microbial mats and living stromatolitic features (see figure 1) supported by an aquatic sulfur cycle and a terrestrial gypsum based ecology in large parts of the valley[1]. Our work there indicates that the microbial lineages of the site carry a signature of an ancient marine ancestry in their genomes[2-8] and understanding the link between this signal and the palogeochemistry 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 Cyanboacteria from CCB demonstrate that many species from Cuatro Ciénégas 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.

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 halophyle grass
Previous studies at analogue site	10 years of research and 15 publications
Primary Landing Site Target	Gale crater(17)
Other	Any other items of interest

Mission Description: 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. A more far ranging goal of the MSL and subsequent sampling initiatives involve the exploration to determine the presence, precedent, or absence of microbial life as Gale crater and the efforts at CCB are easily extrapolated to provide an exploratory platform for this discovery.

Science Merit Related to Mission Objectives: The CCB presents a dynamic hydrologic system. Over roughly 11,000 years, the oasis valley floor records waxing and waning of many spring fed pool systems, as well as multiple sites where evaporative systems have come and gone. Additionally, a more ancient geologic history indicates that CCB was at the very nexus of the breaking apart of Pangea that created what we now know as the Northern hemisphere 220 million years ago. Much later CCB became isolated from the sea with the subsequent uplifting of the Sierra Madre Oriental, roughly ~35 million years ago.[11] It is possible that the CCB was not "buried" by the normal succession of new sediments and this in turn suggests that the ancient microbial mats may have survived these changes as they became isolated from their original marine source. [2, 12, 13] Therefore in the MSL/Mars 2018 mission it should be possible to view the Gale crater candidate landing site as more similar to CCB with regards to the dynamics of the geology. We propose that there may be sites similar to CCB where evaporitic processes might indicate the presence of past water and where it would be feasible to look for evidences of rudimentary microbial mats, i.e., banded structures with isotopic anomalies.

Most Important Question Answered by Site: CCB provides a living laboratory in which a diverse group of scientists have the opportunity to understand microbial evolution in concert with its environment. The ability to directly and empirically evaluate these processes provides the definition for rules and adaptation of earth based microbial populations and provides a definition and estimation of the veracity for biosignatures extra terrestrially. These biosignatures are part of a much larger astrobiological definition effort involving the Virtual Planet Laboratory at U Washington and the ASU Follow the Elements team. Interestingly, the success of the collaborative efforts at CCB by geochemists, geologists, ecologists, and population biologists directly impacts the team's ability to interact with mission specialists in a way that makes crossing disciplinary boundaries and impacting mission outcomes in a positive way.

Logistic and Environmental Constraints: CCB is in the center of the Chihuahuan desert and can be accessed by several routes using international air carriers and land vehicles. Transportation involves air carrier to Monterrey or Saltillo. Overland vehicles complete the route to CCB in 4.5 hours from both airports. Travel directly from Houston through Piedras Negras (Coah, Mx) can be accomplished in roughly 10 hours. The charming town has a population of 10,000 people, has hotels, restaurants and modern amenities such as reliable cell phone connection and WiFi. The field sites are 30km in average from the town. CCB has similar weather as Phoenix. The Mexican team has all the collecting permits in order and has extended its permits to the international collaborators without problem.

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Svalbard as a Mars Analogue Site and the Arctic Mars Analogue Svalbard Expedition (AMASE) Analogue Sites. A. Steele[1], H.E.F. Amundsen[2], AMASE Teams 2003 - 2011. [1]Geophysical Laboratory, Carnegie Institution of Washington, 5251 Broad Bramnch Rd, Washington DC 20015, [2]Earth and Planetary Exploration, Jacod Aals Gate, Oslo Norway.

Introduction: AMASE has been testing instruments at Mars analogues sites on Svalbard since 2003 with focus on instruments onboard MSL, ExoMars and MSR since 2006. The range of geological provinces and rock types exposed in a Arctic dessert environment on Svalbard represent a uniquely diverse set of Mars relevant environments and eight successive field campaigns have developed a library of different Mars analogue sites. Four selected targets with particular relevance to primary proposed landing sites are presented below.
The Sverrefjell (SVF) and Sigurdfjell (SGF) eruptive centers in the Bockfjord Volcanic Complex formed by subglacial eruptions ca. 1 Ma ago and carry ubiquitous magnesian carbonate deposits including dolomite-magnesite globules similar to those in the Martian meteorite ALH84001. Mg-rich carbonates have formed from both meteoric water and CO2-rich mantle fluids and provide a unique opportunity to study abiotic synthesis, biomarkers and habitability associated with volcanic activity on a cold rocky planet. Sulfate bearing Permian evaporite sediments have been studied at Ebbadalen (EBD) in Billefjorden and Colletthøgda (COH) in Kongsfjord, with EBD sediments containing sulfate-rich concretions reminiscent of “blueberries” discovered on Mars by Opportunity. Evaporites have been targeted for mineralogy, biomarker and habitability studies. Devonian Redbed sediments in Bockfjord represent barren and oxidised paleosols and fluvial and lacustrine sediments and have been targeted for mineralogy, biomarker and habitability studies. Neoproterozoic stromatolites at Murchison fjord have been targeted for mineralogy, biomarker and habitability studies.
Mission Description:
Science Merit Related to Mission Objectives:
Our proposed work is relevant to the following goals presented in the Astrobiology Roadmap and the MEPAG Scientific Goals, Objectives, Investigations, and Priorities statement: ***Astrobiology Roadmap:*** **Goal 2**: Determine any past or present habitable environments, prebiotic chemistry and signs of life elsewhere in our Solar System, **Specific objective 2.1**- Mars exploration. **Goal 3**: Understand how life emerges from cosmic and planetary precursors, **Specific objective 3.1**- Sources of prebiotic materials and catalysts. **Goal 7**: Determine how to recognize signatures of life on other worlds and on early Earth, **Specific objective 7.1**- Biosignatures to be sought in Solar System materials. ***MEPAG Goals document (2008):*** **1.A.2** - Determine the geological history of water on Mars. **1.A.3** - Identify and characterize phases containing C, H, O, N, P and S. **1.A.4** - Determine the array of potential energy sources available on Mars to sustain biological processes. **1.B.1** - Determine the distribution and composition of organic carbon on Mars. **1.B.2** - Characterize the distribution and composition of inorganic carbon reservoirs on Mars through time. **1.B.3** - Characterize links between C and H, O, N, P, and S. **1.B.4** - Oxidation chemistry of the near surface through time. **1.C.1** - Characterize complex organics. **1.C.2** - Characterize the spatial distribution of chemical and/or isotopic signatures. **1.C.3** - Characterize the morphology or morphological

distribution of mineralogical signatures. **1.C.4** - Identify temporal chemical variations requiring life. **MEPAG, *ND-SAG report***; This proposal also attempts to answer several outstanding questions that the MEPAG next decade science analysis group outlined in their recent report (NDSAG - www.mepag.jpl.gov/reports/index.html)

Most Important Question Answered by Site:

AMASE has concentrated on the question of answering whether features and mineralogy of the sites are mediated by biological processes. As such we have consistently taken a null hypothesis stance and assume all lithologies are abiotically mediated until this hypothesis can be falsified using mission chosen instrumentation. This approach allows robust science to be undertaken using ExoMars, MSL and potentially MSR bound instruments. Furthermore, this research is shedding light on the challenges of life detection for MSL and ExoMars missions as well as developing criteria for sample selection on the Max-C mission on samples that are the only known or accessible analogues to the ALH84001 meteorite and Commanche outcrop carbonates, as well as sites that contain concretions, stromatolites, phylosilicates and gypsum minerals. All of these lithologies are important for the proposed MSL and potentially MAX-C landing sites. AMASE is a joint ESA and NASA funded project and as such is a platform for greater collaboration and understanding between US and European instrument teams.

Logistic and Environmental Constraints: The logistic platform developed by AMASE through more than 3000 man days in the field is based on a chartered research vessel (R/V Lance) run by the Norwegian Polar institute combined with helicopter- and light boat mobility as well as stationary lab facilities at Ny Ålesund research station (NYA). AMASE is run with a regular staff of safety- and logistic support personnel and all field crews are briefed/trained in Arctic safety issues prior to deployment including proper clothing, team work, radio communication and polar bear safety. Furthermore, static facilities that contain a fully functioning microbiology and geochemistry laboratory have been set up at Ny-Alesund to make confirmatory measurements of common samples tested by flight instrumentation. Most sites have aerial imagery from HSRC analogue instrumentation provided by the DLR.

Table 1: Bockfjord Volcanic Complex and Permian Evaporite Sediments

Site	Bockfjord Volcanic Complex	Permian Evaporite Sediments
Lat/Lon	SVF 79° 25.83' N 13° 18.43' E SGF 79° 15.39' N 13° 36.15' E	EBD 78° 43.88' N 16° 39.03' E COH 78° 53.57' N 12° 40.47' E
Elevation	SVF 10-560 masl SGF 800-1000 masl	EBD 50-100 masl COH 50-300 masl
Areal Extent	SVF 3x3 km, SGF 0,5x2 km	EBD 2x2 km, COH 1x4 km
Science Questions	Formation of ALH84001 and Commanche analogue carbonates. Abiotic synthesis in volcanic rocks. Habitability, biomarkers. Carbonates, olivine, pyroxene, oxides, clay minerals	Formation of blueberry analogue concretions in sulfate bearing evaporate sediments. Habitability, biomarkers. Sulfates, carbonates, clay minerals, oxides
Logistics/Access	18 h sailing (150 km) from LYR. SVF 0,5-2 km from beach. SGF 10 min by helicopter	EBD 2 h (55 km) from LYR, 2 km from beach. COH 30 min sailing from NYA
Environment	0 to +10 °C, dry, zero veget.	0 to +10 °C, dry, zero veget.

Previous Studies	[Ref]	[Ref]
Landing Site Target		
Mars Expr. Data	HRSC-AX coverage (DLR)	HRSC-AX coverage (DLR)

Figure 1: (Left) Dolomite + magnesite cemented lava breccia at Sverrefjell volcano (SVF) in Bockfjord. (Right) Blueberry analogue concretions in sulfate bearing evaporate sediments at Ebbadalen (EBD).

Table 2: Bockfjord Devonian Redbeds and Murchison Fjord Stromatolites

Site	Bockfjord Devonian Redbeds	Murchison Fjord Stromatolites
Lat/Lon	79° 27.75' N 13° 26.83' E	79° 57.02' N 18° 24.93' E
Elevation	0 -1000 masl	0-20 masl
Areal Extent	10x25 km	1x6 km
Science Questions	Habitability, biomarkers in oxidized fluvial/lacustrine sediments. Oxides, clay minerals	Habitability, biomarkers in 870 Ma stromatolites. Carbonates, chert
Logistics/Access	18 h sailing (150 km) from LYR. 0-2 km from beach.	30 h sailing (205 km) from LYR. 0-0,5 km from beach.
Environment	0 to +10 °C, dry, zero veget.	-5 to +5 °C, dry, zero veget.
Previous Studies	[Ref]	[Ref]
Landing Site Target		
Mars Expr. Data	HRSC-AX coverage (DLR)	HRSC-AX coverage (DLR)

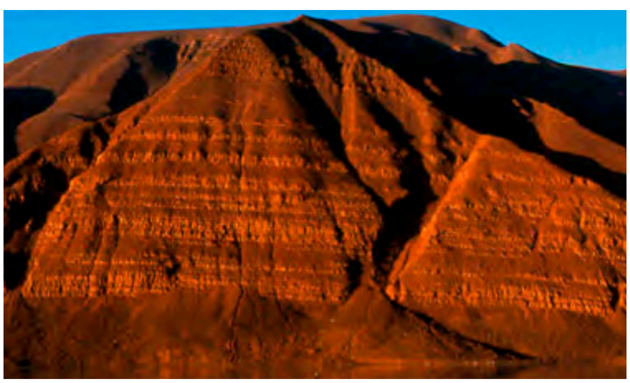

Figure 2: (Left) Cliff face with Devonian Redbed sediments in Bockfjord. (Right) Stromatolites at Murchison fjord.

THE TODILTO FORMATION AND SCIENCE GOALS AT NORTH MERIDIANI. D. T. Vaniman, Group EES-14, MS D462, Los Alamos National Laboratory, Los Alamos, NM 87545 (vaniman@lanl.gov)

Introduction: Sites in North Meridiani were proposed early in site selection discussions for Mars Science Laboratory (MSL) [1] and remain of interest for Mars 2018 [2]. Although all terrestrial analog sites have limitations, and are at best partial analogs, there are certain features of the Todilto Formation in the Southwestern United States (Figure 1) that may be relevant to a North Meridiani mission. The Todilto Formation is a zoned carbonate (calcite with minor late dolomite) to sulfate (gypsum in outcrop, anhydrite where deeply buried) evaporite deposit that developed in a short period (10^4-10^5 yr) after rapid flooding of the vast dune field of the Entrada Formation in the Jurassic. Despite the very different hydrogeologic environments of Mars and Earth, the Todilto setting of short-lived brine incursion into a largely eolian environment, with terminal formation of a salt hydrate common to both planets (gypsum), provides a useful field area for petrogenetic studies of evaporite evolution and of lacustrine interaction with a porous, sandy substrate. Although much is known about a small portion of Meridiani through data collected by the MER rover Opportunity, that knowledge is focused on higher hematite-rich portions of a laterally extensive and very thick stratigraphy. The data from Opportunity show eolian dune forms overlain by eolian sand sheets and interdune/playa sediments [3]. Although the indications from Opportunity are that groundwater brines have predominated and surface discharge is minimal, the situation may be considerably different at North Meridiani where extensive and continuous sedimentary units mark a sedimentary section >1 km thick [1], with greater chance of including both eolian and lacustrine deposits. These deposits are sulfate rich and although the evidence from Opportunity indicates a complex mixture of Mg, Ca, Fe sulfates the chemical data also are best fit by including Ca-sulfate [4], likely as gypsum. A significant aspect of the Todilto Formation is its association with bituminous materials that are extensive enough to yield a small commercial petroleum field where buried beneath the Colorado Plateau. Biochemical occurrences in the Todilto have likely microbial precursors, in a brine-microorganism association that may represent a potential setting for primitive life as might be found on Mars.

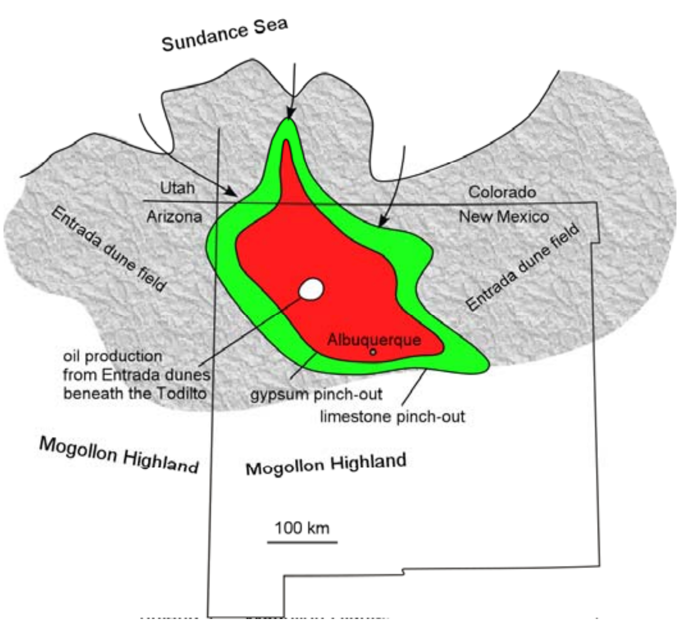

Figure 1: Location map of the Todilto Formation.

Mission Description: The mission envisaged here (Figure 2) is an example from the MEPAG 2-Rover International Science Analysis Group [2]. However, the vast extent of the Meridiani deposits provides other possibilities. Edgett and Malin [1] provide a view of the site in Figure 2 with regional context. One of the hypotheses that could be tested with this mission is whether the deeper section at Meridiani, beneath the hematite plains, includes lacustrine deposits. Large inverted channels shown in [1] indicate that the deeper sulfate-rich sections of Meridiani have had a much wetter history than the spot examined by Opportunity. Mission elements that include a rover with significant range with imaging, spectral, chemical, and mineralogical analysis capability would be suitable, as well as ability to detect biomarker molecules.

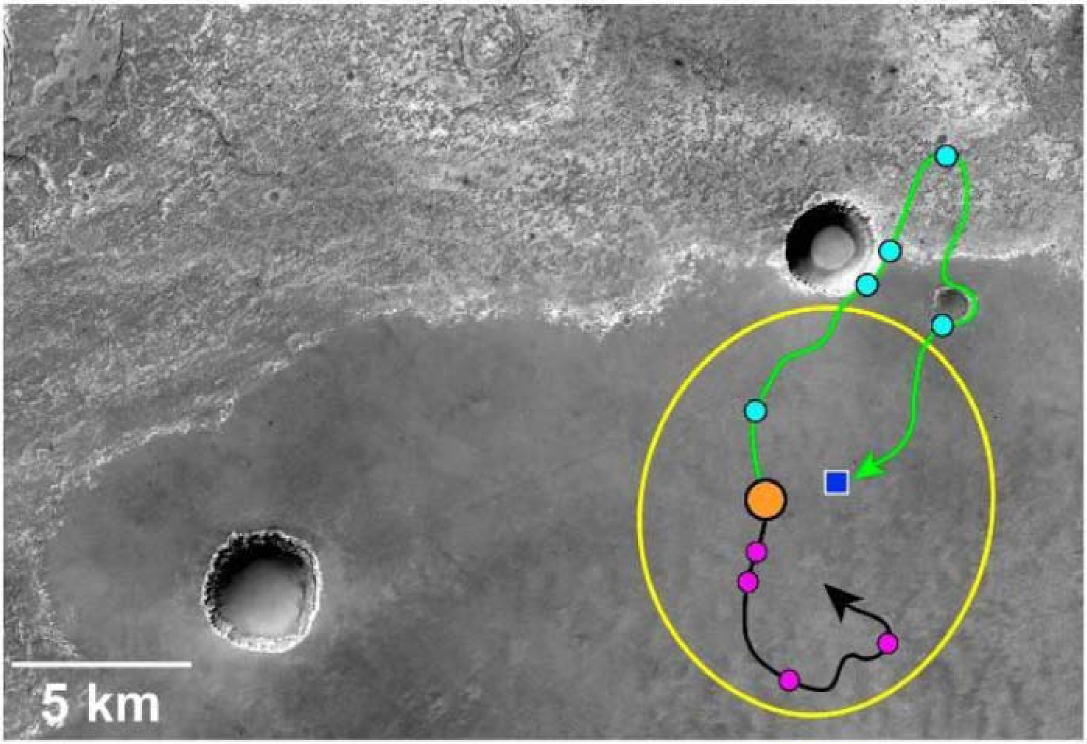

Figure 2: Example North Meridiani locality from [2]. The site is at ~1.5°N, 357.2°E at an elevation of about -1.6 km. Science targets include sulfate-rich sediments north of the hematite-rich plains (north of the yellow landing ellipse). The orange circle marks a possible landing spot; blue circles are example MAX-C sampling sites, pink circles are example EXM sampling sites, and the blue box represents a cache for sample return.

Science Merit Related to Mission Objectives: The Todilto Formation provides a variety of sedimentological, mineralogical, and biogeochemical features relevant to interactions between brines and eolian sediments (see especially [5]). Discussion of the Todilto Formation as a Mars analog with references to the scant literature on biogeochemistry of the Todilto is published in [6-8]. Although the Todilto evaporite deposits are relatively thin (a few tens of meters) they cover a vast area and contain some significant geochemical as well as physical sedimentary boundaries [7].

Most Important Question Answered by the Todilto Site: The most important science question that could be answered at North Meridiani would be whether the observed fluvial features are related to lacustrine systems that were sufficient to provide habitable environments. Studies of the Todilto Formation related to this question include (1) a closer analysis of features in the Todilto evaporites and underlying Entrada sands that demarcate surface water versus groundwater components of site hydrogeology and (2) application of modern biogeochemical methods to defining the microbiology of the Todilto evaporite, with particular emphasis on microbiological differences between the sulfate and carbonate zones.

Logistic and Environmental Constraints: Access to and field conditions for the Todilto Formation are generally excellent; a summary is provided in Table 1 and more extensive descriptions are provided in [8].

Table 1: Todilto Formation as an analog site for North Meridiani.

Center Coordinates Latitude, longitude	Most outcrops are located between 35° and 37.5° N latitude and 105.5° and 109° E longitude.
Elevation	1.5 to 2.4 km
Areal Extent	>150,000 km^2 (much is subsurface)
Prime Science Questions	1) What mineralogical and sedimentological features are characteristic of brine discharge over eolian dunefields? 2) What subhabitats for microbiota and what genera are hosted in evolving, gypsum-precipitating brines?
Distance of Science Targets from nearest road or airstrip	Many localities are readily accessible at a few tens of meters to <1 km from paved or dirt access roads. The Albuquerque International Airport is within 50 km of several Todilto exposures.
Environmental characteristics	Max temp: +43 °C Min temp: -30 °C Precipitation: 20 to 60 cm per year Vegetation coverage: sparse, from scrub to piñon or ponderosa forest. Most outcrops are in cliff or scarp exposures.
Previous studies at analogue site	See references [5,6,7,8]
Primary Landing Site Target	North Meridiani near or within sulfate-rich sediments beyond the hematite plains

References:
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SALINE PLAYA ON QINGHAI-TIBET PLATEAU. Alian Wang[1] and M. P. Zheng[2], [1]Dept. of Earth and Planetary Sciences and the McDonnell Center for the Space Sciences, Washington University in St. Louis, One Brookings Drive, St. Louis, MO, 63130, USA (alianw@levee.wustl.edu), [2]R& D Center of Saline Lakes and Epithermal Deposits, Chinese Academy of Geological Sciences, Beijing, 100037, China (zmp@public.bta.net.cn).

Introduction: We propose the saline playas in a hyperacid region (Qaidam basin) on Qinghai-Tibet Plateau (China) to be a good terrestrial analog for studying the sedimentary mineralogy and the potential habitable environment on Mars. The proposed analog site study can be a reference for the search of a "pattern" for habitability during the Mars Science Laboratory (MSL) mission; it can also help the development of the mission concept and the detailed design of mission operation for ExoMars and MAX-C missions.

Mission Description: The science goal of MSL mission (to be launched in 2011) is to explore and quantitatively assess the habitability and environmental history of a local region on Mars [1]. The major task of ExoMars mission is "searching for traces of past and present signs of life" [2]. The proposed [3] primary scientific objectives for potential MAX-C mission is "at a site interpreted to represent high habitability potential with high preservation potential for physical and chemical biosignatures: evaluate paleo-environmental conditions, characterize the potential for preservation of biotic or prebiotic signatures, and access multiple sequences of geological units in a search for evidence of past life or prebiotic chemistry. Samples necessary to achieve the proposed scientific objectives of the potential future sample return mission should be collected, documented, and packaged in a manner suitable for potential return to Earth".

The four candidate landing sites for MSL mission are all located at ancient terrain (Noachian to early Hesperian), with typical sedimentary geomorphology and the remote sensing evidences for sedimentary mineralogy (phyllosilicates, sulfates, silica, and H_2O/OH bearing species) [http://marsoweb.nas.nasa.gov/landingsites]. The landing sites for ExoMars and MAX-C will be determined based on the findings of MSL.

The analog site that we are proposing bears similarities (to certain degrees) in climate, sedimentary evolution, and H_2O/OH bearing mineralogy with the sites on Mars interested by these three missions. In addition, biomass was found at this extreme terrestrial environment [5, 6]. A comprehensive study from various angles at this site, such as year-round climatic monitoring, geomorphology observation, determination of sedimentary deposition/erosion sequences, mineralogy and petrology characterization, as well as the culturing of biomass and genetic sequencing, can build a good reference (i.e., a useful pattern) in the search of habitable environment on Mars.

Science Merit Related to Mission Objectives: Qinghai-Tibet (QT) Plateau has the highest average elevation on Earth (~ 4500 m, about 50-60% of atmospheric pressure at sea-level). The high elevation induces a tremendous diurnal (and seasonal) temperature swing caused by high level of solar irradiation during the day and low level of atmospheric insulation during the evening. In addition, the Himalaya mountain chain (average height >6100 m) in the south of the QT Plateau largely blocks the pathway of humid air from the Indian Ocean, and produces a Hyperarid region (Aridity Index, AI ~ 0.04), the Qaidam Basin (N32-35°, E90-100°) at the north edge of the QT Plateau. Climatically, the low P, T, large ΔT, high aridity, and high UV radiation all make the Qaidam basin to be one of the most similar places on Earth to Mars [7, 8].

The extreme climatic conditions and evolution history of QT-plateau (was warm and wet) have resulted a specific set of sedimentary deposition/erosion sequences at Qaidam basin. On QT Plateau, Qaidam basin has the most ancient playas (started in Eocene-Oligocene period) and the lakes with the highest salinity. More importantly, Mg-sulfates appear in the evaporative salts within one of the most ancient playas, Da Langtang (DLT), at the northwest corner of Qaidam basin, which mark the final stage of the evaporation sequence of the brines enriched in K, Na, Ca, Mg, Fe, C, B, S, and Cl. The evaporation minerals in the saline playas of Qaidam basin, their alteration, and especially the preservation of the phases with high degrees of hydration under hyperarid conditions can be an interesting analog for the study of hydrous salts and salty regolith on Mars.

We conducted a field investigation at DLT playa in Qaidam basin [9], with combined remote sensing (ASTER on board of NASA's Terra satellite, 1.656, 2.167, 2.209, 2.62, 2.336, 2.40 μm) [10], in situ sensing of a portable NIR spectrometer (WIR, 1.25-2.5 μm continuous spectral range) [11], and the preliminary laboratory analyses of collected samples from the field (ASD spectrometer, 0.4 -2.5 μm, and Laser Raman spectroscopy). From satellite photos, we see the wide spreading of light-toned layered deposits at DLT and in surrounding area. On the ground, we see the spacious deposits of rock salts, gypsum, exhumed layers of clays, and buried hydrous sulfates. The preliminary results of spectral analyses indicate that the materials contributing the high albedo layers in playa deposits are carbonate-gypsum-bearing surface soils, salt-clay-bearing exhaumed Pleistocene deposits, dehydrated Na-sulfates, hydrous Mg- & multication-sulfates, carbonates, and chlorites.

In addition, halophiles were isolated from the collected evaporative salt samples from DLT. They were cultured on modified growth medium (MGM) under different salinity conditions, and eight strains of halobacteria showed different growth curves. 16S rRNA gene sequences for these eight strains suggested that the halophiles from DLT of QT- Plateau had high homology with some species of genera of *Virgibacillus, Oceanobacillus, Halobacillus, and Ter-ribacillus*. The finding of halophiles in this hyperarid and high salinity environment boosts the importance of exploring salty regolith in future surface explorations to Mars (MSL, ExoMars, MAX-C) in the search for similar biosignatures.

The regional geology has been intensively investigated by well-organized Chinese exploration teams since 1950s, mainly for the search of mineral resources. The results were published in science papers, books, and reports, including some chronology studies [12]. Figure 1 shows the satellite photo of DLT area, the highest spatial resolution of local map is 60 cm (purchased from Quick Bird).

Most Important Question Answered by Site: The preservation of hydrous minerals in a hyperarid environment and the environmental conditions for the growth of halobacteria.

Logistic and Environmental Constraints: Our 2008 expedition was planed and conducted in the frame of a scientific collaboration between the Planetary Surface Material Group in Dept.

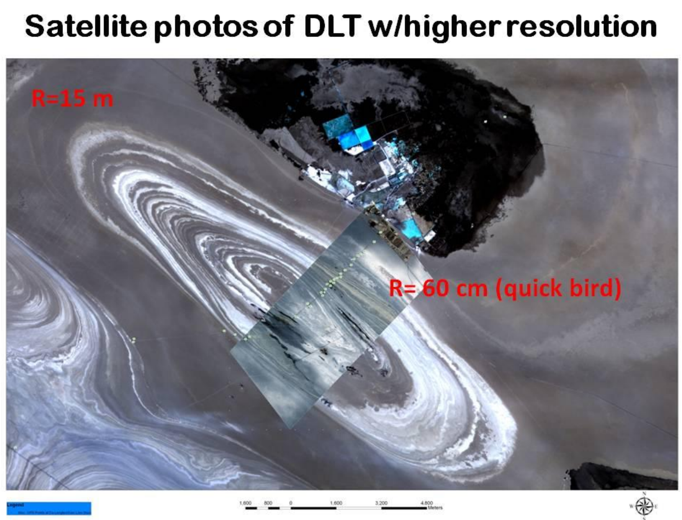
Earth and Planetary Sciences at Washington University and the R&D Center of Saline Lakes and Epithermal Deposits at Chinese Academy of Geological Sciences that is under the Ministry of Land and Resources of China. A set of special permissions were obtained for the expedition at various levels in ministries and province. The nearest town HuaTuGou (with hotel that permits the stay of foreigners) is about 2-3 hours drive from the DLT site, with road conditions from good to poor.

Standard Information Required for Analogue Sites:

Table 1: Example table required for any analogue site proposed.

Site Name	DLT saline playa on QT-Plateau
Area coordinates	91°21' E and 38°30' N
Elevation	28 km (w/uncertainty)
Areal Extent	60 km by 95 km
PrimeScience Questions	The preservation of hydrous minerals in an hyperarid environment and the environmental conditions for the growth of halobacteria,
Distance of Science Targets from nearest road or airstrip	Light-toned layered deposits – 50 km (straight line distance) to the nearest town. The longest distance from a road to LTD base layer – 12 km
Environmental characteristics	Max temp: unknown Min temp: -34°C in the region (w/uncertainty) Precipitation: <25 mm in the region (w/uncertainty) Vegetation coverage: none
Previous studies at analogue site	Many papers and books published by Chinese scientists for mineral resources. Five abstracts for 2009 LPSC, one for 2010 Astrobiology conference, one for 2010 AGU were published by our team from the perspective of Mars analog.
Primary Landing Site Target	Mawrth Vallies
Other	Biomass was found

Figure 1: Satellite photo of DLT area



Acknowledgement: The first field expedition to DLT on QT-Plateau was found by the McDonnell Center for Space Sciences at Washington University in St. Louis.

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EARLY ARCHAEAN TERRANES AS ANALOGUES FOR NOACHIAN/HESPERIAN LANDING SITES ON MARS F. Westal[l1], T. Zegers[2], F. Foucher[1], N. Bost[1], A. Meunier[3], S. Petit[3], A. Hofmann[4], J. Vago[5], M. Viso[6]. [1]Centre de Biophysique Moléculaire, CNRS/OSUC, Orléans, France (frances.westall@cnrs-orleans.fr); [2]Department of Geology, University of Utrecht, The Netherlands; [3]Hydrasa, University of Poitiers, France; [4]University of Johannesburg, Johannesburg, South Africa; [5]ESA/ESTEC, Keplerlaan, Noordwijk, The Netherlands; [6]CNES, Paris, France.

Introduction: Terrestrial early Archaean crustal materials were formed in a geological context remarkably similar to that of Noachian/Early Hesperian Mars [1,2]. They are dominated by igneous lithologogies, including volcanics and their derivatives (sediments, alteration products) as well as hydrothermal precipitates and evaporitic secondary deposits. The sediments were deposited in aqueous basins including littoral environments. Although the early Earth was an ocean covered planet (as opposed to Mars), the few remaining portions of well-preserved Early Archaean crust conserve mostly volcanic and sedimentary sequences formed at relatively shallow water depths or in the coastal environments. These volcanic and sedimentary materials contain traces of primitive life (chemolithotrophic and possibly chemoorganotrophic) of the kind that could have lived on early Mars [2].

The early Archaean terranes occur in the Pilbara (NW. Australia) and the Barberton (E. South Africa) greenstone belts. There are many outcrops in these regions that could serve as useful analogue locations but here we will concentrate our descriptions on one locality from each region as representative examples. The 3.45 Ga-old Kittys Gap Chert (KGC, Fig. 1 [2, 3]) in the Pilbara is located at 20°53'33.56"S, 120°04'22.37"E and includes rhyolytic to mafic/ultramafic (basalts, komatiite) volcanics with intercalated sediments derived from these volcanic sequences. Sedimentary structures record deposition in a littoral mud-flat environment [4]. The environment was directly influenced by contemporaneous moderately high temperature hydrothermal activity (~175°C, [5]. The coordinates for the 3.3 Ga-old Josefsdal Chert (JC, Fig. 2) are 25°57'54.71"S, 31°04'41.22E. This locality records two sedimentary successions between ultramafic pillow basalts flows. Sedimentary structures show that the volcanic sediments were deposited in a relatively shallow basin at depths ranging from sub wave base to the littoral environment [6-8]. There is also evidence for direct and indirect hydrothermal influence on the environment.

Mission Description: These analogue locations are of relevance for any Mars missions with the upper crust as a science objective because they touch on the nature (*i.e.* volcanic, plutonic, sedimentary, hydrothermal, evaporitic) of the crustal materials, depositional environments, habitability, and biosignature preservation. They are thus of relevance to the 2011 MSL, the 2018 Max-C/ExoMars, and the 2022(?) Mars Sample Return missions.

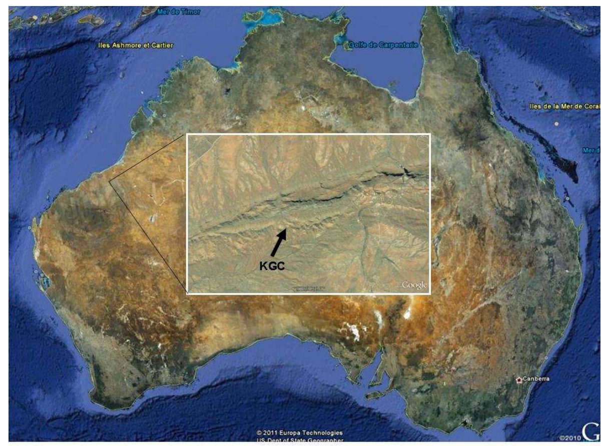

Figure 1. Kittys Gap Chert location in the Pilbara of Australia.

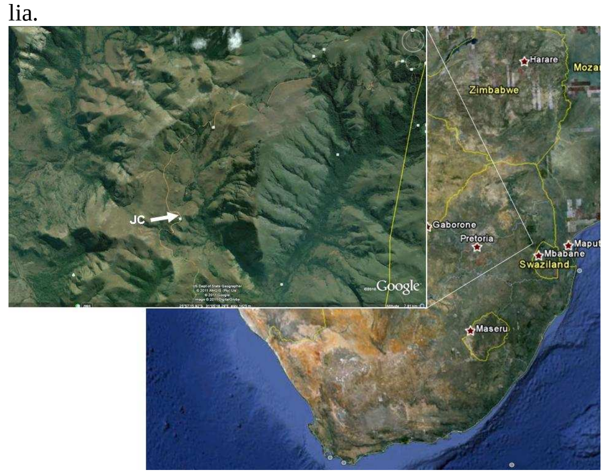

Figure 2. Location of the Josefsdal Chert, Barberton, South Africa.

In terms of access for study and/or field testing of instruments, both locations have nearby roads. The KG site is at a distance of 0.5 km from the road and at an elevation of 100 m above it. The terrain is rocky and slopes to the outcrop levels are ~25°. The most accessible portion of the JC outcrop is a short 50 m walk from the road along a small ridge. The terrain is moderately rocky. Portions of the outcrop occur on the ridge top where there is more or less no slope but other potions are on steep slopes of ~30°.

Science Merit Related to Mission Objectives:

(1) The Kittys Gap Chert: The KGC is part of the Coppin Gap Greenstone Belt. The greenstone belts are associations of extrusive and intrusive volcanics and volcaniclastic sediments that have been penecontemporaneously intruded by primitive granites (TTGs). The KGC has been directly dated at 3.46 Ga and is the stratigraphical equivalent of the Panorama Formation in the Warrawwona Group. Regionally, the sediments were deposited on the edge of a large basinal structure characterized by circum-basinal growth faults [4,9]. Structurally, the growth faults cutting the KGC control depositional thicknesses with thicker volcanic and sedimentary deposits towards the hanging wall of the growth fault. Apart from the syndepositional growth faults, the deposits have been tilted vertically due to regional tectonic disturbance related to the granitoid intrusions. This means that layers of rock exhibiting compositional, habitability, and biosignature diversity are readily accessible at the surface. Younging direction of the various facies is to the north. Metamorphic alteration is limited to burial metamorphism (prehnite-pumpellyite facies). A major influence on the sedimentary facies was their penecontemporaneous silicification. Silicon isotopes show that the silicification was both hydrothermal and due to Si-enriched seawater [5]. Indeed, a number of chert veins penetrate the base of the chert and represent hydrothermal conduits originating in the underlying felsic volcanics.

The volcanics and sediments of the KGC form linear sequences that outcrop laterally over 4 km along an upstanding ridge. The ridge is formed by the resistant silicified sedimentary deposits. Three ~2m thick layers of sediments are interspersed with ~5 m thick layers basaltic composition. The underlying, intervening and overlying volcanics are not silicified and are poorly exposed. The sediments are capped by mafic and ultramafic volcanics including komatiites.

The sedimentary sequences are of particular interest as analogues of volcaniclastics deposited in shallow environments on Mars because (1) of their sedimentary structures and the story they tell about an evolving coastal sedimentary regime; (2) the information concerning the environmental habitability; (3) the biosignatures of primitive life forms living in/on the sediments; and (4) the influence of penecontemporaneous hydrothermal activity on sedimentation, habitability, and preservation of the biosignatures.

Sedimentary structures are clearly observable on the weathered outcrop surfaces (Fig. 3A). Indeed, differential responses to weathering have highlighted the sedimentary structures, thus aiding environmental interpretation. The outcrop consists of mm-cm thick alternating black and white layers, the black layers consisting of fine grained volcanic clasts (silt-sized) and the white layers of coarser, sand-sized clasts. Sedimentary structures include parallel, cross, flaser and channel bedding. These have been interpreted to indicate sedimentation in an infilling tidal channel [4]. There is at least one horizon containing 0.5 cm-sized embedded pumice fragments that has characteristics suggestive of brief subaerial exposure [2, 3]. Rapid silicification of the sediments is indicated by *in situ* brecciation of already lithified lower layers of the sediment pile. The silica is of seawater and hydrothermal origin.

The sediment is a heavily silicified (>85%) volcaniclastic protolith [10]. The volcanic particles now consist of illite/muscovite but were originally Ti-bearing mica, K-feldspar, amphibole, glass shards or mineral debris. The diagenetic aqueous alteration pathway would have been: conversion of the volcanic protolith via (bio?)chemical processes to montmorillonite, conversion of the montmorillonite via hydrothermal alteration and burial metamorphism to illite/muscovite. The particles are angular, indicating local provenance.

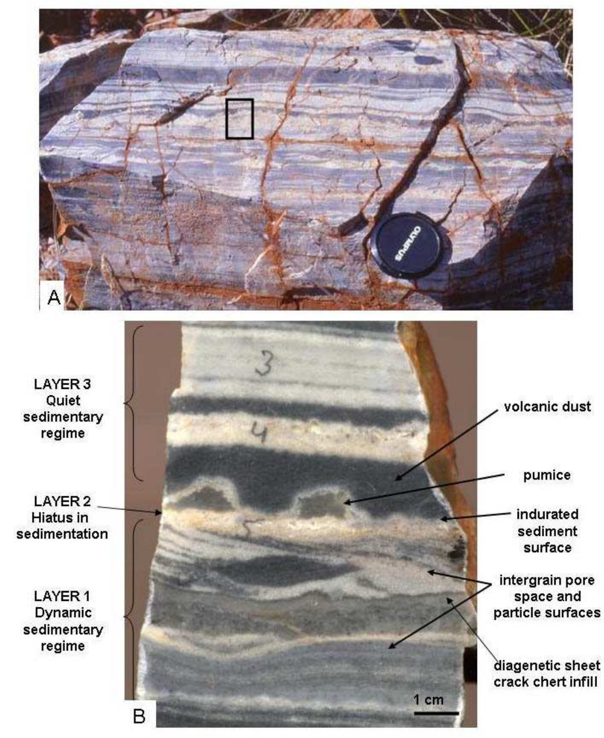

Figure 3. KGC. (A) Field view of sedimentary structures and (B) close-up view of the microhabitats.

These sediments contain morphological, organic and isotopic biosignatures [2, 3]. Different microhabitats in the sediment (Fig. 3B) contain different types of microbial remains. Silicified (probable) chemolithotrophic coccoidal microorganisms colonised the surfaces of the volcanic clasts, pumice and dust (fine silt layers). The exposed sediment surface was coated with a fine multispecies biofilm as well as the torn remains of local microbial mats. The layers containing these remnants have a total carbon concentration of 0.01-0.05% and carbon isotopic values between -26 and -28‰.

Summary: The KGC is an accessible outcrop showing well developed tectonic, volcanic, sedimentological and hydrothermal structures. It consists of a variety of lithologies (ultramafic to acidic volcanics, volcaniclastic sediments and hydrothermal chert). The volcanic clasts have been altered to phyllosilicates (illite/muscovite) and are associated with morphological, organic and isotopic traces of life. The volcano-sedimentological sequence was formed 3.45 Ga at a time when similar volcanoclastic deposits were being deposited in shallow water basinal environments on Mars, possibly influenced by hydrothermal activity.

(2) The Josefsdal Chert: There are many similarities in terms of geological context and environmental setting between the JC and the KGC [7]. The JC consists of sediment layers sandwiched between mafic lava flows [11]. Occurring at the top of the Kromberg Formation of the Onverwacht Group, the JC has an estimated age of 3.3 Ga [8]. It was subjected to lowermost greenschist metamorphism and has been faulted and tilted by tectonic activity resulting in almost vertical strata. The sediments were initially deposited in a littoral environment (a beach sand is preserved) which deepened with time such that later sediments were possibly even deposited below wave base. Sedimentary structures include parallel, ripple, flaser and channel bedding. This outcrop has not been exposed as long as the KGC and the sedimentary structures tend to be more cryptic but are nevertheless visible at outcrop level. As with the KGC, the clasts are volcanic protoliths, now replaced by fuchsite, a Cr-rich muscovite [7]. One major difference between the JC and the KGC is that carbon is concentrated into distinct horizons in the black and white layered JC (Fig. 4A). The black layers may contain up to 0.1% organic carbon (Fig. 5). microscopic observations show that, where deposited in shallow water, the layers represent microbial mats formed on sediment surfaces, whereas in the deeper deposits they simply represent sedimented carbonaceous remains. Isotopic analysis of the carbon results in a – 26.8‰ signature [7]. Morphological remains of microbial mats and other colony-forming organisms occur in this sediment [6-8]. Hydrothermal influence was pervasive and contemporaneous in this environment [6,7,11]. [7] even observed a microbial mat that appears to have formed in a hydrothermal outflow channel (Fig. 4B) and was probably killed by an outpouring of hot, silica-rich fluids.

Summary: The 3.3 Ga-old JC is a very accessible outcrop showing well developed volcanic, sedimentological, hydrothermal, and tectonic structures. It consists of a variety of well exposed lithologies (mafic volcanics, volcaniclastic sediments and hydrothermal chert). The volcanic clasts have been altered to phyllosilicates (illite/muscovite) and the sediments are associated with morphological, organic and isotopic traces of life. The JC also formed in a shallow water environment and at a period when similar sediments were being deposited in basinal settings on Mars.

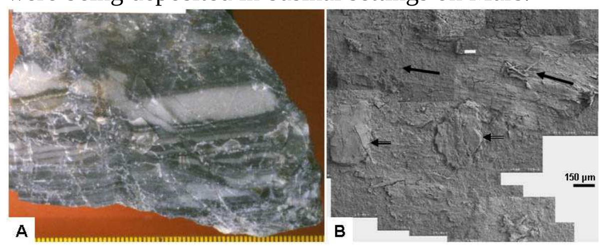

Figure 4. (A) Black and white laminated chert from the JC and (B) microbial mat formed in a hydrothermal outflow channel.

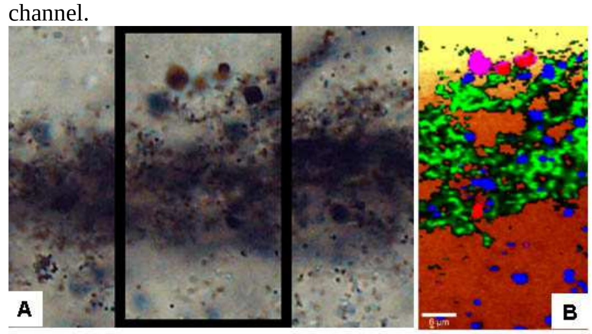

Figure 5. (A) Thin section detail of one of the black layers with (B) Raman mineralogical mapping showing concentration of carbon (green) in the black layer.

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Microbial communities in subzero saline spring environments in the Canadian high Arctic: Martian analogue studies.

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Terrestrial analogues for astrobiological investigations of Mars should include Earth's polar regions and as such, the Canadian high Arctic offers several unique cryoenvironments (sub zero saline springs, permafrost) that resemble the conditions that are known or are suspected to exist on Mars. This presentation will describe our recent research focused on detecting and examining microbial life in the unique cold saline/brine springs on Axel Heiberg Island with the overall goals of determining the low temperature limits of microbial life on Earth and if microbial communities inhabiting such cryoenvironments are active at ambient subzero temperatures. The presentation will focus on the microbiology and geochemistry of the Gypsum Hill (GH) and Lost Hammer Spring (LH) sites (Perreault et al, 2008; Niederberger et al. 2010). These unique subzero (0 to -5ºC) hypersaline springs (7.5 to 23% salinity) are characterized by thick extensive permafrost in an area with an average annual air temperature of -15°C and with air temperatures below -40°C common during the winter months. The presence of geomorphological features linked to water movement, such as fluvial valleys and flood channels on the surface of Mars signifies that water once flowed through the Martian landscape and thus, they could have been a potential abode for past or extant microbial life. These springs support viable microbial communities capable of activity at temperatures as low as -10ºC. The LH site also provides a model of how a methane seep can form in cryoenvironments and presents a mechanism that could possibly be contributing to reported methane plumes on Mars. The GH springs sulfide (25-100 ppm) and sulfate (2300-3700 mg/L) abundant system serving as an analogue for the abundant sulfate deposits and potential sulfate-rich brines on Mars that may have originated in the presence of sulfur-rich groundwater. Gas composition (C_1-C_4 hydrocarbons, He, H_2, O_2, N_2, Ar, & CO_2) and stable isotope ($d^{13}C$ and d^2H values using compound specific isotope analysis) analyses of the saline spring gas samples has revealed the small amounts of hydrocarbons in gases exsolving from the Gypsum Hill springs (0.38 to 0.51% CH_4) were compositionally and isotopically consistent with microbial methanogenesis and possible methanotrophy (Perreault et al. 2008) while the major gas emitted from LH spring is methane (~50 %) with carbon and hydrogen isotope signatures consistent with a thermogenic origin (Niederberger et al. 2010). However, the presence of anaerobic methane oxidizing archaea (ANME) in the LH source provide a model of methane-based metabolism in this extreme hypersaline, subzero environment.

LARGE MARS CHAMBER FOR TESTING SAMPLE ACQUISITION AND HANDLING TECHNOLOGIES. K. Zacny, Honeybee Robotics, 398 West Washington Blvd, Suite 200, Pasadena, CA 91101, zacny@honeybeerobotics.com

Introduction: MSL, MSR and ExoMars share a common payload: sample acquisition tool (a drill). A drilling tool enables acquisition of samples (powder or a core) from beneath the martian surface for scientific instruments (MSL, ExoMars) and earth return (MSR). It is a critical tool, since if it fails no sample will be acquired and in turn no sample will be analyzed. Core acquisition on MSR mission is even more critical. If the MSR Sample Acquisition and Caching system fails or the sample is altered or destroyed during the process of sample acquisition, either no samples will be brought back (hence, no need for Mars Orbiter and Fetch Rover missions) or the samples that will be brought back will not represent the original samples.

Mars low pressure atmosphere bracketing triple point of water poses many challenges to drilling and sample transfer [1, 2]. These challenges became evident during Mars Phoenix lander mission, where icy samples became sticky and could not easily pass through a screen and into an instrument inlet port (TEGA) and in some cases could not be offloaded from a scoop [3].

Drilling under low pressure conditions, where heat dissipation is only via inefficient gaseous conduction [4] will heat up a sample and may cause irreversible changes (transition to a different crystal structure) and loss of volatiles [5].

In low pressure conditions, electrostatic forces also cause challenges to powder flow and could increase the level of cross contamination [6].

Mission Description: Future missions requiring sample acquisition (drilling, scooping), sample transfer and caching can take advantage of this environmental facility. The tests inside the chamber can reveal the actual heating a sample will be exposed to, possible loss of volatiles, level of cross contamination, possible problems with a sample transfer. The chamber will also enable testing of the mechanical systems (gears, motors, bearings) as well as drill bit itself (extent of bit wear) and contamination due to bit wear (friction on Mars is different and hence the wear and contamination will be different). [7]

Science Merit Related to Mission Objectives: The facility enables testing in various rock formations, at different pressure conditions (the pressure can be controlled to 0.1 torr) and temperature (samples and hardware can be cooled). Hence, within a few days, a range of conditions pertinent to different Mars site can be investigated.

Most Important Question Answered by Site: What happens to a sample during drilling and sample transfer under the actual environmental conditions (pressure, temperature, atmospheric gas). How does Mars environment affect drilling operation and hardware (e.g. do you need drilling protocols to allow cooling off of actuators, can a sample acquisition and delivery be done in a single sol?).

Logistic and Environmental Constraints: The chamber is located in a 4200 sq.ft. facility in Pasadena, CA. The facility also includes a machine shop, assembly benches and technical/engineering (electrical/mechanical) support staff.

Standard Information Required for Analogue Sites:

Table 1: Details of the Mars chamber [8].

Site Name	Mars Environmental Chamber
Prime Science Questions	What happens to a sample during a process of sample acquisition and transfer to a science instrument. How Mars environment affects sample acquisition and handling hardware and process.
Environmental characteristics	Min Pressure: 1 torr Min Sample Temp: -80C Atmosphere: Mars gas

Figure 1: Mars environmental chamber in a vertical position (left) and horizontal position (above). The chamber is 3.5m x 1m x 1m and can maintain pressure to within 0.1 torr. Cooling coils are used to control sample and hardware temperature. The chamber has been used for drilling tests (>1m) in analog materials (e.g. ice with 2% perchlorate) and mobility tests.

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