

**Friday, October 17, 2003**  
**Morning Session II**  
**SPECIAL SESSION IN MEMORY OF DAVID WYNN-WILLIAMS:**  
**LIFE AND ITS DETECTION IN EXTREME POLAR ENVIRONMENTS**  
**10:30 a.m. Victoria Room**

McKay C. P. \* [INVITED]

*The Polar Regions and the Search for Evidence of Life on Mars* [#8056]

Cockell C. \* Lee P. Osinski G. Fike D.

*Life in Polar Impact-shocked Rocks — An Analog for Micro-Habitats at the Martian Poles* [#8124]

Edwards H. G. M. \* Moody C. A. Jorge Villar S. E. Wynn-Williams D. D.

*Antarctic Analogues for Mars Exploration: A Raman Spectroscopic Study of Biogeological Signatures* [#8009]

Willerslev E. \* [INVITED]

*The Preservation of DNA in Ice Sheets and Permafrost*

12:00 – 1:30 p.m. LUNCH

**THE POLAR REGIONS AND THE SEARCH FOR EVIDENCE OF LIFE ON MARS.** C. P. McKay<sup>1</sup>. <sup>1</sup>NASA Ames Research Center, Moffett Field, CA, 94035, cmckay@mail.arc.nasa.gov.

**Introduction:** The search for life on Mars and evidence for past life connects to polar exploration in two important ways. First the polar regions on Mars are sites of possible liquid water today, and hence possible locations for extant life. Secondly, ancient permafrost may preserve evidence of the nature of martian life.

**Polar Life:** There is direct evidence that Mars had liquid water early in its history. A plausible comparison with the early Earth and evidence that life appeared quickly on the Earth have led to a focus on the search for life on Mars. However, on Mars today the presence of liquid water is the limiting ingredient for a favorable environment for extant life. The northern polar regions in the summer are arguably the best location for finding liquid water on the surface of Mars today. This is due to the low altitude (2 to 4 km below the datum and hence the surface pressure in the north polar regions is always above the triple point of water), the presence of massive exposed ice, and the continuous sunlight available for heating the polar ice. If a case is to be made for liquid water and life on the surface of Mars today the northern PLD are probably the best location.

**Permafrost Preservation:** The microbiology of permafrost locations on Earth have been investigated and it has been shown that viable microorganism can be recovered from Siberian permafrost that is ~3.5 Myr old [1]. New work in Beacon Valley, Antarctic indicates the presence of recoverable microorganisms in ice that is thought to be 8 Myr old.

On Mars there may be extensive permafrost that dates back 3 to 4 Gyr. Recent data from the Mars Odyssey spacecraft have confirmed the suggestion that the polar regions of Mars are rich in ground ice [2]. The south polar regions, but not the polar cap deposits themselves, are of particular interest because this region contains ancient cratered terrain presumably dating back to the end of the heavy bombardment, 3.8 Gyr ago. The actual polar cap deposits are probably much younger. One region of particular interest is centered on 80°S, 180°W. Here the terrain is heavily cratered, there is ground ice present and furthermore there is strong crustal magnetism in the surface materials [3,4]. The presence of strong crustal magnetism confirms the antiquity of these terrains and suggests that they have been relatively unaltered since their initial deposition. This location may represent the site of the oldest, coldest, undisturbed permafrost on Mars. Martian microorganisms may be trapped and preserved in this permafrost.

**References:** [1] Gilichinsky, D.A., E.A. Vobryova, L.G. Erokhina, D.G. Fyodorov-Dayvdov, and N.R. Chaikovskaya, Long-term preservation of microbial ecosystems in permafrost, *Adv. Space Res.*, 12(4), 255-263, 1992. [2] Feldman, W.C., W.V. Boynton, R.L. Tokar, T.H. Prettyman, O. Gasnault, S.W. Squyres, R.C. Elphic, D.J. Lawrence, S.L. Lawson, S. Maurice, G.W. McKinney, K.R. Moore, R.C. Reedy, Global distribution of neutrons from Mars: Results from Mars Odyssey, *Science*, 297, 75-78, 2002. [3] Acuña, M. H., J. E. P. Connerney, N. F. Ness, R. P. Lin, D. Mitchell, C. W. Carlson, J. McFadden, K. A. Anderson, H. Reme, C. Mazelle, D. Vignes, P. Wasilewski, and P. Cloutier, Global Distribution of Crustal Magnetism Discovered by the Mars Global Surveyor MAG/ER Experiment, *Science*, 284, 790-793, 1999. [3] Connerney, J. E. P., M. H. Acuña, P. Wasilewski, N. F. Ness, H. Reme, C. Mazelle, D. Vignes, R. P. Lin, D. Mitchell, and P. Cloutier, Magnetic Lineations in the Ancient Crust of Mars, *Science*, 284, 794-798, 1999.

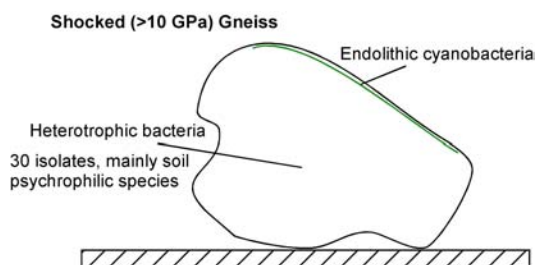
## LIFE IN POLAR IMPACT-SHOCKED ROCKS – AN ANALOG FOR MICRO-HABITATS AT THE

**MARTIAN POLES.** Charles Cockell<sup>1</sup>, Pascal Lee<sup>1</sup>, Gordon Osinski<sup>2</sup>, David Fike<sup>3</sup>. <sup>1</sup> SETI Institute, NASA Ames Research Center, Moffett Field, CA 94035-1000. <sup>2</sup> Planetary and Space Science Centre, Department of Geology, University of New Brunswick, 2 Bailey Drive, Fredericton, NB E3B 5A3, Canada. <sup>3</sup> David A. Fike, Scott Polar Research Institute, Lensfield Road, Cambridge CB2 1ER, England

**Introduction:** We describe the colonization of shocked gneissic rocks from the Houghton impact structure in the Canadian High Arctic (75°N) [1] as a potential analog for habitats at the Martian poles for speculative indigenous life or contaminants that have already been transferred to Mars by vehicles such as the crashed Mars Polar Lander.

We have used 16s RNA sequencing and SEM to demonstrate the presence of a diverse heterotrophic community of microorganisms throughout the rocks, including spore-forming *Bacillus* spp., which are a known genus of microorganisms to be found on spacecraft surfaces [2]. The low nitrate and phosphate abundances in the polar desert and probably the low leaching rate of organics into the rocks mean that these communities are likely to be nutrient stressed and may spend most of their time in a dormant state. Many of these organisms phylogenetically match psychrophilic species, suggesting adaptation to low growth temperatures.

As well as heterotrophic components, the rocks are also colonized by photosynthetic organisms. Cyanobacteria of the genera *Chroococidiopsis* and *Dermocapsa* inhabit the rocks as endolithic bands from the surface to a depth of ~5 mm where light levels are sufficient for photosynthesis [1].



**Figure 1. Impact shocked gneiss provides a habitat for a diversity of microorganisms adapted to survival in the terrestrial arctic.**

The organisms grow as biofilms on the surfaces of impact fractures and are attached to the rocks in a polysaccharide matrix. The organisms probably enter the rocks after wind deposition onto the surface of the rocks and leach into the subsurface of the rocks with water that penetrates into the inter-connected microfractures. Both phototrophic and heterotrophic components derive their water from snow-melt and rain during the brief ~1.5 month growing season and remain

frozen and dormant during the 24 hr darkness of polar winter when temperatures drop to -45°C. We have shown that water can be retained within the rocks for many days after a precipitation event or snow-melt.

During the 24 hr light of polar summer the organisms are protected from UV radiation by the overlying rock and they gain the advantage of thermal heating of the rock [3]. We have shown using sections of rock overlying monolayers of *Bacillus subtilis*, that 0.5mm of rock is sufficient to reduce microbial inactivation by one order of magnitude. The implications of this data are that under 1.5 mm of rock, the damage experienced by micro-organisms entrained into a similar micro-habitat on Mars would be similar to that on the exposed surface of present-day Earth under the protection of the ozone column, demonstrating the effectiveness of the endolithic habitat as a refugium from Martian UV radiation.

Using thermistors embedded into the rocks, we found that at a depth of 1 mm the temperatures rose to 10°C higher than the air temperature [3]. Thus, the communities within the rock may experience substantially higher temperatures in the micro-climate than in the external macro-climate, consistent with observations of Antarctic endolithic communities [4].

The similar obliquity of Mars and Earth, and thus the requirement for any potential Martian polar life (indigenous or contaminant microorganisms) to be able to survive the dark Martian polar winter, makes the study of terrestrial polar microorganisms and their modes of survival of special interest as analogs to guide life detection strategies at the Martian poles. Because the Martian surface has a large number of impact craters, which compared to the Earth, are un-subducted and relatively uneroded, understanding the growth and survival of microorganisms within a polar impact structure can yield important insights into the ability of microorganisms to take advantage of impact habitats in the polar regions of Mars.

**References:** [1] Cockell, C.S., Lee, P., Osinski, G., Horneck, G., Broady, P. (2002). *Meteoritics and Planetary Science*, 37, 1287-1298. [2] Fike, D., Cockell, C.S., Pearce, D., Lee, P. (2003). *International Journal of Astrobiology*, 1, 311-323. [3] Cockell, C.S., McKay C.P., Omelon, C. (2003). *International Journal of Astrobiology*, 1, 305-310. [4] McKay, C.P. & Friedmann, E.I. (1985). *Polar Biology* 4, 19-25.

## ANTARCTIC ANALOGUES FOR MARS EXPLORATION: A RAMAN SPECTROSCOPIC STUDY OF BIOGEOLOGICAL SIGNATURES.

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**Introduction:** The present conditions at the surface of Mars are not conducive to the survival of life forms, with the thin atmosphere, lack of water, a highly-oxidising regolith and significant UV insolation. The Antarctic provides a terrestrial model with a transect from the maritime, where epilithic colonies can survive through the production of protectant biochemicals, to endolithic systems at the “limits of life” where existence at the surface is impossible [ 1,2 ] . In the Antarctic Dry Valleys, the extremely low humidity coupled with low temperatures reaching - 35°C, strong katabatic winds blowing from the Polar plateau and intense UV-radiation exacerbated by atmospheric ozone depletion at higher latitudes provides a putative analogue for the hostile conditions that life must tolerate for survival at or near the Martian surface [ 3,4 ] .

This extreme terrestrial ecosystem is believed to mirror the conditions under which the evolution of organisms would have had to adapt to the steadily worsening environmental situation on Mars , as exemplified by Epochs III and IV , which effectively describe the Martian surface , subsurface and atmosphere over the last 1.5 million years [4 ,5].]The surface temperatures on Mars range from -123 °C to + 25 °C, it's atmosphere is thin and transmits UVB and UVC radiation , and the presence of liquid water at the planetary surface is still conjectural. Clearly , the identification of Antarctic microniches which are amenable to analytical study can provide suitable examples of extremophile terrestrial behaviour of direct relevance to Mars.

**Antarctic extremophiles :**Special strategies are vital for the adaptation of Antarctic lichens and cyanobacteria to these extreme conditions [6,7]; in addition, the Antarctic provides a gradual change in ecosystem tolerance along a transect from the relatively milder maritime conditions experienced at the coast through to the cryptoendoliths , which are effectively the most adaptable colonies in the Polar region, after which only fossil cyanobacterial evidence is found at the highest latitudes [ 8,9]. This means that the different strategies being enforced for the survival of these organisms under worsening environmental habitats can be explored experimentally and evaluated analytically to assist the predictions of response of organisms to extremes of stress.

To reduce the amount of UVB and UVC radiation reaching the organisms , it is essential that the colonies produce a suite of radiation-protective chemicals for filtering out the low-wavelengths whilst still maintaining their capability for accessing the photosynthetically active wavelengths required for their metabolic processes [ 10,11 ] . Hence, it is possible to identify as protective biomolecules complex organic chemicals such as beta-carotene and a range of pigments such as parietin , rhizocarpic acid and calycin --- the former is believed to act as a UV -filter and also function in a DNA-repair mechanism for cell damage caused through radiation exposure, whilst the latter pigments are thought to behave as accessory radiation protectants [ 11,12,13 ] . We have carried out some experiments over a two-year period on Antarctic colonies which have been subjected to full radiation exposure at Jane Col , Leonie Island , compared with other colonies at the same site which have been shielded by UVB- and UVC-absorbent plastic cloches. Using nondestructive Raman techniques, it is possible to monitor the production of pigments in response to changes in the environmental situation---in particular , the relative proportions of parietin and beta-carotene in protected and unprotected colonies indicates a possible dualistic role for these pigments [ 14,15 ] .

The production of hydrated calcium oxalates by colonies under stress is also a key factor of change in other circumstances ; it has been suggested that these oxalates are produced as chelators of heavy metals in the substrate, as water storage devices , acidity controllers and as anti-herbivoral agents. We have recently found evidence for the biogeological modification of iron oxides by extremophilic colonies in the most highly stressed conditions . The importance of this is two-fold , since it not only provides another parameter of knowledge for the understanding of the mechanisms by which terrestrial organisms survive these extremes , but it also gives a clue as to the sort of biogeological changes that have been effected by extremophilic organisms at the limits of life. Hence, in a situation , such as that which probably applied on Mars , any vestiges of extremophilic life would be incapable of tolerating or adapting to the worsening conditions, and they would pass into the fossil record. The clues to their former existence would then be totally found in the geological record and in a suite of unusual relic chemical compounds found there.

**Raman spectroscopy** :The viability of Raman spectroscopy to identify the key spectral biomarkers of extinct or extant life in the biogeological record has been amply demonstrated for the analysis of Antarctic endoliths [16,17] . The Raman biosignatures of key protectant molecules have been established for the identification of the strategies adopted by cyanobacteria for the colonisation of geological strata . An important requirement here is the ability of the analytical spectroscopic technique employed to locate and identify the key biomarkers in the geological systems that might be expected to be encountered in planetary exploration.

The miniaturisation of laboratory-based Raman spectrometers to a size which makes them suitable for part of an instrumentation suite on a robotic lander on a planetary surface has been receiving much attention recently [17-19]. Clearly, the evaluation of prototype instruments for Martian surface or subsurface exploration would be well served by analytical experiments involving Antarctic materials.

In this paper we shall discuss the comparative data obtained from several Raman instruments on Antarctic extremophiles which will include an epilith from Signy Island, a chasmolith from the Lake Hoare LTER site in the Dry Valleys , a cyanobacterial mat from Lake Vanda and an endolith from Mars Oasis (this latter specimen must be considered to be especially relevant to planet Mars !). Some of the advantages of the Raman technique for adoption as analytical instrumentation on a mission to Mars will emerge from this study.

In particular , the capability of the Raman technique for the identification of the spectral biomarkers under different conditions , without special sample preparation and in a micro-sampling mode , giving a specimen “footprint” of only several microns diameter is assessed . A critical factor in this series of experiments is the wavelength selection of the laser excitation employed for the analysis and information from spectra recorded with visible and near-infrared laser sources [20] . This information is relevant for the design of miniaturised Raman instruments that will have the objective of searching for extant or extinct life on planetary surfaces or subsurfaces, especially Mars.

**References** : [ 1 ] Wynn-Williams D.D. et al. (2000) *Biblio. Lichenologica* , 75 , 275-288 . [ 2 ] Wynn-Williams D.D. (2000), in *The Ecology of Cyanobacteria : Their Diversity in Time and Space* , eds. Whitton B.A. , Potts M. , Kluwer, Dordrecht , 341-366 . [ 3 ] Wynn-Williams D.D. et al. (2001), in *Proc 1<sup>st</sup> Euro. Workshop on Exo-Astrobiology, Frascati, May 2000* , eds. Ehrenfreund P. et al., ESA SP 496,225-237 . [ 4 ] Wynn-Williams D.D. , Edwards H.G.M. (2000) *Icarus* , 144 , 485-503 . [ 5 ] McKay C.P. (1997) *Origins Life Evol. Biosphere* , 27 , 263-289 . [ 6 ] Siebert J. et al. (1996) *Biodiversity Conserv.* , 5 , 1337-1363 . [ 7 ] Kappen L. (1993) , in *Antarctic Microbiology* , ed. Friedmann E.I. , Wiley-Liss , New York , 433-490 . [ 8 ] Friedmann E.I. (1982) *Science* , 215 , 1045-1053 . [ 9 ] Friedmann E.I. et al. ( 1988 ) *Polarforschung* , 58 , 251-259 . [ 10 ] Nienow J.A. et al. (1988) *Microbial Ecology* , 16 , 271-289 . [ 11 ] Cockell C.S. , Knowland J. (1999) *Biol. Revs. Camb. Phil. Soc.* , 74 , 311-345 . [ 12 ] Vincent W.F. et al. (1993) *J. Phycology* , 29 , 745-755 . [ 13 ] Wynn-Williams D.D. et al. (1999) *Euro. J. Phycology* , 34 , 381-391 . [ 14 ] Holder J.M. et al. (2000) *New Phytologist* , 145 , 271-280 . [ 15 ] Edwards H.G.M. et al. (1998) *Soil Biol. Biochem.* , 30 , 1947-1953 . [ 16 ] Russell N.C. et al. (1998) *Antarctic Sci.* , 10 , 63-73 . [ 17 ] Edwards H.G.M. et al. (1999) , in *The Search for Life on Mars* , ed Hiscox J.A. , British Interplanetary Soc. , London , 83-88 . [ 18 ] Haskin L.A. et al. ( 1997 ) *JGR Planets* , 102 , 19293-19306 . [ 19 ] Wang A. et al. (1999) *JGR* , 104 , 27067-27077 . [ 20 ] Edwards H.G.M. et al. (2003) *Intl. J. Astrobiology* , 1 , 333-348 .