

## International Journal of Astrobiology

<http://journals.cambridge.org/IJA>

Additional services for *International Journal of Astrobiology*:

Email alerts: [Click here](#)

Subscriptions: [Click here](#)

Commercial reprints: [Click here](#)

Terms of use : [Click here](#)



---

## Human crew-related aspects for astrobiology research

Cora S. Thiel, Vladimir Pletser and Bernard Foing

International Journal of Astrobiology / Volume 10 / Special Issue 03 / July 2011, pp 255 - 267  
DOI: 10.1017/S1473550411000152, Published online: 18 May 2011

**Link to this article:** [http://journals.cambridge.org/abstract\\_S1473550411000152](http://journals.cambridge.org/abstract_S1473550411000152)

### How to cite this article:

Cora S. Thiel, Vladimir Pletser and Bernard Foing (2011). Human crew-related aspects for astrobiology research. International Journal of Astrobiology, 10, pp 255-267 doi:10.1017/S1473550411000152

**Request Permissions :** [Click here](#)

# Human crew-related aspects for astrobiology research

Cora S. Thiel<sup>1</sup>, Vladimir Pletser<sup>2</sup> and Bernard Foing<sup>3</sup>

<sup>1</sup>*Institute of Medical Physics and Biophysics, CeNTech, University of Muenster, Heisenbergstrasse 11, D-48149 Muenster, Germany*

*e-mail: cthiel@uni-muenster.de*

<sup>2</sup>*Human Space Flight Directorate, European Space Agency, ESTEC, P.O. Box 299, NL-2200 AG, Noordwijk, The Netherlands*

<sup>3</sup>*Science and Robotic Exploration Directorate and International Lunar Exploration Working Group (ILEWG), European Space Agency, ESTEC, P.O. Box 299, NL-2200 AG, Noordwijk, The Netherlands*

**Abstract:** Several space agencies and exploration stakeholders have a strong interest in obtaining information on technical and human aspects to prepare for future extra-terrestrial planetary exploration. In this context, the EuroGeoMars campaign, organized with support from the International Lunar Exploration Working Group (ILEWG), the European Space Agency (ESA), the National Aeronautics and Space Administration (NASA) Ames Research Center and partner institutes, was conducted by the crews 76 and 77 in February 2009 in The Mars Society's 'Mars Desert Research Station' (MDRS) in Utah.

The EuroGeoMars encompasses two groups of experiments: (1) a series of field science experiments that can be conducted from an extra-terrestrial planetary surface in geology, biology, astronomy/astrophysics and the necessary technology and networks to support these field investigations; (2) a series of human crew-related investigations on crew time organization in a planetary habitat, on the different functions and interfaces of this habitat, and on man–machine interfaces of science and technical equipment.

This paper recalls the objective of the EuroGeoMars project and presents the MDRS and its habitat layout. Social and operational aspects during simulations are described. Technical and operational aspects of biology investigations in the field and in the habitat laboratory are discussed in detail with the focus point set on the polymerase chain reaction (PCR)-based detection of microbial DNA in soil samples.

*Received 16 January 2011, accepted 4 April 2011, first published online 18 May 2011*

**Key words:** Mars mission, human aspects, astrobiology, Moon–Mars bases, PCR instrumentation for life detection, MDRS, Mars analogues.

## Introduction

Although manned Mars missions are not currently planned, they are likely to occur in the next 20 or 30 years and will typically last for two-and-half to three years including an interplanetary journey of approximately six months, a surface stay of six months to two years and a return interplanetary leg of six months (Hoffman & Kaplan 1997; Horneck *et al.* 2006).

Mars analogues on Earth are used to assess the feasibility of different aspects of the crew's surface activities, to conduct *in situ* Mars-related science investigations and to field test equipment and instrumentation. The Mars Society (2010) has installed two Mars analogue habitats in extreme environments, seen as Mars Analogues on Earth. The first is the Flashline Mars Arctic Research Station (FMARS) (FMARS 2009) installed since 2001 in the uninhabited island of Devon in the Canadian Arctic Circle. The second is the Mars Desert Research Station (MDRS; The Mars Society Mars Desert Research Station 2010) which has been operational since December 2001 in the desert of Utah in the vicinity of the small town of Hanksville. Since 2001, more than 90 crews of six or more persons each have spent periods of up to or more than

two weeks in the MDRS, living and conducting scientific, exploratory and experimental work in isolation. The simulation is made as close to a Mars mission as possible by confining the crews in the habitat without any direct contact with the outside world and by conducting simulated extra-vehicular activity (EVA) expeditions wearing unpressurized EVA space suit simulators. Field operations may be conducted in EVA or non-EVA modes depending on specific goals of the field activities. In other words, the simulation is as realistic as the crew wants to make it. If the main goal of the simulation is to conduct field investigations, a mixed approach (some field outings in EVA mode and some in non-EVA mode) is acceptable, whereas if the goal is to study how crews would organize themselves and conduct field investigations, like a real Mars crew would, then more stringent operational rules have to be followed. This would include confining the crews in the habitat without any direct contact with the outside world and conducting all field investigations following EVA rules and protocols (wearing unpressurized EVA suits, delay in radio-communications, self-autonomy at all stages, etc.).

In order to assess several human and scientific aspects of future manned missions on extra-terrestrial planetary surfaces,

the EuroGeoMars project was proposed to The Mars Society in 2008. The EuroGeoMars project would last for five weeks as follows: first, a technical preparation week (24–31 January 2009) for instrumentation deployment, followed by a first rotation of a crew of six scientists and engineers (MDRS crew 76, 1–15 February 2009) for further deployment and utilization, and concluded by a second rotation of another crew of six scientists and engineers (MDRS crew 77, 15–28 February 2009) for further utilization and in-depth analysis.

The EuroGeoMars project encompassed two groups of experiments:

- (1) a series of field science experiments that can be conducted from an extra-terrestrial planetary surface in geology, biology, astrobiology astronomy and the necessary technology and networks to support these field experiments;
- (2) human crew-related investigations: (i) crew time organization in a planetary habitat, (ii) an evaluation of the different functions and interfaces of this habitat, (iii) an evaluation of science and technical equipment and human–machine interfaces.

Results of field science experiments are not addressed in this paper and can be found elsewhere in this IJA issue (Direito *et al.* 2011; Ehrenfreund *et al.* 2011; Foing *et al.* 2011; Kotler *et al.* 2011; Martins *et al.* 2011; Orzechowska *et al.* 2011; Thiel *et al.* 2011) and in (Borst *et al.* 2009; Ehrenfreund *et al.* 2009; Foing *et al.* 2009a, b; Hendrikse *et al.* 2009; Mahapatra *et al.* 2009; Peters *et al.* 2009; Petitfils *et al.* 2009). Field reports can be found in (Pletser *et al.* 2009a; The Mars Society Mars Desert Research Station 2009).

Section ‘MDRS and habitat overall description’ presents the MDRS and its habitat layout. Social and operational aspects during simulations are described in the ‘Social and operational aspects of the EuroGeoMars campaign’ section. Technical and operational aspects of biology field investigations are addressed in the ‘Technical and operational aspects of biology field investigations’ section. The analysis of the habitat occupation and utilization is summarized in the ‘Analysis of the habitat occupation and utilization’ section. Section, ‘Recommendations for improvement of planning, experimental execution and reporting of biology investigations’ gives recommendations for improvement of planning, experimental execution and reporting of biology investigations. Some crew suggestions regarding operational time optimization are presented in the ‘Some crew suggestions regarding operational time optimization’ section.

### MDRS and habitat overall description

The MDRS in the desert of Utah has been in operation since 2002 from November through April every year. The geologic features of the surrounding Jurassic–Cretaceous terrain also make the desert environment seem Mars-like to crew members.

The MDRS habitat itself is a vertical cylindrical structure of approximately 6 m diameter and 8 m high, composed of two floors. The ground floor (lower deck) includes a front door airlock used for simulated EVA, an EVA preparation room,

a large room used as a laboratory for geology and biology activities (Fig. 1), a small engineering workshop area, a second back door airlock for engineering activities, a small bathroom and a toilet, three small windows, and a stair leading to the first floor. The first floor (upper deck) includes a common area or living room with a central table, a wall-attached circular computer/electronic table, a kitchen corner, and six small bedrooms (The Mars Society Mars Desert Research Station 2010).

### Social and operational aspects of the EuroGeoMars campaign

Prior to the simulation campaign, the EuroGeoMars held several classroom and simulated field training sessions at different locations in Europe for the crew members to get acquainted with each other, to train on the various instruments and equipment to be used during the simulation campaign and to rehearse investigation procedures and protocols.

All field and laboratory scientific equipment (for geophysics and biology investigations) and technical equipment (for other engineering investigations) were shipped to the MDRS in advance of the campaign.

The crew of the technical preparation week was composed of five persons (three males and two females). Crews 76 and 77 (Fig. 2) were composed of six persons (respectively of four males and two females, and three males and three females). Crews 76 and 77 included a Commander, an Executive Officer, an Engineer and three Scientists. Seven nationalities were represented in total.

This multi-cultural and multi-expertise environment was highly beneficial for the crews and the members profited from the complementary knowledge and skills.

Social activities were conducted as a group. Crews took their meals together, during which outings and crew activities were planned, briefed and debriefed. Other team activities were conducted in the evenings, such as seminars, presented by each crew member in turn, watching DVDs and listening to music. Fig. 3(a) shows the time evolution (vertical axis: time of the day, horizontal axis: day date) of common activities of the crew 76: breakfast (coincides with morning briefing), lunch, dinner (all meals in red) and evening common activities (green); beginning and end of each activity are shown, respectively, in dark and light colours. All common activities were conducted in the habitat’s living room. Other whole crew briefings, debriefings and discussions are also indicated (green squares) as they appeared during days.

All chores were shared equally, that is, each day a different crew member was in charge of preparing meals and taking care of kitchen chores. Other specific tasks included refilling of the external water tank every other day by the entire crew, maintaining the power generator, and small maintenance and cleaning taken in turns by crew members. Water usage was not restricted for food preparation and personal consumption, but was restricted for personal hygiene (showers were allowed every 2 or 3 days, the toilet was flushed irregularly, etc.), cleaning, dish washing, etc.



**Fig. 1.** A view of the biology laboratory on the lower deck floor. The upper panel shows the organization of the molecular biology section deployed in the habitat laboratory. The upper right picture shows a scheme of the arrangement of instruments. The lower panel shows a more detailed view of the instruments. (Photo: EuroGeoMars crews 76–77.)

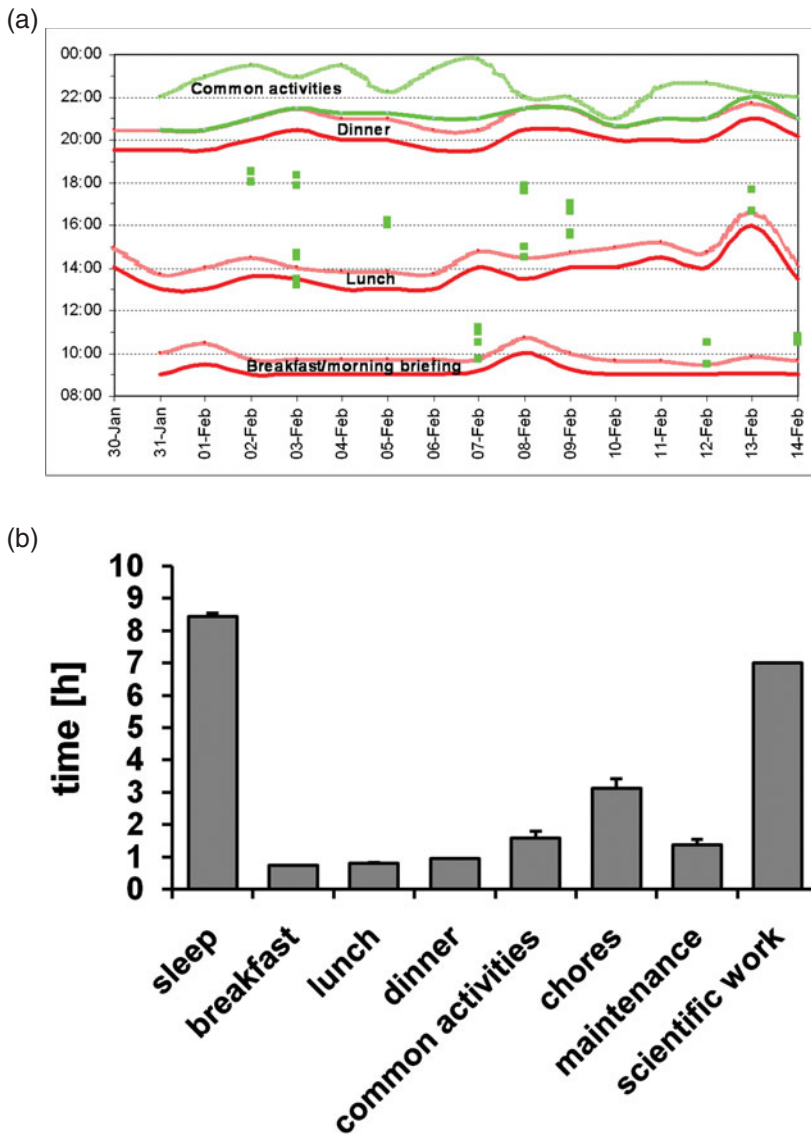


**Fig. 2.** The two EuroGeoMars teams, MDRS crews 76 (left) and 77 (right), at change-over. (Photo: EuroGeoMars crews 76–77.)

Time characteristics of the various day occupations were analysed (Pletser *et al.* 2009b; Pletser & Foing 2010) and are summarized for crew 76 (Fig. 3b). Taken together, a crew-76 member would sleep an average ( $\pm$  standard error, i.e. St. Dev./ $\sqrt{n}$ ) of 8 hours 26  $\pm$  07 minutes, eat breakfast during an average of 44  $\pm$  02 minutes, lunch for 48  $\pm$  02 minutes and dinner for 57  $\pm$  01 minutes, spend about 3 hours 08  $\pm$  18 minutes doing chores and 1 hour 23  $\pm$  10 minutes doing maintenance, and spend an average of 1 hour 35  $\pm$  13 minutes

on evening common activities, which sums up to 17 hours 01  $\pm$  53 minutes, leaving only approximately 7 hours for scientific work, which is significantly low and shows that a lot of time is spent on scientifically unproductive tasks, chores and habitat maintenance, mainly.

The crew of the technical preparation week conducted all outside field activities in a non-EVA mode for reasons of efficiency. Crew 76 and 77 organized their respective field works in semi-confinement and semi-isolation modes, that is,



**Fig. 3.** (a). Evolution of common activities for each day of the two weeks rotation of the first crew, showing the beginning (dark) and end (light) of each activity. (b) Average values of time spent on different daily activities. Due to the large amount of time spent on chores and maintenance only 7 hours were available daily for scientific work.

some of the outings and field expeditions were conducted in non-EVA mode and some in EVA mode using EVA suits and protocols depending on the specific goals of the field activity (reconnaissance/exploration, field science investigations, repair/maintenance of habitat systems). Transportation was provided by all terrain vehicles (ATVs) and rent vans for both EVA and non-EVA activities. A total of 48 EVAs were conducted, eight by the crew 76 and 40 by crew 77.

Failures (habitat power supply, heating system, EVA suits, etc.) occurred regularly and were dealt with by either the rotation engineer and commander or the whole crew as needed, which severely affected the science operation schedule on some days, as most of the instruments used for scientific analyses in the habitat laboratory need power to be operative. The power generator failed several times and had to be repaired and eventually replaced with external help. On one occasion, power was unavailable for an entire day. Internet access was limited in

bandwidth (1.5 Mb/s for download and 365 kb/s for upload, with a maximum transfer of 300 MB per day), which severely delayed or even made impossible the communication of scientific data to remote science teams.

Communication with the outside world (Mission Support, remote science support teams, family and friends) consisted of e-mails and internet connections. Outside e-mails covered MDRS-related work (approx. 45%), other professional-related work (approx. 45%) and private communications (approx. 10%). Computer troubleshooting took time, with most of it on internet issues related to intermittent connections and poor upload bandwidth. Memory sticks were used for the internal exchange of data between personal computers. Despite the limited and intermittent internet access, a total of 109 reports were sent to Mission Support (Pletser, 2009).

Although most of the crew members knew each other only from the training sessions held before the mission, both crews

Table 1. Instruments and consumables used in equipment validation pre-mission tests

Thermal cyclers for PCR analysis (company)	DNA staining dyes (company)	Agarose gels (company)	Agarose gel visualization systems (company)
Master Cycler Gradient (Eppendorf)	Ethidium bromide (Sigma Aldrich)	Self-poured agarose gels (Biozym LE agarose)	Transilluminator (wavelength 312 nm) and digital camera (self-built system)
TProfessional Basic Gradient (Biometra)	SYBR safe (Invitrogen)	Precast agarose gels (Invitrogen)	E-Gel Safe Imager Real-Time Transilluminator (Invitrogen) and digital camera (Nikon Coolpix 995)
Primus 25 (Peqlab)			

Table 2. Instruments selected for detection of microbial DNA by PCR

Instrument	Company (model)	Function
Precision balance	Sartorius	Weigh 0.25 g of soil
Vortex	Fisher Scientific (Vortex Genie2)	Preparation of microbial DNA
Centrifuge	Eppendorf (EPP Cent Mini Spin Plus)	Preparation of microbial DNA
Glove box	Self-build	Pipetting of PCR components
PCR machine	Peqlab (Primus 25)	DNA fragment amplification
Agarose gel system	Invitrogen (E-Gel iBase)	DNA fragment separation
Agarose gel visualization system	Invitrogen (E-Gel Safe Imager Real-Time Transilluminator)	DNA fragment visualization
Digital camera	Nikon Coolpix 995	Data documentation

reported excellent morale and team spirit during their respective rotations. The time spent in the habitat in semi-confinement and semi-isolation (in excess of two weeks) fostered camaraderie, and a mutually supportive cooperative spirit was observed to have increased by the end of the mission.

### Technical and operational aspects of biology field investigations

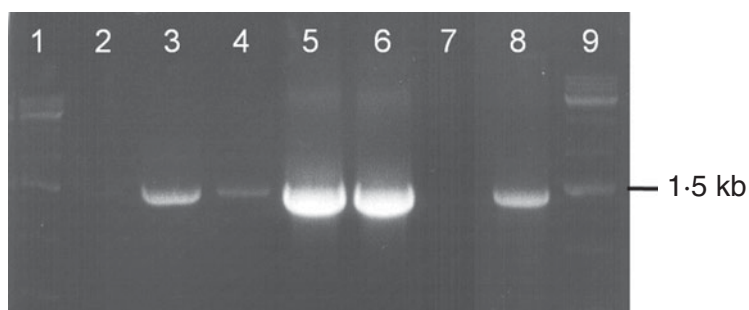
Our team came to MDRS to test the hypothesis that it is possible to apply the polymerase chain reaction (PCR) technique to detect deoxyribonucleic acid (DNA) of microorganisms in soil samples on-site in the habitat laboratory. The PCR has great advantage over techniques previously deployed at MDRS, like microscopy and cultivation of microbial samples on agar or other nutrition media (MDRS crews 1b, 7, 11, 44, 52; Secosky 2008) because it is an effective tool to identify minute amounts of DNA, ideally down to the level of a single molecule (Saiki *et al.* 1985; Mullis & Faloona 1987; Sermon & De Rycke 2007). Another benefit of this technique is the possibility to detect DNA of non-culturable microorganisms rendering it superior to other techniques when the complete microbial content of a sample should be investigated. The demonstration of the PCR technique at MDRS would further support the development of life detection tools for future mars missions but proved very challenging to accomplish, because MDRS is in a remote location, and exchange or

supplementation of instruments and supplies would be almost impossible during the crew rotation. Therefore, all equipment necessary, for the crew's biology experiment, including instruments and consumables were tested extensively beforehand in pre-mission runs to increase chances of success of MDRS field operations. Different models of the required instruments were tested and evaluated for their versatility, simplicity and ease of use in a small laboratory at MDRS (Table 1). The focus was on easy handling with a limited number of procedural steps, non-toxicity of associated consumables and a minimum of working space. The first validation of the optimal instrument- and consumable-selection for the PCR was performed on the model organism *Escherichia coli* K12. Hereafter, DNA from three different soil samples, one garden compost soil sample and two soil samples collected at MDRS by a previous group, was isolated and used to optimize the PCR conditions for this sample type. Based on these pre-mission tests, protocols for a standardized sample collection and analysis were established (for further details see Thiel *et al.* 2011) and the instruments listed in Table 2, together with the DNA samples mentioned above, were used for another, final pre-mission test at the European Space Research and Technology Centre (ESTEC; The Netherlands) (Fig. 4). Thereafter, all equipment were packed and shipped to MDRS to be deployed and tested for functionality by the technical crew and crew 76.

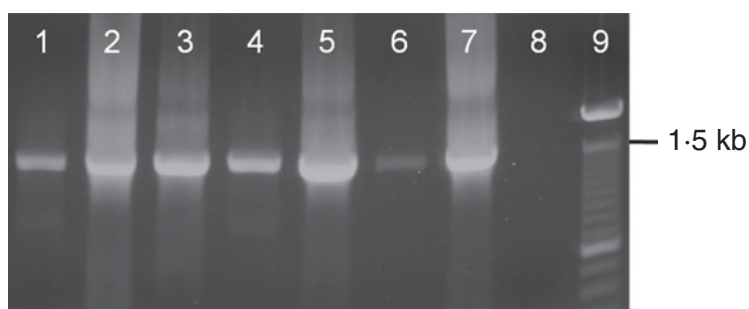
Unfortunately, some of the equipment arrived late, during the first crew rotation and therefore it could only be used to the full extent during the simulation of crew 77.

It was decided before the mission that samples would be collected at the following locations: places without vegetation and near vegetation and at different depths (0 to -2 cm, -10 cm, -30 cm) with a hand-operated drill. Unfortunately, it was realized during the mission that sampling at depths of -30 cm was often not possible because of the stony or solid-clay soil structure. Additionally, the soil was extremely dry so that during the first soil sampling attempts it was impossible to obtain solid drill cores. Therefore, the sampling strategy was changed and samples were collected with a shovel and a soil-sampling spatula instead.

All sample-collecting instruments (shovel, soil sampling spatula) were sterilized before sample collection by wiping them with 70% of ethanol to remove potential contaminations. Surface samples (0 to -2 cm) were directly collected with a sterile soil-sampling spatula. For sample depths of -10 and -30 cm a hole was dug with a sterilized shovel and the soil samples were taken from the side of the hole with a sterile soil-sampling spatula to avoid contaminations from the upper soil



**Fig. 4.** Pre-mission PCR test. Reaction conditions were optimized for the identification of bacterial DNA in the collected soil samples. The agarose gel shows the PCR amplified DNA fragments of one garden compost soil sample and two soil samples collected at MDRS by a previous crew. 1, commercial available DNA fragment length standard; 2, negative control containing all reaction components but no DNA; 3, DNA extracted from MDRS soil sample number 1; 4, DNA extracted from MDRS soil sample number 2; 5–6, positive control containing *E. coli* K12 DNA; 7, negative control containing all reaction components but no DNA; 8, DNA extracted from the garden compost soil sample; 9, commercial available DNA fragment length standard.



**Fig. 5.** PCR experiment performed on-site in the MDRS laboratory. The DNA of the collected samples was analysed for its content of bacterial DNA. Lanes 1–6 correspond to different samples collected near MDRS, lane 7 corresponds to a positive control containing *E. coli* K12 DNA, lane 8 shows a negative control containing all reaction components but no DNA, and in lane 9 a commercially available DNA fragment length standard is applied.

layers. Soil samples were collected in non-EVA and EVA mode to compare the practicability of the soil-sampling procedure in full simulation. The EVA suit, helmet, gloves and backpack were cumbersome, and hindered operations. Simple procedures took at least twice as long to complete during EVA mode as compared to non-EVA mode. Additionally, the helmets fogged easily limiting visibility for the crew member. Nevertheless, all sampling procedures were practicable to the full extent also in EVA mode.

After returning to the MDRS laboratory microbial DNA was immediately isolated from the soil samples and stored at  $-20^{\circ}\text{C}$  for PCR analysis. Amplified PCR fragments were visualized after the PCR run by using an agarose gel system and a digital camera for recording (Fig. 5; for further details see Thiel *et al.* 2011). Based on the described experimental set-up, we were able to show for the first time that microbial DNA can be detected without any cross-contaminations even under harsh conditions prevailing in the MDRS surroundings.

### Analysis of the habitat occupation and utilization

The analysis of questionnaires filled by both crews during and at the end of their rotations (Boche-Sauvan 2009;

Boche-Sauvan *et al.* 2009a, b, c; Pletser *et al.* 2009b; Pletser & EuroGeoMars Crews 76–77 2010a; Pletser & Foing 2010b) gave information (1) on time and location of each crew member each day, and helped us to understand the reasons behind possible problems of space or layout and which areas demanded the largest traffic to improve the layout; (2) on the productivity during the work influenced by the habitat layout, the various area composition and the instrument protocols; and (3) on suggestions made by the crew regarding operational time optimization.

In order to exemplify problems encountered, Figs 6 and 7 show the working and living areas of the habitat's upper and lower decks, which are shared by six people with different needs and different goals carrying out different scientific and technical tasks simultaneously.

For the lower deck, the lack of space felt by the scientists in the laboratory is mainly due to the multiple uses of this room. It is a biology laboratory, a geology laboratory, an engineering workshop and also the central room in the lower deck, leading to large traffic in the experiment and sample analysis areas (Fig. 7). This lack of space led to an uncomfortable working environment, which required items, especially the increasing number of samples collected during EVAs, to be

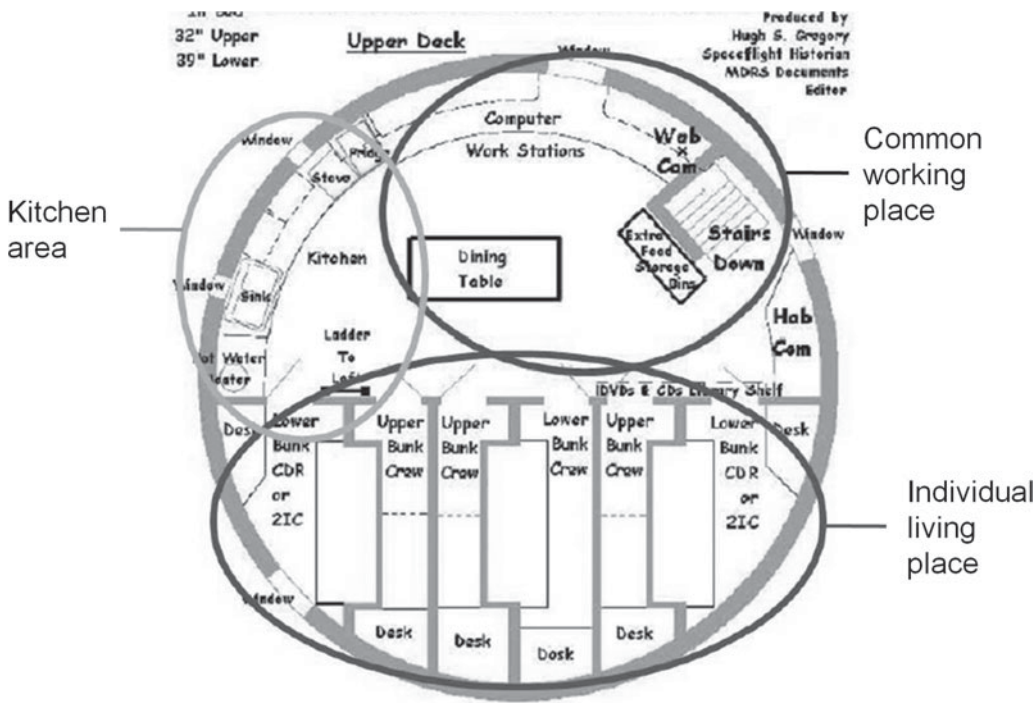


Fig. 6. Upper deck of the MDRS habitat with common working places, kitchen area and individual living places encircled.

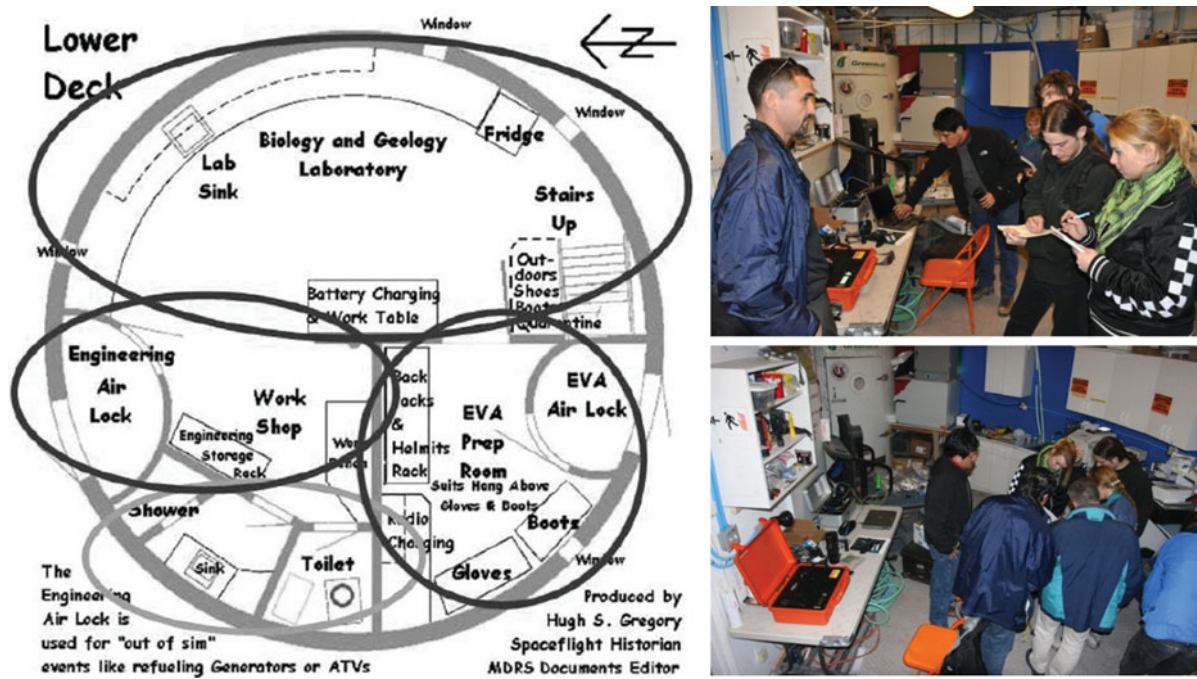


Fig. 7. Left: Lower deck of the MDRS habitat with common working places encircled in black and bathroom and toilet places in grey. Right: Overcrowded working area on the lower deck. Different required working conditions of the geology and biology scientist crew members resulted in alternating working time slots.

moved or stored under the tables. This in turn did not allow the crew to sit properly and decreased the available space in the area through which traffic was moving. This lack of space hampered productivity, and worse, presented a safety issue.

Moreover, organization was important for the scientists, because they had to share the laboratory space at the same time with completely different and often opposing requirements: Geologists needed space to sieve and crush their samples, mainly for Raman spectroscopy, producing a large amount of





**Fig. 8.** Views of the biology (left) and geology (right) labs when work was divided in alternating time slots. (Photo: EuroGeoMars crew 76–77.)

dust. The measurements had to be performed in darkness and no other scientist but the experimenter was allowed to be in the laboratory because of the potential danger caused by the Raman laser beam. In contrast, the crew biologist required an illuminated laboratory as clean and dust-free as possible to prevent contamination of the DNA samples and impairment of the PCR machine by blockage of the cooling fan. The inefficient insulation of the habitat, allowing a constant airflow in the laboratory was a further potential contamination risk. Therefore, the dedicated molecular biology area was cleaned frequently and all reactions were pipetted in a glove box. Another essential requirement was a constant power supply during the PCR run. Unfortunately, the power generator failed several times and PCR experiments had to be redone, requiring precious time that could have been used for further analyses. Due to these unexpected, time-consuming incidents (failure of power generator, extensive daily habitat chores and maintenance), some of the purified soil samples could not be directly analysed by PCR at the MDRS but had to be investigated at the Mesa State College in Grand Junction, directly after the mission. In order to share the use of the single laboratory room, both groups of scientists had to work alternately during nights (Fig. 8). Our compromise of a time-sharing alternate use of the laboratory facilities over nights was found to be acceptable for a simulation of a few weeks. However, this approach may not be suitable for real missions lasting several years.

In order to optimize the laboratory space and provide dedicated places for each activity, temporary partitions could suffice to separate the geology and biology areas (see Fig. 9). However, this may not be sufficient as some instruments and equipment used for biological experiments are very susceptible to large amounts of dust and malfunctions or defects could

result. Instead of temporary partitions, either permanent spatial separation with separated dedicated laboratory rooms, or temporary spatial separation using glove boxes and inflatable clean rooms would be more desirable. Among these suggestions, inflatable clean rooms could have the highest multifunctional usage as for complex molecular biology experiments (e.g. PCR, quantitative Real-Time PCR, sequencing etc.) or even for medical examination or treatment of crew members.

Another aspect crew members commented on was the lack of stowage areas. During simulations, the lack of permanent and temporary stowage room was evident. Containers, books, papers, procedures, workshop tools, scientific instrumentation, samples, personal items, consumables (food, water, etc.) were placed wherever room was available, in dedicated (cupboards, shelves) and undedicated areas (under tables, in laboratories, under stairs and on top of bedrooms). Especially, in the laboratory area, numerous collected stone and soil samples as well as consumables that were left from previous groups occupied most of the available stowage room. Even after cleaning the habitat's lower deck thoroughly, we were unable to vacate sufficient space for all samples collected during both crew rotations (Fig. 10). This situation led to overcrowded areas in the habitat, hampering both productivity and sometimes safety. Generally speaking, before being stowed, items should be strictly divided into two categories: what should be kept and what could be discarded. The items to be kept should then be prioritized according to their importance. Other means of stowage taking less volume should be considered, e.g. papers, books and written procedures should be digitized and properly referenced to keep paper documents to a minimum. Those procedures to be used by the crew in cases of emergency or of power outage that would render computers inoperative

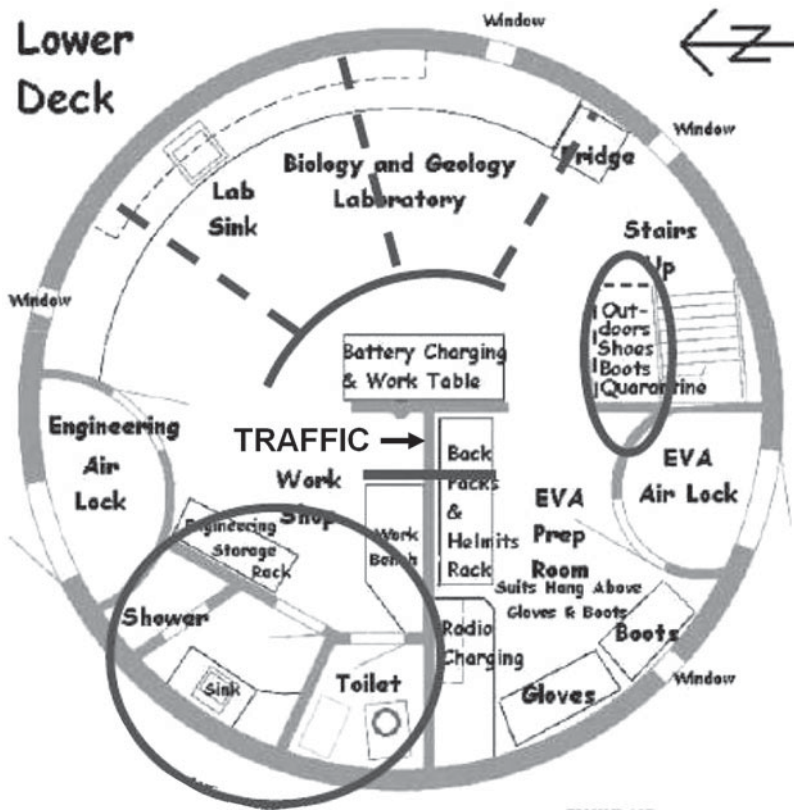


Fig. 9. Lower deck proposed improvement with laboratory temporary partitions (dashed lines), a central corridor (continuous curved black line), and a passage from the engineering area to the EVA preparation room (arrow).



Fig. 10. Accumulation of samples collected during the rotation of crew 77. Samples were stored in dedicated and undedicated areas due to lack of stowage room and overcrowded cupboards.

would be kept on paper as a backup. Tools and scientific instrumentation should be kept to a strict minimum, considering also some redundancy for those on which repair, maintenance and scientific operation depend critically. Collected samples (Figs 8 and 10) should be discarded after characterization and analysis in the laboratory, except for those that are of interest and which deserve further studies and an eventual return to another laboratory. These samples should be immediately catalogued and properly packed and stowed for later shipment. For stowage of these samples, until dispatch, dedicated shelves and cupboards should be installed, to keep the main traffic and working area clear. At the end of the crew rotation all used equipment should be properly cleaned and handed over functionally to the next crew. A regular check-up and calibration of all habitat instruments is recommended, and this would help to immediately identify defective equipment and save crew time.

### **Recommendations for improvement of planning, experimental execution and reporting of biology investigations**

The habitat's laboratory is a multifunctional area used by scientists with different expertise and needs. With a view to reduce instrument space and experimental time as much as possible, to avoid cross-contaminations of the collected samples and to ensure high-quality DNA extraction from soil samples, we recommend the implementation of automated technologies that combine multiple instruments (vortex, centrifuge, pipetting system, cooling and heating module) in one machine, such as the QIAcube (size: 650 × 620 × 570 mm; Qiagen 2010) or the Maxwell16 (size: 325.5 × 432.2 × 326.5 mm; Promega 2010). Although, current protocols do not include the purification of DNA from soil samples, it is only a question of time until procedures, optimized for this kind of samples will be available. Similarly, the ongoing development of faster and smaller PCR machines will be beneficial for saving laboratory space and experimental time. Nowadays, one of the smallest machines is a small battery-operated PCR machine with a size of 71 × 121 × 47 mm (PalmPCR; Ahram Biosystems 2010). It is highly likely, that in the next 10 years combined DNA extraction/PCR machines will be developed that occupy even smaller volumes.

In addition to the existing habitat equipment, the MDRS needs a fluorescence microscope for direct visualization and quantification of micro-organisms per gram of soil sample, a functional and clean autoclave to sterilize sampling equipment and bacterial nutrition media, a 37 °C incubator for growth of bacteria and micro-organisms under standardized conditions, an automated soil analyser (colour, grain size, texture and minerals), a –20 °C freezer for sample storage, crushed ice from an ice machine for storage of reaction components during the set-up of reaction mixtures, a Real-Time PCR machine for the quantification of microbial DNA content in analysed biosamples, a photometer or fluorometer for DNA concentration measurements, a pH meter and conductivity meter for analysis of soil conditions and a DNA sequencer for

direct identification of microbial species. Without these tools, analysis of biological specimens at MDRS will remain very limited.

During the mission of crew 77, 30 soil samples for PCR analysis were collected in total. Although the EVA/field collection time was sufficient, the different analytical methods required a substantial amount of preparation time and a constant supervision. As the amount of time spent on habitat maintenance was large, the time available for the analysis of the biosamples was insufficient. A modified habitat organization and crew time utilization as well as an improved basic supply with constant power, water, bandwidth, etc. would be beneficial for the time management and implementation of the biological experiments. Due to these restraints affecting the time available for scientific research, only a limited number of biology reports were sent from crew 76 and 77 to mission control. In any case, the organization of the science reports should be modified to save time and to obtain a more structured overview of the results from all crews. For example, reports during the ongoing crew rotation should be presented in a short and simple way; as tables or checklists, containing sample locations with global positioning system (GPS) coordinates and characteristic information about the sampling location. A detailed final report should be written at the end of the rotation, including analytical methods and results.

All information sent in these science reports should be collected in a standardized database accessible to all past, present or future researchers at MDRS. Such database would tremendously facilitate the experimental preparation especially with respect to the choice of location for sample collection. Ideally, the database should contain a description of sampling sites, sampling protocols, sampling conditions, analysis procedures and results. Although this is a challenging task and requires a database expert for generating, maintaining and updating the database, this is highly desirable for research crews at MDRS as well as in the future for crews on Mars. Based on these information, scientists would be able to plan their experiments more precisely in advance according to their experimental interest. For example, crews would have access to information about the soil condition and its composition, and could anticipate problems that might be encountered during sampling. Furthermore, information about weather conditions prevailing at the sampling location and sampling time would be desirable. In the desert of Utah, as well as on Mars, frequently sandstorms appear. Storms or winds could be a serious problem during soil sampling due to contamination of soil originating from different sampling depths. Therefore, sampling should be performed in sheltered areas or special wind-sheltered constructions should be designed and used for these occasions. Additionally, the microbial content of the soil should be included for each sample location, as far as it is known, to provide the researcher with first information of what to expect at the sampling site. These data would also greatly help to assign particular micro-organisms like extremophiles to specific soil compositions like high or low amounts of certain minerals.

### Some crew suggestions regarding operational time optimization

The two most problematic issues that significantly reduced the crew time for field and laboratory research was the poor communications system and the Mission Support reporting process. First, the communications transmitting system failed completely many times. When it did work, the amount of available bandwidth precluded transmission of large files, and drastically limited the exchange of scientific files and information between the field crew and the remote science support teams, and limited all science operations in general. Improvements in the communication systems at the habitat must absolutely be improved if MDRS is to become a laboratory where cutting-edge field science is performed.

A reliable communication system is an absolute must for a habitat like MDRS, including internet with a sufficiently large bandwidth to support mission and science operations and data exchange with remote ground support teams. One can imagine that communications and the necessary bandwidth will evolve over time and will depend on the resources available to the crew (antenna size, power and technology available) and on mission goals.

The second major issue we encountered at the MDRS was the amount of reports that each crew member was required to produce during the mission. Several reports are normally prepared either daily or on alternate days. The mandatory daily reports include the Commander's check-in report (on the crew's overall health and performance, and main habitat system status), the Commander's report (detailing various activities that took place during the day), and the Engineer's check-in report (detailing technical status of the habitat's systems). Other reports, although optional, are strongly recommended and have to be sent in regularly every other day: science reports (experiments and preliminary results obtained), EVA reports (after each EVA, on duration, range, activity, results, interpretations, etc.), journalist reports (on more anecdotic aspects of habitat life or expeditions), and a selection of up to six photos of the day's activities. The daily preparation of the various reports from the Commander, the Engineer and Scientists on habitat statuses, operations and EVA field expeditions was extremely time consuming (about one to two hours per day for every crew member). In particular, and although strongly wished by The Mars Society's Mission Support, scientists cannot be asked to write daily to report to the general public in detail about their ongoing research work and the preliminary results. We recommend considering a modified reporting format for scientific status reports, like tables or checklists. Additionally, the writing of reports on computers and their uploading are time consuming, considering also the limited bandwidth and the intermittent unavailability of the satellite connection. In order to save crew time, reporting from a planetary habitat or an Earth-based Mars analogue facility should be reduced and be kept to a minimum. Furthermore, it is worth investigating the possibility of self-reporting by machine or automated

systems in the future and whether or not habitat subsystems could report on their own statuses.

Finally, audio file reports, and to a certain extent video file reports on an 'as needed' basis, should be preferred to typed reports, for further typing and editing by Mission Support.

### Conclusions

A future mission to Mars requires detailed and extensive preparation, including the living and research conditions for the mission crew members. Research sites like the FMARS or MDRS are indispensable for training and evaluating these preparative activities. Here, we report on the living and working conditions at MDRS during the simulation of crew 76 and 77. A special focus was set on the evaluation of crew time utilization, organization of the different habitat sections as well as on the deployment and use of a molecular analysis laboratory. Analysis of the crew time management showed that optimization is necessary, especially for common daily chores and maintenance. Time could easily be reduced by a better overall habitat maintenance, which would leave more time to focus on scientific research. In terms of biology research we succeeded in deploying a molecular analysis laboratory in the habitat. Furthermore, we were able to show for the first time, on-site in the laboratory at MDRS that detection of microbial life is possible by applying a culture-independent research method (PCR) based on the identification of DNA. The constant progress of technology will lead to a further space and time saving development for DNA-based detection of life at Mars analogue sites in preparation for a Mars mission. An optimization of the habitat layout/interior concerning especially the laboratory section is desirable to serve the needs of the scientists of different fields. First suggestions on how to improve the laboratory conditions, like separation of the laboratory area or using inflatable clean rooms, are given. Some of the lessons learnt during the EuroGeoMars campaign in 2009 were already implemented in follow-up campaigns at MDRS conducted in 2010 and 2011 (ILEWG EuroMoonMars /DOMMEX) (Stoker *et al.* 2011; Clarke & Stoker 2011). Further ideas for improvement will come with the frequent use of the habitat by scientists according to their direction of experimental analysis and will help to complement MDRS as a Mars mission training location.

### Acknowledgements

The Mars Society is acknowledged for allowing the EuroGeoMars team to use the MDRS station. The help of the Mission Support team and of the remote science support teams was invaluable in conducting all the science and engineering experiments. The participation of all EuroGeoMars team members especially of crews 76 and 77 and of all remote science team members is greatly acknowledged; without them, none of this would have been possible. We thank ILEWG, NASA Ames, ESTEC and partner institutes for experimental, operational and scientific support. We thank the MDRS mission support (A. Westenberg, J. Edwards), ESTEC remote support (J. Page, P. Voorzaat,

P. Mahapatra) and NASA Ames support (C. Stoker, C. McKay, J. Zavaleta, F. Selch from Carnegie Mellon University). CST acknowledges an ILEWG travel grant.

## References

- Ahram Biosystems. (2010). [online] Available at <http://www.ahrambio.com/product.html> (accessed 20 October 2010).
- Boche-Sauvan, L. (2009). *Lunar Outpost Pre-design: Human Aspects, Master Project BO-F09003*. Arts et Métiers ParisTech – Georgia Tech., ENSAM Bordeaux.
- Boche-Sauvan, L., Pletser, V., Foing, B.H. & EuroGeoMars Crew. (2009a). Human interfaces study: framework and first results. In *European Geosciences Union, General Assembly 2009, 19–24 April 2009*, Vienna.
- Boche-Sauvan, L., Pletser, V., Foing, B.H. & EuroGeoMars Crew. (2009b). Human aspects study through industrial methods during an MDRS mission. In *NASA Lunar Science Institute – Ames Research Center, July 2009*.
- Boche-Sauvan, L., Pletser, V., Foing, B.H. & EuroGeoMars team. (2009c). Human aspects and habitat studies from EuroGeoMars campaign. In *EGU General Assembly 2009, EGU2009-13323, Geophysical Research Abstracts*, Vol. 11, Vienna, Austria, 19–24 April 2009.
- Borst, A., Peters, S., Foing, B.H., Stoker, C., Wendt, L., Gross, C., Zhavaleta, J., Sarrazin, P., Blake, D., Ehrenfreund, P. et al. (2009). Geochemistry of Utah Morrison formation from EuroGeoMars campaign. In *International Conference on Comparative Planetology: Venus–Earth–Mars, ESTEC, Noordwijk, May 2009*.
- Clarke, J. & Stoker, C. (2011). Concretions in exhumed channels near Hanksville, Utah: implications for Mars. *Int. J. Astrobiology* **10**, 161–175.
- Direito, S., Ehrenfreund, P., Marees, A., Staats, M., Foing, B.H. & Röling, W. (2011). A wide variety of putative extremophiles and large beta-diversity at the Mars Desert Research Station (Utah). *Int. J. Astrobiology* **10**, 191–207.
- Ehrenfreund, P., Quinn, R., Martins, Z., Sephton, M., Peeters, Z., van Sluis, K., Foing, B.H., Orzechowska, G., Becker, L., Brucato, J. et al. (2009). Terrestrial field research on organics and biomolecules at Mars Analogue sites. In *International Conference on Comparative Planetology: Venus–Earth–Mars, ESTEC, Noordwijk, May 2009*.
- Ehrenfreund, P., Röling, W., Thiel, C., Quinn, R., Sephton, M., Stoker, C., Direito, S., Kotler, M., Martins, Z., Orzechowska, G.E. et al. (2011). Astrobiology and habitability studies in preparation for future Mars missions: trends from investigating minerals, organics and biota. *Int. J. Astrobiol.* **10**, 239–253.
- FMARS (2009). [online] Available at <http://arctic.marssociety.org/> (accessed 1 October 2010).
- Foing, B.H., Page, J., Poulakis, P., Visentin, G., Noroozi, A., Gill, E., Batenburg, P., Drijkoningen, G., Slob, E., Guglielmi, M. et al. (2009b). ExoGeoLab lander and rover instruments. In *International Conference on Comparative Planetology: Venus–Earth–Mars, ESTEC, Noordwijk, May 2009*.
- Foing, B.H., Peters, S., Borst, A., Wendt, L., Gross, C., Stoker, C., Zhavaleta, J., Sarrazin, P., Blake, D., Ehrenfreund, P. et al. (2009a). Geology and geochemistry highlights from EuroGeomars MDRS campaign. In *International Conference on Comparative Planetology: Venus–Earth–Mars, ESTEC, Noordwijk, May 2009*.
- Foing, B., Stoker, C., Zavaleta, J., Ehrenfreund, P., Thiel, C., Sarrazin, P., Blake, D., Page, J., Pletser, V., Hendrikse, J. et al. (2011). Field astrobiology research instruments and methods in Moon-Mars analogue site. *Int. J. Astrobiol.* **10**, 141–160.
- Hendrikse, J., Foing, B.H., Stoker, C., Zavaleta, J., Selch, F., Ehrenfreund, P., Wendt, L., Gross, C., Thiel, C., Peters, S. et al. (2009). Highlights from remote controlled rover for EuroGeoMars MDRS Campaign. In *European Planetary Science Congress, EPSC Abstracts*, Vol. 4, Potsdam, 13–18 September 2009.
- Hoffman, S. & Kaplan, D. (1997). Exploration of Mars: the reference mission of the NASA Mars exploration study team. In *NASA SP 6107*, Houston, 1997.
- Horneck, G., Facius, R., Reichert, M., Rettberg, P., Seboldt, W., Manzey, D., Comet, B., Maillat, A., Preiss, H., Schauer, L. et al. (2006). HUMEX, a study on the survivability and adaptation of humans to long-duration exploratory missions, part II: Missions to Mars. *Adv. Space Res.* **38**(4), 752–759.
- Kotler, M., Quinn, R., Martins, Z., Foing, B. & Ehrenfreund, P. (2011). Analysis of mineral matrices of planetary soils analogs from the Utah Desert. *Int. J. Astrobiol.* **10**, 221–229.
- Mahapatra, P., Foing, B., Nijman, F., Page, J., Noroozi, A. & ExoGeoLab team. (2009). A prototype instrumentation system for rover-based planetary geology. In *European Planetary Science Congress, EPSC Abstracts*, Vol. 4, Potsdam, 13–18 September 2009.
- Martins, Z., Sephton, M.A., Foing, B.H. & Ehrenfreund, P. (2011). Extraction of amino acids from soils close to the Mars Desert Research Station (MDRS). *Utah, Int. J. Astrobiol.* **10**, 231–238.
- Mullis, K.B. & Faloona, F.A. (1987). Specific synthesis of DNA *in vitro* via a polymerase-catalyzed chain reaction. *Methods Enzymol.* **155**, 335–350.
- Orzechowska, G.E., Kidd, R., Foing, B.H., Kanik, I., Stoker, C. & Ehrenfreund, P. (2011). Analysis of Mars analog soil samples using solid phase microextraction, organic solvent extraction and gas-chromatography/mass spectrometry. *Int. J. Astrobiol.* **10**, 209–219.
- Peters, S., Borst, A., Foing, B.H., Stoker, C., Kim, S., Wendt, L., Gross, C., Zhavaleta, J., Sarrazin, P., Blake, D. et al. (2009). Alluvial fan EuroGeoMars observations and GPR measurements. In *International Conference on Comparative Planetology: Venus–Earth–Mars, ESTEC, Noordwijk, May 2009*.
- Petitfils, E.-A., Boche-Sauvan, L., Foing, B.H., Monaghan, E. & EuroGeoMars Crews. (2009). Basic Mars navigation system for local areas. In *EGU General Assembly 2009, EGU2009-13242-2, Geophysical Research Abstracts*, Vol. 11, Vienna, Austria, 19–24 April 2009.
- Pletser, V. (2009). Preliminary lessons learnt after the rotation of the first EuroGeoMars team – Crew 76. Technical Report HSF-UP/2009/113/VP, ESTEC, Noordwijk, 2009.
- Pletser, V., Monaghan, E., Peters, S., Borst, A., Wills, D. & Hendrikse, J. (2009a). Field reports of science and technology activities of the first EuroGeoMars team – Crew 76 at the Mars Desert Research Station, 1–14 February 2009. Technical Report MDRS-76/FR-01, Mars Desert Research Station, The Mars Society.
- Pletser, V., Boche-Sauvan, L. & EuroGeoMars Crews 76–77. (2009b). European contribution to human aspect field investigation for future planetary habitat definition studies: field tests at MDRS on crew time utilization and habitat interfaces. In *ELGRA Biannual Symposium in the Footsteps of Columbus*, Bonn, September 2009; ELGRA News, Vol. 26, p. 64.
- Pletser, V. & EuroGeoMars Crews 76–77. (2010a). Crew time utilization and habitat interface investigations for future planetary habitat definition studies: field tests at MDRS. In *38th COSPAR Scientific Assembly, Paper B01-0022-10, Session Moon Exploration: Science Results, Missions, Technologies, Robotic Village, International Lunar Base*, Bremen, 18–25 July 2010.
- Pletser, V. & Foing, B.H. (2010b). European contribution to human aspect field investigation for future planetary habitat definition studies: field tests at MDRS on crew time utilization and habitat interfaces. *Microgravity Sci. Technol.* **23**, 199–214.
- Promega. (2010). [online] Available at <http://www.promega.com/maxwell16/> (accessed 20 October 2010).
- Qiagen. (2010). [online] Available at <http://www.qiagen.com/products/automation/qiacube.aspx?ShowInfo=1&r=2721> (accessed 20 October 2010).
- Saiki, R.K., Scharf, S., Faloona, F., Mullis, K.B., Horn, G.T., Erlich, H.A. & Arnheim, N. (1985). Enzymatic amplification of beta-globin genomic sequences and restriction site analysis for diagnosis of sickle cell anemia. *Science* **230**, 1350–4.
- Secosky, J. (2008). Summary of biology studies done at MDRS [online]. Available at <http://desert.marssociety.org/research-summary.asp> (accessed 20 October 2010).
- Sermon, K. & De Rycke, M. (2007). Single cell polymerase chain reaction for preimplantation genetic diagnosis: methods, strategies and limitations.

- In: *Methods in Molecular Medicine, Single Cell Diagnostics, Methods and Protocols*, 132, 31–42, ed. Alan, Thornhill; Humana Press, Totowa, NJ.
- Stoker, C., Clarke, J., Direito, S., Martin, K., Zavaleta, J., Blake, D. & Foing, B.H. (2011). Chemical, mineralogical, organic and microbial properties of subsurface soil cores from the Mars Desert Research Station Utah: analog science for human missions on Mars. *Int. J. Astrobiol.* **10**, 269–289.
- The Mars Society, 2010. [online] Available at <http://www.marssociety.org/> (accessed 1 October 2010).
- The Mars Society Mars Desert Research Station. (2009). [online] Available at <http://desert.marssociety.org/mdrs/fs08/crew76/> and <http://desert.marssociety.org/mdrs/fs08/crew77/> (accessed 1 October 2010).
- The Mars Society Mars Desert Research Station. (2010). [online] Available at <http://desert.marssociety.org/MDRS/> (accessed 1 October 2010).
- Thiel, C.S., Ehrenfreund, P., Foing, B., Pletser, V. & Ullrich, O. (2011). PCR-based analysis of microbial communities during the EuroGeoMars campaign at Mars Desert Research Station, Utah. *Int. J. Astrobiol.* **10**, 177–190.