THE ARCTIC MARS ANALOGUE SVALBARD EXPEDITION 2006

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In order to prepare for future exploration of Mars, both by robotic and human missions, a number of Mars Analog studies are currently being carried out. In the high Canadian arctic the NASA Houghton Mars Project (HMP) is operating a station on Devon island that supports a geobiological science program but also supports an exploration program aimed at the development of new technologies, strategies and operations. At the same location, the Mars society operates the Flashlight Mars Arctic Research Station (FMARS) habitat. A similar station is located in Utah called the Mars Desert Research Station (MDRS). Both of these stations follow an advanced science and human exploration portfolio.

The Arctic Mars Analogue Svalbard Expedition (AMASE) in 2006 was the latest of a series of expeditions whose primary goals are: to test portable instruments for their robustness as field instruments for life detection (for future human missions to Mars); to assess the Mars analogue environments for signs of life and/or abiotic organic synthesis processes; to refine protocols for contamination reduction and to understand the effects of transport on sample integrity by assessing bioloads immediately in the field and then comparing these with laboratory measurements made after transportation. There have been three previous expeditions that were run by the Department of Physics of Geological Processes at the University of Oslo in collaboration with the Carnegie Institution of Washington (CIW), NASA-JPL, NASA-Ames, the Lunar and Planetary Institute, University of Leeds, University of Burgos, Penn State University, MacQuarie University (GEMOC) and the Smithsonian Institution, and with invaluable support from the Norwegian Space Centre, the University Studies on Svalbard (UNIS) and the Norwegian Polar Institute (Amundsen *et al.*, 2004; Steele *et al.*, 2004; Steele *et al.*, 2005; Maule *et al.*, 2005). In 2006, the expedition was primarily funded from a three-year grant from NASA via the Astrobiology Science and Technology for Exploring Planets (ASTEP) program (http://ranier.hq.nasa.gov/astep/astep.html). A total of 34 scientists and engineers participated in this expedition, making it the largest to date. In addition to the science crew, one photographer and two film teams accompanied the teams as part of an extended Education and Public Outreach (E/PO) effort that included daily webblogs from the field[16].

Some of the questions to be addressed during AMASE are:

- Is the mineralogy of rocks (Mars analogues and meteorites) able to preserve the signatures of abiotic/ prebiotic processes or even potential fossil / viable life?
- Are the remnants of organic molecules formed by abiotic processes preserved within the sedimentary layers or within cracks and vesicles of the basalts as found on Earth?
- Does weathering of Martian rocks proceed in a similar manner to terrestrial rocks, and if so, can this preserve biosignatures?

[16] http://www.nasa.gov/mission_pages/mars/news/amase/index.html

1. Why Svalbard?

Svalbard is a Norwegian archipelago located between 77 and 80° N. Spitsbergen is the largest island and contains the settlement of Longyearbyen, the highest mountain group of the islands and the worlds northern-most hot springs above sea level.

Svalbard is considered a Mars Analogue research site due to its cold climate, the presence of hot springs, carbonate terraces and volcanic activity, which have produced carbonate rosettes similar to those found in the Martian meteorite ALH84001 (Figure 1), presenting a unique opportunity to examine aqueous geochemistry like that on early Mars (Treiman *et al.*, 2002; Steele *et al.*, 2006).

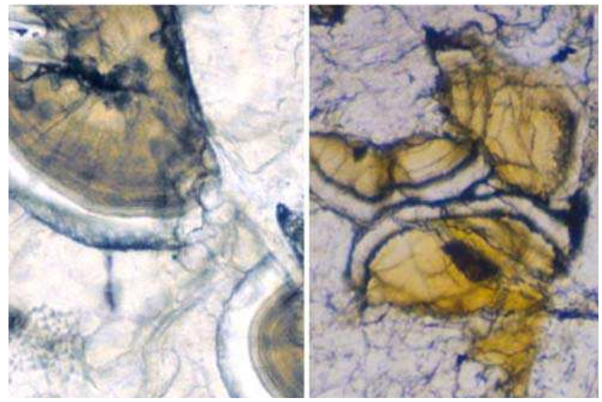

Fig. 1: *Microscopic images of carbonate globule in peridotite xenolith from Sverrefjell volcano (left) and carbonate globule in Martian meteorite ALH84001 (right)*

AMASE Research Sites

Research at AMASE sites primarily consist of initial field measurements of rock, water, ice and microbial communities using field instruments and collecting rock, water and microbial samples for subsequent lab analysis. Taken together the unusual range of geology exposed on Svalbard represents a unique collection of several Mars relevant environments. For 2006, three research sites were selected and visited during the two-week expedition.

Ebbadalen Formation (78°42'35" N, 16°43'04" E). The sediments at the Ebbadalen Formation in Billefjorden, central Spitsbergen, comprise Carboniferous (ca. 320 Ma) Ca-Sulphate bearing evaporates deposited in a shallow marine setting. Outcrops show mixed sulphate/clastic lithologies that might be analogous to evaporate sediments studied by the Mars Exploration Rover (MER) Opportunity at Meridiani Planum on Mars (Klingelhöfer *et al.*, 2004). Spheroidal concretions, morphologically similar to the "Blueberries" on Mars, are covered with lichens, and show a high level of biological activity.

Bockfjord Volcanic Complex (BVC) (79°29'53" N, 13°12'20" E). This region includes the Sverrefjellet and Sigurdfjellet eruptive centers, volcanic soils, and the erosional remnants of extensive flood basalt eruptions about 10 Ma ago that cap Devonian sediments to the east of the BVC. This site is interesting because of the presence of methanogens in weathered olivine xenoliths and the presence of buried blue ice vents near the summit of the Sverrefjell volcano in which microbial activity has been detected. This site also contains the carbonate rosettes mentioned earlier. ,Coring of glacial ice and sampling of snow algae at the adjacent glaciers were carried out to (a) quantify the adaptive strategies of phsychrophiles to nutrient and light limitations (b) determine the presence and preservation potential of organic signatures in ice cores and (c) develop and test planetary protection strategies related to decontamination of flight and experimental hardware. Finally, other investigations in this area included sampling of gases at the Troll and Jotun hot springs and the deployment of the CliffBot and the space suit in the Devonian redbeds on the opposite site of Bockfjorden.

Murchison Fjord (79°52'43" N, 18°29'17" E). Murchison Fjord lies in the northwestern side of Nordauslandet. This site bears outcrops of ~800 Ma old stromatolites and lagoonal carbonates, which were collected for laboratory investigations to find biosignatures.

2. Logistics

The expedition started with commercial flights to Longyearbyen (LYR 78°14'41" N, 15°29'50" E), where the instruments were assembled after their transport and functional tests were carried out in- and outdoors. All equipment was then loaded on the R/V *Lance* (Figure 2), which was sponsored by the Norwegian Polar Institute, Tromsø. Once a research site was reached personnel and equipment was transferred to shore using zodiacs. Due to the strict regulations regarding the environmental protection of Svalbard, no usage of vehicles is allowed on land, so equipment had to be carried by the team members to the sites of interest. For three days, a helicopter was at the disposal of the PI for transport of equipment and personnel and used in particular at Sverrefjell and Sigurdfjell volcanoes. After visiting the three research sites, the ship returned to Longyearbyen for unloading.

Fig 2: *R/V Lance at BVC. In the background, the Eastern shore line of Bockfjorden is visible, featuring Devonian redbeds.*

2. Description of Research Activities

A wide variety of science instruments and platforms was deployed on AMASE 06, including the two instrument prototypes for the Mars Science Laboratory (MSL) mission, a portable Raman spectrometer, a UV excitation spectrometer, a digital color microscope, portable Lab-on-Chip test systems and a complete polymerization chain reaction (PCR) system. A rover carrying a camera and a microscopic imager and a non-pressurized prototype spacesuit with a portable computer system were the primary platforms. A selection of these systems is described in detail.

2.1. Cliffbot

Stratigraphic analysis of sedimentary layers allows to decipher the depositional history of such an environment and to draw conclusions on the conditions of the environment at the time of the deposition. On Mars, sediments have been identified on the centimeter to meter scale inside crater walls. However, access sediments on the scale of tens to hundreds of meters to identify spatially resolved changes in mineralogy with depth, for example by drilling, is technologically challenging. One promising option is to use a rover system that allows the vertical traverse of crater walls or slopes in valleys to access the sedimentary layers horizontally.

The Cliffbot system was deployed from NASA JPL with a field support team of four (Huntsberger *et al.*, 2007). It was deployed in the field three times, once at Ebbadalen and twice at BVC. In all three cases,

Fig. 3: *The Cliffbot Rover moving down the outcrop in the Ebbadalen Formation. The robotic arm with the scoop and the microscopic imager can be seen at the bottom of the image.*

the rover successfully negotiated the slope on its tethers (Figure 3) and collected soil samples from the different sites, which was then analyzed geochemically, organically as well as biologically in the laboratories.

The rover was also used to validate sterilization procedures by measuring the bioload of the scoop before and after a seven-step cleaning procedure and performed a sample handover to an astronaut.

2.2. Integration of Astrobiology with Human Space Flight

The Planetary Society supported the deployment of a non-pressurized prototype of a Mark-III spacesuit (http://www.ilcdover.com/products/aerospace_defense/spacesuits.htm) for a project aimed at the understanding of forward-biocontamination during sample collection on a manned Mars mission. These efforts were combined with a computer-based collection and data-logging sequence that allows the astronaut to catalogue all information on a sample (physical description, images, spectroscopic and biological analyses) into one file during the Extravehicular Activity (EVA).

The contamination studies were carried out using artificial sterilized samples, which were placed in the field by other team members. The astronaut walked up to them, opened them and analyzed the bioload using a Lab-on-Chip (LOCAD) Portable Test System (PTS). The samples were swabbed and introduced into the LOCAD-PTS, where they were analyzed with a Limulus amebocyte lysate (LAL) assay.

2.3. Portable Raman Spectrometer

A field portable Raman spectrometer was deployed to test the applicability of sample screening prior to selecting samples for analysis using the CheMin XRD instrument. The advantage of prescreening samples with Raman is that information can be gained in seconds rather than hours and therefore initial triaging by Raman enables rapid selection of interesting samples, thus conserving resources for more detailed analysis of wide range of different samples. Experiments were conducted on a lava conduit containg several different types of xenolithic material on the Sigurdfjell volcano. Initial results indicate excellent correlation of Raman and CheMin data sets. This philosophy is consistent with MSL operations were instruments have been subdivided into remote, contact and analytical suites. The remote and contact analysis enabling suitable samples to be chosen for further, more detailed and definitive analysis in the analytical suite.

2.4. Mars Science Laboratory (MSL) Instrument Prototypes

One of the main drivers behind the ASTEP funding for AMASE is the field testing of prototype instruments that are part of the science payload of the NASA MSL rover. For AMASE 2006, two instruments were deployed: CHEMIN (Chemistry & Mineralogy) and SAM (Sample Analysis on Mars)

2.4.1. CHEMIN

CHEMIN determines the mineralogy and elemental composition of crushed or powdered samples through the combined application of X-ray diffraction (mineral structure analysis) and X-ray fluorescence (elemental analysis) and has been developed for space flight (Blake et al., 2000; Vaniman et al., 1998). The two techniques are extraordinarily powerful and complementary and they constitute the preferred method for mineralogical analysis of unknowns in terrestrial laboratories. All other mineralogical analysis techniques that claim to be "definitive" ultimately rely on XRD for the definitive identification of unknown crystalline materials. With the exception of the sample introduction system, the CHEMIN XRD/XRF instrument has no moving parts, expendable reagents, or chemicals. Quantitative mineralogical results are obtained from XRD data by Rietveld refinement and other full-pattern fitting techniques. All sample lithologies - both crystalline and amorphous materials - can be analyzed in this way (Blake et al., 2000; Vaniman et al., 1998). Quantitative elemental compositions are obtained from XRF data by fundamental parameters (FP) calculations.

During AMASE 2006, CHEMIN has analyzed 36 samples with full mineralogical annotation. Most of these samples were co-analyzed by SAM as well. CHEMIN was deployed into the Arctic field terrain and operated continuously for 6+ hours on its integrated battery pack. Several fully quantitative, start-to-finish mineralogical analyses were completed during these deployments, some leading to multi-component compositions of up to seven mineral fractions. The instrument was operated for the most part by a single field team member, and sample analyses by comparison with a mineral database were completed within hours after their acquisitions.

2.4.2. SAM

SAM is the primary instrument deployed on MSL to detect organic molecules in Martian soil and rock samples. It consists of three instruments: a quadrupole mass spectrometer (QMS), a gas chromatograph (GC), and a tunable laser spectrometer (TLS). These instruments are integrated with a Sample Manipulating System (SMS), a Chemical Separation and Processing Laboratory (CSPL) and a high capacity pumping station (Mahaffy, 2007). SAM is designed to measure either atmospheric trace species including organics or organics extracted from solid phase material. Three fundamentally different approaches are employed for the measurement of organics in solid phase material delivered by SA/SPaH to SAM: 1) pyrolysis, 2) combustion and 3) solvent extraction and derivatization.

On AMASE 2006, the pyrolysis and extraction/derivatization techniques were tested. Pyrolysis is basically the thermal decomposition of the sample under an inert gas atmosphere. The complex organic molecules embedded in the mineral matrix are likely to break down during thermal processing to produce lower molecular weight pyrolysis products. Information on the parent species can be inferred from the patterns of stable products evolved with temperature. The solvent extraction/ derivatization technique is particularly effective in enabling an analysis of several classes of molecules that could be of biotic or prebiotic relevance including amino acids, amines, carboxylic acids, and nucleobases. Extraction of the organics from the powdered sample delivered to SAM

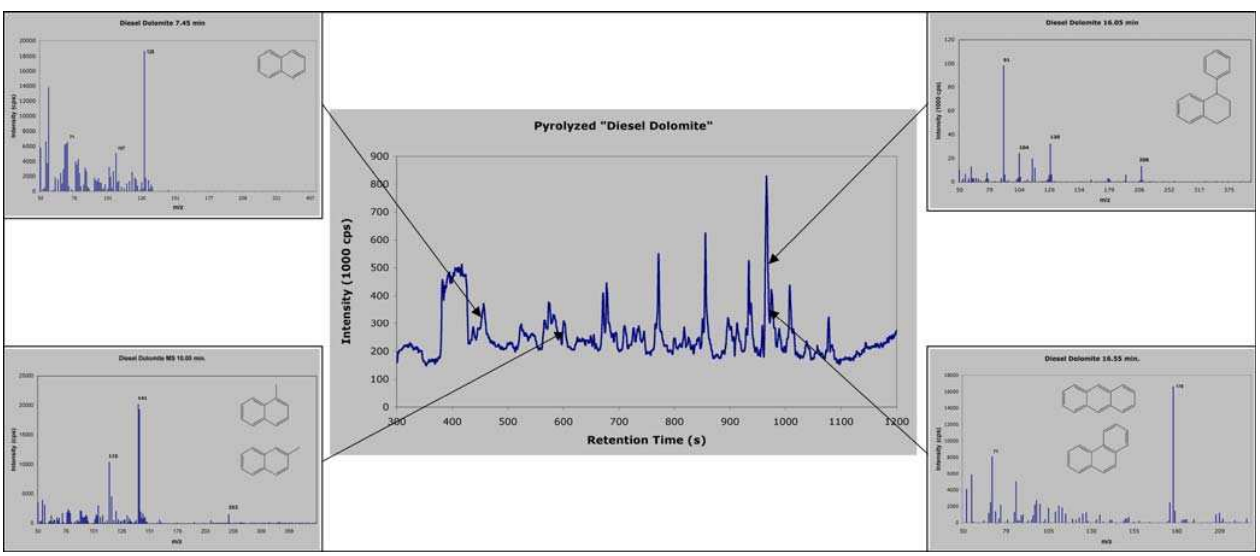

Fig. 4: *Example of the output from the pyrolysis-GC-MS of a dolomite sample from the Ebbadalen Formation. The center panel is the GC-TIC trace, and the small panels show the corresponding mass spectra allowing the identification of the compounds.*

employs dimethylformamide (DMF) and the derivatization agent is a silylation reaction utilizing N,N-Methyl-*tert.*-butyl(dimethylsilyl)trifluoroacetamide (MTBSTFA) (Buch *et al.*, 2006).

Analyses were carried out using a modified commercial GC-ion trap-MS system, for the most part in the ship's laboratory. The instrument was deployed once into the field on the Sverrefjell volcano site and operated as expected. A total of 55 GC-MS runs, both pyrolysis and derivatization, were carried out during the expedition. Figure 4 shows a typical total ion chromatogram (TIC) trace from a pyrolysis GC-MS analysis of a dolomite ($CaMg(CO_3)_2$) sample from the Ebbadalen Formation. A variety of organic compounds were in this analysis. Polycyclic aromatic hydrocarbons (PAHs) such as naphthalene, 1- and 2-methylnaphthalene and anthracene/phenanthrene are typical products that result from the pyrolysis of thermally matured biological material such as coal, bitumens and oils. These are biogenic organic compounds that have been processed under geological conditions. If organic compounds are present in the Martian subsurface, these classes of compounds are the most stable ones and are most likely to be detected. The analytical protocol developed for SAM, and tested during AMASE 2006, shows that this instrument has the capability to detect organic molecules in Martian surface. Work continues on the detailed interpretation of the GC-MS data, which also includes analyses of the samples with the GC-QMS at NASA Goddard and the development of a database of these compounds in different rock types. Finally, these data will be combined with the results of the organic analysis with the results from the other instruments.

3. Conclusions and Future Plans

AMASE 2006 was the fourth of a series of Mars Analog Expeditions to Svalbard with the primary goals to field-test instrumentation for in-situ life detection, instrument prototypes for the MSL mission as well as a prototype rover. Three research sites were visited during the two-week trip. The rover was deployed three times and collected four samples that were analyzed by all instruments. The MSL instrument prototypes were successfully tested in the field at least once and performed as expected. A total of 16 common samples were collected, which were also analyzed by all instruments.

For 2007, the collaboration between the instrument teams and the rover team will be more intensified. Instrument and rover sampling strategy will be tested at an evaporate or concretion site comparable to Meridiani Planum. Also, a simulation of a real Mars rover mission will be attempted, with one team with the rover and another team on the ship that will coordinate the science goals and input communication from the rover into a coherent sampling strategy.

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