THE INTERNATIONAL CONFERENCE:

EXPLORING MARS HABITABILITY

JUNE 13-15, 2011

LISBON, PORTUGAL, EARTH

Final Programme & Abstract Book

Index

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Conference at a glance

	Monday 13 June	Tuesday 14 June	Wednesday 15 June
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Monday 13 June 2011

Habitability Associated with Specific Transitory Environments

Chairs: Ivo Alves and Richard Zurek

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14:30 **Invited Talk**
Transient Processes and Environments on Present-Day Mars
McEwen, A.
[1]LPL, (UNITED STATES

15:45 **Discussion**

16:00 Coffee Break

17:30 **Session Discussion**

18:00 Poster Session: Thirst for Knowledge

Tuesday 14 June 2011

Ancient Habitability and its Relationships to the Long-Term Evolution of Mars I

Chairs: Pascale Ehrenfreund and Jack Mustard

Ancient Habitability and its Relationships to the Long-Term Evolution of MarsII

Chairs: Francois Forget and Gian Gabrielle Ori

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Wednesday 15 June 2011

Modern Habitability and the Possibility of Extant Life

Chairs: Gerhard Kminek and Andrew Steele

The Possible Effects that the Planet's Internal Structure and Movements may have had on Habitability Issues

Chairs: Agustin Chicarro and Steve Clifford

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Leaders: David des Marais and Mark Sephton

16:30 Wrap-up Ancient Habitability and its Relationships to the Long-Term Evolution of Mars
David Beaty and Francis Westall

16:45 Wrap-up The Possible Effects that the Planet's Internal Structure and Movements may have had on Habitability Issues
Bruce Banerdt and Dehany

17:00 Wrap-up Habitability Associated with Specific Transitory Environments
Abby Allwood and Olivier Witasse

17:15 Wrap-up Modern Habitability and the Possibility of Extant Life
Lisa Pratt and Fernando Rull

17:30 **Conference Discussion**

18:00 Adjourn

POSTERS: Thirst for Knowledge

Ancient Habitability and its Relationships to the Long-Term Evolution of Mars

The Possible Effects that the Planet's Internal Structure and Movements may have had on Habitability Issues

Recent Habitability Associated with Obliquity-Driven Cyclic Glacial Processes

Habitability Associated with Specific Transitory Environments

Modern Habitability and the Possibility of Extant Life

Abstracts

Habitability Associated with Specific Transitory Environments

Fluvial Landforms and Hydrated Minerals due to Impact Craters Hydrothermalism on Mars

Mangold, N.[1]; Carter, J.[2]; Poulet, F.[2]; Ansan, V.[1]; Loizeau, D.[2]; Bibring, J.-P.[2]; Murchie, S.[3]
[1]CNRS/LPGNantes, FRANCE; [2]CNRS/IAS, FRANCE; [3]John Hopkins, APL, UNITED STATES

The frequency of impact craters was higher during the heavy bombardment, which questions the link between impacts and the formation of fluvial valley networks or hydrated minerals. Here we report (1) the presence of small valleys on fresh craters ejectas as examples of fluvial landforms triggered by impact warming and (2) mineralogical indicators of hydrothermal activity related to the same impact warming. Fluvial landforms were identified on ejecta and interior of tens of craters from 10 to 150 km in diameter. Many craters post-date Noachian valley networks, showing these landforms are not due to a warmer early Mars climate. Regional mapping shows a clear latitudinal zonation between 25° and 42° in both hemispheres, which suggests a climatic influence. The formation of fluvial landforms is explained by both warming on the impact rim and thermal heating of ejecta melting shallow ice or snow deposits.
CRISM data were analysed for several craters for which fluvial activity was observed on the impact ejecta and interior. These craters display hydrated minerals such as smectites, chlorites, opaline silica, and prehnite on central peaks, rims and locally on ejecta. While the presence of hydrated minerals is often questionable between crustal excavation and in situ hydrothermalism, the association of these minerals with local fluvial landforms on craters post-dating the Noachian period pleads in favour of local hydrothermalism related to the impact formation. Theoretical works have pleaded for hydrothermal activity related to impact craters, but only few well defined examples were identified yet. Craters coupling fluvial landforms and hydrated minerals are among best candidates for such hydrothermalism. Their role is important to be deciphered to better understand the primitive climate. The preservation potential of organics in such craters should be studied in details, especially as large craters are potential targets for future in situ missions.

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The Effects of Meteorite Impacts on the Availability and Distribution of Bioessential Elements for Endolithic Organisms

Pontefract, A.[1]; Osinski, G.R.[1]; Cockell, C.S.[2]; Lindgren, P.[3]; Parnell, J.[4]; Southam, G.[1]
[1]University of Western Ontario, CANADA; [2]Open University, UNITED KINGDOM; [3]University of Glasgow, UNITED KINGDOM; [4]University of Aberdeen, UNITED KINGDOM

Introduction: Arguably one of the most ubiquitous geological processes in the solar system, meteorite impacts have the ability to destroy as well as create habitats for life. Generating extreme temperatures and pressures, the target substrate may undergo deformation, vaporization, melting and shock metamorphism. These processes favourably change the habitability of the target substrate for lithophytic organisms, which are then able to (re)colonize microfractures, pore spaces and glasses created during the impact [1,2]. Of further interest is the generation of post-impact hydrothermal systems and the role they play in hosting microbial life. Previous work has revealed the creation of hydrothermal systems immediately following an impact into a H2O-bearing substrate [3]. These systems, depending on the size of the impactor, are capable of being active for up to several million years in large (100 km-scale) impact craters. When considering the current view of the thermophilic origins of life, as well as the continuity of impact events throughout the lifetime of a planetary body, it is plausible that such impact-generated systems could have played host to the origins of life [4].

Previous Work: Studies by Cockell et al. [2,5,6] have shown that growth of endoliths within impact shocked substrate correlates with shock level in both sedimentary and crystalline targets; however, the specifics of this relationship are still unclear. Increased porosity and translucence of the substrate may be major contributors to this relationship, but what is still unknown is the scaling of available nutrients with an increase in shock level. At high shock levels, melting occurs, which may result in either a loss or a redistribution of elements essential for microbial metabolism. There are six major elements essential to life, C, H, N, O, P and S, as well as dozens more that play critical roles in DNA synthesis, membrane stability etc. [7]. Previous work on sedimentary targets has shown, through bulk ICP and XRF analysis that there is no visible relationship between shock level and bulk chemistry [8,9]. In contract, another study [10] did show a lowering of bioessential elements with increasing shock level in crystalline targets.

This Work: New data that has been collected through bulk-ICP analysis on 22 samples of shocked gneiss from the Haughton impact structure, correlates with previous work done on sedimentary targets from the same structure, and reveals no visible relationship between shock level and bulk chemistry (Figure 1.)

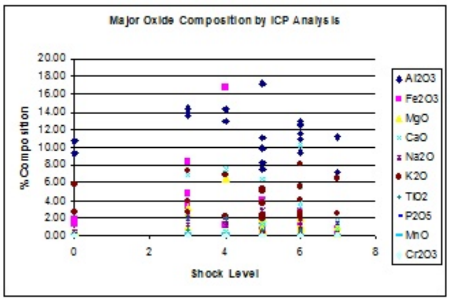

Figure 1. Bulk ICP analysis of shocked gneiss samples showing the relationship of the major oxides to shock level, categorized as in Singleton et al. [11].

If indeed there is no measurable loss of bioessential elements with increasing pressures, it is likely then that impact-cratering results in a redistribution of these elements within the rock, either as a heterogenous distribution within glasses, and/or possibly preferentially lining vesicles within the target rock. Future microbeam work *in situ* could reveal such distributions and further serve to clarify the relationship between impact events and habitability for life.

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Vacant Habitats on Mars

Cockell, CS; Balme, Matt
Open University, UNITED KINGDOM

Planetary environments can be placed into one of three categories: 1) uninhabitable, 2) inhabitable and inhabited, 3) inhabitable, but uninhabited. The search for life on other planets usually makes the assumption that where there is a habitable environment, it will contain life. This is because on the present-day Earth, the third category, uninhabited habitats (or vacant habitats), are rare. They may occur in pockets of subsurface oils or impact craters that have been thermally sterilized in the past. Beyond the Earth, vacant habitats may be more common. They might exist on inhabited planets, similarly to the Earth, and they might also exist on uninhabited planets, for example on a planet that is habitable, but where life never originated. The hypothesis that vacant habitats are abundant is experimentally testable by studying other planets. On ancient Mars, vacant habitats may have existed in environments such as transient impact-generated or volcanic hydrothermal systems. On more recent Mars, vacant habitats might have been created in places such as melted subsurface permafrost or regions of surface glacial melting during periods of changing obliquity. The possibility that some habitable Martian environments were vacant has important consequences for which habitable environments should be the highest priority for robotic and human exploration. The study of vacant habitats might ultimately inform an understanding of how biology has influenced geochemistry on the Earth. References: Cockell CS (2011) Vacant habitats in the Universe. Trends Ecol. Evolution, 26, 73-80

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Volcanically Driven Hydrothermal Systems in Post-Noachian Mars: Hotspots of Habitability on a Changing Planet

Skok, J.R.; Mustard, J.F.
Brown University, UNITED STATES

Volcanically driven hydrothermal systems form a self-contained environment capable of supporting life with significant water flow as well as thermal and chemical energy that on Earth provide a rich habitat for a variety of life forms [1]. Noachian Mars would have been rich with near surface ground water, a warm and chemically altering crust and significant volcanic and impact related hydrothermal systems [2] creating many potential zones of habitability. Post-Noachian Mars experienced a changing climate that lead to acidification and a reduction in surface liquid water related features [3] and to a surface environment less conductive to wide spread life. However, intense and spatially significant Hesperian volcanism [4] would provide opportunities to mobilize existing ground ice, water reservoirs or concentrate magmatic waters to form potentially habitable environments relatively recently in Martian history.

Previous work have suggested that terrestrial hydrothermal systems provide a potential genesis point for Earth-based life forms highlighting the importance of such geologic features in understanding the habitability of a planet [5]. While the transient nature of hydrothermal systems that derive energy from plutonic bodies may limit opportunities for life to develop, the environments would provide an ideal location for life to flourish and be preserved in silica sinters created in the systems [6]. The hydrothermal systems would have their root near the magmatic pluton embedded in the Noachian crust and may connect to a buried subsurface biosphere below the volcanic, linking these localized features with a wider potential habitable zone.

Hesperian-aged volcanically driven hydrothermal systems have been proposed since the first understanding of the extent of the Hesperian volcanism [7]. Until recently, observations focused on areas that combine both the morphology of volcanic edifices or flows and the erosional features indicative of present water. Recent observations from the Compact Reconnaissance Imaging Spectrometer for Mars (CRISM) have detected silica deposits on and around a Hesperian-aged volcanic edifice in the Nili Patera caldera of the Syrtis Major volcanic systems [8]. The context and distribution of the deposits suggest they are the remnants of a hydrothermal system operating in the late stages of the Syrtis Major volcanism (Figure 1). Extensive work on similar terrestrial analogs indicate that the surface expression is minor part of the entire system that could stretch deep into the subsurface [9].

The confirmation of Hesperian-aged hydrothermal systems extend the timeframe that a complex and self preserving habitable environment could have existed on Mars. Terrestrial work has shown that the silica sinters observed in these Martian hydrothermal systems are ideal for preserving microfossils and biosignatures of any extant life [6]. Just as these systems provide a robust ecosystem on Earth, they may be the best stable near-surface habitable environment type in the post-Noachian Mars and should be considered exploration hot spots for the search of Martian habitability.

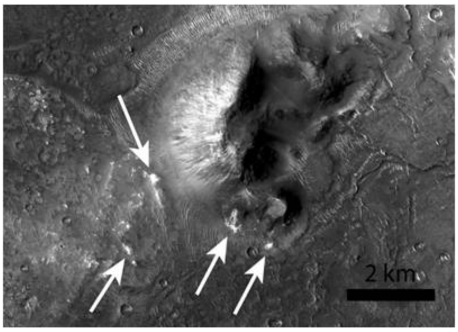

Figure 1: Volcanic cone in the Nili Patera caldera (9.13°N, 67.37°E). Light-toned deposits marked by arrows show spectral signatures consistent with silica sinter indicating the presence of a extinct hydrothermal system.

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The Nakhlite Impact Hydrothemal Cell: Mineralogy, Fluid and Habitability

Bridges, J.C.[1]; Schwenzer, S.P.[2]
[1]University of Leicester, UNITED KINGDOM; [2]Open University, UNITED KINGDOM

The nakhlite meteorites are samples from within ≤100 m depth of an ultramafic lava flow or intrusion on Mars. The extent of compositional equilibration and volume of mesostasis within the meteorites shows that they sample different depths [1]. The nakhlites have also preserved a secondary mineral assemblage, which consists mainly of siderite, smectite-serpentine and an amorphous silicate gel. Soluble salts are also present in some of the nakhlites [2-4]. The alteration minerals occur within veins and also, for some nakhlites, in the mesostasis. This hydrothermal cell formed as a result of a local impact, creating a rapidly cooled ≤170 ^{o}C, metastable assemblage with varying composition e.g. Mg#, related to depth of origin [4]. The hydrothermal action was terminated by evaporation of soluble salts near the surface. Fe K XANES analyses of the veins and surrounding minerals show that the fluid was oxidising compared to the original igneous assemblage [5].

Our current knowledge of the secondary mineral assemblages and how they vary between nakhlites, allows us to accurately model the composition of the fluid. We are using CHILLER [6] which enables modelling of the minerals precipitated at different P, T, CO2 molarities and ionic concentrations. We have performed runs at varying W/R ratios and ionic concentrations based on complete and partial dissolution of a nakhlite (Lafayette) composition based on that of [7]. The W/R ratio is a critical constraint [8] and our model predicts that Ca-rich siderite of the composition found in Lafayette [2-3] is precipitated together with serpentine [4] at a W/R ratio of ~100.

The secondary mineral assemblages associated with the nakhlites are the best proxy for a potential martian habitable niche that we yet have to study. Our studies of the nakhlites aim to constrain further the nature of impact hydrothermal environments and their potential for hosting life on Mars.

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Microbial Growth and Survival in Extreme Habitats on Kilimanjaro

Ponce, A.; Beaty, S. M.; Lee, C.; Noell, A. C.; Stam, C. N.; Anderson, R. C.; Connon, S. A.
Jet Propulsion Laboratory, UNITED STATES

The summit of Kilimanjaro in equatorial East Africa hosts melting/subliming glaciers with stratigraphic layering, including embedded atmospheric dust, that are believed to be nearly 12,000 years old [1]. The periglacial soils and supraglacial meltwater ponds are among the most extreme microbial habitats on Earth [2], as microbes eking out a living in these near-sterile environments face extreme diurnal freeze-thaw cycles, high UV flux, half an atmosphere of pressure, and extreme low organic carbon content. The Kilimanjaro summit also contains fissure vents and fumaroles that afford the possibility of investigating microbial habitability, in terms of viability, diversity and abundance, across temperature and water gradients that represent a continuum of microenvironments. These factors make Kilimanjaro an excellent Mars analog that will further our understanding of microbial growth boundary conditions, habitability, and preservation of organics.

As glacier melting accelerates and water availability in periglacial environments is increasing, research has expanded to characterize glacier systems as microbial habitats where active microbial growth is occurring on, within and beneath glaciers [3]. The Kilimanjaro glaciers, in particular, provide a glimpse into microbial ecology of the glaciers during past East African droughts via embedded microflora associated with dust-rich layers. To date, there are no investigations published on the microbiology of Kilimanjaro glaciers. We aseptically collected near basal ice from a vertical glacial cliff of the Northern Ice Field, and filtered particulate matter from eight ice layers, including two layers that contained visible accumulations of dust. Microbial diversity data show that at the time of dust layer formation, the glacier surface hosted an active microbial, cold-water ecosystem [4]. We found that a majority of bacterial clones, as determined by bacterial 16S rRNA gene sequencing, are most closely related to those isolated from cold water environments. This is further supported by the observation of a large mud-rich pond on the surface of NIF in 2008, which likely represents conditions present when the ice dust layers formed. We anticipate that future investigations of this tropical-alpine, supraglacial, cold-water ecosystem will yield insights into microbial activity at the temperature, water and organic carbon limits for life on Earth.

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

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Habitability in Mars Transient and Local Environments: Field Analogue Sample Studies

Foing, B.H.[1]; Stoker, C.[2]; Loizeau, D.[1]; Blake, D.[2]; Kotler, J.M.[3]; Ehrenfreund, P.[4]; Martins, Z.[5]; Direito, S.O.L.[6]; Röling, W.F.M.[6]; Davies, G.R.[6]; Rodrigues, L.[7]; Thiel, C.S.[8]; Orzechowska, G.E.[9]; Kidd, R.D.[9]; Clarke, J.D.A.[10]; Pletser, V.[1]; Borst, A.[6]; Peters, S.T.M.[6]; Wendt, L.[11]; Gross, C.[11]; Wilhelm, M.B.[2]
[1]ESA/ESTEC, NETHERLANDS; [2]NASA Ames Research Centre, UNITED STATES; [3]Leiden Institute of Chemistry, NETHERLANDS; [4]Space Policy Institute, George Washington University, Washington D.C., UNITED STATES; [5]Imperial College London, South Kensington Campus, London, UNITED KINGDOM; [6]Faculty of Earth and Life Sciences, VU Amsterdam, NETHERLANDS; [7]Aveiro University & VU Amsterdam, PORTUGAL; [8]Institute of Medical Physics and Biophysics, University of Muenster, GERMANY; [9]Jet Propulsion Laboratory; CalTech, Pasadena, UNITED STATES; [10]Geoscience Australia, AUSTRALIA; [11]FU Berlin, GERMANY

There are on Mars some specific niches that could have been habitable during transient and local episodes. This includes environments in fluvial and lacustrine deposits, gullies, transient geothermal and/or hydrothermal conditions that can be triggered by large impacts or by proximity with igneous activity. There are also areas with specific delivery and burial of constituents including volcanic ashes spring deposits, atmospheric deposits, in addition to extraterrestrial delivery of cometary and meteoritic organics. Some special mineral sites can interact with transient conditions to change the habitability conditions.

We have performed field analogue campaigns to study the spatio-temporal variations in habitability signatures by analysing geochemical context and samples. The EuroGeoMars2009 and DOMEX/EuroMoonMars campaigns [4,1,8] were conducted at Mars Desert Research station (with the support of NASA Ames, ILEWG, ESA/ESTEC, and partners). The desert near Hanksville in Utah provides a diversity of sites relevant to Mars (and to potential landing sites for MSL and ExoMars).

We deployed a suite of instruments and techniques [4,8,1], relevant to Mars habitability research (including sample collection, context imaging from remote to local and microscale, drilling, GPR, X-Ray Diffractometry/Fluorescence spectrometry XRD/XRF, Raman spectrometry, Polymerase Chain Reaction PCR). A number of soil and rock samples were selected from diverse geological habitats, documented, analysed in situ. They were sent for detailed analysis in remote laboratories using XRD/XRF, Infrared spectrometry, amino-acid analysis, Solid Phase Microextraction and Organic solvent Extraction with GCMS analysis, composition and organics analysis, and biota diversity studies using culture-independent molecular analyses directed at ribosomal RNA genes [2,3,5,7,8] We shall describe the in-situ and sample analysis results relevant to habitability for specific MDRS sites that are analogue for Mars transient and local environments: Mancos fluvial sandstone; gullies; Morrison lacustrine and fluvial clays; Bluegate carbonaceous pyritic units; Late Jurassic inverted paleochannels; small scale mineral and subsurface niches; concretions & endolithic environments.

We shall discuss how transient geological and geochemical episodes have affected local parameters (mineralogy, organics content, environment variations) and therefore the habitability and the signature of organics and biota.

References in "Astrobiology Field Research in Moon/Mars Analogue Environments", (Foing, Stoker & Ehrenfreund, editors) Special Issue of International Journal of Astrobiology (IJA 2011),

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[6] Kotler et al. (2011). Analysis of mineral matrices of planetary soils analogs from the Utah Desert. IJA accepted

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Post-Early Mars local aqueous environments in Noctis Labyrinthus Chasmata

Thollot, P.[1]; Mangold, N.[1]; Milliken, R. E.[2]; Mustard, J. F.[3]
[1]LPGN, UMR6112 CNRS/Université de Nantes, FRANCE; [2]JPL, Caltech, now at University of Notre Dame, UNITED STATES; [3]Dep. of Geological Sciences, Brown University, UNITED STATES

Introduction: Phyllosilicates on early Mars are interpreted as evidence for persistent liquid water at low temperatures. Formation of sulfate deposits postdating phyllosilicates could reflect increasingly dry conditions with time in early Mars history [1]. Yet, the relative roles of geological processes and timing of the formation of alteration minerals on Mars remain poorly constrained.

Background: We recently characterized several classes of alteration minerals in the chasmata of Noctis Labyrinthus (NL) [2], next to which tens of shield volcanoes of similar age have been identified [3]. Deposits in a chasma of NL have one of the most diverse mineralogy observed on Mars, and a relatively young age (Late Hesperian or younger).

Data: Mineralogy was determined from data acquired by CRISM [4]. We looked for absorption bands diagnostic of hydrated minerals (Figure 1). We define and map spectral criteria for these bands (Figure 2).

Observations: Spectral features diagnostic of various Fe-sulfates span a continuous outcrop. A distinctive signature given by other small outcrops fits jarosite, another Fe sulfate. Absorption bands at 1.4, 1.9 and 2.2-2.3 µm reveal phyllosilicate bearing units : a 1:1 Al-phyllosilicate bearing unit (dubbed "kaolinite" unit) and a Fe-smectite bearing unit. Spectra with a distinctive broad 2.2 µm band sign Si-OH bearing material. Finally, a distinctive unit has spectra with a 2.21-2.28 µm double absorption, consistent with a mixture of the Si-OH, Fe-smectite and jarosite bearing materials. Most units show different patterns of polygonal fractures, consistent with dehydration. The sulfate unit bears parallel dune-like landforms indicative of a past eolian deposition or reworking. The Fe-smectite unit appears to drape kaolinite and sulfate outcrops, and is finely layered. The doublet unit is distinctively deformed and is found at the base of a spectrally neutral landform.

Discussion and implication for habitability: A stratigraphic sequence consistent with observations is, from most ancient to youngest : kaolinite bearing and Si-OH bearing materials, sulfate bearing material, Fe-smectite draping in thin, successive layers, with occasional enrichment in Fe sulfate, and late landslide events forming the deformed doublet-bearing layer at their base. Kaolinite and Si-OH materials might be the result of the hydration of different basement forming volcanic units. The bulk of the minerals of the large sulfate unit was likely formed by precipitation of iron and sulfate rich solutes. The finely layered structure and draping setting of the smectite bearing unit, given the proximity of volcanic vents in the area, is consistent with volcanic ash deposits. Alteration of ash material to Fe-smectite requires the presence of liquid water, and preservation of several 100m of these deposits requires rapid cementation. The presence of sulfate salts cementing this unit is evidence for precipitation likely driven by periodical variations in water-table level. Changing conditions in pH could explain alteration of primary minerals to kaolinite or smectite, usually neoformed from alteration by acid and dilute ; or neutral and evolved solutions, respectively. Iron in sulfates and smectites observed here could either be in ferrous or ferric state, or both. The geological record here could be consistent with the presence of liquid water for a period of time sufficient to form alteration minerals, and pH and redox disequilibria that could have provided an energy source for hypothetical living organisms. Preservation of the unique deposits in NL show that local environments with liquid water have existed after the end of the early Mars era.

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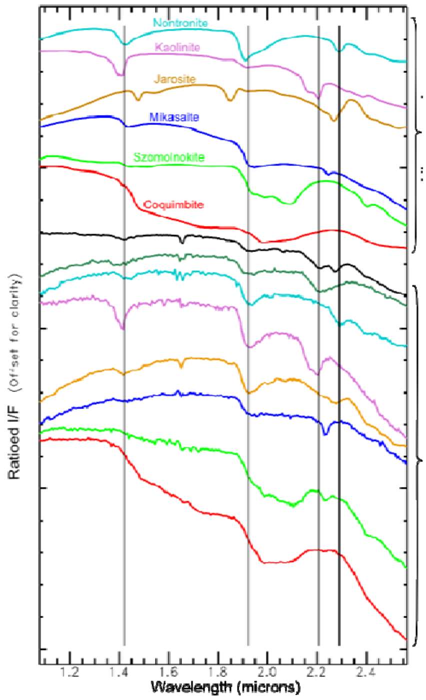

Figure 1. Spectra from CRISM data over the studied site from spectral libraries.

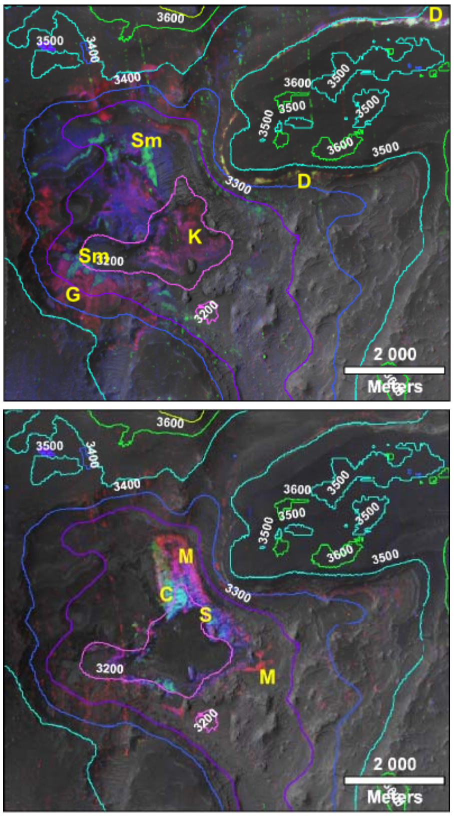

Figure 2. Spectral criteria maps from CRISM (RGB composites): 2.2-2.3-1.9 µm bands (top), 2.23-1.75&1.9-2.1 µm bands (bottom), D: 2.21-2.28 doublet material (hydrated glass), M: Mikasaite, C: Coquimbite, S: Szomolnokite.

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The Phyllosian era: the two different cases of Mawrth Vallis and Tyrrhena Terra

Loizeau, D.[1]; Mangold, N.[2]; Carter, J.[3]; Poulet, F.[3]; Bibring, J.-P.[3]
[1]ESA-ESTEC, NETHERLANDS; [2]LPGN, Nantes, FRANCE; [3]IAS, Orsay, FRANCE

Phyllosilicates on Mars have been detected in many outcrops of Noachian rocks with the near-infrared imaging spectrometers OMEGA/MEx and CRISM/MRO leading to propose to name the first era of Mars, the Phyllosian [1]. Of the phyllosilicate-rich rocks, clays particularly are considered to favor the preservation of biosignatures [2].
We propose to compare here two very different cases of phyllosilicate detection, through the mineralogy, the stratigraphy and the morphology: Mawrth Vallis, and Tyrrhena Terra.

The plateaus around Mawrth Vallis expose a thick (>150 m), finely layered (thickness ~1 m), clay-rich unit. At most outcrops, the clay mineralogy varies with depth from Fe-smectites in the lower layers to Al-phyllosilicates in the upper layers [3][4]. Unmixing modeling of OMEGA data evaluates the abundance of clay minerals to be as high as 50% on most outcrops [5]. While the largest outcrops of this unit are spread over a region of ~300 km by 400 km, smaller detections of clays are found aver a ~1000 km by ~1000 km region [6].
Formation processes likely involved long-term aqueous alteration, at low temperature, near surface, and changing conditions in time and/or depth.

The Tyrrhena Terra region we consider lies between Isidis and Hellas basins, and Syrtis Major and Tyrrhena Patera (~1000 km by ~2000 km). The mineralogy of the crust is revealed by ~150 crater ejecta, bearing hydrated silicates. The craters excavated rocks from a few tens of meters to few kilometers depth, and OMEGA and CRISM detect on their ejecta mainly chlorite-like spectra (or mix-layered minerals with chlorite), smectites, prehnite and zeolites. Hydration signatures are weak, and outcrops are generally small (few hundreds of meters maximum), with generally non-layered rocks [7]. The origin of these minerals is likely an in situ alteration of the rocks at higher temperature and depth, by hydrothermal circulation in the crust, enhanced locally by large impacts.

These different observations come from different formation processes:

1. Tyrrhena Terra represents a location typical of elevated cratered highlands where the excavation of deep altered crust is predominant and where shallow alteration minerals either formed in limited amount or were eroded away or metamorphized;
2. The clay unit at Mawrth is at lower elevation, where preservation of low temperature minerals may have required concentration of altered products (maybe related to the depositional process), and/or more efficient surface alteration by water.

We will present how these two cases can be typical or exceptional windows in the early Mars.

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Habitability and its Correlation with Hydrated Minerals - Evidence from Deposits in Aureum Chaos

Sowe, M.; Wendt, L.; McGuire, P.C.; Neukum, G.
Freie Universitaet Berlin, Institute of Geological Sciences, GERMANY

We identified and mapped hydrated minerals within light-toned deposits (ILD) in Aureum Chaos (Fig. 1A) based on short wave infrared data from CRISM, imagery and elevation data. The ILD display three stratigraphic units (Fig. 1B): The lowest unit (1) shows massive, light-toned monohydrated sulfate (MHS; 20-650m thick) with intercalated hydroxylated ferric sulfates (HFS) and ferric oxides. The overlying polyhydrated sulfate (PHS; (2)) is commonly layered (20-40m thick), smooth to heavily fractured, and partially contains ferric oxides (Fig. 1C-D). Spectrally neutral, distinctly layered, and bumpy cap rock ((3), 40-300m thick) forms the top. Unconformities between the units indicate periods of erosion. The phyllosilicate nontronite was found attributed to chaotic terrain as light toned fractured exposure (Fig. 1E) or within dark, smooth, and indurated mantling. The facies and relative timing of ILD and sulfate formation remain unresolved. PHS might have formed by evaporation in a lake. Alteration by diagenesis might have formed MHS and ferric oxides [1]. Post-ILD sulfate formation by groundwater intruding into previously formed, sulfate-free ILDs is another possibility. Altogether, water must have reached -3600 m, the maximum elevation of hydrated deposits. Phyllosilicate on at most Late Hesperian terrain could indicate in-situ formation that occurred in the Noachian after [2] assuming its excavation, or after chaos formation in the Late Hesperian, or instead that phyllosilicate formation is allochthonous assuming materials have been transported to their present places. Both is conceivable here, since we identified them in one discrete outcrop (Fig. 1E) as well as related to indurated mantling. This shows that local conditions could have allowed clay formation after the phyllosian era [2]. Phyllosilicate formation at near-neutral pH values (either in-situ or allochthonous) took place before HFS and MHS were formed, since the preserved sulfate minerals indicate the prevalence of dry conditions with short-lived acidic wetting events as in Meridiani after their formation. In contrast to sulfates, phyllosilicates indicate the presence of water for long time-periods, which in consequence could have allowed the evolution of life.

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Acknowledgement This research was supported by the Helmholtz Association through the research alliance "Planetary Evolution and Life."

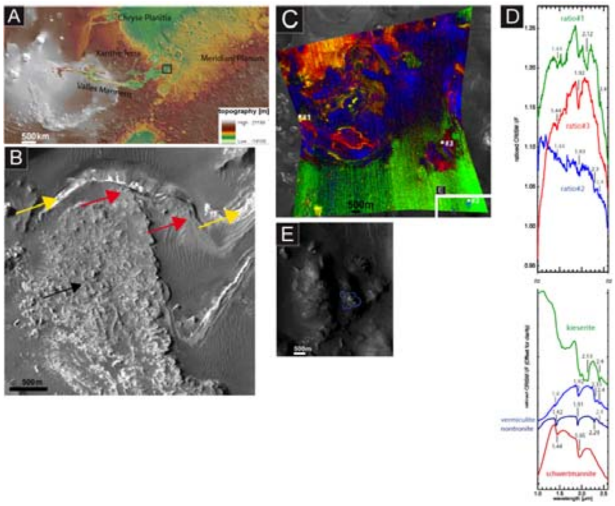

Figure 1. (A) MOLA map of Aureum Chaos and surrounding regions. (B) CTX blow-up indicates light toned MHS at the base with overlying darker, layered PHS, and finely layered anhydrous cap rock at the top. (C) CRISM parameter map on CTX. (D) CRISM ratioed spectra and best matching lab spectra. (E) CTX image shows a light toned phyllosilicate outcrop outlined blue on a chaotic terrain mound (ratio 2).

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Subsurface Aqueous Alteration on Ancient Mars: Implications for Habitability

Ehlmann, B.[1]; Mustard, J.[2]; Murchie, S.[3]; Bibring, J.-P.[1]; Meunier, A.[4]; Fraeman, A.[5]
[1]IAS/U. Paris-Sud, FRANCE; [2]Brown University, UNITED STATES; [3]JHU-APL, UNITED STATES; [4]U. Poitiers, FRANCE; [5]Washington U. in St. Louis, UNITED STATES

Alteration minerals preserved in the ancient crust of Mars provide a means of tracing the availability of water, climate, and habitability during the first billion years of planetary evolution. Clays discovered in Noachian (>3.7 Gyr) terrains indicate long-duration alteration under circum-neutral pH conditions, although to date, evidence for their formation environment(s), i.e. surface vs. subsurface, has been ambiguous. To determine the nature of Noachian aqueous environments, we (1) review the prevalence of recently identified diverse alteration minerals, grouped by geologic setting; (2) consider the relative ages of the mineral-bearing deposits, correlating regional stratigraphies; and (3) evaluate geochemical and mineralogical models derived from terrestrial data for alteration of basalt under varying water:rock ratios and open- and closed-system conditions. Collectively, mineralogic, chemical, and geomorphic data are most consistent with surface water on Mars during a limited interval at the late Noachian to early Hesperian transition, leading to formation of Al-clays and fluvial sedimentary basins with clay-salt deposits. Most clay minerals on Mars, however, i.e. the thick, mostly buried units with Fe/Mg-smectite- and chlorite-bearing materials, were produced in the subsurface under closed system conditions at low water:rock ratios and at temperatures ranging from ambient to low-grade metamorphic/hydrothermal (<300 C). On ancient Mars, the earliest, longest duration, and most volumetrically abundant aqueous environments were in the subsurface. Efforts to understand the habitability of these systems, populated on Earth with diverse chemosynthetic and heterotrophic microbial communities, as well as the mechanisms of biosignature preservation should be intensified.

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Early Mars: The First Billion Years

Craddock, R.A.
Smithsonian Institution, UNITED STATES

Introduction. Valley networks are often cited as the best evidence that liquid water was stable on the surface of Mars early in its history (Carr, 1981). However, other geologic features, such as modified impact craters, outflow channels, putative evidence for ancient shorelines, and even volcanoes offer some evidence as to the ancient climatic conditions that may have existed during the first billions years or so on Mars. These features suggest that conditions on early Mars were very similar to the conditions that probably existed on the Earth when life was forming on our own planet. This has important implications for Mars habitability during the first billion years.

Clues From Valley Networks. The ages of a majority of valley networks appear to be late Noachian to early Hesperian (Fassett and Head, 2008; Hoke and Hynek, 2009; Bouley et al., 2010). It is important to note that while crater ages provide an estimate as to when fluvial processes ceased and the surface became stable, they do not provide any clues as to when fluvial processes began. Instead, this evidence comes from the drainage density, or maturity, of the valley networks, which suggests that valley network formation occurred during a "climatic optimum" during the late Noachian (Howard et al. 2005). Valley networks are concentrated in a region located roughly between ±30° latitude. Preliminary climatic models that deduce the conditions on Mars while assuming that there was a large ocean in the lowlands show that during northern hemisphere winters large monsoons would have been generated (Richardson and Soto, 2008). These monsoons would have moved south into the highlands, and rainfall would have preferentially occurred where valley networks are located (Richardson and Soto, 2008).

Clues from Impact Craters. The other important clue about the early climatic and geologic history of Mars comes from modified impact craters. These features often lack a raised rim or an ejecta blanket, and they often have flat floors and steep interior walls that have been incised by gullies. The only way to produce craters with these characteristics is through rainfall and surface runoff (Craddock and Howard, 2002). However, modified impact craters are preserved in various states of degradation and occur at all crater sizes. If crater modification occurred during a single, short-lived "climatic optimum", then it would be expected that modified craters would be preserved in a single degradational state with smaller craters being more eroded than larger ones. Instead, the geologic record indicates that crater modification persisted throughout the Noachian (Craddock and Howard, 2002).

The Bigger Picture. While it is probably that valley networks and modified impact craters formed in an arid to semi-arid climate, these features indicate that rainfall and surface runoff persistent throughout most of the early history of Mars. The only way for such conditions to have existed is if water in the atmosphere was in equilibrium (Soto and Richardson, 2008). Basically, rain cannot occur if it falls into dry vacuum. It is possible that modified impact craters record the period when most of the volatile inventory on Mars still persisted as a steam atmosphere following accretion. As impact craters were forming, they were slowly being eroded by rainfall as the steam atmosphere condensed and precipitated down to the surface. Eventually enough of this atmosphere collapsed and precipitated to the surface to create the conditions necessary for a "climatic optimum" initiating valley network formation. The continued collapse of the steam atmosphere into the regolith eventually built up an aquifer with a sufficient hydraulic head to initiate outflow channel formation. Coupled with the increased volcanism during the Hesperian, it is possible that climatic conditions during this time period were the most favorable for life.

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The History of Water on Mars: Synthesis of New Results from Valley Networks and Deltas

Hynek, B.
University of Colorado, UNITED STATES

Geomorphic indicators, such as valley networks and deltas, are the strongest and most widespread signs of warm and wet conditions on early Mars. Water-altered minerals provide additional evidence for fluid-crust interaction, although their formation mechanisms are less clear. Assessing the habitability of early Mars relies upon knowledge of the magnitude, duration, and capacity of water at or near the surface. New mapping, analysis and modeling have elucidated the Red Planet's aqueous history.

Recent data has allowed identification and understanding of the spatial distribution of valley networks on Mars [1-2]. While Viking-era analyses showed immature drainage patterns [3], recent global mapping reveals >7 times more valleys [2]. Many signs of abundant and prolonged water exist in the valleys, including inner channels and terracing. Additionally, network morphometry strongly suggests long-lived water with integrated drainage patterns, smaller tributaries reaching drainage divides, and correlation with other fluvio-sedimentary features.

Crater age-dating of individual valleys points toward formation around the Noachian-Hesperian boundary [4-5], and new mapping [2] shows very few valley networks on the Early-Middle Noachian crust or Amazonian terrains. In a few systems, reactivation of existing networks suggest multiple formation periods. Minor precipitation-fed valley incision continued through the Hesperian and into the Early Amazonian epoch, to roughly 2.8 billion years ago. Since that time, valley formation has been localized to a few volcanoes and most have morphology consistent with groundwater processes.

Physically-based terrestrial sediment transport models have recently been applied to the larger valley networks on Mars [6]. While there are many unknowns in such work (such as channel depth, and intermittent vs. continuous flow) exploration of parameter space shows formation timescales of 10,000 to 1,000,000 years, with reasonable assumptions adapted from terrestrial work.

During our valley mapping efforts, we also cataloged 52 fan deltas from new identification and past work [7]. Roughly 2/3 of the known deltas on Mars are found near the dichotomy boundary at a uniform elevation of -2540m. These results, combined with valley networks, led to reconstruction of a putative past ocean, occurring around 3.7 Ga.

Life as we know it depends on at least a semi-continuous source of water. Recent and ongoing studies are constraining the history of water on early Mars. Collectively, it appears the latest Noachian through the Early Hesperian was a time of an active hydrological cycle that led to development of most of the large valley networks, deltas, and many water-altered mineral deposits, including chlorides. This system may have been fed by a vast northern ocean. Thus, there was a several hundred million year period of clement and wet conditions at Mars' surface around the time when the first known life appeared on Earth. Still, questions remain, including why are there not more widespread signs of water on the oldest surfaces of Mars? Perhaps earlier deltas and valley networks were not preserved. Alternatively, Mars may have only gained a dense atmosphere toward the end of the Noachian as the solar EUV flux waned [8] and an influx of water came from formation of the Tharsis complex [e.g. 9] or cometary input from the Late Heavy Bombardment [10].

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A Review of Martian Organic Material from Martian Meteorite Analysis; Implications for Habitability.

Steele, Andrew
Carnegie Institution of Washington, UNITED STATES

The Martian meteorites are currently are only sampling of a potential Martian habitable environment. Portions of the organic material contained in these meteorites contain organic carbon.

In the debate to understand whether relic Martian life is present in ALH84001, significant research has been conducted to understand the presence and provenance of organic materials, specifically polyaromatic hydrocarbons (PAHs) in this meteorite (Bada et al., 1998; Becker et al., 1999; McKay et al., 1996). Steele et al., (2000) showed the presence of contaminating terrestrial organisms in the meteorite. Carbon isotope analysis (C13 and C14) shows that there is a high temperature phase of carbon, that comprised approximately 20% of the carbon in the meteorite (~240 ppm), both within the carbonate globules and the host pyroxene of ALH84001 that is indigenous to the meteorite (Jull et al., 1998). Steele et al., (2008) found polyaromatic macromolecular carbon species (MMC) as well as graphite in intimate association with magnetite in ALH84001. We demonstrated that the MMC synthesis appeared to be associated with known abiotic reactions within the Fe-C-O system and that MMC was produced during precipitation of the carbonate globules (Steele et al., 2008).

The presence of organic substances in Nakhla and other meteorites (e.g. polycyclic aromatic hydrocarbons, amino acids and aliphatic hydrocarbons) has previously been demonstrated, (Bada et al., 1998; Wright et al., 1998;, Toporski and Steele 2004). Jull et al., (2000) argued through C13 and C14 data that 75% of the carbon inventory in Nakhla was Martian in origin, with terrestrial contamination representing the other 25%. Polycyclic aromatic hydrocarbons, amino acids, and aliphatic hydrocarbons have been detected in Nakhla (Glavin et al., 1999; Flynn et al., 1999). Sephton et al., (2002) showed the presence of benzene, toluene, C2 alkyl benzene and benzonitrile in pyrosylates of the Nakhla meteorite that have a carbon isotope distribution similar to the Murchison meteorite. Due to this similarity these compounds are attributed to meteoritic infall to Mars. Glavin et al. (1999) concluded that most of the amino acids in Nakhla were derived from terrestrial sources, probably bacteria. Toporski and Steele (2004) showed the presence of terrestrial organisms throughout a depth profile of the Nakhla meteorite. Using stepped combustion Grady et al., (2004) showed the presence of a high temperature phase of carbon (released between 600 and 1000oC) that the authors claim is a crystalline carbon phase indigenous to the meteorites. This work follows on from previous observations and represents a consistent data set over 12 Martian meteorites (Wright et al., 1989, 1992; Grady et al., 1997). Martian meteorites do contain an inventory of organic carbon indigenous to Mars and therefore igneous terrains on Mars represent an environment that would be habitable. This is shown by the fact that terrestrial microorganisms do colonise and thrive within Martian meteorites (Steele et al., 2000, Toporski and Steele 2007).

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Early Carbon Cycle and the Emergence of life on Mars

Fernández-Remolar, D. C.[1]; Sánchez-Román, M.[1]; Prieto-Ballesteros, D. C.[1]; Gómez-Ortíz, D.[2]; Amils, R.[1]
[1]Centro de Astrobiología (INTA-CSIC), SPAIN;
[2]Universidad rey Juan Carlos, SPAIN

The presence of extensive and thick deposits of phyllosilicates on early Mars has been used as an evidence for wet and temperate conditions. Both promoted a strong weathering on the surface basaltic crust and the development of different sedimentary systems like deltaic and fluvial [1]. Although it is not well understood how this process was geochemically driven, it is clear that a specific atmosphere should have produce aggressive waters that conducted the weathering of the crust, and the production of phyllosilicates. On Earth, such a geochemical process is performed by the aqueous speciation of CO2, which currently produces acidic solutions ending on the carbonate formation through a simple buffer reaction. However, as expected from a CO2-buffering, Mars phyllosilicates show no association with carbonates excepting on some specific settings related to hydrothermal activity and alteration in deep crustal regions [2], [3], [4]. This apparent paradox has been explained as a result of weathering and clay precipitation under an impoverished atmosphere in CO2 that would prevent oversaturation and precipitation of carbonates [5]. However, recent studies on the primordial atmosphere of Mars suggest that CO2 may have been one main component in a highly pressurized planetary atmosphere [6], [7]. Under these circumstances (high pressure and f CO2), meteoric solutions could have a pH lower than 4.5, which would have prevented carbonate subsaturation in the surface, but precipitation in the subsurface. Whereas on Earth, a permanent hydrological activity may have triggered of three different agents devoted to the control of the hydrosphere pH, the punctuated hydrology of Mars may have collapsed this process at planetary scale. These three major agents such as the crustal buffering, biosphere and plate tectonics have emerged over the first billion of years to favor a neutral to subalkaline hydrosphere. As a consequence, the terrestrial solutions have extensively precipitated carbonates over the last three billion of years.

Life could have emerged during the first million of years in different habitats of Mars. Given that there is a close link between carbonate formation and microbial activity, it could be hypothesized that, in base of the carbonate absence, life did not emerged on Mars. Microbial life promotes carbonate formation that can have planetary impact but in very localized environments, which the planetary probes may have not detected. This is the case of the subsurface regions, where the carbonate factory could have been operating during eons promoted by pH-Eh gradients and microbial activity. Some evidences of carbonate formation in the subsurface would be the exposed underground material in Syrtis Major [4], where carbonates have been found in association to phyllosilicates. Same mineral association have found in terrestrial Mars analogs like Rio Tinto where microbial activity plus crustal buffering favor the formation of carbonates below a surface acidic environment [8].

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Interaction Between Organic Compounds, Minerals and Microbes: Habitability Studies From Mars Analogue Samples

Martins, Z.[1]; Kotler, J. M.[2]; Direito, S. O. L.[3]; Sephton, M. A.[1]; Stoker, C.[4]; Foing, B. H.[5]; Ehrenfreund, P.[2]
[1]Imperial College London, UNITED KINGDOM; [2]Leiden Institute of Chemistry, Leiden University, NETHERLANDS; [3]VU University, NETHERLANDS; [4]NASA Ames, UNITED STATES; [5]Science and Robotic Exploration Directorate, European Space Agency (ESA), ESTEC, NETHERLANDS

In upcoming years various space missions will investigate the habitability of Mars and the possibility of extinct or extant life existing in the Red Planet. Preliminary analyses of Mars analogue soils on Earth provide crucial information to determine whether signatures of past and/or present life may still exist in the Martian regolith. These analyses also help when choosing target locations for molecular signatures of life on Mars. Amino acids are among the biosignatures possibly present on Mars [1]. We have characterized the amino acid content of several Martian analogue soil samples collected close to the Mars Desert Research Station (MDRS), Utah, during the EuroGeoMars 2009 campaign (organized by ILEWG, NASA Ames and ESA ESTEC) [2], [3]. Total amino acid abundances were very heterogeneous in the MDRS samples, with values ranging from no amino acids detected to 100,000 parts-per-billion (ppb). When present, the most abundant amino acids were L-glutamic acid, D-glutamic acid, L-aspartic acid, L-valine, L-alanine, L-leucine and glycine [4]. The presence of both D- and L-amino acids suggests that racemization has occurred over time and amino acids may be fossil remains. Our results indicate that the mineralogical composition of the soils influences their organic content. Desert soils with the higher percentage of total clay were the ones with lower abundances of detectable amino acids. In addition, the exact clay mineral content (e.g. smectite/illite ratio) influences the extraction potential of compounds such as amino acids and DNA from the mineral matrices [4], [5], [6]. Our data also shows that samples containing a high percentage of gypsum (calcium sulfate dihydrate) have a high/medium amino acid content [6]. The relationship between microbial and organic analysis was also investigated. All three domains of life (Archaea, Bacteria and Eukarya) were observed but not in all samples [5]. While one of the soil samples did not contain any microorganism, it had a high level of present life amino acid (i.e. presence of L-amino acids only). Spiking experiments revealed that this is due to adsorption or degradation of DNA on the mineral surface. No significant correlation was observed between amino acid content and DNA yield or detection of microorganisms. This may be explained either by different adsorption characteristics of amino acids and DNA, or the fact that different amino acids can last longer than DNA once an organism dies. The variations in the organic matter abundances appear to reflect the ability of soils to host living organisms, to preserve their organic signatures and allow their extraction. These multidisciplinary findings help in the preparation phase for future Mars missions, and are crucial to successfully target locations that may host organic matter, as well as extract and detect biosignatures on Mars.

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Modeling the Early Martian Climate, Water Cycle and Habitability

Forget, F.; Wordsworth, R.; Millour, E.; Madeleine, J-B; Charnay, B.
LMD, IPSL, FRANCE

The spacecrafts sent to Mars regularly reveal new evidence suggesting that the environmental conditions on early Mars where very different than today, with liquid water flowing on the surface. Which climatic or geophysical processes enabled such conditions? Were the conditions suitable for liquid water stable on long time-scales, or the consequence of of episodic, possibly catastrophic events? Can we explain the distribution of the valley networks and other ancient landforms ?

To help understand this key issue, we have developped a 3D global climate model (GCM) designed to understand the possible climate that would occur on Mars if 1) the sun luminosity is decreased by 25% like 3.8 Billion years ago and 2) the surface pressure is increased up to several bars (no other greenhouse gases than CO2 and H2O are assumed to be present). We paid particular attention to the radiative transfer in a dense CO2 atmosphere in which collision-induced absorption can be of great importance. We found that previous parameterisation of this phenomenon significantly overestimated the greenhouse effect, and derived a new approach based on recent studies.

We analyse the effects of clouds and water vapour on the surface temperature and discuss the likely nature of the early hydrological cycle. CO2 ice clouds are found to form in the middle atmosphere above 10 km. They contribute to significantly warm the surface through their scattering greenhouse effect. However, their effect can be counterbalanced by the the albedo effect of the water ice clouds forming lower. Overall, it seems difficult to have annual mean surface temperature significantly above 0°C anywhere on the planet. Nevertheless, above freezing temperature are possible, especially in the lower plains, due to the atmospheric adiabating warming.

In our simulations that include a water cycle, we find the amount of precipitation over the valley network regions depends strongly on the local distribution of water sources. If a stable northern ocean exists, transport of water to the valley highlands is relatively easy to achieve, while placing surface water sources only at the poles results in dry equatorial regions. We are currently investigating the possibility that even without a northern ocean, a local source of water from e.g., Hellas basin would still allow sufficient precipitation in the equatorial highlands.

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The Martian Sedimentary Mass: Constraints on its Composition, Age and Size

McLennan, Scott M.
SUNY at Stony Brook, UNITED STATES

In order to place any potential biological or prebiotic chemical record on Mars into geological context, it is necessary to understand the physical, chemical, mineralogical and temporal nature of the sedimentary record. Since the terrestrial biological record is the only one available for comparisons, it is especially important to understand both similarities and differences between the sedimentary records of Mars and Earth. The chemical and mineralogical composition of the sedimentary mass on any planet is controlled by the composition of exposed crust that erodes to produce sediments and sedimentary rocks and by the nature of volatiles that may be added during weathering and other alteration processes (e.g., diagenesis). Mars is characterized by a basaltic crust, which differs in terms of major and trace element chemistry and mineralogy from the "granodioritic" upper continental crust that is the ultimate source of most terrestrial sediment. The overall result is that Martian sedimentary mineralogy is dominated by mafic primary minerals (olivine, pyroxene, plagioclase, Fe-Ti-oxides, mafic rock fragments) and secondary minerals that are Fe-Mg-rich and Na-K-poor compared to the terrestrial record (quartz, K-feldspar, felsic-intermediate rock fragments, K-Na-rich secondary minerals). A second conclusion is that Martian surficial processes, over significant periods of geological time, were controlled by some form of a S-cycle rather than the well-known C-cycle that dominates terrestrial weathering. Among other things, this difference influences the chemical sedimentary record such that sulfates dominate over carbonates, the composition of the Martian hydrosphere, and the order of precipitation of evaporite minerals during brine evolution. Crustal evolution on Mars proceeded on very different timescales than on Earth. The terrestrial continental crust is relatively young, having grown episodically since about 4 Gyr and with a mean age of about 2.5 Gyr. Stratigraphically, the terrestrial sedimentary mass is very much younger than the ultimate crustal sources due to various cannibalistic recycling processes. Although volcanic activity on Mars has continued through to the present, the Martian crust on average is very old with most being in place by ~4.5-4.4 Gyr, most likely related to solidification of a primary crust formed from an early magma ocean. The mean age of the Martian crust is certainly >4 Gyr and thus much older than terrestrial crust. Although there are inadequate constraints on the age of the Martian sedimentary mass, it also appears to be old, possibly suggesting that sedimentary recycling processes have been less important than on Earth. Although model dependent, it may be possible to place some quantitative constraints on the overall size of the Martian sedimentary mass. Assuming that plate tectonics have not operated on Mars, it is reasonable to assume that the vast majority of degassed S remained in the near-surface environment. Using models of volcanic degassing over geological time, assuming that degassed S reacted in the near surface to form chemical sediment (i.e., sulfates), adopting soil S/Cl ratios and constraining amorphous silica by that expected from basalt alteration, it is possible to estimate the size of the Martian chemical sedimentary record. In turn, using the ratio of siliciclastic/chemical sediments on Earth, a minimum estimate of the Martian sedimentary mass is calculated to be ~2-20% of the size of the terrestrial mass. Given that the surface area of Mars is only one-third of the Earth's and that sedimentary recycling and preservation associated with plate tectonics probably has not occurred, these calculations indicate a very substantial sedimentary record.

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Evidence for Habitability in Gusev Crater

Ruff, S. W.
Arizona State University, UNITED STATES

The Mars Exploration Rover Spirit in Gusev crater encountered two locations along its traverse in which rocks show clear evidence for interaction with abundant water. Outcrops rich in opaline silica were identified adjacent to the Home Plate feature [1] and the Comanche outcrops in the Columbia Hills have abundant carbonates [2]. Here I present the current state of knowledge about the origin of these water-derived materials and how it applies to the issue of habitability. Spirit exposed light-toned soil (regolith) with its broken wheel that is >90 wt% SiO_2. But it is the abundant opaline-silica dominated outcrops adjacent to Home Plate that provide the most compelling clues to the origin of the silica. [3] demonstrate that these outcrops occur as eroded, meter-scale ridges and knobs that are part of a stratiform unit. The millimeter-scale texture of the exposed interiors of broken pieces reveals angular clasts and porosity that resembles breccia. Together, these observations are consistent with silica sinter produced in a hot spring environment. Hot springs and geysers are the chief sources of the silica-rich waters that precipitate terrestrial sinter deposits. Sinter is a sedimentary precipitate that is deposited when silica-saturated hydrothermal waters rise to the surface, vent, de-gas and cool, driving the precipitation of silica. Although this process produces layered rocks, the most widespread and common sinter lithofacies is composed of brecciated, reworked, and cemented sinter from other facies types. The Home Plate silica outcrops resemble this type of rock unit. Microbes are common in hot spring environments on Earth where they can become entombed and preserved by silica. By analogy with terrestrial hot spring silica deposits, the Home Plate deposit may represent the product of a habitable environment. [3] show that diagenetic maturation of the opaline phase at Home Plate has not occurred, suggesting that this material is relatively pristine except for aeolian erosion. The Comanche outcrops are olivine-rich volcaniclastic rocks with 16-34 wt% Mg-Fe carbonate, perhaps as a cement [2]. A hydrothermal origin was suggested by [2] based largely on analogy with the carbonate globules in the Martian meteorite ALH84001, laboratory synthesis of hydrothermal carbonate globules, and similar ones found in volcanic rocks in Spitsbergen, Norway. But a major difference between these carbonate globules and Comanche is the remarkable abundance of carbonate in the latter. [4] presented an alternative in which precipitation from an evaporating brine could have produced the abundant carbonate in Comanche outcrops. This was based on the apparent absence of other alteration products expected from hydrothermal alteration and the spectral similarity between the Comanche outcrops and nearby outcrops named Algonquin.

It appears that carbonates were added to the Algonquin outcrops with little else. This suggests that the precursor rocks were little altered in the process of carbonatization, unlike what would be expected by hydrothermal alteration of mafic rocks. So carbonates were either precipitated as a primary phase from a brine or dissolved from existing carbonate-bearing rocks and then re-precipitated, perhaps from hydrothermal fluids. In either case, this implies conditions favorable for the production of low temperature carbonates that may have also been favorable for life.

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Diverse Habitable Environments During the Noachian-Hesperian Transition

Mustard, J. F.[1]; Ehlmann, B. L.[2]; Skok, J.[1]
[1]Department of Geological Sciences, Brown University, UNITED STATES; [2]Institut d'Astrophysique Spatiale, Université Paris-Sud, FRANCE

The evolution of distinct eras on Mars defined by specific hydrous mineral phases as proposed by Bibring et al. [2006] provides a broad framework for assessing the nature of habitable environments and the interaction of water with the crust and surface through time. Multiple data sets show that processes on early Mars resulted in alteration mineralogies dominated by phyllosilicate minerals (dominantly Fe/Mg smectite clays), followed by processes resulting in sulfate and other evaporite minerals during the middle period of Mars' history. It is fundamental to understand the transitions between these eras by thorough analysis of regions that contain intact stratigraphies of the key mineralogic eras. The region of the western Isidis Basin, that transitions from Noachian and late Noachian deposits to the volcanic deposits of Syrtis Major Planum (Hesperian deposits) that we refer to as North East Syrtis (NE Syrtis), is an extraordinarily well preserved stratigraphic section that has datable and in place rock units that traverse this critical time stratigraphic boundary. Importantly this region preserves diverse assemblages of aqueous mineralogy that imply distinct habitable environments. We recognize three distinctive aqueous environments characterized by Fe/Mg phyllosilicate, carbonate, and sulfate minerals in stratigraphic section. The base unit containing Fe/Mg smectite clay is overlain by an ultramafic unit with olivine that has been altered in places to mineral assemblages containing Mg carbonate in some places and serpentine in others. There are a few isolated outcrops of Fe/Mg basement that also show definitive evidence for overlying kaolinite. Recent mapping has shown that a layered unit rests on the Fe/Mg phyllosilicate bearing crust and the olivine-carbonate-serpentine assemblages. In places this layered unit has spectral properties indicating the presence of sulfate minerals, including jarosite. These layered rocks are in turn overlain by lavas from the Syrtis Major volcanic shield of Hesperian age. All units can be placed in a well-defined regional stratigraphic framework and span an interval of time from the mid-Noachian to mid-Hesperian. In this compact area we propose that the alteration mineral assemblages indicate the nature of water-rock interaction varied systematically with time from near-surface fluvial to hydrothermal and from alkaline to acidic.

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Habitability in Noachian/Hesperian Materials on Mars: Relevance of Early Archaean Volcanic and Sedimentary Rocks for the Preservation of Ancient Habitability:

Westall, F.[1]; Foucher, F.[1]; Zegers, T.[2]; Bost, N.[1]; Hofmann, A.[3]; Vago, J.[4]
[1]CNRS-OSUC-Orleans, FRANCE; [2]Univ. Utrecht, NETHERLANDS; [3]Univ. Johannesburg, SOUTH AFRICA; [4]ESA, NETHERLANDS

Habitability on a microbial scale on Mars, or on any other potentially habitable planet (for example, the early Earth or early Venus) can be defined in two ways: (1) an environment hosting conditions conducive to an origin of life, i.e. presence of carbon, liquid water in contact with certain minerals, essential elements and a source of energy, for periods of time ranging from several 105 to 1 or 2.106 years, and (2) ephemerally habitable conditions that can host already developed life forms for brief periods of time (days, weeks, years, 102-103y) [1]. Precious information about the preservation of ancient traces of habitability can be gleaned from ancient terrestrial rocks that formed in environments similar to those reigning during the Noachian/Early Hesperian and that have compositions similar to martian rocks. Examples include ancient (3.5-3.3 Ga) terrestrial volcanic, volcano-sedimentary and hydrothermal deposits that record evidence of both long term and short term habitability [2,3]. These habitable environments have been preserved in the rock record for more than 3 billion years. Furthermore, they also host morphological and organo-geochemical biosignatures [4, 5].

Such deposits occur in the Early Archaean rocks in the Barberton and Pilbara greenstone belts. Although the early Earth was an ocean planet, the volcanic, sedimentary, and hydrothermal rocks record mainly deposition in shallow water basins and at their edges (littoral). Pervasive hydrothermal activity strongly affected crustal materials and influenced the environment and the prevailing forms of life. Sea water temperatures were <55°C and higher in the direct vicinity of hydrothermal vents [4]. Ambient conditions were anaerobic [2,3].

From a microbial point of view, numerous microhabitats existed in these Mars-analogue environments and materials [5,6]. Hydrothermal systems could have been the location of the origin of life and were certainly habitats of thermophilic and hyperthermophilic life (at temperatures <120°C). Volcanic lavas and sediments extruded or deposited under water, including the surfaces of pillow lavas and volcanic particles [7,8], as well as the pore spaces of volcanic sediments, were suitable habitats for chemolithotrophic microorganisms. The spatial scales of these habitats were of the order of tens to hundreds of microns. The surfaces of sediments in the photic zone also provided habitats for (anoxygenic) photosynthetic microbial mats, although it is not certain that martian life had the chance to evolve to this sophisticated level of metabolism. Chemo-organotrophs would have lived off the carbonaceous components associated with both the photosynthetic and lithotrophic microbial materials. Thus the Early Archaean rocks demonstrate a wide variety of microbial habitats hosting diverse microorganisms that help understand habitability on Mars.

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Environmental Signatures for Habitability: What to Measure and How to Rank the Habitability Potential of Mars

Conrad, P.[1]; Eigenbrode, J.[1]; Mahaffy, P.[1]; Steele, A.[2]
[1]NASA Goddard Space Flight Center, UNITED STATES;
[2]Geophysical Laboratory, Carnegie Institution of Science, UNITED STATES

The environmental signatures for habitability are not necessarily biosignatures, even though on Earth, they are definitive proof of habitability. It is the constant overprint of the chemical signatures of life that makes it difficult to recognize the chemical and physical properties of a potentially habitable environment as distinct from an inhabited one. Mars Science Laboratory (MSL) will soon embark on a mission to Mars to assess its past or present habitability, so it is useful to examine how we measure habitability on Earth and prepare for how that approach may differ for Mars. This exercise includes: (a) articulation of fundamental assumptions about habitability, (b) an inventory of factors that affect habitability, (c) development of metrics, measurement approach and implementation, and (d) a new classification scheme for planetary habitability that goes beyond the binary "yes" or "no."

There may be many factors that affect habitability and they can be weighted as a function of specific environment. However a robotic, in situ investigation even on Earth has constraints that prevent the measurement of every environmental factor, so metrics must be reduced to the most relevant subset, given available time, cost, technical feasibility and scientific importance. Many of the factors could be measured with a combination of orbital data and the MSL payload.

We propose, at a minimum, a designation of high habitability potential requires the following: (a) thermal stability with respect to extremes and frequency of fluctuation, (b) more than one energy source, (c) sufficient chemical diversity to make compounds with covalent and hydrogen bonds, (d) moderation of ionizing radiation to allow a stable or evolving pool of organic molecules, (e) must have water or other polar solvent, (f) must be able to renew chemical resources.

A measurement approach we have used to measure habitability on Earth is [1]:
1. Study remote sensing data, maps, etc.
2. Decide how big an area to measure.
3. Determine the spatial sampling rate.
4. Determine temporal sampling rate.
5. Determine order of measurements
6. Decide where to begin measurements
7. Select targets and proceed
This approach is also executable on Mars.

Measurement of past habitability is more challenging both for Earth and Mars, requiring both subsurface access and confrontation with an unknown preservation potential for the martian past [2]. Some environments preserve evidence of past habitability better than others, and this is where selection of the landing site to maximize the preservation potential of habitability indicators will be key. Mars presents an opportunity to discover transitional states between habitable or not, and we present a ranking scale for planetary habitability:

CLASS I: Uninhabitable and has never been so
CLASS II: Has a high potential but no confirmed observation of life
CLASS IIIA: Globally inhabited
CLASS IIIB: Life, not globally established
CLASS IIIC: Life exists in isolated refugia
CLASS IV: Post-habitable (life is now gone)

MSL provides an opportunity to carefully investigate the habitability of at least one site on Mars and it will reveal much about the possible states of planetary habitability.

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Habitability of a Large Ghost Crater in Chryse Planitia, Mars.

Oehler, D.; Allen, C.
NASA - Johnson Space Center, UNITED STATES

Summary: A 120 km-diameter ghost crater in northern Chryse (Fig. 1) could have provided a long-lived habitable environment, including a crater lake. The crater could be a candidate for Mars missions aimed at seeking evidence of life, as it could contain surface sediments with preserved, organic biosignatures.

Observations/Discussion: Large (1.5-4 km-diameter), variably shaped mounds with rounded bases occur along the rim of this crater (Figs. 2-3). The rounded shape of these mounds and their alignment with the crater rim suggest an origin related to fluid flow up the impact fracture system. This may have involved impact-related hydrothermal activity [1] and glaciovolcanic processes [2]. Hundreds of smaller (0.4-0.9 km-diameter), circular mounds occur within polygonally fractured, crater fill (Figs. 2-3). The smaller mounds are similar to features in Acidalia that have been compared to terrestrial mud volcanoes [3].

Both types of mounds suggest a fluid-rich substrate. In addition, this crater's location may have enhanced its development of a long-lived habitable environment. The crater sits in the lowlands, where upwelling of late Noachian/early Hesperian ground waters has been suggested from global hydrologic modeling [4]. Such upwelling could have contributed to fluid flow up impact-related fractures, providing a renewing source of nutrients for potential life in the crater. The crater is also located in the path of the Hesperian floods (Fig. 1), and a lake could have filled from combined hydrothermal activity, upwelling, and fluvial runoff. It has been proposed that hydrothermal circulation in martian craters >50 km in diameter would be sufficient to keep crater lakes from freezing for thousands of years [1]. A lake in this 120 km crater, therefore, might have been long lived.

On Earth, polygonal faults are often associated with fluidized injections in fine-grained sediments [5]. Thus, both the polygons and potential mud volcanoes in this crater are consistent with a fine-grained interior fill and a history of fluid-based diapirism. Fluid activity could have persisted from the initial impact-related circulation to the time of polygon- and mud volcano-formation, post sediment-filling. If martian life developed either within the crater or in its watershed, burial of *in-situ* or transported biosignatures in a fine-grained fill could have aided preservation of organic biomarkers [6-7]. As occurs in mud volcanoes on Earth, diapirism could have carried those biomarkers from depth to the surface [3, 7].

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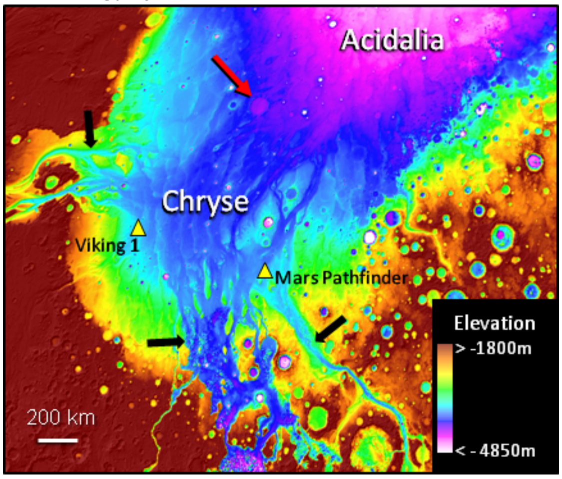

Figure 1. Location of ghost crater (red arrow) in Martian lowlands. Black arrows point to major Hesperian outflow channels. Stretched MOLA basemap.

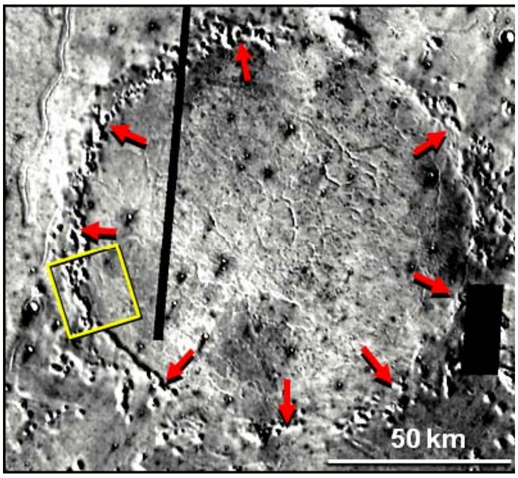

Figure 2. Ghost crater with polygonally fractured fill and large mounds (arrows) aligned with rim. Yellow rectangle is area of Fig. 3. THEMIS Daytime IR mosaic, Centerpoint: 34°N, 323°E.

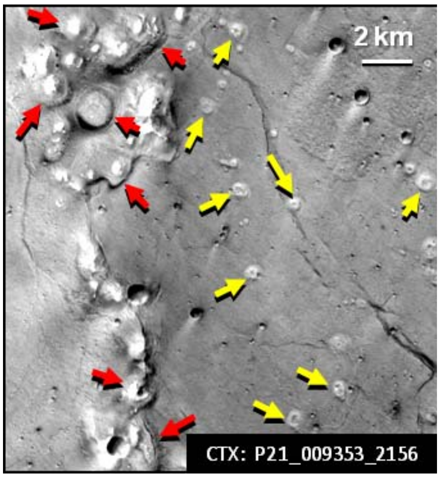

Figure 3. Large mounds at crater rim (red arrows). Fig. 2 shows location.

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Modern Habitability and the Possibility of Extant Life

Ehrenfreund, P.
Space Policy Institute, UNITED STATES

Scientists are at odds when it comes to evaluating the chances for detecting life on Mars. There is scientific consensus that past conditions on Mars may have allowed life to develop and that the search for extinct life may be more fruitful than looking for extant life. Life on Earth originated approximately 3.5 billion years ago and has adapted to nearly every explored environment, including hydrothermal vents, arid deserts, and ice lakes in Antarctica. Immense progress in the study of extreme life has changed our view of habitability beyond Earth. Recent data suggest that endolithic life can survive in cold and dry climates and inside salt deposits. These and other ecological niches could harbor extremophiles in the subsurface of Mars. However, a wide distribution of life as observed on our planet is not expected on Mars; an overall low amount of biomass, restricted to localized areas, is more probable.

The search for organic material and biosignatures on Mars is a highly complex endeavor. Instruments on future Mars missions are limited to searching for signs of life that conform to our preconceived notions of biomarkers. A combination of solar ultraviolet radiation and oxidation processes in the soil are destructive to organic material and life on and close to the surface. Galactic cosmic rays (GCRs) and solar energetic protons (SEPs) can penetrate the surface and effectively destroy organic and biological materials over geological timescales. The successful hunt for extant biosignatures will be a tradeoff between multiple parameters, including accessibility, biomarker concentration, the preservation potential, extractability, and instrument performance. When deploying organic detection instruments on Mars, consideration only of the geological context and the history of regional aqueous processes for landing site selection may be insufficient. The host microenvironment of putative microbes on Mars must be compatible with the capabilities of the instrumentation payload.

Earth-based field research in extreme environments (such as dry deserts and permafrost regions) that investigates metabolic processes of microbes and their geological environments will therefore be a vital research activity in the preparation phases of future space missions. Subjecting terrestrial microbes to simulated Mars environments that include appropriate UV and ionizing radiation, atmospheric constituents and reactions, aridity, temperature conditions, surface oxidation, salinity and acidity, and aeolian processes will provide important data on habitable regions on Mars. The detection of extant life prior to Mars sample return missions will depend strongly on instrumentation that can distinguish biological from non-biological organic matter and fossil organic matter from recent remains.

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Atmospheric Signatures of Habitability and Habitancy

Mark Allen, A.[1]; DesMarais, D.[2]; Eiler, J.[1]; Sherwood Lollar, B.[3]
[1]California Institute of Technology, UNITED STATES;
[2]NASA/Ames Research Center, UNITED STATES;
[3]University of Toronto, CANADA

Signatures of Mars habitability and habitancy may be present in the current Mars atmosphere. Most likely in the subsurface, if they exist at all, extant geological processes and biological processes may inject into the atmosphere trace gases that uniquely indicate the presence of active processes since most of these chemical compounds cannot otherwise be formed in the atmosphere. The extent to which various trace gases are uniquely indicative of specific active processes will be illustrated. While widely considered to be signatures of specific processes, ratios of isotopologues can be highly ambiguous while ratios of different chemical species may be more discriminating. If areas on Mars show localized concentrations of an unusual trace gas, only with consideration of the atmospheric circulation might the surface source of the trace gas be identified. Future opportunities to detect and localize evidence of active subsurface processes via inventorying and mapping atmospheric composition will be discussed.

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Temperature, Liquid Water, Time and Habitability

Möhlmann, D.
DLR, GERMANY

It is quantitatively demonstrated on the basis of measured bio-activity data and by applying Arrhenius's relation that decreasing temperature constraints life-processes via slowing down bio-chemical reaction rates. Thus, longer time-scales are to be taken into account when studying life in cold environments. Low temperatures clearly slow-down but do not exclude life processes! Compared to Earth, slower bio-chemical processes and related life-forms on and in iced bodies of the Solar system, incl. Mars, cannot be excluded by a solely temperature-based argumentation. Liquid water is the necessary ingredient for terrestrial type life. The presence of water vapour is described by the equilibrium-"water activity" a_w, where the presence of liquid water is given for saturation at a_w = 1, and a_w-values near 1 are sometimes misunderstood as to be a necessary condition for life to exist. It is shown that there can be temporary saturation phases of the atmospheric water vapour on Mars while the diurnal average is 0.5 or less. Organisms could uptake water in these diurnally repetitive saturation phases with available liquid microscopic interfacial water. Metabolic processes will be more efficient during the warmer but dryer phases in course of the day. These aspects indicate the necessity to widen the definition of habitability with respect to low temperature and related longer time-scales and to also take into account that an only temporary availability of liquid water can be sufficient to support metabolic processes. Consequently the habitability limit in the planetary system is to be shifted outwards into zones with iced bodies, incl. Mars. A related and yet open issue is to develop techniques to detect and to directly observe and measure (traces of) forms of slow life.

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Evidence for the Long-Term Persistence of Habitable Conditions in the Deep-Subsurface of Mars.

Clifford, S. M.[1]; Max, M. D.[2]
[1]LPI-USRA, UNITED STATES; [2]Hydrate Energy International, UNITED STATES

Based on the geomorphic interpretation of a wide variety of Martian landforms, and a conservative estimate of the volume of water required to erode the outflow channels, Carr [1, 2] has estimated that, at the time of peak outflow channel activity (~2-3 Ga), Mars possessed a planetary inventory of water equivalent to a global equivalent layer ~0.5-1 km deep. As the outflow channels significantly post-date the period when the most efficient mechanisms of water loss (impact erosion and hydrodynamic escape) were thought to be active (>4 Ga) [3], it is expected that the bulk of this water still survives on Mars today, 90-95% of which is believed to be stored in the subsurface, as either ground ice or groundwater [2, 4].

Although a recent theoretical investigation of the evolution of subsurface H2O on Mars [5] suggests that the equatorial regolith should have been completely desiccated, just a few hundred million years following the inferred transition from a warm to cold early climate, ~3.7-3.9 Ga, there is evidence of significant, and geologically recent, outflow channel activity at several equatorial locations, including: Mangala Valles (~0. 2-1 Ga [7], Kasei and Echus Chasma (~0.07 0 - 1 Ga [8, 9], and Cerberus/Athabasca Valles (~2 Ma [10-12]).

Recent atmospheric methane observations also appear to indicate a low-latitude subsurface source [13]. Since there is no obvious evidence of local volcanism, the most plausible origin of this methane appears to be either the serpentization of olivine or the presence of methanogenic bacteria - both of which require the presence of a significant subsurface reservoir of liquid water.

Thus, if the methane is recent, that reservoir of liquid water should still exist. However, if the methane is old (i.e., formed during the Noachian and preserved to the present day as gas hydrate by the diffusion limiting properties of the regolith) then it implies that the vast majority of the H2O that existed in the equatorial subsurface at the time of peak outflow channel activity should still be there (either as ground ice or groundwater). This follows because the diffusion coefficient of methane is greater than that of H2O - implying the presence of more restrictive subsurface diffusive conditions than generally assumed by most theoretical models [e.g., 5].

If life did arise on early Mars, and successfully adapted to a subterranean existence (as it did on Earth) - with both warmer temperatures and abundant groundwater - then it is difficult to imagine how such life, once established in the comparative isolation and stability of a subpermafrost environment, could become extinct. The most probable threat to life, under these conditions, would be if the growth of the crysophere, in response to the long-term decline in the planet’s internal heat flow, led to the eventual assimilation of the entire groundwater inventory into the frozen crust [4]. However, the geologic evidence for comparatively recent (Mid- to Late Amazonian) outflow channel activity, combined with contemporary releases of subsurface methane, strongly supports the persistence of habitable conditions in the deep-subsurface of Mars to the present day.

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Does Mars Have Groundwater Today?

Grimm, R.E.
Southwest Research Institute, UNITED STATES

Today the surface of Mars is a frozen desert, but it is generally thought that groundwater is widely distributed in the subsurface. However, a recent global-scale model for subsurface volatile transport on Mars (Grimm and Painter, GRL, 2009) predicts massive loss of subsurface H_2O. This occurs because excursions to low obliquity strongly drive ice sublimation at low latitudes, which in turn allows high-latitude H_2O to migrate toward the equator and also escape. On timescales of a billion years, the subsurface becomes deeply undersaturated and the predicted end state is just a few monolayers of adsorbed water. A thick layer of ground ice remains at high latitude, largely aligned with the present surface ice-stability regime. Our low-latitude loss rates are comparable to those of Mellon et al (1997) and Clifford and Hillel (1983) where 10-um pores are assumed. However, the latter workers focused on 1-um pores (scaled from Viking soil) and therefore favored longer ice-retention times. We view the larger pores as typical of the upper crust, but ice could be locally trapped at low latitude in fine-grained materials. We suggest that lobate-ejecta craters record such spatial heterogeneity. As vapor diffusion will exploit pathways in coarser-grained near-surface materials, runaway H_2O loss may occur nonetheless. This predicted fate of ground H_2O results in an uninhabitable martian subsurface, as adsorbed water has insufficient conductivity to accommodate microbial nutrient and waste transport. The subsurface of Mars may also be a desert.

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Ice Lens Formation and Habitability of the Phoenix Landing Site

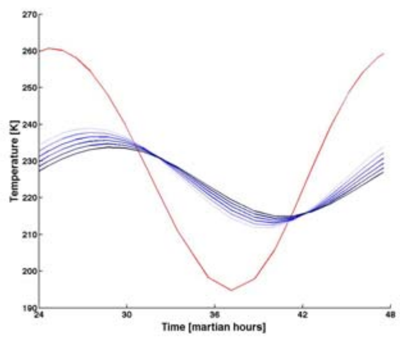
Zent, A.[1]; Sizemore, H.[1]; Rempel, A.[2]
[1]NASA Ames Research Center, UNITED STATES;
[2]University of Oregon, UNITED STATES

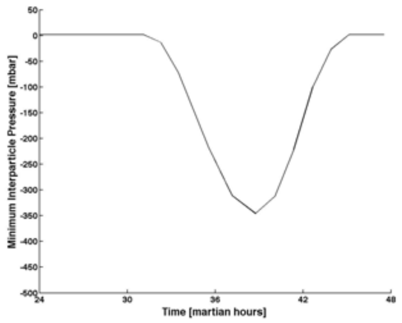
Introduction: The volume of shallow ground ice in the martian high latitudes exceeds the pore volume of the host regolith. [1,2] and ice deposits containing only 1-2% soil by volume were excavated by Phoenix [3]. The leading hypothesis for the origin of this excess ice is that it developed in situ by a mechanism analogous to the formation of terrestrial ice lenses and needle ice [4]. Problematically, terrestrial soil-ice segregation is driven by freeze/thaw cycling and the movement of bulk water, neither of which are expected to have occurred in the geologically recent past on Mars. If however ice lens formation is possible at temperatures < 273 K, there are possible implications for the habitability of Mars permafrost, since the same thin films of unfrozen water that lead to ice segregation are used by terrestrial psychrophiles to metabolize and grow down to temperatures of at least 258 K.

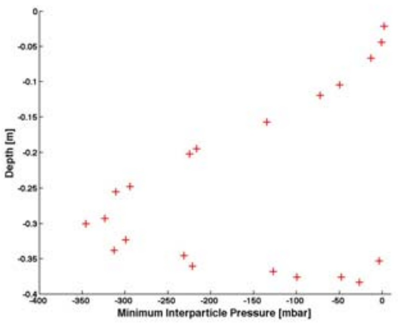
Model: We have developed a numerical model that applies the physics of pre-melting to track phase partitioning in soil pores and test for conditions under which ice lenses could initiate on Mars. The model balances the thermomolecular forces that arise from intermolecular interactions against gravity and the effective soil overburden pressure. The model distinguishes between initiation of an ice lens, which does not involve migration of unfrozen water, and the subsequent growth of an ice lens, which does. Here, we rigorously test for lens initiation, and discuss qualitatively the possible subsequent lens growth to macroscopic scale. In a freezing soil, gravitational forces, and the repulsive thermomolecular force are balanced by the forces transmitted vertically between soil grains. The depth of the ground ice, and the surface temperatures are taken from the historical ground ice model of Zent[5] which provides estimates of ice depth and surface environment over the last 10^7 years. One simply integrates the force balance equation from the surface down, and if the interparticle pressure $p_p < 0$ at any depth, z, then the interparticle forces can unload, and lenses are assumed to initiate.

Results: Our results indicate that diurnal cycling in the ice-cemented regolith and resultant pressure gradients in thin films at grain ice interfaces can cause interparticle forces to unload, initiating ice lens formation at temperatures as low as 245 K. Figures 1-3 show a recent case, from 30 ka bp, where the ground ice is ~ 2 cm deep, and ice temperatures never exceed 240 K. Nonetheless, the very small changes in pore ice over the 30K diurnal temperature swings can produce enough net force to lift up to 30 cm of overburden. Thus, we predict that even it recent times, ice lenses have the potential to at least initiate on Mars. Lens growth however, is dependent on mass transport in very thin films, with permeabilities expected to be extremely low at these temperatures. This may not however, be prohibitive of ice segregation in the long term.

We argue that, unlike Earth, a martian proto-lens may continue its incremental growth from year to year, adding a fraction of a micron each year, until a macroscopic segregated ice lens emerges. No forces arising from premelting physics in the Mars environment would degrade a lens once it initiates, although there may be circumstances where individual solid particles are able to regelate through an ice lens at a speed comparable to its growth rate. Potential growth rates, mortality and overall habitability will be addressed in light of this evidence for thin film transport.







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The Near Subsurface Habitat of Mars: Caves, Vugs, & Drilling

Boston, Penelope[1]; Kieft, T.[1]; Northup, D.E.[2]; Spilde, M.N.[2]
[1]New Mexico Institute of Mining and Technology, UNITED STATES; [2]University of New Mexico, UNITED STATES

One of the biggest epiphanies that people new to caving have is how radically different the near subsurface of Earth is to the aboveground world, even when only a few meters of rock separate the sky and sun from the underground realm. This is not only perceived by humans but long known to the microbial inhabitants that make the shallow to mid-range crust of Earth their homes. How indigenous are these microbial ecosystems to the subsurface on our planet and what can we learn from them to help inform our notions of subsurface habitability on Mars?

Some of the clues that will help us in this task are emerging from studies of natural caves at depths ranging from a few meters to over 2 km in depth, and from human-delved mines, some of which reach depths greater than 4 km. Although all of these environments are "subsurface", they present a dramatic range of environmental conditions and ecological niches for microorganisms that track along several highly significant gradients.

Systematic differences in microbial biodiversity, nutritional strategy, and other properties with depth are distinguishable between shallow and deeper crustal levels. These differences include a trend toward decreasing heterotrophy and an increasing tendency to chemoautotrophy with depth. This often manifests as a decreasing total biodiversity with depth. Sheer availability of living space may also act as a major gradient between macroporosity (caves) and mesoporosity (vugs and fractures) at shallow to moderate depths, and extremely small rock fractures and intergrain spaces available to microorganisms at greater depths reached in mines and borehole samples.

Systems also appear to differ markedly with respect to energetics. On Earth, very near-surface systems are typically dependent on the products of photosynthesis (organic C and/or O2) but at greater depths, ecosystems are anaerobic and are fueled by the products of water-rock interactions that produce H2, and indirectly, abiotic short chain hydrocarbons. This results in a gradient of increasing importance of abiotic energy sources with depth. Exceptions occur, including geochemically enriched shallow systems that push chemolithotrophic communities in the direction of oxidation of reduced gases and minerals.

In Earth's subsurface there are two potential sources of energy available, 1) reduced gases coming from geologically deep sources, and 2) oxidizable materials contained within the bedrock upon which organisms might be growing. The first case, reduced gases, has been suggested for Mars. Examples of such energy sources supporting Earth subsurface microbial communities have been found in Columbia River basalt fractures and in uniquely self-reliant, very deep subsurface organisms in South African gold mines. Likewise similar energy sources have been suggested to be present in deep-seated serpentinization reactions. Since hydrogen gas is the major reductant for CO2-reducing methanogens in the deep subsurface, any process that can produce H2 is a potential energy source. Water-rock interactions in the Martian subsurface at latitudes where potential subsurface liquid water may underlie an icy overburden may facilitate such aqueous transformations. In light of new ideas about geologically long variations in so-called obliquity seasons and recent modeling showing the plausibility of long timescale persistence of ice in Mars caves, the potential exists for a number of different "habitability sweet spots" to exist at different depths, latitudes, and during geological eras on Mars.

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Sampling and sequencing Volcán Copahue, an acidic, sulfur-rich terrestrial analog of Mars

Lui, C. S.[1]; Carr, C. E.[1]; Zhu, T.[1]; Johnson, S. S.[2]; McManus, K.[3]; Zuber, M. T.[1]; Ruvkun, G.[4]
[1]Massachusetts Institute of Technology, Department of Earth, Atmospheric and Planetary Sciences, UNITED STATES; [2]Harvard Society of Fellows, UNITED STATES; [3]Massachusetts Institute of Technology, Department of Biology, UNITED STATES; [4]MGH Department of Molecular Biology & Harvard Medical School, Division of Genetics, UNITED STATES

Volcán Copahue (37.85°S, 71.17°W, 2980m above sea level) is located on the rim of the large ~2Ma Caviahue caldera in the province of Neuquen, Argentina and contains an acid crater lake (pH ~ 0.2-1.1) and acid hot springs (pH ~ 0.3-2.4), which feed into an acidic river system, the Upper Rio Agrio (pH ~ 0.5-2.5). The condensation or dissolution of sulfur-rich volcanic gases in meteoric waters is believed to give rise to the acid fluids in this region. Rock-forming elements are leached from the surrounding rocks, forming patterns of hematite, cristobalite, and gypsum, with some regions rich in alunite or jarosite. Deposits of red hematite are also found within streambeds, and the surrounding fluids are saturated with K-jarosite. Given these features, Copahue may represent a terrestrial analog of Meridiani Planum on early Mars.

Despite the low pH of the Copahue waters, microbial organisms have been successfully isolated, cultured, and sequenced. Prior sequence results have been obtained using pre-enrichment and culturing methods. We pursued a strategy to assess microbial diversity with less bias by direct metagenomic analysis of the samples. Samples of water, sediment, and soil were collected in WhirlPak bags from 6 different sites along the Upper and Lower Rio Agrio, and temperature and pH were measured *in situ* at each sample point. Soil and sediment samples were processed with a MoBio PowerSoil kit for DNA extraction and purification. Analysis using canonical ribosomal 16S all-bacterial and archaeal primers yielded little or no amplification. Further analysis using primase-based whole genome amplification with the pWGA kit from BioHelix helped eliminate bias due to poor priming or environmental contamination, and successful amplification was demonstrated in all the tested samples, with no amplification in negative controls. The extremely acidic river associated with the volcano shows a strong gradient of microbial life: DNA recovered dwindles toward the source and increases significantly downstream. Metagenomic sequencing is currently ongoing and will be presented. The work presented here will help inform the search for life on Mars by complementing the development and optimization of the SETG (Search for Extraterrestrial Genomes) nucleic acid-based life-detection instrument.

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Raman and Mossbauer Spectroscopic Mineralogical Characterisation of Rio Tinto and Jaroso Ravine Mars Analogue Sites

Rull, F.[1]; Klingelhöfer, G.[2]; Venegas, G.[1]; Martinez-Frias, J.[1]; Henrich, C.[2]; Sansano, A.[1]; Fleischer, I.[2]; Sanz, A.[1]
[1]Unidad Asociada UVA-CSIC, Centro de Astrobiologia, SPAIN; [2]Institut für Anorganische and Analytische Chemie, GERMANY

The presence of sulphates has been observed on Mars using orbiter spectrometry and the two MER vehicles on the surface. In particular Jarosite (KFe33+ (SO4)2(OH)6) was unambiguously identified at Meridiani Planum on Mars by Miniaturized Mossbauer spectrometer onboard the MER's rover Opportunity [1]. These results show that sulphates are of prime importance in the geological evolution of Mars. Investigation of sulphate formation on Earth in similar conditions than those experienced in Mars in the past is of considerable interest in connection with the future missions to the red planet and in particular with Exomars mission which has a very important Astrobiological objective.
Rio Tinto is considered a modern model of formation of sulfates, linked to significant acidophilic biogenic activity [2]. Sulfates mainly come from aqueous alteration of iron-rich sulfide minerals of the Iberian Pyrite Belt. On the other hand Jaroso Ravine, located in Sierra Almagrera (Almeria, Spain) and the "world locality type of Jarosite", is part of the Jaroso Hydrothermal System (JHS). This system constitutes an ancient model of formation of supergenic sulfates associated with polymetallic (Fe,Pb,Ag) sulfides and sulfosalts which are genetically linked to the calc-alkaline shoshonitic volcanism (Upper Miocene) of the SE Mediterranean margin of Spain [3].
In the present work results obtained using a combined suite of Raman and Mossbauer spectrometers in situ at both locations and on collected samples at the laboratory are presented and discussed. Raman is being developed for Exomars mission and Mossbauer has a wide experience at the surface of Mars. The capability of each technique and their synergies on working in coordination are stressed. Also, by comparing the results obtained in laboratory and in situ the capacity of these field instruments and possibilities for in-situ studies in terrestrial conditions and the potential for application in planetary exploration is analysed.

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Oxide Residues Overlying Sulfide Mineralization (Gossans) in Greenland Provide Insight into Potential Niches for Life on Present-Day Mars

Pratt, L.[1]; Onstott, T.[2]; Young, S.[1]; Cadieux, S.[1]; Hardisty, D.[1]
[1]Indiana University, UNITED STATES; [2]Princeton University, UNITED STATES

Partially to fully oxidized iron sulfates are common on the surface of Mars and understanding the formation of these minerals is crucial for recognition of potentially habitable environments that are accessible for sampling by robotic rovers. The combination of low temperatures, limited water, and abundant sulfur on present-day Mars suggests that mineralogical and microbiological study of Arctic gossans will provide crucial constraints on metabolic pathways, activity of water, and ultra-violet protection for putative martian life forms. Ferric sulfate minerals such as jarosite and schwertmannite are commonly identified while ferrous sulfate minerals such as szomolnokite and melanterite are sporadically reported or inferred for both Mars and Arctic gossans [1], [2]. Lack of information on iron and sulfur speciation and stable sulfur isotopic composition for minerals and seasonal brines associated with Arctic (and Antarctic) gossans is a serious gap in knowledge given the life-focus for the coming decade of Mars exploration.

Gossan samples overlying sulfide-rich metavolcanic rocks at High Lake in Nunavut, Canada, were analyzed to determine their mineral components and to define parameters for the geochemical environment in which they formed [2]. A decimeter-deep crust from the weathered margin of a mafic dike collected near Kangerlussuaq, Greenland was scrutinized and found to contain a diverse suite of sulfur species including pyrite, elemental sulfur, and sulfate minerals. Mineralogical and isotopic data from Nunavut and Kangerlussuaq will be compared with published data from Citronen Fjord in Northern Greenland where microbial communities in the high Arctic have been studied by other research groups [3], [4]. Relationships among mineral composition, grain size/texture, and microbial activity have not been assessed seasonally for any Arctic gossan. In particular, changes in mineral and microbe assemblages need to be determined when gossans are wetted by melting snow in the spring followed by evaporation during the summer and fall. We intend to pursue this integrated mineralogical and microbiological field campaign on the ice-free margin of Greenland with a focus on deeply eroded Paleoproterozoic tectonic terranes separated by strongly deformed orogenic belts, including the Southern Nagssugtoqidian Orogen, which consists predominantly of reworked gneisses of Achaean age [5], [6]. Critical for the proposed Mars-analogue study is the presence of numerous sulfide-mineralized veins and a mafic alkaline dyke swarm with varying amounts of pyroxene, olivine, hornblende and carbonate minerals [7], [8]. Although more alkaline than the tholeiitic basalts on Mars, the dikes contain abundant olivine and pyroxene indicating a mineralogically useful analogue for rocks on Mars[9], [10]. 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 of intersecting weathering crusts and porous fracture zones harboring microbial communities linked to oxidation/reduction cycling of iron and sulfur.

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A Potentially Habitable Environment within the Salt-rich Subsurface in Equatorial Regions on Mars

Wang, Alian
Washington University in St. Louis, UNITED STATES

Introduction: A wide variety of salts were found at Martian surface by orbital remote sensing. In addition, hydrous sulfates and carbonates were excavated from the Martian subsurface by Mars Exploration Rovers and Phoenix lander. These materials contain the most bioessential elements. We will discuss the environmental conditions within the salt-rich subsurface and the potential existence of liquid water, based on mission observation, terrestrial analog study, and laboratory experiments, and the habitability of this type of environments.

Observation on Mars: Temporal spectral change was observed for the ferric-sulfate-bearing salty soils excavated by the Spirit rover and after their exposure to current Mars surface atmosphere conditions. The change of spectral pattern is consistent with the dehydration of Fe-sulfates, indicating that these subsurface salty soils were originally NOT in equilibrium with surface atmospheric conditions, and an environment with higher RH exists within the subsurface salt-rich regolith.

Terrestrial analog study: Da LangTan (DLT) saline playa occurs in a hyperarid region (Qaidam basin) on Qinghai-Tibet (QT) Plateau. The extreme climatic conditions in the region, including low P, low T, large delta T, hyperaridity, and high UV radiation, all make DLT to be one of the most similar places on Earth to Mars. A preliminary finding was the preservation of Mg sulfates with high degrees of hydration ($MgSO_4.6H_2O$ & $MgSO_4.5H_2O$) within the subsurface salt layers. These hydrates would dehydrate quickly at relative humidity (RH) ≤ 33% and in 5°C ≤ T ≤ 25°C range. Their preservation indicates, analogously to the observation by Spirit rover, the existence of an environment with higher RH exists within the subsurface salt-rich layer.

Laboratory experiments: Our systematic laboratory experiments on Mg-sulfates and Fe^{3+}-sulfates yielded the following three related findings: (1) at low temperature (≤ -10°C), sulfates with high degrees of hydration, e.g., $MgSO_4.7H_2O$ & $Fe_{4.67}(SO_4)_6(OH)_2.20H_2O$, have a large field of stability (or metastability) over a wide RH range (7-88%); (2) these hydrous sulfates are all good RH buffers: a space filled with $MgSO_4.7H_2O$ at -10°C can maintain the RH in a 96-97% range, whereas $Fe_{4.67}(SO_4)_6(OH)_2.20H_2O$ at -10°C can maintain 75-79% RH in an enclosure; (3) thin film of liquid water was found forming at the grain surface of $Fe_{4.67}(SO_4)_6(OH)_2.20H_2O$ at 45% ≤ RH ≤64% and 5°C.

Habitability: an environment with locally high RH and the thin film of water forming on salt grains (at low Tave) could be life-supporting for halophiles. This hypothesis was proven on Earth by the finding of halophies under the salt crust of Atacama desert by Wierzchos et al (2006), and by a similar discovery of different chains of halophiles within the salt crust at DLT saline playa on the QT Plateau by our team (2009, 2010).

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The Possible Effects that the Planet's Internal Structure and Movements may have had on Habitability Issues

Interior of Mars and its habitability

Dehant, Veronique
aa, BELGIUM

Our fundamental understanding of the interior of the Earth comes from seismology, geodesy, geochemistry, geomagnetism, geothermal studies, and petrology. For the Earth, measurements in those disciplines of geophysics have revealed the basic internal layering of the Earth, its dynamical regime, its thermal structure, its gross compositional stratification, as well as significant lateral variations in these quantities. Planetary interiors not only record evidence of conditions of planetary accretion and differentiation, they exert significant control on surface environments. We study recent advances in possible in-situ investigations of the interior of Mars, a truly Earth-like planet other than our own, using experiments and strategies that provide unique and critical information about the fundamental processes of terrestrial planet formation and evolution investigations. New seismological methods and approaches based on the cross-correlation of seismic noise by two seismic stations/landers on the surface of Mars and on joint seismic/orbiter detection of meteorite impacts, as well as the improvement of the performances of VBB seismometers have made it possible to secure scientific return with only two simultaneously recording stations. In parallel, use of interferometric methods based on two Earth-Mars radio links simultaneously from landers tracked from Earth has increased the precision of radio science experiments by one order of magnitude. Magnetometer and heat flow measurements will complement seismic and geodetic data in order to obtain the best information on the interior of Mars. In addition to studying the present structure and dynamics of Mars, these measurements will provide important constraints for the astrobiology of Mars by helping to understand why Mars failed to sustain a magnetic field, by helping to understand the planet’s climate evolution, and by providing a limit for the energy available to the chemoautotrophic biosphere through a measurement of the surface heat flow. The landers of the mission will also provide meteorological stations to monitor the climate and obtain new measurements in the atmospheric boundary layer.

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Early Habitability of Mars: Looking Beyond a Pretty Face

Banerdt, B.
Jet Propulsion Laboratory, UNITED STATES

The investigation of the habitability of Mars has a long history, from fancifully interpreted telescopic observations in the late 19th century, to the disappointing images returned by the first fly-bys in the 1960s, to the orbital evidence for flowing water and the chemical evidence against extant life in the 1970s, to the increasingly detailed mineralogical and geochemical investigations of the past fifteen years or so. These latter, from orbit and on the surface, have provided a wealth of clues about environmental conditions early in Mars’ history, which almost certainly included warmer temperatures, greater atmospheric pressure and more abundant water than is the case today. This fundamentally fascinating avenue of exploration is continuing with the upcoming launch of a sophisticated analysis payload on MSL and ongoing plans for exobiological investigations on the ExoMars rover and, eventually, on rocks returned from Mars.

However, virtually all the attention over this entire time span in characterizing the habitability history of Mars has focused on observations of its surface, the outermost few cm (or at most, few km) of the planet. This is in fact a volumetrically insignificant (albeit disproportionately interesting) portion of the planet, as well as the region most susceptible to being obliterated or obscured from view through time by forces such as cratering, volcanism and erosion. I contend that many of the keys to the early habitability of Mars reside in the deep interior of the planet, accessible through relatively straightforward geophysical observations.

The deep interior (from a few km deep through the central core) is important to the question of habitability for two different reasons: the intrinsic importance of the bulk of the planet in determining the surface conditions thought to be required to harbor life; and the persistence of evidence therein that can be queried to further our understanding of the early environment. The initial bulk composition and the thermal, mechanical and chemical processes by which it differentiated into the current core, mantle and crust determine the composition, mass and timing of volatile release: outgassing of the interior through magma generation and transport is likely a major contributor to the past and current atmosphere, and the oxidation state of the mantle can have profound effects on geological sources of atmospheric methane. The onset and collapse of the core dynamo is directly related to the ability of the planet to support a thick atmosphere, with its implications for the stability of water and the maintenance of a UV shield. The average thermal gradient in the near subsurface, key factor for any chemoautotrophic organisms, is affected by the partitioning of radiogenic elements during planetary differentiation and by the subsequent thermal history, including the style and vigor of mantle convection.

These and other key factors in the study of early habitability can be addressed by relatively broad measurements of interior structure, such as the thickness and large-scale layering in the crust, the density, stratification and thermal state of the mantle, and the radius, density and state (solid vs. liquid) of the core, as well as the possible existence of a distinct inner core, all of which provide direct evidence of the conditions of Mars' formation, early evolution, and ancient surface conditions.

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Joint Use of MGS-MAG and MGS-ER Measurements to Better Describe the Martian Magnetic Field and Understand the Complex Magnetic Story of Mars.

Langlais, B.[1]; Purucker, M.[2]; Lillis, R.[3]
[1]LPGNantes, FRANCE; [2]NASA/GSFC, UNITED STATES; [3]U. Berkeley, UNITED STATES

The Mars Global Surveyor probe stayed in orbit during almost one decade, from Sept. 1997 to Nov. 2006. During its tour, it acquired valuable measurements of the Martian magnetic field at a range of altitudes, using both direct (i.e., involving MAGnetometers) and indirect methods (i.e., using Electron Reflectometry). The MAG dataset consists in a complete and repetitive survey of the three components of the magnetic field at altitudes ranging between 370 and 430 km, with additional sparse measurements at lower altitudes, which were acquired during the initial mission phases. These measurements have an error noise of the order of 1 nT, but they are sensitive to both internal and external contributions. The ER dataset consists in an incomplete and remote coverage of the magnetic field of internal origin, at an altitude of 185 km. This lower altitude (and closer distance to the magnetic sources) and better exclusion of external fields compensates for the lack of vector information, as well as the poorer geographical resolution related to the remote sensing method. In this paper, we present the first combined use of these two datasets into a single magnetization model of the Martian lithosphere. The model aims first at predicting the magnetic field vector of internal origin at low altitude, allowing an easier comparison of the magnetic field of Mars with its geology, with an improved horizontal resolution when compared to previous models which used only one dataset. Second, the model is based on the equidistant Equivalent Source Dipole method, which can be used to estimate what are the lateral variations of the magnetization. The details of this new crustal field map provide us with a unique opportunity to remotely characterize Mars' interior and evolution. It also yields important information about the inter-connected histories of volcanism, magmatism, impacts and the ancient Martian dynamo. In particular we focus on the magnetic field signature above craters and volcanoes to re-assess the cessation of the dynamo.

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Mars Magnetic Microdomains and Life

Alves, E. I.[1]; Madeira, V. M. C.[2]; Peixinho, N.[3]
[1]Instituto Geofísico, Centro de Geofísica, Departamento de Ciências da Terra, Universidade de Coimbra, PORTUGAL; [2]Departamento de Ciências da Vida, Universidade de Coimbra, PORTUGAL; [3]Observatório Astronómico, Centro de Física Computacional, Universidade de Coimbra, PORTUGAL

The actual radiation doses on the surface of Mars are unknown. Models have been designed based on the filtering power of the atmosphere [1] and on radiation counting by the Martian Radiation Environment Experiment (MARIE) onboard the 2001 Mars Odyssey spacecraft [2]. Both models ponder that most radiation reaching the surface originates in galactic cosmic rays (GCR) basically isotropic, with occasional directional bursts produced by solar events. This was the reason for the lack of areoreference of the MARIE data archival. However, knowledge of the existence of remnant magnetic fields [3] raises the question whether those fields can regionally shield the surface. Albeit mild, shielding is detectable on the long (almost one Martian year) and dense (more than 20 million records) dataset that is now areoreferenced (Fig. 1). Local micro-magnetospheres that have been active for at least 4 Gy could have provided magnetic microdomains where the rates of random mutation were slowed enough to allow the evolution of specialized microorganisms who could cope with the adverse Martian environment.

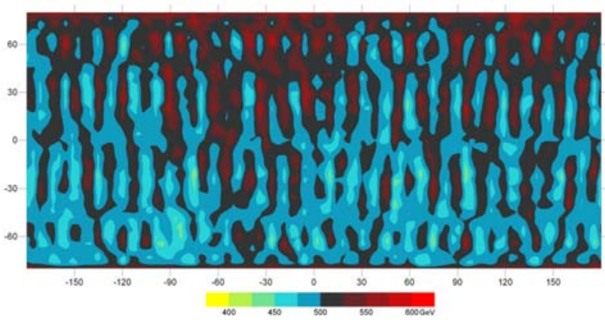

Figure 1 - Total energy collected by the A and B sensors of the MARIE spectrometer during 536 days on the mission mapping phase.

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Mars Aqueous Mineralogy: A Comparison of Thermal-Infrared and Visible/Near-Infrared Spectral Data

Amador, E. S.; Bandfield, J. L.
University of Washington, UNITED STATES

The analysis of spectral datasets from Mars spacecraft is providing new details about the aqueous mineralogy of the planet. We are examining deposits using thermal infrared (TIR) data from the Thermal Emission Imaging System (THEMIS) aboard the 2001 Mars Odyssey spacecraft and visible/near-infrared (VNIR) data from the Compact Reconnaissance Imaging Spectrometer for Mars (CRISM) aboard the Mars Reconnaissance Orbiter. The two datasets contain highly complementary and unique sensitivities to mineralogical features in their respective wavelength regions that can either reinforce or alter interpretations made using only one. This allows for a more complete understanding of the formation of aqueously altered materials on Mars, and subsequent interpretations of the past habitability of the planet.

TIR and VNIR images are spatially correlated using JMARS, a GIS program that allows us to start with CRISM results and then overlay THEMIS stamps to assess spectral variability. Preliminary results are demonstrating that spectral interpretations are much more complicated than expected. In some regions hydrated silica and phyllosilicate spectral features in VNIR datasets have spatially associated spectral variability in the TIR data. For example, in Valles Marineris, TIR data indicates a higher abundance of high silica material in locations where hydrated silica has been identified [1]; this is indicated by a deeper absorption at shorter wavelengths in TIR emissivity data. Likewise, for some phyllosilicate deposits as identified by VNIR data, such as in Mawrth Vallis [2], TIR data indicates a higher silica abundance in the region, consistent with the presence of these phyllosilicates. But, there are examples of phyllosilicate deposits in Terra Sirenum that when observed with TIR show no indication of higher silica abundance, and in fact are consistent with unweathered basaltic material [3]. Preliminary investigations of hydrated sulfate deposits, such as in Columbus Crater [4] and Sinus Meridiani [5], indicate little to no spectral variability in TIR data.

Geologic interpretations may be incomplete if only one dataset is sampled; both provide important clues to the puzzle. Areas such as Columbus Crater, where CRISM has identified hydrated sulfates, would be misinterpreted if only examined using TIR data. Conversely, when only VNIR data is used, the dominance of basaltic materials is not apparent. TIR data can be used to constrain the extent of aqueous alteration in these regions, and thus give us an idea for how much water was present and available for past life to utilize. Combining TIR and VNIR data is necessary for a complete interpretation of Mars aqueous processes, but integration is complicated and needs further investigation.

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Potential Site of Preservation of Early Sedimentary Environment on Mars in Terby Impact Crater and North Hellas Rim

Ansan, V.[1]; Loizeau, D.[2]; Mangold, N.[1]; Le Mouélic, S.[1]; Carter, J.[2]; Poulet, F.[2]; Dromart, G.[3]; Bibring, J.-P.[2]; Gendrin, A.[4]; Gondet, B.[2]; Langevin, Y.[2]; Murchie, S.[5]; Mustard, J.[6]
[1]LPG Nantes- Université de Nantes, FRANCE; [2]IAS-université Paris XI, FRANCE; [3]ENS-Lyon, FRANCE; [4]I, FRANCE; [5]Johns Hopkins Univ, UNITED STATES; [6]Brown Univ, UNITED STATES

The 174 km diameter Terby impact crater (28.0°S - 74.1°E) and other impact craters located on the northern rim of the Hellas basin display anomalous inner morphology [e.g. 1], including a flat floor and light-toned layered deposits [e.g. 2]. Although some of anomalous impact craters show small well preserved alluvial fans, dated of the Hesperian epoch, the more remarkable evidence of huge amount of liquid water at the surface of Early Mars comes from the geometry of layered deposits outcropping inside the flat floor of impact craters, like Terby. The geometry of layered deposits was consistent with that of clastic sediments that settled mainly in a sub-aqueous environment. The analysis of these deposits was performed using multiple datasets with visible images for interpretation, infrared data for mineralogic mapping, and topography for geometry.
In Terby impact crater, the inner geometry of thickest sediments is similar to that observed in terrestrial fan deltas, as identified by 100 m to 1 km long clinoforms, as defined by horizontal beds passing to foreset beds dipping by 6°-10° toward the center of the impact crater [3]. The identification of distinct sub-aqueous fan sequences, separated by unconformities and local wedges, showed the accumulation of sediments from prograding/ onlapping depositional sequences, due to lake level and sediment supply variations [3]. The mineralogy for several layers with hydrated minerals, including Fe/Mg phyllosilicates, supports this type of sedimentary environment. The volume of fan sediments was estimated as >5,000 km3 [6] (a large amount considering classical Martian fan deltas such as Eberswalde (6 km3, [4])) and requires sustained liquid water activity.

Such a large sedimentary deposition is characteristic of the Noachian/Phyllosian period [3] during which the environment favored the formation of phyllosilicates. The latter were detected by spectral data in the layered deposits of Terby crater in three distinct sequences. During the Hesperian period, sediments experienced strong erosion, possibly enhanced by more acidic conditions (in the Theiikian), However, small fluvial valleys and alluvial fans formed subsequently, attesting to late fluvial processes dated as late Early to early Late Hesperian. After this late fluvial episode, the northern boundary of Hellas was submitted to aeolian processes and permanently cold conditions as confirmed by viscous flow features in this area.
The northern rim of Hellas and the Terby impact crater display, in a single region, geologic features that characterize the three main periods of time on Mars, with the presence of one of the thickest sub-aqueous fan deposits reported on Mars.

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Habitability and Organic Preservation in Cold Seep Precipitated Jarosite on Earth and Mars

Battler, Melissa M.[1]; Leoni, Lisa[2]; Preston, Louisa J.[1]; Osinski, Gordon R.[1]; Lim, Darlene S. S.[3]; Davila, Alfonso F.[3]; Michel, Frederick A.[4]; Craig, Michael A.[1]; Izawa, Matthew R.M.[1]; Slater, Greg F.[2]; Fairen, Alberto G.[3]; Banerjee, Neil R.[1]
[1]University of Western Ontario, CANADA; [2]McMaster University, CANADA; [3]SETI Institute and NASA Ames Research Center, UNITED STATES; [4]Carleton University, CANADA

Surficial deposits of the iron sulfate mineral jarosite have been observed in several places on Mars, including Meridiani Planum [1], and Mawrth Vallis [2] 105 km from a proposed landing site for NASA's Mars Science Laboratory mission [3]. Based on our findings from a jarosite-rich terrestrial analogue site, we propose that the sulfate deposits found in Meridiani Planum and Mawrth Vallis should be considered as potential targets in the search for organics [1]. Specifically, we report on the mineralogy, geochemistry, and organic preservation in the Golden Deposit (GD; [4]), a 140 x 50 m deposit of jarosite precipitating from numerous seeps of cold, acidic (pH 2.3), iron-bearing groundwater (Fig. 1). The GD is located in a cold semi-arid desert in the Canadian Arctic (65°11'58" N, 124°38'15" W) and underlain by permafrost. Acidic, Fe-rich waters form through reactions of ground water with a pyritiferous shale bed at depth [5], and flow from seeps in channels throughout the GD. Mineralogy, as determined by X-Ray Diffraction (XRD) and Ultraviolet-Visible-Near Infra-Red (UV-Vis-NIR) spectral analysis, is dominated by natrojarosite and jarosite, with hydronium jarosite, goethite, quartz, clays, and hematite in some areas. The GD is spectrally homogeneous in the UV-Vis-NIR, but mineralogically and geochemically heterogeneous at sub-metre scales. Visual observations of microbial filament communities, phospholipid fatty acid analyses, and the identification of sulfate reducing bacteria confirm the GD is capable of supporting life for at least part of the year.

The GD is mineralogically similar to jarosite-rich deposits at Rio Tinto, Spain, and thus analogies can be drawn between these two deposits, and those on Mars. The Rio Tinto River has been a natural, active acid rock drainage site for more than 2 Ma, and has supported and preserved a diverse microbial community for that duration [6, 7, 8]. Jarosite and goethite samples from present day to 2 Ma contain organic-bearing features (confirmed by FTIR spectroscopy) that are morphologically consistent with microbial cells [9]. These are interpreted as fossilized cells, and similar features are expected at the GD. The basic ingredients needed to create a martian jarosite patch similar to the GD are Fe-sulfides at depth, groundwater circulation and upwelling, and arid, oxidizing surface conditions. There is evidence for all three on Mars at scales from planetary to local. Therefore, jarosite deposits such as those at Meridiani Planum and Mawrth Vallis may have been produced through acidic cold seep processes, and could have supported life and preserved organics. These sites should be targeted by future missions searching for evidence of life; particularly those equipped with an IR spectroscopy instrument.

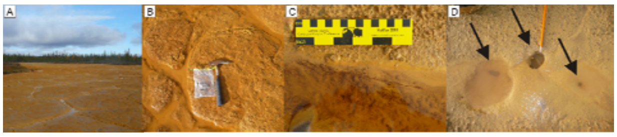

Figure 1: The Golden Deposit (GD). A: Water flows between 1 - 3 m polygonal "islands". B: Close-up of jarosite-rich sediment; ~30 cm rock hammer for scale. C: Suspected microbial community forming streamer-style biofilaments in relatively fast-flowing water; below scale bar. D: Active acidic seeps within the GD indicated by arrows; pencil for scale.

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A Spectroscopic Method for Identifying Biotic Carbonates in Terrestrial Rocks and Application to Mars

Blanco, A.[1]; Orofino, V.[1]; D'Elia, M.[1]; Fonti, S.[1]; Mastandrea, A.[2]; Guido, A.[2]; Russo, F.[2]
[1]University of Salento, ITALY; [2]University of Calabria, ITALY

Searching for traces of extinct and/or extant life on Mars is one of the major objectives for remote-sensing and in-situ exploration of the planet. In previous laboratory works [1,2,3] we have investigated the infrared spectral modifications induced by thermal processing on different carbonate samples, in form of fresh shells and fossils of different ages, whose biotic origin is easily recognisable. The goal was to discriminate them from their abiotic counterparts. In general, it is difficult to identify biotic signatures, especially when the organisms inducing the carbonate precipitation have low fossilization potential (i.e. microbes, bacteria, archaea). Actually a broad variety of microorganisms are implicated in the carbonatogenesis, and their direct characterization is very difficult to be evaluated by traditional methods, both in ancient sedimentary systems and even in recent environments. In the present work we apply our analysis to problematic carbonate samples, in which there are no clear evidences of controlled or induced biomineralization. This analysis indicates a very likely biotic origin of the aragonite samples under study, in perfect agreement with the conclusion previously reported by Guido et al. [4] who followed a completely different approach based on a complex set of sedimentary, petrographic, geochemical and biochemical analyses. We show that our method is actually reliable for discriminating between biotic and abiotic carbonates, and therefore it is a powerful tool for the search of life on Mars in the next generation of space missions to the planet.

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Astrobiology of Clays: Habitability Potential and Biosignatures Detection in Desert Analog Environments of Mars Science Laboratory/ExoMars Landing Sites.

Bonaccorsi, R[1]; Shirey, T.B.[2]; Valdre', G.[3]; McKay, C.P.[1]; Chen, B.[1]; Dellisanti, F.[3]; Moro, D.[3]
[1]NASA Ames Reseach Center, UNITED STATES; [2]Department of Biological Sciences. The University of Alabama. Tuscaloosa, AL, UNITED STATES; [3]Department of Earth and Geo-Environmental Sciences, University of Bologna, ITALY

The Mars Science Laboratory (MSL) Mission will primarily search for potentially habitable, ancient geological environments as a preliminary step to future life detection missions e.g., the ESA/US 2018 Pasteur ExoMars. Landing site candidates include hydrated clay minerals, or phyllosilicates, evaluated by context, diversity, habitability, and preservation potential of organics. Phyllosilicates are indicators of past aqueous activity on Mars [2-4]; furthermore they are of particular interest owing to their high preservation potential [3] against oxidation [e.g., 6 and ref. therein].

Preservation potential is better understood than habitability, which is an ambiguous criterion. Habitability can be defined as capability to support living microorganisms, and can be applied to both past and present environments [5].

Where should the Curiosity rover go searching for habitable environments on Mars? To address this question, we have been using multi-component techniques, i.e., microbiological analysis (culture and non-culture based), X-ray diffraction, and microRaman spectroscopy, to assess the potential for present and past habitability in mineralogical Mars analogs [5-6]. These include hyperarid to semiarid desert (<2 to 700 mm/year rainfall) analogs of hydro-climatic conditions/timescale argued for a wetter/warmer Mars e.g., Noachian-Hesperian transition [1].

Specifically, we analyzed sedimentary and hydrothermal clay-rich materials from Atacama (Chile), Namibia (Africa), Arkaroola (Australia), Death Valley (California, USA), and the California Coast. Lipopolysaccharides (LPS)-based biomass (gram negative-like), adenosine 5'-triphosphate (ATP activity), and extractable deoxyribonucleic acid (DNA) were assayed for total viable and fossil biomass.

We found that: (1) in three out of five cases clay-rich samples appear to contain less gram negative-like biomass than non-clay (or oxidized) materials; (2) Atacama clay-rich palaeolacustrine deposits and contiguous hematite-rich deposits contain the lowest biomass (~10^4 and ~10^5 cells/g, respectively), which is even lower than that of coarse-grained soil nearby (~10^6 cells/g); (3) the Atacama clay-rich samples (illitemuscovite and kaolinite) are three orders of magnitude lower than those from an intracrater fill deposit (Al-smectites, illite, and chlorite) from the arid Death Valley; (4) unexpectedly, the gram negative-like biomass (10^8 cells/g) colonizing the dry mud (Al smectites-bearing) is up to six times higher than that (1.5 x 10^7 cells/g) detected in water-saturated blue clays (kaolinite, illite and montmorillonite) from the California Coast (wetter end-member); (5) last but not least, phyllosilicate-rich samples from different locations in Atacama (26° to 21° S) contain extractable DNA (e.g., 6.3 to 16.6 ng/µl). However, they have slower (after 48hr incubation at 37°C) or not observable bacterial growths vs. those of background (non-clay) materials i.e., plant-colonized sand (growths after 24hr).

MicroRaman spectroscopy investigation on samples from the Death Valley indicates that gypsum (1008, 618, and 414 cm-1 Raman shift), and inferred associated organic biosignatures (plausibly scytonemin and Chlorophyll) (1281 cm-1) for the measured gram-negatives (cyanobacteria) were successfully captured [5]. This can be relevant to future astrobiology missions involving microRaman instruments such as ExoMars.

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The European Space Analogue Rockstore: a Key Tool for Determining Habitability in In Situ Missions on Mars.

Bost, N.[1]; Westall, F.[1]; Foucher, F.[1]; Pullan, D.[2]
[1]CNRS, FRANCE; [2]Space Research Centre, UNITED KINGDOM

In the new double rover scenario for the 2018 NASA-ESA mission to Mars, the science objectives of the European rover, ExoMars, are to search for traces of past or present life and to understand habitability conditions by studying the water/geochemical environment as a function of depth in the shallow subsurface. Noachian/Early Hesperian terrenes are the preferred landing site locations because of the higher likelihood of their containing traces of habitability and preserved past life (even, possible present life in certain circumstances).

In terms of the origin of life, habitable environments need to record relatively stable conditions where liquid water has been in contact with rocks in the presence of carbon, nutrients, and a form of energy over periods of time long enough for life to have appeared (n100x103 to 1-2 106y). For already established microbial life, habitable environments can be relatively to very short lived (days, years, n103y. The ExoMars rover needs to be able to identify and distinguish these situations in the rocks on Mars, as well as trying to identify potential biosignatures in the materials, with its payload of instruments (spectral pancam, HR camera, close up imager, IR and Raman, XRD, GCMS). Testing these instruments with the same suite of rocks, including those containing examples of habitable environments and biosignatures of the kind potentially to be found on Mars, will contribute significantly to the success of the mission.

To this purpose, the European Space Analogue Rockstore (ESAR), a collection of well-characterised Mars and space materials analogue rocks, is being established in Orléans. The ESAR is hosted by the Observatoire des Sciences de l'Univers en région Centre (OSUC).The preliminary rock collection (it is growing) contains materials that cover a range of lithologies found on Mars, including a variety of basalts (plus cumulates) as the most common martian lithilogy, hydrothermally-influenced Early-Mid Archaean shallow-water volcanic sands (Barberton, South Africa; the Pilbara, Australia), an Early Archaean banded iron formation (Pilbara) (the latter not yet found on Mars), and clays. Even lavas can represent habitable environments when extruded under water: their vitreous surfaces, cracks, fractures and vesicles can host lithotrophic and heterotrophic life forms. Seeing as life is thought to have originated in hydrothermal environments, rocks containing evidence of having been influenced by hydrothermal fluids, or hydrothermal deposits (e.g. sinters), constitute useful analogues. Established life forms can colonise and, indeed, many be involved in the formation of different minerals, such as carbonates and salts.

Apart from hosting a physical collection of rocks and other materials, an ESAR website is under construction that contains relevant information about material type plus all the textural, geo-organochemical and geotechnical analyses. All materials have been characterized by standard laboratory instrumentation (microscopes, Raman, IR, XRD, ICP, GCMS). The materials for instrument testing and the website will be accessible to scientists and payload instrument builders.

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*ESAR team: Frances Westall, Nicolas Bost, Frédéric Foucher, Derek Pullan, Claire Ramboz, Axelle Hubert, Beda Hofmann, Elisabeth Vergès, Iris Fleischer, Goestar Klingelhofer, Andrew Steele, Hans Amundsen, Tanja

Zegers, Sabine Petit, Alain Meunier Michel Viso, Jorge Vago, Christelle Briois, Bruno Scaillet, Michel Tagger.

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The ExoMars WISDOM GPR: Searching for Evidence of Past and Present Life in the Martian Near-Subsurface.

Ciarletti, V.[1]; Clifford, S.[2]; Plettemeier, D.[3]; Corbel, C.[1]
[1]LATMOS-IPSL, CNRS-UVSQ, FRANCE; [2]LPI-USRA, UNITED STATES; [3]University of Dresden, GERMANY

The WISDOM Ground Penetrating Radar (GPR) is among the instruments selected as part of ESA's 2018 ExoMars Rover mission, whose scientific objectives are: to search for signs of past and present life; characterize the geologic environment and distribution of water as a function of depth in the shallow subsurface; study the surface environment and identify hazards to future human missions; and investigate the planet's subsurface to better understand the evolution and habitability of Mars.

Investigations by previous spacecraft have significantly advanced our understanding of Martian geologic and climatic history, as well as the various processes that have shaped and altered its surface. However, without the additional perspective and constraints provided by knowledge of the subsurface, our understanding of the planet's evolution, and its past and present habitability, is incomplete. Past efforts to investigate the nature of the Martian subsurface have focused on measurements of average water abundance within the top ~0.5 m (by the Gamma Ray Neutron Spectrometer) and the large-scale structure and volatile content at depths ranging from several tens to thousands of meters by the MARSIS and SHARAD orbital radar sounders.

WISDOM operates over a frequency range of 0.5 - 3 GHz, giving it the ability to investigate the top ~2-3 m of the regolith, with a vertical resolution of several centimeters - assisting in the identification and location of sedimentary layers, massive ice deposits, and other geologic environments where organic molecules are the most likely to be found and well-preserved - within the depth range most accessible to the other ExoMars investigations, including the Rover's 2-m drill.

WISDOM, in combination with the Rover's Panoramic Camera (PanCam), will be used to perform large-scale scientific investigations of the landing site, while the Analytical Laboratory Instruments will analyze the core samples obtained by the drill, searching for organic compounds and other potential evidence of past and present life. WISDOM's observations will be crucial to the identification of optimal drilling sites and the successful retrieval of subsurface samples - providing a valuable tool for determining the nature, location and extent of potential targets and helping to ensure the safety of drilling operations by indentifying potential hazards.

The resulting ExoMars data sets will characterize a domain that, until now, has remained relatively unexplored – providing important information on the nature of the shallow subsurface that is essential to understanding the processes and environmental conditions responsible for its formation, as well as its past and present habitability.

A WISDOM prototype instrument, representative of the final flight model, has been field tested in a variety of glacial, periglacial, sedimentary and volcanic environments. High-resolution 2D profiles have been obtained that reveal details of subsurface stratigraphy and structure. Interpolated 3D maps of the subsurface, have also been constructed by obtaining parallel and orthogonal 2D profiles in the form of a grid. The acquisition of full-polarimetric measurements has demonstrated their ability to: (1) provide an improved understanding of subsurface structure and (2) significantly reduce the ambiguity associated with identifying the location of off-nadir reflectors, relative to the Rover path. Additional field investigations, conducted in a wide variety of simulated and natural Mars analogue environments, are planned to make further improvement in the instrument's signal-to-noise ratio and to build a database of well-characterized terrestrial geologic environments for comparison with the data ultimately returned from Mars.

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Following the Kinetics: Iron-oxidising Microbial Mats in Cold Icelandic Volcanic Habitats and Their Rock-Associated Organic Biomarkers

Kelly, L; Cockell, C; Summers, S; Nixon, S; Marteinsson, V
Open University, UNITED KINGDOM

Icelandic streams with mean annual temperatures of less than 5°C that receive the cationic products of basaltic rock weathering were found to host mats of iron-cycling microorganisms. We investigated two representative sites. Iron-oxidising Gallionella and iron-reducing Geobacter species, as determined by microscopy and culture-independent methods, were present. The mats host a high bacterial diversity. a-Proteobacteria, Actinobacteria, á-Proteobacteria and Bacteroidetes were abundant microbial taxa. The mat exhibited a high number of phototroph sequences. The carbon compounds in the mat displayed a broad, but prominent G band by Raman spectroscopy. This signature becomes incorporated into the weathered oxidised surface layer of the basaltic rocks and this biomarker was observed on rocks no longer hosting mats. The presence of iron-oxidising taxa in the microbial mats, but the lack of them in previously studied surface volcanic rocks in Iceland can be explained by the kinetic limitations to the extraction of reduced iron from rocks, showing that the search for microorganisms using redox couples derived from minerals can be guided by a 'follow the kinetics' approach. The data show that one promising location to test the hypothesis of the existence of past life on Mars is the surface of volcanic rocks that were previously within water courses, but now buried under sediment and that the biomarkers of life, if it ever existed, could be sought on and in these rocks. References: Cockell CS, Kelly L, Summers S, Marteinsson V. (2011) Following the Kinetics: Iron-oxidising Microbial Mats in Cold Icelandic Volcanic Habitats and Their Rock-Associated Organic Biomarker. Astrobiology (in review). Cockell CS (2011) Life in the Lithosphere, Kinetics and the Prospects for Life Elsewhere. Phil. Trans. Royal Soc. 369, 516-537.

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Formation of Sulfates from Sulfide-rich Basalts: Implications for Acidic Environments on Mars

Dehouck, E.[1]; Chevrier, V.[2]; Gaudin, A.[1]; Mangold, N.[1]; Mathé, P.-E.[3]; Rochette, P.[3]
[1]Laboratoire de Planétologie et Géodynamique de Nantes, FRANCE; [2]Arkansas Center for Space and Planetary Science, UNITED STATES; [3]Centre Européen de Recherche et d'Enseignement en Géosciences de l'Environnement, FRANCE

Introduction. Martian sulfate-bearing deposits have been interpreted as the result of a planet-wide acidic period due to large SO2 emissions [1]. Such conditions would certainly have been hostile to life. Furthermore, acidic weathering would have removed any biosignatures present in the sedimentary record. However, this scenario is difficult to reconcile with the recent discovery of Noachian/Hesperian carbonates [2], because they should have been dissolved by the acidic conditions [3]. Here, we present the results of a 4-year-long experiment designed to test a model first proposed by [4] in which Martian sulfates were formed from the weathering of sulfide-rich basalts.

Experimental protocol. We used as initial material several primary silicates: Mg-olivine (Ol1 & Ol2), diopside (CPx) and enstatite (OPx). Using an apparatus similar to the one of [5], we exposed these minerals over 4 years to a ~0.8-bar, CO2-rich atmosphere containing either H2O or H2O+H2O2 vapor at saturation at ~20°C. Ol1, CPx and OPx samples were also weathered as 50 wt% mixtures with pyrrhotite Fe0.9S (HPo).

Results. Initial and secondary phases found by XRD in the silicate-only and silicate/sulfide samples at the end of the experiment are summarized in Table 1. The samples without sulfide underwent only minor alteration: the only secondary phase found was the Mg-carbonate nesquehonite Mg(HCO3)(OH)·2H2O, detected in small quantities in 3 olivine samples. In contrast, mixtures with pyrrhotite showed extensive weathering: all samples produced several secondary phases including sulfur, hydrated sulfates and Fe-(oxy)hydroxides. Infrared spectra of the samples without sulfide were very similar before and after weathering. However, for the samples where nesquehonite was detected by XRD, absorption bands appeared at ~3.8-3.9 ìm, consistent with bicarbonate ions in the mineral structure. Spectra of silicate/sulfide mixtures showed more extensive modifications: the spectral signature of silicates completely disappeared and instead, absorption features of goethite and hydrated sulfates became dominant.

Conclusion. Our results strongly support the idea that Martian sulfates could have formed from the weathering of sulfide-rich basalts under a CO2-rich atmosphere similar to today's, but with a higher H2O content. In such a scenario, acidic weathering would have occurred at local-to-regional scale, where sulfide-rich basalts were deposited and exposed to erosion and reworking. In other places, conditions more favorable to life (and allowing the formation and preservation of carbonates) would have been maintained.

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Scale: 0 5 10 15 30 50 wt% (• = 5, •• = 10, ••• = 15, •••• = 30, ••••• , •••••• = 50)

Samples ↓ / Identified minerals →	Initial assemblage						Sulfur and sulfates				Fe-oxides		Carb.	
	Olivine	Clinopyroxene	Orthopyroxene	Amphibole	Talc	Pyrrhotite	Sulfur	Gypsum	Hexahydrite	Jarosite	Goethite	Hematite	Nesquehonite	
Ol1-H2O	••••••		••											Olivine samples
Ol1-H2O2	••••••		••										•	
Ol1-HPo-H2O	•••••		•	•	•	•	••••	•	•••		•••			
Ol1-HPo-H2O2	•••••		••	•		•	•••	•	••••		••	••		
Ol2-H2O	••••••												•	
Ol2-H2O2	••••••												•	
CPx-H2O		••••••												Clinopyroxene samples
CPx-H2O2		••••••												
CPx-HPo-H2O		•••••		••	•	•	••••	•••	•	•	•••			
CPx-HPo-H2O2		•••••		••		••	•••	••	•	••••	••			
OPx-H2O			••••••	•										Orthopyroxene samples
OPx-H2O2			••••••	•										
OPx-HPo-H2O			•••••	•	•	••••	••••	••	•		••			
OPx-HPo-H2O2			•••••	•	•	•	•••	••	•	••••	••			

Table 1

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Methods and Technologies to Characterize Habitability of Sub-surface Mars

Fletcher, L[1]; Cockell, C[2]; McKay, C[3]; Bowles, N[1]
[1]University of Oxford, UNITED KINGDOM; [2]Open University, UNITED KINGDOM; [3]NASA Ames Research Center, UNITED KINGDOM

The surface of Mars is extremely hostile due to high UV radiation, desiccation, oxidants, and low temperatures, among a variety of conditions that limit the capability to support macroscopic life. But increasingly it is believed that past and present Mars has or does provide habitable conditions sufficient to support micro-organismal life forms. Sub-surface ice abounds in the polar regions as evidenced by satellite observations and the recent Phoenix mission. There is increasing evidence of liquid water in ancient times when conditions were similar to those on Earth during the first emergence of life, as well as in recent times from the gullies discovered by Malin, et al. in 2006.

Analog environments on Earth can provide us a deeper understanding of where and how to look for life on Mars. In this paper we explore the variability of extreme environments on Earth and what are the characteristics of these areas that lead us to call them "Mars-Like." Here we will compare the microbiology, soil organic materials, and spectral analysis of rocks from our work and others in these regions and identify the implications to Astrobiology and the search for habitable environments on Mars.

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Detecting Geological Evidence of Past Habitable Locations on Mars with the ExoMars PanCam instrument

Griffiths, A[1]; Coates, A[1]; Leff, C[1]; Muller, J-P[1]; Jaumann, R[2]; Josset, J-L[3]; Paar, G[4]; Barnes, D[5]
[1]UCL/MSSL, UNITED KINGDOM; [2]DLR Berlin, GERMANY; [3]Space Exploration Institute, SWITZERLAND; [4]Joanneum Research, AUSTRIA; [5]University of Aberystwyth, UNITED KINGDOM

The ExoMars mission has evolved into a joint European-US mission to deliver a trace gas orbiter and a pair of rovers to Mars in 2016 and 2018 respectively. The European rover will carry the Pasteur exobiology payload including the 1.56 kg Panoramic Camera. PanCam consists of a pair of Wide Angle Cameras (WACs) with 34 deg horizontal field-of-view based on Beagle 2 Stereo Camera System heritage [1] and a High Resolution Camera (HRC) with a 5 deg horizontal field-of-view [2].

The Panoramic Camera instrument is designed to provide 3D digital terrain mapping capability as well as providing multispectral geological imaging, colour and stereo panoramic images and solar images for water vapour abundance and dust optical depth measurements. The HRC can be used for high resolution imaging of interesting targets detected in the WAC panoramas and of inaccessible locations on crater or valley walls. Additionally HRC will be used to observe retrieved subsurface samples before ingestion into the rest of the Pasteur payload.

PanCam therefore provides the overview and context for the ExoMars experiment locations, required to enable the exobiology aims of the mission. Specifically the detection of current or ancient habitable sites based on the local geology and mineralogy. He we discuss the scientific objectives of the instrument related to the detection of extant and extinct life on the Martian surface.

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Soils, soil formation, and paleosols on Mars: Habitability and organic preservation in surface and near-surface sediments

Horgan, B.; Farmer, J. D.; Christensen, P. R.
Arizona State University, UNITED STATES

Soil formation, or pedogenesis, encompasses all of the chemical processes that lead to vertical chemical differentiation of surface sediments above the shallowest impermeable layer; therefore, soils and paleosols record surface and near-surface environmental conditions. Terrestrial soils are also fertile environments for microorganisms, as the dissolution and translocation of minerals in soils is a non-equilibrium process that provides energy for chemoautotrophs and makes life-sustaining nutrients available for all organisms. Additionally, soils are major repositories for organic material, due in part to their high volume fraction of clay minerals, which take in organic compounds and protect them from degradation. On Mars, soils could also increase the potential for habitability and organic preservation in the near-surface by providing a buffer against oxidizing and desiccating surface conditions. While these general properties make martian soils a valuable target for investigations into past and present habitability on Mars, the range of soil types and processes that may have occurred on Mars is currently not well constrained.

In order to understand martian soils, we would like to draw on terrestrial studies of volcaniclastic soils. On Earth, a variety of soil types can form in mafic sediments, and the primary factors that determine the soil type are composition, crystallinity, and climate. Soil characteristics that may be used to identify the soil type and place constraints on these factors include bulk and vertical variations in clay/oxide mineralogy, as well as outcrop and grain morphologies. However, martian soils have several attributes that limit direct analogy with terrestrial soils, including a lack of vegetation and potentially much lower weathering rates.

Thus, the purpose of this study is to synthesize previous studies of terrestrial mafic, arid, and polar soils in order to (1) place constraints on the types of soils that may have formed on Mars, (2) identify which soil types would have best promoted habitability and organic preservation, and (3) search for evidence of soils at sites with clay mineral detections. From these results, we will make recommendations for observations by MSL and other future *in situ* missions to identify and characterize soils and paleosols at the outcrop scale.

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Mawrth Vallis: a Candidate Site for Rovers Looking for Ancient Habitability

Loizeau, D.[1]; Mangold, N.[2]; Poulet, F.[3]; Bibring, J.-P.[3]; McKeown, N.[4]; Carter, J.[3]; Ehlmann, B.[3]; Michalski, J.[5]
[1]ESA-ESTEC, NETHERLANDS; [2]LPGN, Nantes, FRANCE; [3]IAS, Orsay, FRANCE; [4]Mac Ewan University, Edmonton, CANADA; [5]PSI, UNITED STATES

1. Introduction
The Mawrth Vallis region is at this moment (February 2011) one of the four candidate landing sites for the next rover to be sent to Mars, the Mars Science Laboratory (MSL). The plateaus of this region expose a thick (>150 m), finely layered (layer thickness ~1 m), clay-rich unit [1][2]. At the proposed landing site, the clay mineralogy varies with depth from Fe-smectites in the lower layers to Al-phyllosilicates in the upper layers [3][4] with a ferrous component at the transition [5][6]. Unmixing modeling of data from OMEGA/Mars Express estimates the abundance of clay minerals to be as high as 50% for most outcrops [7]. Furthermore, while the largest outcrops of this unit are spread over a region of ~300 km by 400 km, smaller detections of clay minerals in similar stratigraphy are found over a ~1000 km by ~1000 km region [8].
Formation likely involved long-term aqueous alteration to result in such a thick clay-rich unit, and changing conditions in time and/or depth to create this compositional stratigraphy. Clays are also considered to favor the preservation of biosignatures [9].
2. High resolution datasets
The landing site between Oyama crater and Mawrth Vallis (341°E, 24°N) has been entirely imaged by the high resolution instruments of Mars Reconnaissance Orbiter: the CRISM visible/near-infrared imaging spectrometer (~18 m/pixel) and the HiRISE camera (~28 cm/pixel). HiRISE also offers partial color coverage, which enables higher resolution mineralogic mapping [3][4].

3. Habitability mission preparation
These datasets are unique for the preparation of future rover missions. From the combined use of these mosaicked and co-registered images and compositional maps, we are making a geological map of the landing ellipse and its contiguous outcrops, from Oyama walls on western side to Mawrth Vallis floor on eastern side. This map will enable mission scientists to know the position of the rover with respect to the different compositional and morphological units, and identify which are the most relevant target-units for habitability evaluation.
Additionally, many key, local targets are being identified across the site and outside of the ellipse to help prepare possible traverses for a rover. This includes places with high mineralogical variation at small scale, outcrops of unique mineralogy, interlayered craters, large fractures where fluids may have circulated, ancient valleys, or layers of unique erosion pattern.
This mapping will help to identify the targets with the highest potential for preserving evidence of habitable environments and biosignatures to prepare for MSL or future missions with habitability goals.

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Exploration of the Habitability of Mars with Chemical and Isotopic Measurements from the 2011 Mars Science Laboratory

Mahaffy, Paul R.[1]; Conrad, Pamela G.[1]; Steele, Andrew[2]; McAdam, Amy C.[1]
[1]NASA Goddard Space Flight Center, UNITED STATES; [2]Carnegie Institution of Washington, UNITED STATES

The goal of the combined ten science investigations of the 2011 Mars Science Laboratory (MSL) Rover named "Curiosity" is to provide a quantitative assessment of habitability through chemical and geological measurements [1]. With a diverse set of instruments on Curiosity and a rich data set from orbit used to examine the selected landing site, this mission seeks to understand if the conditions for life on ancient Mars are preserved in the near-surface geochemical record. The SAM suite of instruments on the "Curiosity" Rover of (MSL) provides chemical and isotopic analysis of volatiles sampled either from the atmosphere or extracted from solid samples [2,3]. SAM has the capability to sample both organic and inorganic volatiles and a suite of isotopic measurements is planned with precisions greatly exceeding those available from previous missions. The instruments of SAM are a quadrupole mass spectrometer (QMS) that works either alone or in concert with a gas chromatograph (GC) to search for organic compounds and a tunable laser spectrometer (TLS) that provides precise isotope measurements [4] for H, C, and O in CO2, CH4, and H2O. Gaseous samples are directly sampled from the atmosphere, thermally evolved from solid samples, or solvent extracted and then chemically derivatized. A highly complementary instrument to SAM is the CheMin instrument that can analyze the same batch of powdered sample processed by SAM to provide identification of minerals.

Examples of SAM planned measurements that most directly address habitability are (1) a search for amino acids and carboxylic acids present rocks by chemical derivatization; (2) comparison of 13C/12C, 18O/17O/16O, and D/H ratios in volatiles released from ancient rocks and in these same compounds in the present atmosphere; (3) examination of patterns in molecular weight and chemical structure in organic compounds that might be thermally released from heated secondary minerals (e.g., clay minerals, salts and/or carbonates).

In preparation for the landed mission that starts in 2012, the SAM team has concluded its calibration of the instrument suite under the range of expected Mars conditions in specially designed simulation chamber [5]. In addition, the team is better able to understand how instruments such as SAM and CheMin provide complementary information by conducting field experiments in which Mars analog tactical operations are simulated. The ASTEP-supported AMASE expedition has conducted this activity over the last five years [6] enabling SAM and CheMin teams to explore the synergy of those investigations in preparation for MSL tactical operations. The scope of the measurements planned for the Mars landed investigations in the next set of surface missions can be productively examined with these field campaigns and the development of operational models for complementary science investigations that measure the habitability potential of Mars. References: [1] Grotzinger, J., Nature Geoscience 2, 231, (2009). [2] Mahaffy, P.R., Space Sci. Rev. 135, 255 (2008). [3] Mahaffy, P.R. (2009) Geochem. News, 121. [4] Webster, C. R., Mahaffy, P. R., Planet. Space Sci. (2010) doi:10.1016/j.pss. 2010.08.021. [5] Mahaffy, P. R., et al.,(2010) Lunar and Planetary Institute Science Conference Abstracts, 41, 2130. [6] Steele, A., H. E. F. Amundsen, and O. Botta. Mars2030 - AustroMars Science Workshop, edited by G. Groemer, pp. 55-60. 2007.

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Determining Martian Habitability at a Grain Scale: the MicrOmega IR Investigation on ExoMars

Pilorget, C.; Bibring, J.-P.; Berthe, M.
IAS, FRANCE

With respect to the previous *in situ* exploration of Mars, the astrobiological relevance of the upcoming Mars missions, ExoMars specifically, will be greatly improved in two ways: 1. with the possibility to land in a site preserving minerals formed while Mars hosted long standing bodies of surface water (phyllosilicates), and 2. with the capability to thoroughly study samples at a microscopic scale, in a combined protocol, with a suite of highly performing instruments. MicrOmega, part of this Pasteur suite within the ExoMars Analytical Laboratory, is designed to characterize the sample composition, in a purely non destructive manner, at the scale of their constitutive grains.

More specifically, MicrOmega is a microscopic NIR reflectance hyperspectral imager, capable of identifying the composition of samples a few millimeters in size, with a spatial sampling of 20 µm. Its spectral range, 0.9 to 3.5 µm, and its spectral sampling of ~ 20 cm^{-1}, have been chosen to enable the identification of most potential constituents: silicates, oxides, salts, hydrated minerals, ices and frosts, as well as organic compounds, discriminating between specific members in each family (e.g. low and high Ca pyroxenes, forsterite and fayalite, Mg and Al rich phyllosilicates, aliphatic and aromatic compounds).

In particular, in identifying and discriminating between the various phyllosilicates and sulfates, MicrOmega will provide key clues to decipher the early aqueous History of Mars, as each specific mineral preserve the record of the environment at the time it formed, in presence of water. Moreover, if the stability of surface liquid water was favored by CO_2 as the dominant greenhouse gas, small inclusions of carbonates should be trapped within these soils, readily detectable with MicrOmega. Importantly, MicrOmega will be able, and for the first time, to identify carbon-rich phases at a microscopic scale, and to ascribe the mineralogical context in which they nucleated, through the unique capability of coupling spectroscopy to imaging.

Finally, MicrOmega will be able to locate, within the samples, with automated algorithm, specific "grains of interest" – containing for example hydrated or C-rich phases -, to enable their further analysis by complementary investigations, within the ExoMars Analytical Laboratory.

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Infrared Spectroscopic Characterization of Organic Matter Associated with Microbial Bioalteration Textures in Basaltic Glass

Preston, L.J.; Izawa, M.R.M; Banerjee, N.R.
The University of Western Ontario, CANADA

Studies have shown that microbes play an important role in the weathering of basaltic glasses in the terrestrial environment (e.g., 1,2,3,4 and references therein) and that basaltic glass may act as a growth medium for a variety of microbes, providing a source of energy and nutrients (e.g., 4,5 and references therein). Microorganisms have been found to etch volcanic glass within volcaniclastic deposits from the Ontong Java Plateau creating micron-sized tunnels and pits, which have been observed to be associated with enrichments of carbon and probable nucleic acids (5)

Bioalteration features within glass clasts from Leg 192 of the Ocean Drilling Program have been investigated through optical microscopy and Fourier Transform Infrared (FTIR) Attenuated Total Reflectance (ATR) spectroscopy of petrographic thin sections (Figure 1a) to study the organic molecules present within tubule clusters and tubule-free areas. FTIR spectroscopy is a powerful tool for astrobiology offering the user the ability to non-destructively characterize organic matter associated with microbial textures in rocks in situ with a high degree of chemical specificity.

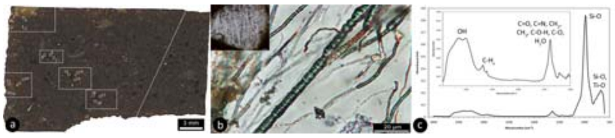

Figure 1 a. b. Transmitted light extended depth of focus image of microbial tubules within volcanic glass shards from the Ontong Java Plateau. Inset shows a complete glass shard cross-cut by tubule bioalteration features. c. FTIR spectrum taken from image b, with the main organics broadly identified.

FTIR spectroscopy identified Si-O, O-H and Ti-O absorption bands within the glass clasts. A range of organic functional group absorption bands were also identified within the tubule-rich areas of the glass clasts. These included aliphatic hydrocarbons (CH2 and CH3 moieties), amides (C=O), esters and carboxylic acids (Figure 1b,c). The tubule-free areas in the cores of glass clasts were found to contain no organic absorption bands within FTIR spectra.

This study further constrains the nature of the carbon compounds preserved within the tubules. The identification of these organic bands within a single FTIR spectrum spatially associated with the tubules, and correlated to previous research that identified organic carbon and nucleic acids, may imply the FTIR spectra are displaying molecular vibrations from biomolecules linked to the microorganisms that created the tubules. Basalts are amongst the most widespread rocks in the solar system. Basaltic glass in contact with liquid water may constitute a habitable environment on icy satellites such as Europa and Enceladus, and in the deep subsurface of Mars providing a potential refuge from impact bombardment and irradiation.

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The Preservation and Degradation of Filamentous Bacteria and Biomolecules at Rio Tinto, Spain and their Implications for Mars

Preston, L. J.[1]; Shuster, J.[2]; Fernández-Remolar, D.[3]; Banerjee, N.R.[1]; Osinski, G.R.[1]; Southam, G.[1]
[1]The University of Western Ontario, CANADA; [2]University of Western Ontario, CANADA; [3]Centro de Astrobiología, (INTA-CSIC), SPAIN

One of the keys to understanding and identifying life on other planets is to study the preservation of organic compounds and their precursor microorganisms on Earth. Rio Tinto in southwestern Spain is a highly acidic natural rock drainage system precipitating iron sulphates and oxides, with a well documented diverse biota (1,2, 3). River terrace deposits here have been forming for at least two million years (4) creating a natural laboratory to allow living cells to be studied and correlated to morphological and biomolecular fossils in the geological record. This study has investigated the preservation of filamentous iron oxidising bacteria and organics through microscopy techniques and Fourier Transform Infra-Red (FTIR) spectroscopy, from laboratory cultures of natural samples to contemporary natural materials to million-year old river terraces.

Sediment samples cultured in the laboratory are dominated by iron oxidising, acid tolerant, filamentous microorganisms, similar to a Leptothrix sp. These filamentous organisms examined by Transmission Electron Microscopy (TEM) are observed to be ~1 µm in diameter, of variable length and are commonly seen to be completely enveloped by iron oxide mineralization (Figure 1A). The filamentous organisms within the modern river sediments and river terraces are darker in colour and held suspended within the jarosite and goethite mineral matrices (Figure 1B). Scanning Electron Microscopy (SEM) EDS analyses identified up to 40% elemental carbon and > 7% nitrogen within these preserved microbial filaments and cell clusters in all samples studied.

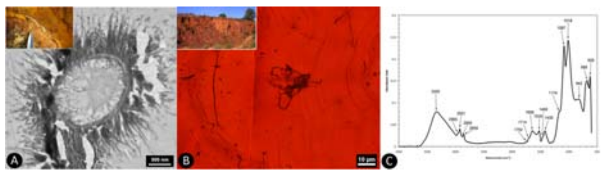

Figure 1 a.TEM image of filament cross section (inset: river sediment sampling site). b. Transmitted light extended depth of focus image of filaments within goethite crystals (inset: oldest river terrace outcrop). c. FTIR spectrum taken from image b, with the main absorption bands identified.

FTIR spectroscopy identified C-Hx absorption bands between 2960 and 2800 cm-1, Amide I and II absorption bands at 1656 and 1535 cm-1 respectively and functional group vibrations from within nucleic acids at 917, 1016 and 1124 cm-1. Absorption bands tracing the diagenetic transformation of jarosite to goethite to hematite through the samples are also identified (Figure 1C). The number of FTIR spectroscopic organic absorption bands identified within the samples is greatest in the youngest samples and decreases in the older terraces. This combination of mineralogy, microbial morphology and biomolecular evidence allows us to further understand how organic fossils are created and preserved in iron-rich environments, and ultimately will aid in the search for potential organics on Mars.

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Planetary Simulation and Hypervelocity Impact at the Open University

Rolfe, S. M.[1]; Patel, M. R.[2]; Ringrose, T. J.[2]; Leese, M. R.[2]
[1]The Open University, UNITED KINGDOM; [2]Planetary and Space Sciences Research Institute, The Open University, UNITED KINGDOM

Topic: Simulated environmental conditions and processes used to study possible extant or extinct life and habitats on Mars and other solar system environments.

The Open University hosts a wide range of facilities capable of simulating a range of environments and processes of interest within the solar system. Here we present the range of facilities available for martian, other planetary and solar system simulation. These cover two broad areas; environmental simulation and impact simulation. Specialist environmental chambers have been commissioned in order to simulate a range of solar system environments, providing combined simulation of pressure, temperature and solar illumination. Using these parameters the surface of Mars, environments in space, and airless/icy bodies in the solar system (among others) are simulated. Hypervelocity impacts are simulated using a two stage light gas gun, and a Van de Graaff particle accelerator.

These facilities provide an extensive capability in simulating environments and processes of great scientific interest within the solar system, and are designed in such a way as to be available for both pure research and instrument testing purposes for the wider community in a collaborative manner. Here we present the full capabilities of the various facilities, and initial results from experiments.

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Detecting Life-Forms using Immuno-assay Techniques: A Progress Report on the Life Marker Chip Instrument for ExoMars

Sims, M[1]; Cullen, D[2]; Rix, C[2]; Buckley, A[2]; Sephton, M[3]; Court, R[3]; Bulloch, C[4]; Kitchingman, I[4]; Ali, Z[4]; Lowe, C[4]; Pullan, D[1]; Holt, J[1]; Blake, O[1]; Sykes, J[1]; Samara-Ratna, P[1]; Canali, M[1]; Borst, G[5]; Norfini, A[6]; Geraci, E[6]; Tavanti, M[6]; Brucato, J[7]
[1]University of Leicester, UNITED KINGDOM; [2]Cranfield University, UNITED KINGDOM; [3]Imperial College London, UNITED KINGDOM; [4]Magna Parva Ltd., UNITED KINGDOM; [5]Dutch Space Bv, NETHERLANDS; [6]Kayser Italia Srl, ITALY; [7]INAF Osservatorio Astrofisico di Arcetri, ITALY

Most life detection instruments proposed to date for missions apart from the Viking experiments are based around using heat to extract organics from samples or rely on optical/IR signatures. A few instruments for example Urey as proposed for the original ESA ExoMars mission have suggested liquid/solvent based extraction. A Life Marker Chip (LMC) based upon using solvent extraction and bio-technology immuno-assay technology to detect organic molecules was proposed to the ESA ExoMars Project in 2003. This instrument has been under development since 2000. Following re-organisation of the ExoMars Project as a joint ESA-NASA Project the LMC is now part of the baseline mission payload assuming it can be developed in time for flight to Mars in 2018.
Engineering design work shows that such an instrument is feasible and extraction of organics from regolith samples with a novel solvent mix has been shown to work. Development of the assays based around antibody technology is underway. A progress report on the instrument is given highlighting its engineering design, and progress in terms of sample extraction and measurement.

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The Photochemistry of Early Mars: Implications for Sedimentary Minerals and Life

Smith, Megan[1]; Catling, D.C.[1]; Claire, M.W.[1]; Zahnle, K.[2]
[1]University of Washington, UNITED STATES; [2]NASA Ames Research Center, UNITED STATES

In 2008, NASA's Phoenix lander detected several salts on the surface of Mars using wet chemistry, including soluble sulfates [1] and perchlorate [2], where the latter was unexpected. While it is generally hypothesized that perchlorate is likely produced in the atmosphere from oxidation of past chlorine volatiles [3], sulfates could have atmospheric or aqueous origins. Distinguishing aqueous and atmospheric origins for salts is important for determining the nature of past environments on the surface of Mars, that is, whether they were wet and potentially conducive to life or dry.

Here, we investigate the capability of the past atmosphere of Mars to produce sulfates using a one-dimensional photochemical model [4]. We investigate how different levels of prolonged and transient volcanism may have affected the atmospheric composition and rate of deposition of these salts. We first validate our model by replicating observed species concentrations on modern Mars. We then test the sensitivity of our model to different factors, such as changes in the water vapor profile. Next, to adapt the code for early Mars, we input all sulfur chemistry associated with volcanic eruptions, after [5]. Species modeled in the sulfur chemistry include H2SO4, SO3, SO2, SO, S, S2, S3, S4, S8, OCS, HS, and H2S, and also H2SO4 and S8 aerosols. We test the effect of increasing volcanic emissions of SO2 on the atmospheric concentration of critical redox constituents, such as CO, O2, H2.

To put a constraint on the emissions of volcanoes, we compare the integrated volcanic emissions with the inferred sulfate abundance on the entire Martian surface. We also calculate the atmospheric oxidation state in the model. Within the model, we increase the level of volcanism until the atmosphere becomes chemically reducing. Additionally, we test the effect of changing boundary conditions of the species. For example, volcanic emissions can be distributed over a range of altitudes or emitted just at the lower boundary. Also, the surface deposition velocities of species can be changed.

Anoxic and weakly-reducing atmospheres, like the one hypothesized to have existed on the early Earth and early Mars [6], are thought to be more conducive to the origin of life [7]. Organic carbon is best preserved in anoxic environments (e.g., black shales) and fossils are also well preserved in such sediments. On Earth, phyllosilicate minerals can form shales in aqueous anoxic environments, including river deltas, which are morphologically similar to delta features observed on Mars. Phyllosilicate minerals on Mars are largely restricted to the Noachian [8]. Therefore, understanding conditions that may have led to an anoxic early Martian atmosphere are important for the possible origin and preservation of life on early Mars.

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Solubility of Sulfate Salts and Implications for Ancient Martian Aqueous Environments Conducive to Life

Sobron, P.[1]; Sobron, F.[2]
[1]Washington University in St. Louis, UNITED STATES;
[2]Universidad de Valladolid, SPAIN

Sulfur enrichment has been confirmed in martian surface materials by most landed missions to date. OMEGA has identified kieserite, gypsum, and bassanite along with some unspecified polyhydrated sulfates [1]. Jarosite (which only forms in dilute sulfuric acid in ground water) and other yet undefined ferric sulfates within the outcrop at Meridiani Planum were identified by the Opportunity rover [2]. The Spirit rover has observed the possible dehydration of ferric sulfates after 200 sols of exposure under current martian surface atmospheric conditions [3]. Magnesium carbonate has been identified in the Nili Fossae in association with serpentine and olivine-bearing units [4], and calcium carbonate has been found in the Phoenix landing site [5]. In addition, chloride-bearing salts have been observed in the southern highlands [6], providing further evidence of the presence of extensive reservoirs of surface and/or subsurface groundwater in Mars' early history.

Taken together, these observations raise several pertinent questions: (1) what environmental conditions have produced the broad range of secondary mineral settings that can be observed across Mars today?; (2) what are their time-scales?; and (3) was the unquestionable aqueous past of Mars conductive to life? The characterization of the interaction of the martian saline mineral assemblages and the aqueous solutions necessary for their formation is critical for understanding Mars' hydrological and mineralogical history. Among other properties, mineral solubility in acidic sulfate solutions can provide crucial information about martian hydrogeochemistry. We have developed a novel model-based methodology that aims to fuse experimental measurements and model data to calculate the solubility of a suite of Fe2+ hydrated sulfates in an acidic aqueous system in different environmental conditions; i.e., day-night and seasonal temperature measured or implied on Mars, and pH of the aqueous solutions (Figure 1).
With the study of the solubility of salts in aqueous systems we move a step closer to understanding some of the properties of ancient Mars' hydrogeochemistry

that might constrain life such as the water's temperature, acidity, and salinity [7]. Although the aqueous system considered here is the simplest approximation to the complex suspected Martian hydrology and will not therefore be able, in principle, to predict the properties of potential ancient aqueous systems on that planet, studying it paves the way for the development of more elaborate models in which multi-ionic electrolyte interactions and equilibria will be incorporated. The inverse application of these extended models to the current martian multicationic mineral phases might yield the properties of realistic ancient liquors from which they were formed, namely temperature, pH, and salinity or water activity (a thermodynamic measure of salinity). The latter is a measure of the energy status of the water in a system; that is, it determines the lower limit of available water for biological processes. In line with some of the objectives of the NASA Astrobiology Roadmap, the obtained results will serve as a basis for future attempts in modeling the extremely complex martian acidic aqueous systems from which today's mineralogy is thought to have originated, and in which the presence of microorganisms could have played a crucial role.

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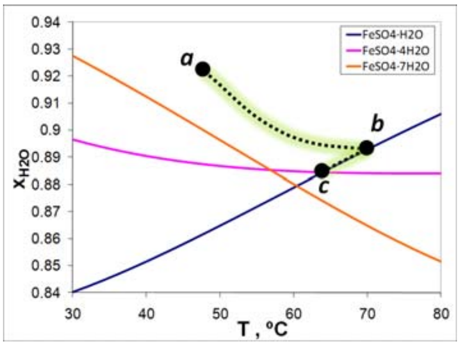

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Channel Networks 2D Longitudinal Slope Analysis on Mars

Vaz, D. A.; Alves, E. I.; Barata, M. T.
Centre for Geophysics of the University of Coimbra, PORTUGAL

The existence of valley networks (VN) is one of the more compelling arguments in favour of a wetter Mars on the past [1]. The study of this type of morphologies generally involves the mapping and analysis of channel networks through the examination of imagery and altimetry. Automated mapping procedures have recently been applied to the mapping and characterization of VN through automatic DTM analysis [2; 3]. Three main classes of parameters are commonly used to characterize valley networks: topological parameters, with the classic stream order classification; spatial parameters, such as drainage density [2]; and morphometric parameters, derived from the analysis of longitudinal profiles. This last class is used to generate plots of elevation vs. distance, allowing the characterization of the longitudinal shape and slope of the VN [ex. 4; 5]. The semiautomatic morphometric framework introduced in Vaz [6] is used in this work to obtain a longitudinal 2D analysis of VN located in the Protva Valles region. The mentioned technique was primarily developed for tectonic mapping purposes, but enables a full morphometric characterization of any type of scarps on Mars surface, allowing the evaluation of the spatial distribution of the longitudinal slope. The resultant analysis successfully highlights the relations between the tectonic activity, the surface runoff and the local influence of aquifer seepage on the evolution of the channels networks in the region.

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Study of Carbonaceous Material in Archean Samples from Barberton (South Africa) and Possible Astrobiological Implications.

Venegas, G.; Medina, J.; Rull, F.
Unidad Asociada UVA-CSIC al Centro de Astrobiología. Parque tecnológico Boecillo, 47151, SPAIN

Barberton Greenstone Belt (BGB) it's a famous site in the world for its Archean geology, wich represents around 3.5 billion years of earth's history. For that this area provide us the possibility to study and understand an important part history of our planet, and also allow to compare with the geological history of other planets in our solar system [1].

Mineralogical and geochemical characterization of these rocks has been undertaken in the recent years using several techniques and in particular Raman spectroscopy [2]. Of particular interest is the characterization of carbonaceous material present in the samples and the possible connection of these carbonaceous phases with ancient biogenic activity. Raman micro-spectroscopy has proved to be a very important non-destructive tool for distinguish micro-sized particles of C-polymorphs, as it is very sensitive to the nature of carbon bonding [3].

In the present work several layered samples of chert obtained in the BGB during the expedition carried out in August 2010 and sponsored by CNES and ESA have been studied with Raman microspectroscopy. A complementary analysis has been performed with XR-Diffraction to assess the bulk mineralogical composition of the samples.

Results obtained allow to describe precisely the mineralogical composition of the samples at micro and macro scale. In the case of carbonaceous material a detailed Raman spectral analysis has been performed in the 1200-1800 cm-1 (first order) and 2500-3200 cm-1 (second order) regions [4]. Spectra show important changes in the G-D bands in the layered structure of chert.

These results are discussed in detail in connection with the possible biotic or abiotic origin of the carbonaceous materials in the samples. Nevertheless, at present state is not possible to deduce a clear conclusion on the basis of these spectroscopic results. A more detailed study is being undertaken using complementary techniques trying to introduce some more insight in the problem.

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Terraforming Mars: Global Warming Scenarios using Different Combinations and Pressures of 5 Greenhouse Gases

Cervantes Núñez, S.; Gay García, C.; Sánchez Meneses, O.; Mendoza Castro, V.M.; Garduño López, R.

Centro de Ciencias de la Atmósfera, Universidad Nacional Autónoma de México, MEXICO

Terraforming Mars, could mark the beginning of our ability to long-term survival as a specie. Terraforming, is a set of techniques by which, the weather, the surface and the known properties of a planet are deliberately modified, with the intention of make it habitable for Earth life, especially for humans. Mars is now a frozen desert, so Mars terraformation would require two stages. The first stage would consist of raising the average temperature above the freezing point of water, while increasing the atmospheric pressure on Mars. The second stage would consist in introducing organisms that produce the oxygen required by most plants and animals to live. During the past two decades there have developed several proposals for global warming on Mars, ranging from, import greenhouse gases (GHG's) from earth or through Kuiper Belt comets or asteroids that have frozen ammonia (NH3); making orbital mirrors pointed at the Martian poles to melt them; the development of GHG's factories on the surface of Mars, etc. However, since the late 90's, was found on Mars, the presence of carbon dioxide ice (CO2) and water (H2O) in the Martian regolith beneath the surface of middle and polar latitudes. The regolith is a continuous layer of fragmented material produced by meteorite impacts, which is usually the soil on planets, satellites and asteroids where the atmosphere is thin or absent. Several authors propose that the CO2 at the poles and in the Martian regolith, is in balance with the planet's surface temperature. Raising of 4 ° to 5 ° C surface temperature south pole of Mars, could release into the atmosphere from 50 to 100 millibars of CO2, which would be sufficient to start the regolith massive degassing, generating a temperature positive feedback in the atmosphere regolith system, increasingly raising the surface temperature of Mars. Our work is on the first stage of terraforming and we gonna analyze, using a radiative-convective and a thermodynamic models, the global warming at the hemispheric level, that is generated by different combinations and pressures of CO2, methane (CH4), NH3, H2O and a perfluorocarbon (PFC). In addition, we will develop a proposal, which would be the best combination

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The Possible Effects that the Planet's Internal Structure and Movements may have had on Habitability Issues

The Influence of Degree-1 Mantle Heterogeneity on the Past Dynamo of Mars

Amit, H.[1]; Christensen, U.[2]; Langlais, B.[1]
[1]University of Nantes, FRANCE; [2]Max-Planck-Institut fur Sonnensystemforschung, GERMANY

The hemispheric dichotomy in the crustal magnetic field of Mars may indicate that the planet's past dynamo was influenced by a degree-1 heterogeneity on the outer boundary of its liquid metallic convecting core. Here we use numerical dynamos driven by purely volumetric internal heating with imposed degree-1 heat flux heterogeneities to study mantle control on the past dynamo of Mars. We quantify both south-north and east-west magnetic field dichotomies from time-average properties that are calculated according to two different end member crust formation scenarios. Our results indicate that a moderate heat flux anomaly may have been sufficient for obtaining the observed dichotomy. Because of the excitation of a strong equatorial upwelling in the dynamo, the efficiency of a mantle heterogeneity centered at the geographical pole in producing a south-north dichotomy is much higher than that of an heterogeneity centered at the equator in producing an east-west dichotomy. These results argue against a significant True Polar Wander event with major planet re-orientation after the cessation of the dynamo.

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Planetary Radio Interferometry and Doppler Experiment for Current and Future Martian Missions

Cimò, G.[1]; Pogrebenko, S.V.[1]; Gurvits, L.I.[1]; Molera Calvés, G.[2]; Duev, D.A.[3]; Bocanegra-Bahamon, T.[4]; for the PRIDE collaboration, [5]
[1]Joint Institute for VLBI in Europe, NETHERLANDS; [2]Aalto University, Metsähovi Radio Observatory, FINLAND; [3]Moscow State University, RUSSIAN FEDERATION; [4]University of Technology Delft, NETHERLANDS; [5]

The Planetary Radio Interferometry and Doppler Experiment (PRIDE) is a multi-disciplinary enhancement of the scientific suite of current and planned interplanetary missions. We will present the capabilities of PRIDE to measure accurately the state-vector of spacecraft using Very Long Baseline Interferometry (VLBI) tracking and multi-station Doppler measurements as demonstrated very efficiently with the VLBI observations of the Huygens probe during its descent on the surface of Titan. Accurate measurements of the state-vector of spacecraft allows precise orbit determination, which is fundamental in order to conduct relativistic celestial mechanics experiments. The PRIDE technique is complementary to Mars habitability studies and it can help to understand the possible effects that the planet's internal structure and movements have on Mars habitability.

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Mars' Thermal and Atmospheric Evolution and Trace Gases

Karatekin, Ozgur[1]; Witasse, Olivier[2]
[1]Royal Observatory of Belgium, BELGIUM; [2]ESA, NETHERLANDS

Understanding the physical mechanisms responsible for the production and destruction mechanisms of traces gases such as Methane is one of the key objectives of the next Trace Gas Orbiter to Mars. Concentration of these trace gases appear to be locally enhanced and change with seasons. Their evolution can be affected by geological and or biological activity. In this study we review our current understanding of thermal state of the crust and atmospheric evolution and their implications on sources and sinks of trace gases, especially of methane.

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Coupled Magmatic and Atmospheric Evolution: Implications for the Habitability of Early Mars

Plesa, A.-C.[1]; Morschhauser, A.[2]; Grott, M.[2]; Breuer, D.[2]
[1]Dept. of Planetary Physics, Joint Planetary Interior Physics Research Group of the University Münster and IfP DLR Berlin, GERMANY; [2]Institute for Planetary Research, DLR, Berlin, Germany, GERMANY

The composition and evolution of the Martian atmosphere is an important aspect of planetary habitability and sensitively influences the climatic conditions on the planetary surface. Atmospheric evolution is driven by loss processes and volcanic outgassing, which in turn is linked to the production of partial melt in the Martian mantle. Thus, the atmospheric evolution of Mars is directly coupled to the planet's thermal evolution.

We show volcanic outgassing rates of carbon dioxide throughout the Martian history using parameterized thermal evolution models [1]. Melt production has been treated with a fractional melting model considering the release and consumption of latent heat, the formation of crust and the redistribution of radioactive heat sources in a self-consistent manner. We compare models with an initially wet or dry mantle and for the wet mantle, we further consider dehydration stiffening, i.e., mantle material will be dried out due to partitioning of water from the minerals into the melt during the melting process resulting in an increase of viscosity and hence stiffening of the mantle material. To calculate the atmospheric pressure as a function of time, we neglect all atmospheric sources and sinks except early hydrodynamic escape and volcanic outgassing. Our results show that a partial pressure of CO_2 in the late Noachian of more than 0.5 bar necessary for fluid water to exist [2] is difficult to reconcile if constraints from SNC meteorites, the crustal and lithospheric evolution of Mars are met. Additional 2D convection models that further consider density effects due to melt generation and crust formation even strengthen that conclusion: compositional layering in the Martian mantle tends to reduce volcanic degassing from the interior.

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Probing the Interior Structure of Mars by Studying its Rotation

Rivoldini, A.; Van Hoolst, T.; Dehant, V.
Observatoire Royal de Belgique, BELGIUM

Studying the rotation of Mars provides knowledge about its interior structure, which is of essential importance to the understanding of its past and present state as well as its future evolution. In particular from rotation, the state of the core can be determined, and its composition and size be constrained. Those quantities are fundamental for understanding the history of Mars' magnetic dynamo, which in turn has important consequences for the retention of the atmosphere and the possible habitability of the early in Mars' history. Moreover, from rotation studies the density distribution within the mantle can be obtained. The evolution of the mantle is tightly related to surface volcanism, which in turn is responsible for releasing volatiles into the Martian atmosphere. Here, we show how precession and nutation measurements can be used to infer knowledge about the interior structure of Mars.

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Detection of Periglacial Punctual Features on Mars

Machado, A.[1]; Alves, E. I.[2]; Barata, M. T.[1]; Veiga, N. A.[3]; Saraiva, J.[4]

[1]Centre for Geophysics, University of Coimbra-CGUC, PORTUGAL; [2]Instituto Geofisico, Dep. Ciencias da Terra, Centre for Geophysics, University of Coimbra-CGUC, PORTUGAL; [3]Dep. Ciencias da Terra, Centre for Geophysics, University of Coimbra-CGUC, PORTUGAL; [4]CERENA/IST, PORTUGAL

Several doubts remain over the spatial distribution, origin, and even the existence of hummocks, frost boils, and pingos on Mars. Due to the fact that such features, on Earth, occur on a meter scale, their remote sensing on Mars was not possible until recently. Some areas, namely the basketball terrain type [1] have been associated with hummocks, although on a decameter scale. Recall that [1] is based on Mars Global Surveyor (MGS), Mars Orbital Camera (MOC) imagery, whose best resolution (on narrow-angle mode) is of 1.5 m/pixel (mpp). Others [2] have used MOC, Mars Odyssey THEMIS (Thermal Emission Imaging System) and Mars Express HRSC (High Resolution Stereo Camera) images together with MOLA (MGS Mars Orbiter Laser Altimeter) altimetry of Utopia Basin, suggesting that some dome, cone, and ring-shaped features could be pingos.

Today we have access to Mars Reconnaissance Orbiter (MRO) High Resolution Imaging Science Experiment (HiRISE) images of 0.25 mpp resolution. Furthermore, super-resolution of HiRISE stereo pairs should be able to yield images of at least 0.15 mpp resolution [3]. These resolutions ought to be enough to detect hummocks, frost boils and pingos of comparable dimensions to those on Earth (Fig. 1).

The origin and evolution of periglacial features are associated with freeze-thaw cycles (e. g. [4]) and their effective detection on Mars would be an indicator of liquid groundwater seasonal presence.

We are beginning a periglacial features survey, establishing a comparison between the hummocks, frost boils and pingos at Longyearbyen (Svalbard - Norway) and the features found on Mars [5]. At project completion, we will be able to deliver a georeferenced database of periglacial punctual features on Svalbard, and an algorithm for their automatic recognition on Earth and, hopefully, also on Mars, based on our previous work [6].

At the survey conclusion, we expect to develop a software package designed to analyze automatically the information overload produced by the HiRISE images.

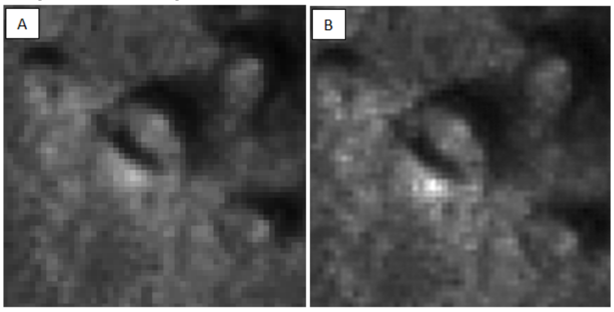

Figure 1. Example of super-resolution of basketball terrain. (A) Sample of HiRISE image ESP-011816-2300, red (0.50 mpp); (B) quadruple resolution (0.13 mpp) possible frost boils. (Image side 27.5 m).

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Amazonian Alluvial Fan Formation in Margaritifer Terra, Mars

Grant, J.; Wilson, S.
Smithsonian Institution, UNITED STATES

Alluvial fans within impact craters in southern Margaritifer Terra record information about runoff and the climate when they formed [1-2]. Moreover, the distal fan deposits may form repositories for information useful in evaluating whether conditions where habitable when they were emplaced.

Crater statistics using high resolution MRO data [3, 4] constrains the timing of fan development within the global framework of fluvial activity on Mars. The study included Eberswalde and Holden craters, final candidate landing sites for MSL [5]. These and other craters bearing alluvial fans typically display well-developed alcoves and fan surfaces preserve distributary channels standing ~15 m in relief (via inversion of topography) [1].

Craters were mapped using CraterTools [6] in ArcGIS and Craterstats software was used to derive relative and absolute ages [7] based on the chronology function of [8] and production function of [9]. Cumulative crater plots for the alluvial fans yield best fit isochrones ranging from 1.5 to 2.5 Ga (1.9 +/- 0.5 Ga) and suggest the alluvial fans formed in the Amazonian or near the Hesperian-Amazonian boundary.

A paucity of craters <200-300 m across is consistent with the erosion required for topographic inversion of fan distributaries. At larger diameters, the statistics match the expected production population of craters and there are no inflections suggesting other intervals of burial and/or exhumation.

An Amazonian age for the exposed fans likely requires precipitation relatively late in Martian history. Moreover, craters with fans lack any mappable relationships to large, young impact craters in the region (e.g., Hale crater [10]), thereby suggesting precipitation was not impact related. One possible source of water for the fans includes precipitation derived from redistribution of outflow channel discharge [e.g., 11] into the highlands [12]. Because two of the craters with fans are finalists for the MSL landing site, these relatively young fan ages imply MSL could evaluate the potential habitability of materials deposited relatively late in Martian history.

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Acid-sulfate Weathering Experiments and Geochemical Modeling: An Early Mars Analog

Marcucci, E.[1]; Hynek, B.[1]; McCollom, T.[2]
[1]LASP/University of Colorado at Boulder, UNITED STATES; [2]LASP, UNITED STATES

Observations of Mars by landers and orbiting instruments have identified numerous locales of sulfate deposits [1-3]. It is generally agreed that they are formed through acid-sulfate weathering, but the specific environment in which it occurs is still under investigation. One proposed mechanism is the alteration of primary basaltic mineralogy by high temperature, low pH, and sulfur-rich vapors in a volcanic hydrothermal setting [1,4]. An analog site at Cerro Negro (CN), Nicaragua is used to examine this proposal. CN is an ideal analog system because it is a young volcanic field with recorded real-time alteration and primary lithology very similar to that of unaltered Mars basalt [5]. We are characterizing this system in order to understand the geochemical pathways involved in acid-sulfate weathering. To do this, we are analyzing, in tandem, the results of field samples, experiments, and geochemical modeling. Constraining the formation environments of the observed sulfate deposits will lead to an understanding of paleoconditions on Mars, which gives implications to past habitability.

Field samples, including altered and unaltered rock products, fluid, and condensed steam, were collected during three field excursion by Drs. Hynek and McCollom. XRD, SEM, and thin section petrography were used to analyze solid products of field samples and experiments. Experiments have been run by breaking down CN basalt into its component minerals [6,7]. Minerals of a consistent grain size are reacted, in time series, with 1M H_2SO_4 at 65°C and varying fluid:rock ratios. Temperature-varying experiments are also planned. At the termination of each experiment a fluid sample was taken and analyzed by ICP. The final approach to this study is modeling using Geochemist's

Workbench (GWB) [8]. Oxide composition of minerals and sulfuric acid were added to the system and reacted using the REACT module.

In general, minerals produced in each of the approaches are in good agreement, namely Ca- and Mg-sulfate. Natroalunite has also been observed. Abundant Ca-sulfate minerals are observed at CN, forming after the release of Ca2+ from plagioclase. This Ca is either enriched with respect to unaltered basalt or depleted, indicating its mobility within the system. Weathering should similarly produce Mg-, Fe-, and Al-sulfates, confirmed by closed experiments, but they are less prevalent in the field, indicating possible removal from the system. Alteration in experiments was quick, showing extensive alteration in the shortest timestep. Additionally the same suite of minerals is produced in short and long experiments. Mg-sulfates were very prevalent in augite experiments, occurring in multiple crystalline forms. However, both experimental fluid chemistry and modeling indicated that Mg-sulfates should be undersaturated. This contradiction has led to the idea that Mg-sulfates are precipitating as residual fluid evaporated off experimental products. Indeed, evaporation models in GWB produce Mg-sulfates in the final steps. There may also be evaporitic effects in bytownite and forsterite experiments, each which produce a gel layer during experiment duration. Bytownite gel is largely an Al-Si-SO4 mix. Forsterite experiments have amorphous surface coating material, which EDS recognizes as a Mg-sulfate phase, but crystals have not been observed. Little to no alteration is observed in quartz and obsidian experiments. Changes in the fluid:rock ratio appear to mainly influence abundance, size, and in some instances crystalline shape, of secondary minerals; however, the mineral types remain the same.

Minerals observed in experiments and models are like those found at many locations on Mars, namely Mg-sulfates. The family of natroalunite and jarosite may be diagnostic in indicating past environments as they form in specific conditions. These hydrothermal, volcanic settings can quickly weather fresh basalt into products seen on Mars in locations such as Valles Marineris.

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Habitability in Hydrothermal Deltaic Environment on Mars

Popa, C.[1]; Esposito, F.[1]; Colangeli, L.[2]; Vito, M.[1]
[1]INAF-OAC, ITALY; [2]ESA-ESTEC, Noordwijk, NETHERLANDS

The water on Mars is connected often with the presence of standing bodies of water, hosted in depression areas (e.g. craters). There are numerous evidences that point to water residence in such paleolakes. These evidences are mostly related to geomorphology of some deposits (stepped fan deltas), and associated mineral alteration that record water-rock interaction.
The types of minerals produced in these geologic settings suggest that the main water-rock interaction is related to hydrothermal processes (sinters). These settings are of high biologic interest, because similar (silica rich) deposits are hosting the earliest traces of life on Earth [1], and [2]. The opaline silica recorded in one Mars crater-delta system (west Xanthe Terra) may present sufficient requirements of an extremophile life sustaining environment. Similar terrestrial sites present large extremophile biota communities, described in the presence of silica rich waters [3].
This particular hydrothermal deltaic environment constitute excellent astrobiological site(s) to look for the presence of life or preserved traces of fossils.

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Assessing the Ancient Habitability of Eberswalde Crater

Rice, M.[1]; Bell, J.[2]; Rice, M.[1]
[1]Cornell University, UNITED STATES; [2]Arizona State University, UNITED STATES

The putative delta in western Eberswalde Crater provides the best known evidence for persistent fluvial activity on the surface of Mars [1-5]. Based on the presence of this landform, and the interpretation that it formed in a lacustrine environment [1-5], Eberswalde Crater has been selected as one the final four candidate landing sites for Mars Science Laboratory (MSL). The primary objective of the MSL mission is to search for past and present habitable environments on Mars [6]. In this work we address the potential habitability of Eberswalde Crater during two distinct eras of the crater's evolution: (1) during an era of possible hydrothermal activity following the crater's formation; and (2) during a later era of fluvio-lacustrine activity.

We have mapped the distribution of stratigraphic and geomorphic units within Eberswalde crater, and have found that the deeply eroded crater floor units are cut by light-toned, vein-like ridges up to several kilometers in length (Figure 1). In bedrock interpreted as megabreccia [7,8], these features are typically randomly aligned with varying thicknesses. Within other crater floor units, the vein-like features can occur as isolated, linear (e.g., Figure 1b) to arcuate (e.g., Figure 1d) forms. Where these features meet, they consistently do so at right angles (e.g., Figure 1d-e), and in places they occur as networks of polygonal patters (Figure 1c). Similar features elsewhere on Mars have been interpreted as breccia dikes [e.g. 9,10], and based on terrestrial analogs [11], they are consistent with impact-induced hydrothermal alteration. Here we present an analysis of the ridges' morphology and mineralogy, and we discuss the astrobiological implications for a hydrothermal environment following the formation of Eberswalde Crater.

The vein-like features do not occur within the light-toned, layered sediments that comprise the fan and cover much of the basin floor (Figure 2). These sediments lie disconformably above outcrops interpreted as Holden Crater ejecta [7,8], and were likely deposited during a later era of fluvial activity into an Eberswalde Crater lake [1-5]. We have mapped the distribution of this unit within the basin, and have identified plateaus of layered rock in the center and far eastern portions of the crater; if these are indeed lacustrine sediments, the ancient Eberswalde lake must have covered the entire crater floor. We also have mapped inverted channels and other fan-shaped landforms that suggest a complex history of fluvial activity and deposition in the basin [6,7].

Sediment deposition in a low-energy environment, such as a quiescent lake, typically has very high biopreservation potential [12]. Phyllosilicate minerals identified at the fan terminus and in the crater basin [13] have enhanced Eberswalde's appeal as an MSL site. Regardless of whether Eberswalde is selected as the final MSL landing site, however, the evidence for sustained aqueous activity in the crater, and the possibility of an ancient hydrothermal environment, makes it a critical target for future Mars exploration.

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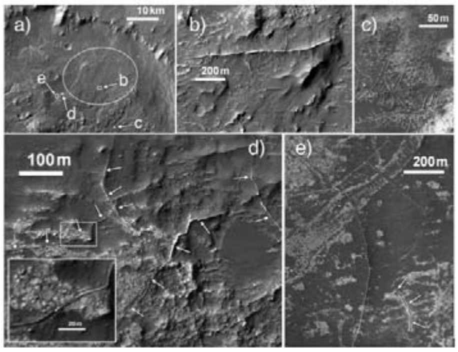

Figure 1. Examples of vein-like features: CTX mosaic of Eberswalde Crater indicating the location of 1b-e and the proposed MSL landing ellipse; (b) a ~1 km linear, isolated vein-like ridge near the center of the landing ellipse (from HiRISE observation ESP_012610_1560_RED); (c) complex pattern of vein-like features (from HiRISE observation PSP_017845_1560_RED); (d) arcuate, vein-like ridges, the inset shows where polygonally fractured material overlies a ridge (from HiRISE observation PSP_004356_1560_RED); (e) arcuate, vein-like features in southwest Eberswalde, the arrows indicate an arcuate fracture (from HiRISE observation PSP_004356_1560_RED). North is orientated at the top of the page in all images.

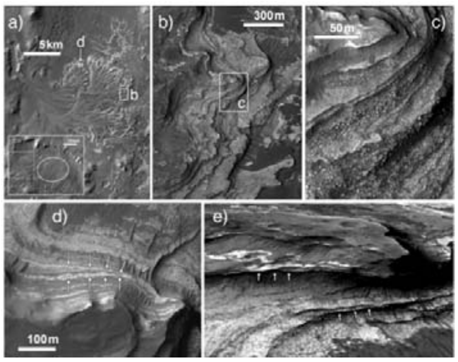

Figure 2. Examples of the layered light-toned unit exposed at the putative Eberswalde delta: (a) the location of 2b,d at the terminus of the putative delta (from CTX observation P01_001336), with the inset indicating the locations of the putative delta and the proposed MSL landing ellipse within Eberswalde Crater ; (b) context along the south rim of Eberswalde Crater (from HiRISE observation PSP_001534_1560_RED), the white box indicates the location of 2c ; (c) polygonal fracturing in light-toned layers ; (d) a possible downlap relationship at the north lobe (from HiRISE observation PSP_004000_1560_RED) ; (e) perspective view showing shadows cast by overhanging layers (from HiRISE observation PSP_004000_1560_RED draped over a DTM). North is orientated at the top of the page in all images.

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Raman Spectroscopy Analysis on Powdered Samples inside the Exomars Mission

Rull, F.; Lopez, G.; Catala, A.; Medina, J.; Sansano, A.; Sanz, A.; Sobron, F.
Unidad Asociada UVA-CSIC, Centro de Astrobiologia, SPAIN

ExoMars mission is the first European flagship mission within the long term Aurora program. ExoMars will address directly essential questions related with the possibility to detect extinct or extant signs of life on the red planet. The mission after the recent collaboration agreement between ESA and NASA is now a two rovers mission scheduled for 2018.

The Raman spectrometer (RLS) part of ExoMars payload and in the present configuration of the mission's operation cycle the instrument will perform in-situ analysis of post-crushed samples obtained by the drilling system attached to the rover. The goals of the instrument are directly related with those of the mission: the detection of organics related with biogenic activity, the study of water related processes and the analysis of igneous materials and their alteration products. The Raman analysis will be carried-out along a line on the surface of powdered samples deposited in small containers inside the rover's analytical laboratory. This particular operation mode stress the need for the instrument to optimise the possibilities of returning detailed structural information at mineral grain scale on the surface of powdered samples.

In this work results obtained with a simulator of the operation mode developed at our laboratory and allowing a totally automatic in-situ analysis of powdered samples are presented and discussed. A set of samples prepared in the laboratory with controlled grain size distribution and samples actually prepared by a prototype of the crusher located inside the ExoMars rover are analysed and results compared and discussed. Of particular interest are those materials showing traces of potential biogenic activity or related with the alteration by water.

In general the Raman instrument can supply precise structural information of the grain surface and most of the mineral species are unambiguously identified. Limiting factors as fluorescence, thermal damage threshold in labile samples and organics identification are also discussed.

These results are compared with those obtained analysing the bulk samples with XR-Diffraction using a portable diffractometer (InXitu Inc.).

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Modern Martian Habitability—Some Planning Questions associated with Mars Sample Return

Bass, D.S.; Beaty, D.W.
NASA/Caltech Jet Propulsion Laboratory, UNITED STATES

Assessing the current potential for the habitability of the martian surface and near-surface environment is one of our long-standing goals for the exploration of Mars. This is important both for intrinsic scientific reasons (could indigenous martian life forms be living there?) and for planetary protection reasons (could Earth-sourced microbes transported by spacecraft prosper and grow?). If we carry out MSR, evaluating the potential of the modern martian environment to host life, and whether or not that environmental niche is occupied, would presumably be objectives assigned to the mission. However, answering these kinds of questions with MSR suggests some unique challenges.

The return of unsterilized samples to Earth from Mars would require processing and at least initial analysis in a Sample Receiving Facility (SRF) to ensure the biocontainment of any hazards to earth organisms, and also to minimize contamination of the samples. Preserving the geochemical character of the samples is necessary to understand the nature and context of the samples. While the need for one or more SRFs is not questioned, the implementation is a matter of some debate (see, for example Beaty et al, 2009).

To assess the possibility of modern martian life, the relationship of the analysis instrumentation to the containment system and the sample purity system needs considerably more planning. How could we set up instruments on Earth that are clean of both living and dead terrestrial bacteria? We would need to avoid detecting ourselves. The conduct of the tests may require the use of robots that would be verifiably cleaned of both particulates and organics (constrained by instrument detection limits currently ~ 1015 C atoms/cm2). An argument can be made that considerable insight into these issues would be accomplished through the construction of an experimental testbed. In this manner, instrument performance, and its relationship to robotics and the isolation system could be understood. Clean room (~ISO4), double walled vessels with transport ports, glove boxes and clean barriers for instruments (negative pressured, HEPA-filtered) are some specifics that would be included in the testbed.

Constructing a testbed to prototype the kinds of scientific analyses that would be executed inside the SRF would require instrument modification and customization so that portions of the instrument that contact the sample could either remain permanently inside the SRFor else could be sterilized, due to the need for biocontainment. A prototype SRF would enable a better understanding of these unique requirements. Additionally, personnel protective clothing (BSL-4 equivalent suiting) that also meets the cleanliness requirements could be tested.

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Radiation Sensitivity of Biological Reagents for Life Detection on Mars

Carr, C.E.[1]; Rowedder, H.[2]; Vafadari, C.[3]; Lui, C.[1]; Cascio, E.[4]; Zuber, M.T.[1]; Ruvkun, G.[2]
[1]MIT Department of Earth, Atmospheric and Planetary Sciences, UNITED STATES; [2]MGH Department of Molecular Biology, UNITED STATES; [3]MIT Department of Nuclear Engineering, UNITED STATES; [4]MGH Francis H. Burr Proton Therapy Center, UNITED STATES

Life on Mars, if it exists, may share a common ancestry with life on Earth derived from meteoritic transfer of microbes between the planets [1-6]. We are building an instrument, the Search for Extra-Terrestrial Genomes (SETG), to target life-as-we-know-it by isolating, detecting and sequencing RNA or DNA, in-situ on Mars, from soil, ice, or brine samples [7-9]. The most viable approaches for automating these instrument functions require biological and chemical components, including nucleotides, DNA primers, enzymes such as polymerase and reverse transcriptase, and fluorescent dyes such as those used to label nucleic acids. Other instruments including some already slated for flight depend upon similar biological components; furthermore, NASA is currently exploring potential future applications for synthetic biology in space. Using real-time polymerase chain reaction as a readout, we show that these reagents survive several analogs of the radiation environment expected during a nominal Mars mission, including proton, heavy ion (Fe, O), and neutron bombardment. However, some reagents have reduced performance or fail at higher exposure levels. Our findings have implications for the long-term performance of instruments with biological components, the habitability of the Martian surface and near-subsurface, and the meteoritic transfer of microbes between Earth and Mars.

References: [1] Gladman, B.J., et al., Science, 1996. 271(5254): p. 1387-1392. [2] Gladman, B.J. and J.A. Burns, Science, 1996. 274(5285): p. 161b-165. [3] Melosh, H.J., Nature, 1988. 332(6166): p. 687-8. [4] Mileikowsky, C., et al., Icarus, 2000. 145(2): p. 391-427. [5] Burchell, M.J., J.R. Mann, and A.W. Bunch, Monthly Notices of the Royal Astronomical Society, 2004. 352(4): p. 1273-1278. [6] Horneck, G., et al., Astrobiology, 2008. 8(1): p. 17-44. [7] Ruvkun, G., et al., A Robotic-PCR Detector for DNA-based Life on Other Planets, in Signs of Life: A Report based on the April 2000 Workshop on

Life Detection Techniques. 2002, Space Sciences Board, The National Academies Press: Washington, DC. p. 137-40. [8] Isenbarger, T., et al., Appl. Environ. Microbiol., 2008. 74(3): p. 840-849. [9] Isenbarger, T., et al., Orig Life Evol Biosph (2008), 38:517–33, doi: 10.1007/s11084-008-9148-z.

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Mapping the Methane on Mars: Seasonal Comparison

Chizek, M.[1]; Murphy, J.[1]; Fonti, S.[2]; Marzo, G.[3]; Kahre, M.[3]; Roush, T.[4]
[1]New Mexico State University, UNITED STATES; [2]Universita del Salento, ITALY; [3]NASA Ames Research Center/ Bay Area Environmental Research, UNITED STATES; [4]NASA Ames Research Center, UNITED STATES

Introduction:
Methane has been detected in the Martian atmosphere at abundances of 10 parts per billion (ppb) or greater [1,2,3], and because of the short photochemical lifetime (~300 Earth years) [3,5] these detections suggest recent geological or biological activity. The observations suggest a spatially and temporally variable methane abundance with a lifetime (~0.6 Earth years) much shorter than expected from photochemical destruction. The observations provide a limited amount of data, and none occur during the same season, so there are few constraints on the spatial and temporal evolution of Martian methane. In order to understand the sources and sinks of the gas, an extensive dataset with more spatial and temporal coverage is needed. Tools have been developed to utilize an already existing dataset to fill in this gap. I will use a statistical clustering technique developed by [6] to investigate the available Mars Global Surveyor Thermal Emission Spectrometer data to derive methane abundances at seasons analogous to the observations of [1].

Tools:
A statistical clustering technique has been developed by [6] which works by comparing thousands of spectra and grouping spectra together based on similar characteristics. This technique has been demonstrated through analysis of a large number of Mars Global Surveyor Thermal Emission Spectrometer (TES) spectra and successfully reproduced results of surface mineralogy mapping, and identified CO_2 and H_2O aerosol and water ice content in the Martian atmosphere [6,7]. The clustering method provides a time efficient manner to process a large number of spectra without a need for reduction of individual spectra or pre-processing.

Application to Methane:
This clustering technique has been applied by [4] to derive putative methane abundances using TES spectra at 7.8 microns. The spectral resolution (6.25 or 12.5 cm-1) of an individual spectrum from the TES instrument should not be sufficient to detect the narrow methane band feature at 1306 cm-1, but by averaging together a few thousand spectra the methane feature is detectable [4]. Global average methane abundances and distribution maps for the cardinal seasons (L_s 0°, 90°, 180°, 270°) of 3 Martian years (MY 24/25, 25/26, 26/27) have been derived to demonstrate the usefulness of this technique. These data can be used to study the spatial and temporal distribution of methane because they are globally extensive and cover a wide seasonal range.
Three methane sources have been identified from these maps, Arabia Terra (source identified by [1]), and Elysium and Tharsis volcanic provinces. These sources appear to be most active during late Northern Summer, and least active in late Northern Autumn. Peak methane abundances of ~70 ppb are comparable to those derived by [1], ~45 ppb.

Seasonal Comparison:
I will utilize the clustering technique of [4] with available TES spectra to investigate the methane distribution at the seasons observed by [1] (L_s 17°, 121°, 155°). I will derive methane abundance maps like those of [4] at the observed seasons of [1], and I will compare the latitudinal abundance distributions from these maps with abundance distributions from [1]. I expect to find methane abundances similar to those from the TES derivations in the longitude ranges observed by [1]. This will be the first comparison of two different sets of detections of Martian methane at the same seasonal dates. These detections are also made in two different methane bands (TES at 7.8 microns, [1] at 3.3 microns).

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Recent Mars: A Habitable Planet? – Results from Investigations in Space, in Mars Analogue Habitats and from Laboratory and Theoretical Studies

de Vera, J.P.P.[1]; Hauber, E.[1]; Jänchen, J.[2]; Koncz, A.[1]; Lorek, A.[1]; Möhlmann, D.[1]; Spohn, T.[1]
[1]Institute of Planetary Research/ DLR e.V., GERMANY; [2]TH Wildau, Technical University of Applied Sciences, Wildau, GERMANY

Mars is a frozen desert planet. Considerable intense UV radiation fluxes reach its surface and with its thin and 95 % CO2 rich atmosphere and an atmospheric pressure of approximately 6 mbar this planet is not supposed to be habitable. But according to a variety of different experiments during the last decade where microorganisms were investigated under Mars-like environmental conditions there is evidence that even recent Mars appears to be a habitable planet. The habitability of the surface and upper subsurface of Mars depends on one hand on the viability and adaptation capacity of microorganisms to Mars-like environments and on the other hand on the planet's energy resources and liquid water availability. Besides chemical, inorganic energy sources in the soil intense solar radiation is available as additional energy source on the surface of Mars but might be harmful for most of known terrestrial life forms. However, previous studies on extremophilic microorganisms which were performed on space exposure platforms (e.g. BIOPAN on the satellite FOTON and EXPOSE on ISS) show the high resistance of tested bacteria, archaea and lichens to space radiation and desiccation caused by vacuum. During Mars simulation experiments photosynthesizing microorganisms are even able to do photosynthesis periodically. The periodicity of the photosynthetic activity depends on the diurnal cycle with its varying temperatures and relative humidity. It is important to emphasize that the aforementioned space resistant microorganisms are mainly collected in polar and alpine habitats. They are living in permafrost regions with high UV radiation income and extreme dryness provoking high adaptation strategies. Because of these environmental parameters the alpine, desert and polar habitats were characterized as Mars analogue. The Mars analogy of these regions can also be justified by comparing the colonized alpine and polar field profiles with surface structures on Mars. Numerous investigations were done during field campaigns in the Alps, the Arctic (Svalbard) and in Antarctica. Based on these field investigations it becomes obvious that gullies, polygon rich regions and micro caves, fissures and cracks in rocks can be seen as suitable candidates for habitable areas on the surface of Mars in addition to the supposed ice rich environment in the subsurface. As mentioned above, the habitability of Mars depends also on the availability of liquid water. Due to the presence of salts and perchlorate rich soils on Mars water can for sufficient relative humidity remain in a liquid phase, forming at least temporary liquid cryobrines far below the freezing point, which e.g. might be useful for some halophilic microorganisms. This may be in favour of the habitability of the Martian surface. In addition the habitability can also be influenced by the sorption and desorption capacity of other soil particles. These particles and salty solutions could enhance the liquid phase of water. Processes enhancing the liquefaction of water might explain the recently observed rheological events provoking e.g. the formation of gullies on the surface of Mars which are known as real habitats for a diversity of microorganisms on terrestrial martian analogue environments mostly present in the polar regions. All presently enumerated factors are positively emphasizing that habitability of recent Mars is particularly probable for some of terrestrial life forms.

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Searching for Mars Subsurface Polar Habitability - Automated Drilling in Icebreaker

Glass, B.[1]; McKay, C.[1]; Stoker, C.[1]; Zacny, K.[2]; Thompson, S.[1]

[1]NASA Ames Research Center, UNITED STATES;
[2]Honeybee Robotics, UNITED STATES

This paper will discuss the requirements, design concepts and some tradeoffs regarding the drill and drilling operations for the proposed NASA "Icebreaker" mission concept. In order to look for organics and signs of past or extant habitable environments on Mars, we propose to delve below and through the ice layers that stymied the Phoenix scoop. Automated drilling from a Phoenix-derived lander can retrieve specimens down to 1m depth, which can be transferred to on-deck instruments.

The proposed "Icebreaker" mission is a return to the Mars polar latitudes first visited by the Phoenix mission in 2007-08. But this mission concept could also apply to the newly discovered subsurface ice in midlatitudes (eg. near the Viking 2 landing site). Given the hard icy layers and perchlorates found by Phoenix, Icebreaker is based on the Phoenix spacecraft bus but carries both an automated 1m rotary-percussive drill, the SOLID life-detection instrument, APXS and a non-pyrolytic instrument (JPL's Wet Chemistry Lab) capable of detecting organics in the presence of perchlorates. Downhole materials (cuttings) will be captured in the bottom 10cm of the drill string and raised to the surface periodically where they will be mechanically removed and transferred to on-deck instruments.

Planetary drilling and sampling beyond the Moon requires intelligent and autonomous systems. Unlike terrestrial drills, the Icebreaker drill will work dry (without drilling muds or lubricants), blind (with no prior local or regional seismic or other surveys beyond Phoenix's excavations), and weak (very low [100N] downward force or weight on bit, and perhaps 100W power available). Given lightspeed delays, teleoperation of a drill on Mars is not feasible and hence drilling placement and control, both nominal and in fault modes, must be fully automated. This paper will examine the tradeoffs in drill power and mass, drill architectures and software automation in the operations and requirements for drilling on Mars.

A planetary drill must be able to drill a broad range of materials, including ice, icy-cemented soil, sand, basalt and sedimentary rocks without getting stuck. Icebreaker, as a lander system that is specifically investigating potential Martian life, would be a COSPAR Category IVb mission. As with parts of the Mars Phoenix spacecraft, planetary protection requires that the part of the drill extending below the ground be dry heat sterilized following the Viking protocol. The current Icebreaker approach is to sterilize components that will either be placed below the ground or be in contact with the components that will penetrate below the ground, and place these inside a biobarrier.

The Icebreaker prototype drill has been tested to a depth of 1m under Mars conditions in a 3.5m tall Mars Environmental Chamber, and was tested at an Antarctic Mars-analog site in November 2010. We have also demonstrated full hands-off drilling operations (including detection, safing, recovery and resumption of drilling) to 2-3m depths in regolith-like impact crater breccia permafrost. Our approach to testing in analog environments, and the past 8 years of tests leading to a flight-proposable automated drill, achieves a relevant environment for achieving technology readiness through the parallel use of Mars chambers and drilling at terrestrial Mars analog sites. Further planned testing in Mars chambers and at analog sites is important, as the drill performance data drives the design iterations of the drill structure, drilling software, drilling protocols, and the drill operational sequence. Future variations of the Icebreaker concept may be proposed for New Frontiers or as a combined astrobiology-human precursor mission.

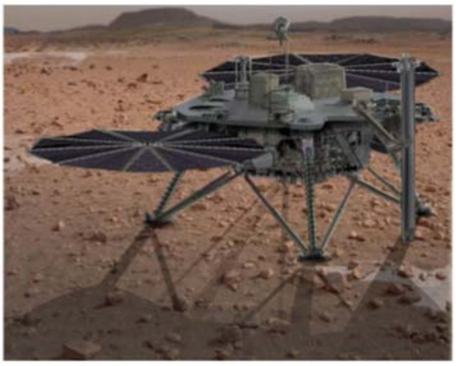

Figure 1. Icebreaker in-situ drilling mission concept

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Tumbleweed: Wind-propelled Habitability Measurements for Mars

Kuhlman, K.R.[1]; Behar, A.[2]; Jones, J.[2]; Coleman, M.[2]; Boston, P.[3]; Antol, J.[4]; Hajos, G.[4]; Kelliher, W.C.[4]; McKay, C.P.[5]; Rothschild, L.J.[5]; Buehler, M.G.[6]; Northup, D.[7]; Choi, D.S.[8]
[1]Planetary Science Institute, UNITED STATES; [2]NASA Jet Propulsion Laboratory, UNITED STATES; [3]New Mexico Institute of Technology, UNITED STATES; [4]NASA Langley, UNITED STATES; [5]NASA Ames, UNITED STATES; [6]Decagon Devices, Inc., UNITED STATES; [7]University of New Mexico, UNITED STATES; [8]University of Idaho, UNITED STATES

Tumbleweeds are wind-propelled, long-range, autonomous vehicles based on well-developed airbag technology (Figure 1) or rigid structure technology, which could survey Mars for variations in habitability using the Mars exploration paradigm, "Follow the Water [1]. Tumbleweed seeks to expand our ability to obtain ground truth from large areas of an environment to determine the nature and distribution of habitable environments. Tumbleweed fills an important niche between in-situ rover-based measurements and measurements from orbit. The sampling strategy is not random. Rather, it is downwind. The trajectory of the vehicles can be modeled given documented wind patterns and topography. Inexpensive and numerous, such units could cost-effectively provide data across an extremely broad area unavailable by other strategies.

Soil and atmospheric moisture, biologically relevant gases and other elements of interest can be mapped using relatively simple instruments onboard multiple Tumbleweeds during transects of the deployment site. The instruments currently proposed for use on Tumbleweeds are either relatively mature instruments that have been developed through NASA funding or are modifications of available commercial handheld instruments. Many other instruments are currently under development for in situ extraterrestrial applications using minimal power and mass through various NASA programs and the commercial marketplace. We anticipate that within a few years, these more sensitive instruments will be readily deployable on Tumbleweeds. Such instruments include gas chromatograph mass spectrometers (GC-MS), quantum cascade tunable diode laser (QC-TDL) gas sensors and ground-penetrating radar (GPR).

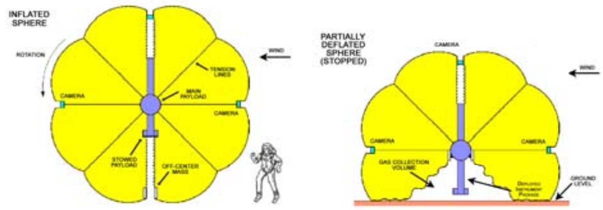

Figure 1. Inflatable Tumbleweed based upon airbag technology developed at JPL.

References: [1] Kuhlman, K.R. et al. (2010) in Mars: Prospective Energy and Material Resources, V. Badescu, Ed. Springer: London, UK. 401-429.

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Transient Slope Lineae: Possible Summertime Briny Flows on Mars

McEwen, A.[1]; Ohja, L.[1]; Dundas, C.[2]; Byrne, S.[1]; Mattson, S.[1]; Wray, J.[3]; Cull, S.[4]; Murchie, S.[5]; Thomas, N.[6]
[1]LPL, UNITED STATES; [2]USGS, UNITED STATES; [3]Cornell U., UNITED STATES; [4]Washington U., UNITED STATES; [5]APL, UNITED STATES; [6]U. Bern, SWITZERLAND

Salts depress the freezing point and reduce the evaporation rate of water [1-6], improving prospects for near-surface habitability. MRO/HiRISE has observed transient slope lineae (TSL) [7-8], defined as narrow (up

to a few m wide) relatively dark albedo markings on steep (>25°) slopes that are present in late spring to early fall images but faded or absent in the cold seasons. They extend downslope from bedrock outcrops or rocky areas, often associated with small channels. They have been confirmed from repeat coverage at 20 locations ranging in latitude from 10-48°S; favoring equator-facing slopes at the higher latitudes. TSL are not dusty slope streaks as they form on low-dust slopes, have seasonal preferences, grow incrementally, and reform each year on the same slopes.
The summertime afternoon brightness temperatures from THEMIS [9] on TSL-covered slopes range from 250-300 K, similar to the Spirit landing site in Gusev Crater (14.6°S). At Gusev the subsurface temperature at the hottest times should exceed 273 K down to ~0.8 cm depth and exceed 253 K to ~2 cm [10]; 253 K is the lowest temperature with demonstrated metabolic activity in terrestrial methanogens [11]. Some brines are liquid at temperatures as low as ~200 K [3]. CO_2 sublimation drives many dynamic phenomena on Mars [12-13], but isn't present on the TSL slopes. Water or brines, if present, could melt or remain liquid at the surface to drive TSL formation. Brines are more likely than pure water because it is more stable over time, and some activity occurs near the end of summer when temperatures should be too cold for pure water. Shallow brines could mobilize thin flows or seeps if the liquid fills the pore space between particles; interfacial water [14] is probably not sufficient. MRO/CRISM spectra have not confirmed the presence of water or salts on slopes with many TSL, but HiRISE shows color and albedo changes consistent with wetting [15]. A difficulty with this model is the source of water for brines. Equator-facing slopes reaching the melting point should be too warm to preserve ground ice. Deliquescent salts probably don't trap sufficient atmospheric water vapor to create flows. TSL formation may be a non-equilibrium process.
An alternative model is that adsorbed water (making grains sticky) is released in the summer, allowing dry mass wasting, but the association with bedrock is not explained. Another hypothesis is that thermal expansion triggers rock falls and dry granular flows, but it is difficult to explain likely concurrent incremental growth of hundreds of flows. Neither of these hypotheses explain why TSL fade or disappear in cold seasons. We have not found definite TSL in the northern hemisphere, perhaps due to the current seasonal asymmetry or the bedrock geology. The putative chloride deposits, hypothesized to result from ponding of surface runoff or groundwater upwelling, are concentrated in the low-albedo regions of the southern hemisphere [6], as are TSL. Subsurface brines (frozen or liquid) might be stable over geologic time, until formation of a crater or trough exposes the brine layers on warm slopes.

References: [1] Clark, B. (1978) Icarus 34, 645. [2] Sears, W. and Chittenden, J. (2005) GRL 32, L23203. [3] Renno, N. et al. (2009) JGR 1124, E00E03. [4] Zorzano, M.-P. et al. (2009) GRL 36, L20201. [5] Hecht, M. et al. (2009) Science 325, 64. [6] Osterloo, M. et al. (2010) JGR 115, E10012. [7] McEwen, A. et al., (2011) LPSC 42, #1450. [8] Ojha, L. et al. (2011) LPSC 42, #2101. [9] Christensen, P. et al. (2004) SSR 110, 85. [10] Ulrich, R. et al. (2010) Astrob. 10, 643. [11] Rivkina, E. et al. (2002) Dokl. Biol. Sci. 383, 179. [12] Hansen, C. et al. (2011) Science 331, 575. [13] Dundas, C. et al. (2010) GRL 37, L07202. [14] Kossacki, K. and Markiewicz, W. (2010) Icarus 210, 83. [15] Gunderson, K. et al. (2007) Planet. Space Sci. 55, *1272.*

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Habitability of the Martian Subsurface for Methanogenic Life

Monaghan, E.P.; Patel, M.R.; Cockell, C.S.; Olsson-Francis, K.
PSSRI, The Open University, UNITED KINGDOM

Methane was first observed in the atmosphere of Mars in 2003. This organic molecule has an expected atmospheric lifetime of less than 600 years, which points to a current or recent source of the gas. Several localised methane sources have been postulated, the most likely of which being either the hydration and serpentization of ultramafic silicate minerals, or the existence of methanogenic life in the planetary subsurface. Release of the gas by clathrate hydrates has also been suggested; however these are not a source in of themselves, but rather a mechanism of sequestration and release. If clathrates were shown to be linked to the episodic release of methane, the point of genesis would remain elusive.

Our work is designed to assess the habitability potential of the martian subsurface for methanogenic life by investigating the viability of methane-producing archaea living on, and interacting with, rocks and minerals analogous to those found on Mars. We quantify this relationship using the archaea strains Methanosarcina barkeri and Methanobacterium formicicum as models of putative martian life, and here present some initial findings in our study: strains growing under an atmosphere of H_2/CO_2 and on reduced media containing several rock/mineral types including basalt, montmorillonite and olivine.

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Analysis of the possiblilities of life transfer from the earth to Mars from past automatic missions.

Muller, C.; Moreau, D.
B.USOC-BIRA-IASB, BELGIUM

Since the very beginning of astronautics, missions have been aimed at Mars and several early missions crashed on Mars before clear planetary protection policies were enforced. The VIKING landers in 1976 led the majority of scientists to consider Mars as sterile and the missions of the 1990's did not go through the baking process used for VIKING, it was only later discovered that new resistant microorganisms could survive the applied cleaning procedures and that the Martian environments were more favourable to life than what was inferred from VIKING results. Other discoveries in extremophiles and research exposing microorganisms to space conditions extended also considerably the envelope of life.

This communication will show a map of sites concerned and will analyze their capability to support life on the basis of the recent studies of space resistant organisms both in the near surface and in possible underground habitats. The sites of the Mars-2 and Mars-3 landers which reached the planet in 1971 will be especially analyzed.

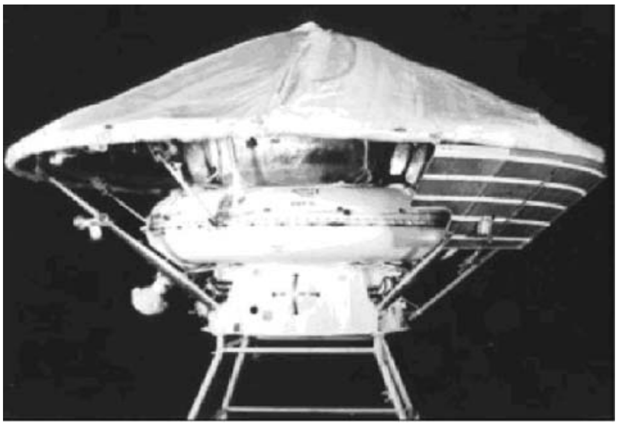

Figure 1. The Mars 3 lander (V.G. Perminov, the difficult road to Mars), the lander included complicated scooping mechanisms and symbolic objects including a Soviet pennant, the cleans spacecraft operated a few seconds on the surface while its sister spacecraft crashed without emitting telemetry. The cleansing procedures of the time did not involve baking.

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Stability of Organic Evidences of a Past Habitability of Mars: The MOMIE project

Noblet, A.[1]; Coll, P.[1]; Szopa, C.[2]; Stalport, F.[1]; Poch, O.[1]
[1]LISA, Universities Paris 7 & 12, FRANCE; [2]LATMOS, University Pierre & Marie Curie Paris 6, FRANCE

The environmental conditions at Mars seem to have been favourable to the emergence of Life. The search for organics at Mars surface/subsurface is then the main goal of the future NASA MSL (2011) and ESA ExoMars (2018) in situ space missions. Due to the current extreme conditions at the Mars surface, the comprehension of organics stability in such an environment is essential to prepare these missions and the interpretation of the data they will provide.

Currently the Mars surface is a place for solar energetic and cosmic particle bombardment, for intense UV solar radiation and oxidation processes. We develop the MOMIE (Mars Organic Molecules Irradiation and Evolution) project in order to experimentally study the fate of organic matter submitted to those evolution processes in martian environmental conditions (Szopa and Coll, in preparation). The stability of organic matter submitted to solar energetic and cosmic particle bombardment has been investigated in collaboration with the NASA Goddard Space Flight Center ... laboratory (Stalport et al., in preparation). We also develop an experimental device simulating the UV radiation at Mars surface. We investigated the stability of amino acids, carboxylic acids and biomarkers (Stalport et al., 2008, 2009, Stalport et al., 2010). More recently we extended the experimental device to focus on the stability of organic matter submitted to oxidation processes and UV radiation. We highlight the importance of the synergies between UV radiation, minerals and ices on the stability of organic matter at the Mars surface (Noblet et al., submitted), and develop an experimental device allowing the study of those interactions (Noblet et al., in preparation). We summarize here the philosophy of the MOMIE project and the main results associated to this project.

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Searching for Habitable Environments on Mars: Contributions from ChemCam, a Remote Chemistry Instrument on the Mars Science Laboratory

Ollila, A[1]; Wiens, R[2]; Maurice, S[3]; Clegg, S[2]; Newsom, H[1]; Lasue, J[2]; Blank, J[4]

[1]University of New Mexico, UNITED STATES; [2]Los Alamos National Laboratory, UNITED STATES; [3]IRAP, Universite Paul Sabatier, FRANCE; [4]BAER Institute/NASA Ames Research Center, UNITED STATES

Introduction: The primary objective of the Mars Science Laboratory (MSL) rover, scheduled to land on the red planet in 2012, is to assess habitability, past and present, of the local martian environment. One of the MSL instruments, ChemCam, uses Laser-Induced Breakdown Spectroscopy (LIBS), a spectrochemical technique capable of determining the elemental composition of a sample. The ChemCam LIBS will be used to characterize rock and soils up to several meters from the rover.

The ChemCam Instrument Suite: ChemCam consists of a remote microimager (RMI) and a LIBS instrument. The RMI will provide targeting and microtextural context for LIBS analyses. It has a 20 mRad field-of-view, capable of resolving objects ~0.5 mm diameter at 5 m. The LIBS instrument uses a Nd:KGW (1067 nm) pulsed laser that ablates a small portion of a target surface, producing a plasma of electronically excited ions, atoms, and small molecules. As the excited species in the resulting plasma relax, light is emitted at characteristic wavelengths and a portion of the light is collected through a telescope and transmitted via an optical fiber to one of three spectrometers that cover 240-850 nm [1].

Capabilities of LIBS: In addition to the wide range of elements that can be detected using this in-strument, the ChemCam LIBS has several key features that will prove useful on MSL.

- Very small spot size, 120-500 µm pit diameter, depending on distance, allows focused analyses to be conducted.
- Low power requirements (~15 mJ to obtain a useful spectrum).
- Short analysis time (< 6 minutes/analysis).
- Remote operation (1.5-7 m) capability allows a range of targets to be sampled without moving the rover body.
- Ability to measure dust coatings and also penetrate to rock surfaces below; LIBS can be used to analyze dust and alteration rinds by taking multiple shots on surfaces.

Habitability Assessment: ChemCam will assist in MSL's habitability assessment by providing:

- Direct element detection and quantification. ChemCam can detect light elements such as H [2], C [3], and S [4]; calibrations are underway to determine detection limits in various samples. Fig 1 shows the primary H peak at 656.5 nm and a minor C peak at 658.8 nm.
- Spectral classification to determine rock type using multivariate analysis techniques as Independent Component Analysis (ICA), Principal Component Analysis (PCA) and Sammon's non-linear mapping [eg. 1,5,6,7].
- Micro-textural information of rocks and outcrops.

Conclusion: We have a spectral database of more than 60 standards of various rock types, including organic materials, which we are using for element quantification and sample classification [8].

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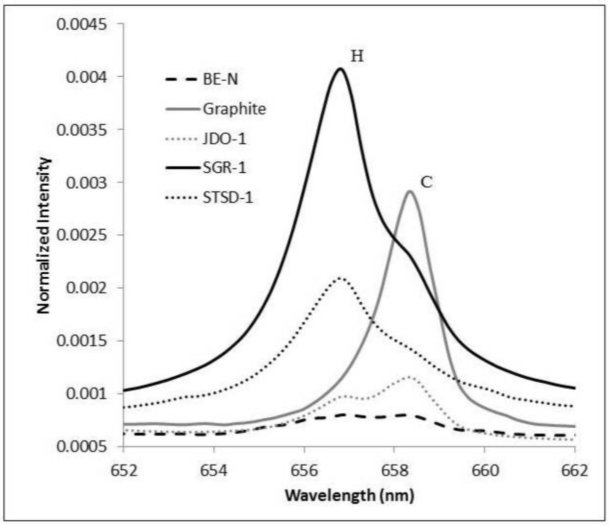

Figure 1. H (656.5 nm) and C (658.8 nm) peaks in geochemical reference standards; BE-N (basalt, 2000 ppm C), Graphite (99.9 wt% C), JDO-1 (dolomite, 12.8 wt% C, 0.17 wt% H_2O), SGR-1 (petroleum shale, 28 wt% C), STSD-1 (stream sediment, 12.3 wt% C, 4.5 wt% H_2O). Intensity has been normalized to the total emission for each spectral range.

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Variation of light at the surface of Mars: UV, visible and near-infrared radiation

Patel, M.R.; Otter, S.; Zarnecki, J.C.
The Open University, UNITED KINGDOM

The spectral content of martian solar radiation at the surface has been studied previously at ultraviolet (UV) wavelengths, however to date no studies on the comparison of the full UV, visible and near infrared (NIR) spectrum have been conducted. UV radiation plays a crucial role in determining the conditions for life, since solar light at wavelengths <280 nm can be extremely damaging to living organisms. The amount and extent of solar radiation reaching the surface below 280 nm is therefore of vital importance in any discussion relating to the question of life at the martian surface. Conversely, longer wavelength solar radiation is beneficial to some forms of life, providing an energy source for growth via photosynthesis at visible wavelengths. Thus knowledge of the relative balance between damaging UV and beneficial visible radiation is always required in astrobiological investigations concerning the surface of Mars. Here we present results from modelling of surface irradiances covering the wavelength range 200-1100 nm under a variety of conditions, examining the relative behaviour of the UV, visible and NIR regions of light.

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How Wet has been the Soil of Mars? An In-situ Determination from the Phoenix Microscope Station.

Pike, W. T.[1]; Staufer, U.[2]; Hecht, M.[3]; Goetz, W.[4]; Parrat, D.[5]; Sykulska, H.[1]; Vijendran, S.[1]; Madsen, M.[6]
[1]Imperial College London, UNITED KINGDOM; [2]Technical University of Delft, NETHERLANDS; [3]Jet Propulsion Laboratory, UNITED STATES; [4]Max Planck Institute for Solar System Research, GERMANY; [5]University of Neuchatel, SWITZERLAND; [6]University of Copenhagen, DENMARK

The microstructure of a soil can reveal and quantify the dominant processes involved in the soil's formation. The particle size distribution (PSD) for the Martian soil has been determined at the Phoenix site over a range from 0.1 to 200 ìm by a combination of optical and atomic-force microscopy.

In order to verify these results, an identical procedure was used on a functional copy of the flight instrumentation to determine the PSD of terrestrial Martian analogue soil. In turn these analogue results were compared to a PSD determined using a scanning electron microscope (SEM). There is excellent agreement between the two techniques, and with published sieve data, verifying the analytical technique used to determine the PSD of the martian soil in situ.

An important diagnostic of the formation processes is the fragmentation fractal dimension derived from the power-law relationships between the cumulative mass and the particle size of the soil. For terrestrial soils the power law gives three fractal dimensions corresponding to the separate formation processes for sand, silt and clay particles, the latter formed by the interaction with water. The PSD of the martian analogue also reveals a fractal dimension corresponding to clay formation, indicative of a contact with liquid water during its formation. In comparison the lunar regolith shows a single power law, as expected for a single process of meteorite gardening.

For the Phoenix soil three fractal dimensions can be identified. The fractal dimension for the smallest particle domain is close to zero up to 7 µm, indicating that these fines have recorded the smallest-scale formation processes. The extension of this fractal dimension to 7µm, an order of magnitude greater that that is seen in clay formation processes, would indicate that an interaction with water is not responsible for the formation of the fines. More probably the fines originate from long-lived global aeolian weathering under very dry conditions. We can use the low concentration of clay-sized particles to determine an upper limit for the interaction of the Phoenix soil with liquid water. Using the slowest measured formation rates this is quantified as less than 5,000 years exposure to liquid water over the history of the soil. The second fractal dimension indicates this soil derives from two processes that have separately formed the grains and the fines. It is possible that the grains originate from a local source such as the nearby Heimdal crater impact.

This result is in agreement with observations of both perchlorates and carbonates seen by other instrumentation at the Phoenix site, with a best estimate of 1000 years exposure to liquid water derived from all the available data. The fines at the Phoenix site are likely to be representative of the planet as a whole given the global nature of material transport at this length scale. Hence, as signs of liquid-water activity are minimal as determined by its microstructure, the martian soil in general will be a poor choice of sample for future in-situ investigations of past or present life.

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Remote Sensing of Chiral Signatures on Mars

Sparks, W.[1]; Hough, J.[2]; Germer, T.[3]; Robb, F.[4]; Kolokolova, L.[5]

[1]Space Telescope Science Institute, UNITED STATES; [2]University of Hertfordshire, UNITED KINGDOM; [3]National Institute of Standards and Technology, UNITED STATES; [4]University of Maryland School of Medicine, UNITED STATES; [5]University of Maryland, UNITED STATES

Introduction

We describe circular polarization as a remote sensing diagnostic of chiral signatures which may be applied to Mars. A high quality biosignature arises uniquely from biological processes. If a biosignature can be additionally be detected with remote sensing, then it can be useful to survey extensive surface areas to identify interesting regions for in-depth study. The remarkable phenomenon of homochirality, whereby the chiral building blocks of life use only L-amino acids and D-sugars, may be such a biosignature which can be amenable to remote sensing through circular polarization spectroscopy. Observations of selected areas of the Mars surface could reveal chiral signatures and hence explore the possibility of extant or preserved biological material.

Laboratory Work

Photosynthesis is a remarkable life strategy offering enormous evolutionary advantages, which arose early in the Earth's history and which globally impacted the Earth's atmosphere. An inherently surface phenomenon, photosynthesis operates using strong circularly dichroic electronic transitions and is hence observable using circular polarization spectroscopy. Sparks et al. (2009a,b) [1], [2], Martin et al. 2010 [3] presented spectropolarimetry of photosynthetic microorganisms. We found significant circular polarization in electronic absorption bands of primary and antenna photosynthetic pigments, with null mineral controls including Mars regolith analogue, JSC-1.

Telescopic Results

We obtained high-quality imaging circular polarimetry of a portion of the Mars surface during the favorable opposition of 2003 to seek evidence of anomalous optical activity that might indicate large scale surface chiral phenomena. With two narrow band filters and a spatial resolution 210 km, we did not find any areas of circular polarization [4]. However the observations covered only a tiny fraction of parameter space: we cannot exclude optical activity at other wavelengths, in other locations, or at higher spatial resolution.

Future Exploration

Wide spectral coverage and high spatial resolution are required to probe effectively for localized surface chiral signatures. Though extant life is thought unlikely on the Mars surface, historical surface water and the tolerance of halophilic archaea to extreme environments enhances the probability that life may be present now or have been present in the past. If it is present now, and if it follows terrestrial microbial communities which typically thrive in compact tight knit colonies for protection and to take advantage of localized niches of habitability and nutrients, their detectability for remote sensing is enhanced over dispersed microbial communities. There are potential habitats (methane vents, localized regions of moisture and nutrients, the near surface subsurface), and potential strategies (photosynthesis, UV protection with pigments, endolithic growth) that would result in remotely detectable extant or preserved life. Though speculative, a positive result from such a survey would be extremely interesting for follow-up study.

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Finding CO_2-formation pathways in the Martian Atmosphere

Stock, J.W.[1]; Boxe, C.S.[2]; Grenfell, J.L.[3]; Lehmann, R.[4]; Patzer, A.B.C.[3]; Rauer, H.[5]; Yung, Y.L.[6]

[1]Institute of Planetary Research/DLR, GERMANY; [2]JPL/Caltech, UNITED STATES; [3]ZAA/TU Berlin, GERMANY; [4]AWI Potsdam, GERMANY; [5]Institute of Planetary Research/DLR, ZAA/TU Berlin, GERMANY; [6]Caltech, UNITED STATES

The atmosphere plays a major role both for the evolution of a terrestrial planet and its potential to sustain life on its surface. Its chemical composition can be critically influenced by trace gases, which can act as catalysts.

On Mars, chemical pathways (e.g. catalytic cycles) determine the abundance of the main atmospheric component and greenhouse gas, CO_2 and thus influence habitability. Since the number of chemical species and reactions in complex systems like an atmosphere can be very large (and hence, also the number of chemical pathways), it is, generally, a challenging task to identify the important chemical pathways that control the abundance of major species.

Hence, effective methods for the investigation of such reaction networks are needed. To investigate the atmosphere of modern Mars, we have applied a unique algorithm, called *PAP* (Pathway Analysis Program) which is capable of determining all significant chemical pathways. This algorithm has been applied to the results of the Caltech-JPL-1D column model for the Martian atmosphere. The pathway analysis shows multiple chemical pathways that produce CO_2 at different altitudes.

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Quantitative Evaluation of Landing Site Habitability: Application to the Phoenix Mission

Stoker, Carol
NASA Ames Research Center, UNITED STATES

Recent and upcoming Mars missions have the objective of assessing the habitability of Mars. Stoker et al. [1]presented a framework for quantitatively evaluating habitability of sites on Mars based on landed spacecraft data and applied it to the Phoenix mission. In this paper, I will review that framework and show the results for the Phoenix mission, updated with new information about organic detection [2], and further evidence for liquid water action in the region [3].

Given our current understanding of life, the potential for habitability in a specific time and space encompasses four factors that are evaluated as probabilities: the presence of liquid water, the presence of a biologically available energy source, the presence of chemical nutrients, and the presence of a benign environment. The habitability index (HI) is the product of the probabilities. Each of the probabilities is decomposed into factors that combine for its evaluation. The probability is computed as the normalized sum of relevant factors, weighted relative to each other by the importance of each factor, and the uncertainty associated with the observation.

The factors considered in the evaluation of HI for the Phoenix site are as follows. Observational evidence for the presence of liquid water (past or present) includes ice segregations, chemical etching of soil grains, carbonate minerals, and variations in abundance of the soluble salt perchlorate. The presence of surface and near subsurface ice, along with thermodynamic conditions that support melting, suggest that liquid water is theoretically possible. Presently, unfrozen water can form only in adsorbed films or saline brines but more clement conditions recur periodically due to variations in orbital parameters. Energy to drive metabolism is available from sunlight, when semi-transparent soil grains provide shielding from ultraviolet radiation, and chemical energy from redox couples involving perchlorate and reduced iron species. Nutrient sources including C, H, N, O, P and S compounds are supplied by known atmospheric sources or global dust. Organic compounds were searched for and not detected but their combustion in the presence of perchlorate is predicted to release carbon dioxide as was observed by the Thermal and Evolved Gas Analysis experiment[4]. Environmental conditions are within growth tolerance for terrestrial microbes. Surface soil temperatures currently reach 260K and are periodically much higher, the pH is 7.8 and is well buffered, and the water activity is high enough to allow growth when sufficient water is available.

The HI evaluation framework allows comparative assessments of habitability at different landing sites. Computation of HI for the sites already visited by landers shows that Phoenix is the most habitable of any site visited to date. Furthermore, the site is habitable under modern conditions due to the presence of near surface ground ice and variations in insolation caused by cyclical changes in orbital parameters including season of perihelion and obliquity. Thus, a mission to search for extant life the Northern plains of Mars may be warranted.

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The Gas Chromatograph-Mass Spectrometer of the Sample Analysis at Mars Experiment Onboard the MSL 2011 Rover: Search for Organic Indices of a Prebiotic or Biotic Activity on Mars and the Mars Habitability

Szopa, C.[1]; Coll, P.[2]; Cabane, M.[1]; Coscia, D.[1]; Stalport, F.[2]; Buch, A.[3]; Noblet, A.[2]; Mahaffy, P.[4]; Glavin, D.[4]; Eigenbrode, J.[4]; Conrad, P.[4]; Freissinet, C.[5]; Brault, A.[3]
[1]LATMOS, University Pierre & Marie Curie Paris 6, FRANCE; [2]LISA, Universities Paris 7 & 12, FRANCE; [3]Ecole Centrale Paris, FRANCE; [4]NASA Goddard Space Flight Center, UNITED STATES; [5]Ecole Centrale Paris, UNITED STATES

In past times, life might have emerged under Martian conditions milder than the present ones, and left some remnants at the surface. Even if this did not happen, prebiotic molecules may have been preserved in the soil, and they might be similar to those that prevailed on the Earth surface some 3.5 to 4 billion years ago. NASA's MSL2011 rover will explore the surface and subsurface of Mars, seeking traces of prebiotic or biological activity. Organic signatures are among the main signatures of interest in this frame, and they will be among the main targets of the Gas Chromatograph Quadrupole Mass Spectrometer (GC-QMS) which constitutes the core of the Sample Analysis at Mars (SAM) analytical laboratory, developed by the NASA/GSFC. The main goal of this instrumentation is indeed to determine molecular abundances and isotopic ratios of organic molecules present in the collected samples, by analyzing gases either sampled from the atmosphere, or obtained from soil processing, either by physical heating or chemical reactions. This paper will present a preliminary view of the analytical capabilities of the GC-QMS, with a focus on the GC part, which is the French hardware contribution to SAM. Based on results obtained with laboratory tests performed during the development of the GC, and also on first tests performed with the engineering and flight models of the GC and QMS coupled together, we will give a first view of the analytical capability for the experiment to detect and identify a broad range of organics, including large molecules of astrobiological interest and chiral organics. The data acquired with this instrumentation should thus be of primary importance to give an insight into the potential existence of a present or past life on Mars, and to determine the influence of the environmental surface conditions on the current potential habitability of Mars.

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A Scytonemin-iron Complex : a New Biomarker for Extremophiles

Varnali, T.[1]; Edwards, H.G.M.[2]
[1]Bogazici University, TURKEY; [2]University of Bradford, UNITED KINGDOM

Scytonemin is a cyanobacterial sheath pigment with potent UV absorbing (UV-A, UV-B and UV-C) properties. The importance of this biomolecule lies in its photoprotective function which is fundamental to the major survival strategies adopted by extremophiles in environmentally stressed conditions. Also , iron compounds (particularly iron (III)oxides) have attracted attention by offering an additional UV-protecting facility to subsurface biological colonization in rock matrices. Cyanobacterial colonies frequently use sandstone rocks as host matrices for subsurface colonization, which is accompanied by a zone of depletion of iron and chemical transportation of iron compounds to the surface. An iron complex of scytonemin is the subject of this work , which is a continuation of our studies on scytonemin [1,2,3], in which we have suggested that an iron-scytonemin complex could feature in this survival strategy and facilitate the movement of iron through the rock3.

The forthcoming NASA/ESA ExoMars mission for the robotic interrogation of the Martian planetary surface for signatures of life will contain a suite of novel analytical instrumentation for the detection of extinct and extant life. In this , Raman spectroscopy (RLS) will provide a first-pass analytical capability based on its ability to detect recognised key biomolecular signatures for specific protectants . Although the characteristic molecular features of scytonemin in the Raman spectrum are known ,any spectral changes induced through its complexation with iron need to be evaluated ; the current study involves an assessment for this spectroscopic characterisation , which will assist in the identification of iron-scytonemin complexation in extremophilic colonies and expand the database for both terrestrial and planetary instrumental recognition purposes. The vibrational frequencies of a scytonemin-iron(III)complex are studied computationally using DFT calculations at the B3LYP /6-31G** level of methodology and assignments have been made for the normal vibrational modes which will be potential targets for Raman spectroscopic identification .

Acknowledgement
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Challenges and Methods of Sample Acquisition and Delivery to In-Situ Instruments Exploring Mars Habitability

Zacny, K.; Paulsen, G.
Honeybee Robotics, UNITED STATES

There are many reasons for penetrating below the surface of Mars. One of these include obtaining a core or powdered samples that have been preserved and unaltered for millions of years. Another reason is to provide subsurface access for in-situ scientific instruments such as neutron spectrometers. However, there are a number of challenges associated with penetrating extraterrestrial bodies. These include specific mission requirements (depth, size of a sample, acceptable level of contamination), mission constraints (mass, power, volume, communication delay) and environmental constraints (temperature, atmospheric pressure or vacuum, dust, geological uncertainty). Having such a large number of variables leads to diverse sampling approaches.

Over the past decades, exploration of Mars was limited to the martian atmosphere and its surface. Viking and Mars Phoenix lander used a scoop to penetrate a few centimeters below the surface of loosely consolidated soils and acquired samples for analysis. Rock Abrasion Tool penetrated a few millimeters into rocks. A drill on the Mars Science Laboratory rover will penetrate up to 5cm into surface rocks and outcrops in 2012. However, in order to find habitable zones, one has to go deeper than a few centimeters and reach areas where radiation damage is minimal.

This presentation will start with an overview of challenges associated with sample acquisition (drilling, scooping) and sample transfer on Mars. From the science stand point, the main challenges are due to Mars low pressure conditions bracketing triple point of water, temperatures ranging from sub-freezing to above freezing, presence of water-ice, and presence of perchlorate that depress freezing point of water. In particular, areas with perchlorate (e.g. Mars Phoenix landing site) could be most challenging because of sticking problems of icy-soils containing perchlorate. These areas, because of the presence of water-ice, are also of most interest for exploring the habitability of Mars.

A detailed survey of the past, present and future technologies for sample acquisition and transfer will also be given. This will include a description of each of the specific technologies such as drills, and scoops and their pros and cons. A particular emphasis will be given to issues related to planetary protection and cross contamination, as well as sample preservation. An example of a 1 meter drill class, called the IceBreaker will be given. The drill was demonstrated in Dry Valleys of Antarctica (Mars analog) and penetrated 1 meter in ice cementer ground and acquired samples. The same drill was also demonstrated inside 3.5m vacuum chamber in ice, ice with perchlorate, icy-soils, and rock. Lessons learned from the chamber and analog tests will be described in detail.

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Self-replicating Cell-like Membrane Systems: Could They Exist on Mars?

Zhu, T.[1]; Carr, C[1]; Lui, C[1]; Zuber, M[1]; Ruvkun, G[2]
[1]Massachusetts Institute of Technology, UNITED STATES;
[2]Massachusetts General Hospital, UNITED STATES

All life as we know it are membrane-bound (1). Two key questions concerning the existence of cellular life on Mars include: 1) whether the lipid molecules that constitute cell membranes exist and 2) whether a primitive membrane system could self-replicate under the Mars environment. A plausible pathway for the reproduction of a model membrane system has been described (2). It has been shown that feeding large multilamellar fatty acid vesicles with fatty acid micelles results in their growth into long thread-like vesicles. Under modest shear forces, these thread-like vesicles divide into multiple daughter vesicles, each inheriting any encapsulated genetic molecules such as RNA. The robustness and simplicity of this pathway suggests that similar processes might occur under early Earth or Mars conditions where sources of amphiphilic lipid molecules and bodies of liquid water exist. Thus, here we propose to search for, in addition to liquid water, simple lipid molecules (such as fatty acids and phospholipids) in future Mars exploration missions (3).

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