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AB1 abstracts

Panspermia in tightly-packed habitable multi-planet systems

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Abstract

The discovery of multiple planets in the habitable zone of the TRAPPIST-1 system is a watershed in exoplanetary science. As missions such as PLATO extend habitable zone sensitivity out to 1 au, we can expect an increasing number of similarly exciting systems. Consequently, developing analytical techniques to quantify extrasolar intra-system panspermia will become increasingly important. Here, we apply an impulse formalism from [2] to determine the asteroid impact characteristics which would be necessary to transport life both inwards and outwards within tightly-packed multi-planet habitable systems. We provide estimates for the dissemination of life within those systems, and assess the prospects for eukaryotic and microbial survival at both impact and in space.

1. Introduction

Although studies of the transport of life-bearing rocks between planets has a long history [4], the discovery of the potentially life-bearing Martian meteorite ALH84001 in the mid-1990s accelerated investigations into panspermia within the Solar system. The last two decades has since featured detailed work outlining delivery dynamics, impact physics and chemistry, and biological survival requirements with respect to Earth, Mars and other solar system bodies. Consequently, a detailed foundation for panspermia-related processes has been established.

Despite these advances, the applicability of these processes to extrasolar planetary systems is still in question, partly because in those systems we lack the detailed knowledge of our own planetary system.

Nevertheless, efforts to characterize panspermia between different extrasolar systems, or between the solar system and extrasolar systems, have contributed to our understanding. However, panspermia amongst extrasolar planets within the same system has received little attention. A potential reason for this dearth of study is the lack of observational evidence of multiple planets in the habitable zone of the same star. This situation has now changed with the groundbreaking discovery of multiple potentially habitable planets in the TRAPPIST-1 system [1], and the subsequent analyses [3,5].

2. Our contributions

Here, we study several aspects of panspermia within multi-planet habitable systems, with a focus on analytics and dynamical delivery, but also addressing eukaryotic and microbial survival given an arbitrary flux from the central star. We also consider the timescales for Hohmann transfers for advanced life.

Advancing the impulse formalism of [2] allows us to assess prospects for panspermia algebraically, i.e., without resorting to numerical simulations, which have been common features of previous studies.

Figure 1 illustrates how the direction of ejecta from an impact translates into the orbital location for different kick speeds. Figure 2 illustrates how vertically coincident (with regard to orbital inclination) multiple planets (in this one case, the TRAPPIST-1 planets) must be in order for panspermia to occur.

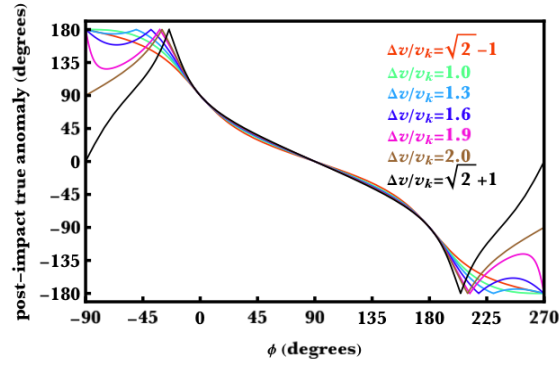


Figure 1: Relating the post-impact true anomaly with kick direction from impact.

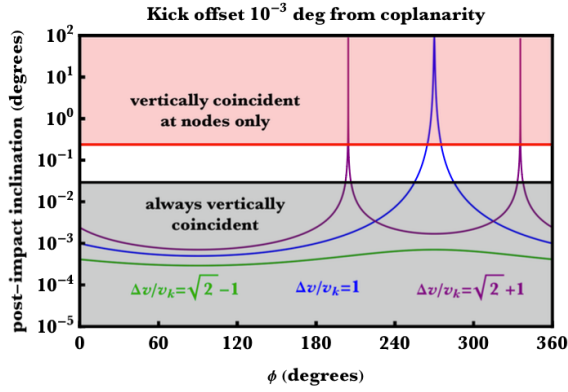


Figure 2: How the kick direction affects the inclination of the ejecta orbit. By assuming coplanarity amongst all TRAPPIST-1 planets, we plot, for three different values of the ratio of kick velocity to circular Keplerian velocity ($\Delta v/v_k$), the dependence on the kick direction in the source's orbital plane ϕ . The gray region corresponds to where the resulting ejecta orbital inclination is never large enough to exceed the radius of any TRAPPIST-1 target at any point in the orbit, and the red region corresponds to the opposite extreme, where vertical coincidence occurs only near the orbital nodes.

Acknowledgements

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Lipidic biosignatures in diagenetically stabilized ironstones terraces of Río Tinto, an acidic environment with analogies to Mars

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Abstract

The characterization of extreme environments with analogies to Mars is important for understanding if/how life may have thrived in the Red Planet. Río Tinto in SW Spain is an extreme environment with constant acidic waters (mean pH of 2.3) and high concentration of heavy metals, which are direct consequence of the active metabolism of chemolithotrophic microorganisms thriving in the rich polymetallic sulfides present in the massive Iberian Pyritic Belt. Abundant minerals rich in ferric iron and sulfates, which result from the pyrite metabolism (e.g. jarosite, goethite, hematites, etc.) are of special interest for their potential for organics preservation [1]. Here, we investigate the occurrence and preservation of biological signatures in diagenetically stabilized ironstone deposits in Río Tinto, by using geolipidic markers.

1. Introduction

Río Tinto sedimentary deposits record aspects of the geochemical and biological environment of the regional ecosystem, that persist through diagenesis to provide a geobiological chronicle of Río Tinto processes through time. Diagenetically stabilized ironstones in the Río Tinto terraces preserve macroscopic and microscopic biosignatures in iron oxide precipitates [1], which may help to understand the potential for life preservation in a similar environment such as Mars iron outcrops.

1.1 Study area and Sampling

Three terraces recording different depositional episodes (from the late Pliocene to the Holocene) and a regionally developed Gossan from the end of the Miocene were sampled to analyze diverse lipidic

families with diagnostic value. The molecular distribution patterns and the relative abundance of functionalized geolipids allowed to infer organic source inputs and preservation degree.

2. Results and Discussion

Unusually high contents of total organic carbon indicated the relatively good preservation of the organic fraction in the old geological deposits, what is discussed to be potentially related to organo-FeOx sorption, organo-Fe precipitates, and/or ternary associations among FeOx, organic matter, and clay minerals [2]. The distribution patterns of functionalized lipids showed mixed inputs of organic matter dominated by microbial sources (bacteria, archaea) and higher plants, with a fading trend in the diagnostic fingerprints with the increasing age of the samples. These are relevant findings for understanding life thriving and survival strategies in an acidic environment developed on a Fe- and S-based chemistry with analogies to Mars.

3. Figures

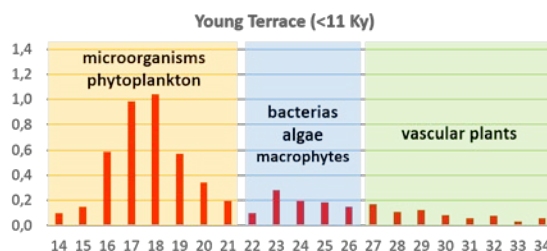


Fig. 1: *n*-Alkanes distribution patterns in one of the three Río Tinto terraces, showing the most likely source inputs associated with the carbon units and even/odd preferences.

4. Acknowledgements

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Biomarkers and taphonomic processes in fresh and fossil biosignatures from Hot Spring silica deposits in *El Tatio* Chile, as a Mars Analogue.

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Abstract

Biomarkers characterization and taphonomic process of recent and fossil biosignatures in extreme environments with analogies to Mars is essential to understanding how life could develop and survive in this conditions. Siliceous sinter deposits on Mars where similar to those found in the hydrothermal hot springs and geysers from *El Tatio*, Chile. Here we present data on different lipids functional groups and characterize this systems. Biosignatures and organic preservation in this particular system over time could be used in future planetary exploration.

1. Introduction

Siliceous sinter deposits are hot spring related rocks formed by a dynamic process of evaporation and cooling of thermal waters; large underground hydrothermal systems open to the surface by hot springs and geysers, which are of mayor importance for geothermal and mineral exploration. Hot spring waters are characterized by the high concentration of many elements (chloride, sulphate, etc.) and can be supersaturated regard to an array of minerals.

Hot spring and their silica deposits are extreme environments that have received attention by many different research areas. Despite their importance in geothermal and ore exploration due to their link to high temperature (>175 °C) hydrothermal reservoirs at depth [1]. They have value information about the development and preservation of life in extreme environments that can contribute to understand early Earth environments and thus to search for possible fossil life on Mars [2].

El Tatio hot springs and geysers have unique features, like their high altitude (4200 m.a.s.l), high UV-A and UV-B radiation, a lower water boiling point (86 °C), and a high concentration of toxic elements (As, B, etc.). These special characteristics lead to a particular interest in understanding the processes that govern

the organic preservation in the hot-spring silica deposits.

2. Sample collection

Fresh and fossil hot spring sinters (n=4) and geysers (n=4) were sampled to investigate the preservation of organic matter, by using clean protocols. Samples were aluminum foil wrapped and disposed in close containers for further analysis. Water samples (n=4) from geysers and hot springs were also analyzed geochemically.

2.1. Geolipid Extraction, Fractionation and Analysis

3. Target soil samples (100 g) were extracted with a mixture of dichloromethane/methanol (DCM/MeOH, 5:1, v/v) during 24 h with a Soxhlet apparatus. Internal standards (tetracosane-D₅₀ and 2-hexadecanol) were added prior to extraction. The total lipids extracts were concentrated using rotary evaporation to 2 ml. After this step, activated copper was added and stay overnight for elemental sulfur removal. The extracted sample was separated in three fractions using a Bond-elute column chromatography (bond phase NH₂, 500 mg, 40 µm particle size).

2.2. GC-MS Analysis

The samples (non-polar, acid and polar fraction) were analyzed by gas chromatography mass spectrometry using a 6850 GC system coupled to a 5975 VL MSD with a triple axis detector (Agilent Technologies) operating with electron ionization at 70 eV and scanning from m/z 50 to 650. The analytes were injected (1 µl) and separated on a HP-5MS column (30 m x 0.25 mm i.d. x 0.25 µm film thickness) using He as a carrier gas at 1.1 ml min⁻¹.

3. Figures

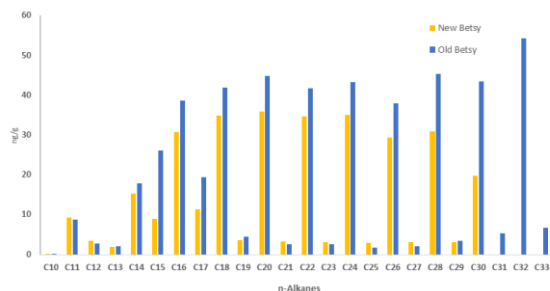


Figure 1. *n*-Alkane signature in the fresh and fossil sinter samples

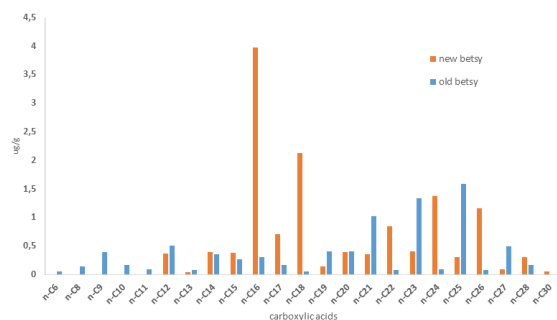


Figure 2. *n*-Carboxylic acids signature in the fresh and fossil sinter samples.

4. Summary and Conclusions

Organic preservation have been shown in this study. Many different labile functional groups (i.e., carboxylic acids, alcohols, aldehydes, etc.) were found in both “age” samples. A shift in congener pattern for the different lipids families were found and discuss. This results give insight in taphonomic processes actin in this extreme environment, which could be used as a baseline in Mars exploration..

Acknowledgements

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Preservation and detection of biomarkers in mineralized communities and its potential link to the variations in ORP

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Abstract

The search for traces of life is one of the principal aims of Mars exploration. Within the MASE project (Mars Analogues for Space Exploration) we work to improve approaches and methods for biomarker detection and extraction from Mars analogue sites. One promising strategy to study the preservation of biosignatures in Mars conditions consists of the combined study of biomarkers detection and monitoring physicochemical parameters in mineralized samples. We have observed that there is a correlation between biomarker detection and changes in oxi-reduction potential (ORP) during mineralization process. In addition, these methods and the study of samples from MASE sites have enabled us to develop an antibody microarray for competitive sandwich immunoassays as a potential tool for the detection of biomarkers in salty and anaerobic conditions.

1. Introduction

Physic-chemical processes of living organisms leave tell-tale signals in the environment. The search for these signatures is one of the main goals for Astrobiology and improving and optimizing its detection regarding Mars conditions is part of the MASE project objectives. Besides, the traces of some kinds of microorganisms can be well preserved, provided that they are rapidly mineralized and that the sediments in which they occur are rapidly cemented [1].

A developed antibody multiarray competitive immunoassay (MACIA) for the simultaneous detection of compounds of a wide range of molecular sizes or whole spores and cells [2] [3] is a suitable option for biomarker detection in samples with low biomass from Mars analogue sites as well as with

biomineralized microorganism communities. Moreover, biomineralization is often the first step of fossilization and produces particular chemical, structural and morphological features that can be preserved in fossil biominerals or microfossils [4] and some parameters as ORP or pH vary over the process.

2. Methods and objectives

Samples from the three MASE campaigns in Iceland (Graenavatn Lake), United Kingdom (Boulby Mine) and Germany (Sippenauer Moor, Regensburg) were used to obtain enrichments and isolates as well as to extract and detect biomarkers in them. Some of the enrichments were exposed to mineralization to study, among others, the preservation of biosignatures by the assessment of antigen-antibody binding at different times. Simultaneously, the evolution of ORP through this process was monitored by two modules system (DTIVA: automated tools for microbial life detection) where ORP variations in those communities were followed through continuous measurements of nanosensors in closed chambers.

An additional objective for MASE project has been to develop a specific microarray with antibodies performed from natural samples and isolates from MASE sampling sites.

3. Summary and Conclusions

The presence of traces from some microbial metabolic groups were detected in the mineralized communities at three different times over the fossilization process. It was undertaken by using a 168 antibody microarray for the immunoassay. There were observed variations in the resulting immunoprofiles. There seems to be a probably correlation between these changes and those in ORP through time. We consider that the simultaneous use

of both approaches arises a promising tool to broaden the knowledge and consequent improvement in the search for traces of past and present life.

Acknowledgements

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3D climate-carbon modelling of the early Earth

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Abstract

Oxygen isotopes in marine cherts have been used to infer hot oceans during the Archean with temperatures between 60°C (333 K) and 80°C (353 K). Such climates are challenging for the early Earth warmed by the faint young Sun. The interpretation of the data has therefore been controversial. 1D climate modelling inferred that such hot climates would require very high levels of CO₂ (2-6 bars). Previous carbon cycle modelling concluded that such stable hot climates were impossible and that the carbon cycle should lead to cold climates during the Hadean and the Archean.

Here, we revisit the climate and carbon cycle of the early Earth at 3.8 Ga using a 3D climate-carbon model [1, 2]. We find that CO₂ partial pressures of around 1 bar could have produced hot climates given a low land fraction and cloud feedback effects. However, such high CO₂ partial pressures should not have been stable because of the weathering of terrestrial and oceanic basalts, producing an efficient stabilizing feedback. Moreover, the weathering of impact ejecta during the Late Heavy Bombardment (LHB) would have strongly reduced the CO₂ partial pressure leading to cold climates and potentially snowball Earth events after large impacts.

Our results therefore favor cold or temperate climates with global mean temperatures between around 8°C (281 K) and 30°C (303 K) and with 0.1-0.36 bar of CO₂ for the late Hadean and early Archean. Finally, our model suggests that the carbon cycle was efficient for preserving clement conditions on the early Earth without requiring any other greenhouse gas or warming process.

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Detection of bio-signature by microscopy and mass spectrometry

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Abstract

We demonstrate detection of micro-sized fossilized bacteria by means of microscopy and mass spectrometry. The characteristic structures of lifelike forms are visualized with a micrometre spatial resolution and mass spectrometric analyses deliver elemental and isotope composition of host and fossilized materials. Our studies show that high selectivity in isolation of fossilized material from host phase can be achieved while applying a microscope visualization (location), a laser ablation ion source with sufficiently small laser spot size and applying depth profiling method. Our investigations shows that fossilized features can be well isolated from host phase. The mass spectrometric measurements can be conducted with sufficiently high accuracy and precision yielding quantitative elemental and isotope composition of micro-sized objects. The current performance of the instrument allows the measurement of the isotope fractionation in per mill level and yield exclusively definition of the origin of the investigated species by combining optical visualization of investigated samples (morphology and texture), chemical characterization of host and embedded in the host micro-sized structure. Our isotope analyses involved bio-relevant B, C, S, and Ni isotopes which could be measured with sufficiently accuracy to conclude about the nature of the micro-sized objects.

1. Introduction

Searching for the instrumentation and method capable of the detection of life and bio-relevant material on the other planets is important task of

current planetology and space research. This involves usually preparation of the instruments capable of analyses with high spatial resolution. Planetary materials are typically highly heterogeneous on the micrometre-level and both material visualisation and possibility to interrogate the small surface area for the chemical analysis are necessary. Chemical information on the surface composition typically can be delivered by optical and mass spectrometric analyses. In both cases optical microscopy is necessary to visualise the surface details. Typically after this inspection the chemical analyses can follow up. We demonstrate that by combining a miniature microscope-camera and a miniature mass spectrometer is possible to deliver multiple information on the origin of the investigated material. The isolation of the material, accuracy and precision of the laser mass spectrometer is sufficiently high to deliver conclusive information on the surrounding host and entrapped inclusion including its possible bio-origin. Our studies can deliver detailed chemical information of individual sample components with the sizes down to a few micrometres. The results of such investigations can yield mineralogical surface context including mineralogy of individual grains or the elemental composition of the objects embedded in the sample surface such as micro-sized fossils. The identification of bio-relevant material can follow by the detection of bio-relevant elements and their isotope fractionation effects [1], [2].

2. Experimental

For chemical analysis of heterogeneous solid surfaces we have combined a miniature laser ablation mass spectrometer (LMS) and microscope-camera

system. The microscope (spatial resolution $\sim 2\mu\text{m}$, depth $30\mu\text{m}$) yields the optical characterisation of the surface material including morphology and sample texture providing also some insights into mineralogical sample context. It helps to find the micrometre-sized objects such as fossilised structure or mineral grains across the rock surface. Using microscope-camera system one can define accurately the location of the objects of interest for the direct mass spectrometric analysis by the LMS instrument. The LMS instrument combines an fs-laser ablation ion source (775 nm, 180 fs, 1 kHz; the spot size of $\sim 20\mu\text{m}$) [4], [5], [6] and a miniature reflectron-type time-of-flight mass spectrometer (mass resolution ($m/\Delta m$) 400-600; dynamic range 10^7 - 10^8).

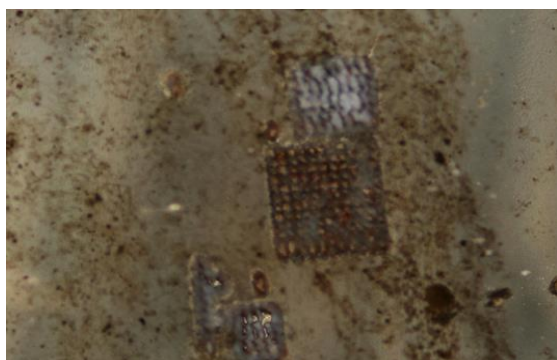


Figure 1: Photograph of a Gunflint sample with microbials phase (small spheres, rods and filaments) embedded in the silica. The microbials structure sizes are less than 10 micrometres in size and their age is determined to be close to 2 billions. The spot-like matrix are laser ablation craters.

Both stepwise surface analysis (chemical mapping of the surface) and depth profiling (layer-by-layer) can provide deep insights into the surface and subsurface mineralogy (as derived from the element correlation analysis).

3. Results and discussion

A number of heterogenous rock samples containing micrometre-sized fossils and mineralogical grains were investigated together with appropriate Standard Research Materials (SRM) for controlling the quantitative performance of the instrument.

Both elemental and isotope analysis of fossilised microbial structures (spheres, rods, filaments) of age from hundred thousand to billions of years embedded in aragonite or silica phases and hosted in rock

materials were investigated. Large fraction of the measurements could be conducted with sufficiently high accuracy and precision allowing the analysis of isotope fractionation effects. With combined optical mineralogical, elemental and isotope analysis the assignment of analysed features to fossilised microbials or mineralogical grains could be made conclusively.

The analysis of the micro-sized objects can be conducted with high selectivity; the host composition was typically readily different to that of the analysed objects. In depth chemical analysis (chemical profiling) is found in particularly helpful allowing relatively easy isolation of the chemical composition of the host from the investigated objects [6], [7], [8]. Analysis of the isotope compositions can be measured with high level of confidence, nevertheless, presence of cluster of similar masses can make sometimes this analysis difficult. Based on this work, we are confident that similar studies can be conducted in situ planetary surfaces delivering important chemical context and evidences on bio-relevant processes.

4. Summary and Conclusions

Laser mass spectrometer (LMS) combined with a microscope-camera system can be to be important instrumentation for the investigation of micro-sized microbials. Current studies show that by combining optical visualization, mineralogical, elemental and isotope composition one can conclusively derive nature of the putative fossilized materials.

Acknowledgements

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Photodegradation of selected organics on Mars

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Abstract

At least as much as 2.4×10^6 kg of unaltered organic material is estimated to be delivered to the Martian surface each year [1]. However, intense UV irradiation and the highly oxidizing and acidic nature of Martian soil cause degradation of organic compounds. Here we present first results obtained with the recently developed PALLAS facility at Utrecht University. This facility is specifically designed to simulate planetary and asteroid surface conditions to study the photocatalytic properties of relevant planetary minerals. Our results tentatively show degradation of several compounds and preservation of others.

1. Introduction

Even if life has never been able to flourish on the Martian surface, and thus no biogenic organic material is present, we should still be able to find organics delivered through interplanetary dust particles and meteorites. At least as much as 2.4×10^6 kg of unaltered organic material is estimated to be delivered to the Martian surface each year [1] and it has been estimated, based on Ni concentrations in Martian surface materials, that the Martian soil contains about 1 to 3 % of meteoritic material [2]. Furthermore, organic carbon has been confirmed to be present in meteorites and can survive meteorite impact [3] and should therefore be present at the Martian surface. A rough estimate of the concentration of organic carbon that should be present in the Martian soil is ~ 60 ppm [4]. This is a very rough estimate based on a constant meteorite influx, a lack of degradation of meteoritic organic carbon, efficient mixing of newly delivered material with the regolith, and a homogenous 100 m thick layer of regolith, with a density of 1200 kg m^{-3} .

The Sample Analysis at Mars (SAM) instrument on board MSL's Curiosity rover recently detected chlorinated hydrocarbons in drilled samples at Gale crater [5]. Additionally, sulfur-containing organics

were discovered [6]. Both types of compounds could have been released as such from the sample or, and most likely for the chlorinated compounds, have formed inside SAM by reactions of low temperature decomposed perchlorate or high temperature released SO_2 . This implies that some pristine organics can be found on the surface.

The Martian surface, however, is subject to intense radiation [7,8] and oxidation [9]. These processes significantly lower the likelihood of the presence of pristine organics on the Martian surface. In light of future organic detection missions to Mars it is therefore important to understand and characterize the reaction products of these processes and equally important the catalytic or protecting effect of minerals found on the Martian surface. Here, we present first results of laboratory simulations investigating the adsorption properties of organic compounds on minerals and the molecular degradation under Mars-like conditions.

2. Experiments in PALLAS

PALLAS, the Planetary Analogues Laboratory for Light, Atmosphere, and Surface Simulations, is a planetary surface simulation facility [10], is a $50 \times 50 \times 50$ cm stainless steel vacuum chamber, equipped with a turbo pump to create and maintain atmospheric pressure.

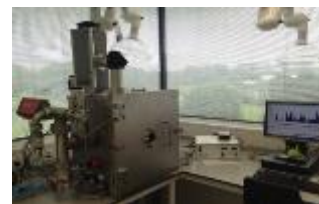


Figure 1: PALLAS

Samples were placed on a cooling table in the beam spot of a solar simulator equipped with a water filter to remove residual heat (LOT-Oriel, 450 W UV enhanced Xe, 180–900 nm). Experiments were carried out at 20°C and -55°C in vacuum (10^{-7} mbar) and Mars-like atmospheric conditions (10 mbar CO_2) for 24–48 hours.

3. Sample preparation and analysis

Samples were prepared using two methods. In method 1 the organics were mixed with minerals and ground, then a small amount of water was added to promote binding of the organics to the mineral. The water was left to evaporate after which the dried sample was transferred to the sample holder. In method 2 the mineral powder was mixed with dilute aqueous solutions of organics, after which the suspension was homogenized by vortex and put on a test tube rotator for a time sufficient to reach steady state equilibrium. After equilibrium adsorption, the suspensions were centrifuged to pellet suspended mineral particles, which were dried at 50 °C to remove the residual water.

Before and after exposure the samples were analysed with Diffuse Reflectance Infrared Fourier Transform Spectroscopy (DRIFTS) and Raman Spectroscopy, enabling direct probing of the effects of the exposure to the Martian conditions, as the samples holders can be placed directly in the DRIFTS and the Raman.

4. Results

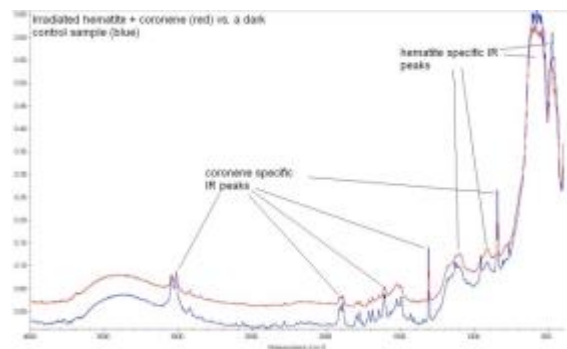


Figure 2: DRIFTS spectra of hematite spiked with coronene, before (blue) and after (red) irradiation

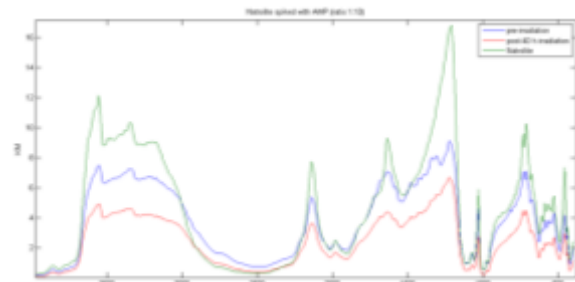


Figure 3: DRIFTS spectra of natronite (green), and natronite spiked with adenosine monophosphate before (blue) and after (red) irradiation.

5. Summary and Conclusions

Photocatalysis is a process known to effectively degrade organic compounds [11]. Previous work has shown that several organic species can be photo-oxidized on very common minerals, such as olivine [12]. Our results indicate that some minerals are more effective catalysts whereas others aid in the preservation of organic compounds. Furthermore, some of the compounds tested appear to be more stable than others. Further studies are underway to better understand the chemistry underlying these results.

Acknowledgements

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