Workshop Report

1st Canadian Astrobiology Workshop

1er atelier canadien sur l'astrobiologie

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Centre GEOTOP-UQÀM-McGill
Université du Québec à Montréal
Montréal, Québec

Report to the Canadian Space Agency

1st Canadian Astrobiology Workshop

Report compiled by:

Richard Léveillé
Centre-GEOTOP-UQÀM-McGill
Université du Québec à Montréal
Montréal, Québec
email: leveille.richard@uqam.ca

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Abbreviations used in this report:

AWG	Astrobiology Working Group
CAB	Centro de Astrobiología (Spain)
CCGS	Canadian Coast Guard Ship
CSA	Canadian Space Agency
EANA	European Astrobiology Network Association
ESA	European Space Agency
CIAR	Canadian Institute of Advanced Research
GC-MS	Gas Chromatography Mass Spectrometry
LIDAR	Light Detection and Ranging
MET	Meteorological Suite (Phoenix Mars Lander)
MARS	McGill Arctic Research Station
NAI	NASA Astrobiology Institute
NASA	National Aeronautics and Space Administration
NEPTUNE	North-East Pacific Time-Series Undersea Networked Experiments
NSERC	Natural Sciences and Engineering Research Council of Canada
SEAC	Space Exploration Advisory Committee (CSA)
VENUS	Victoria Experimental Network Under the Sea
UQÀM	Université du Québec à Montréal

Preamble:

Since the mid 1990s, astrobiology has experienced a surge in interest as a result of a number of scientific findings and space exploration missions combined with the public's fascination with this scientific discipline. Astrobiology is loosely defined as the scientific study of the origin, the evolution, the distribution and the destiny of life in the universe. While this definition includes life on Earth - our only known example of life - the most fascinating aspects of astrobiology are perhaps those that deal with the search for life on other worlds.

Since 1999, astrobiology has been a discipline of the Canadian Space Agency's Space Exploration program and Canada's Space Plan, which is a co-ordinated approach to space exploration of our Solar System. As noted by the agency : "the search for life, either extinct or extant, on Solar System bodies beyond Earth is of the highest scientific interest and possibly of the greatest potential impact on human society"[1].

In recent months, the CSA has been making the case for a Canadian-led mission to Mars. Any such mission needs to be science-driven and technology-enabled. Mars is an ideal target for astrobiology as mounting evidence suggests that there was abundant liquid water on its surface in the past. Canada has a demonstrated heritage in several key technological areas relevant to space exploration. While, it has also been argued that Canada has a similar heritage in astrobiology-related science, this heritage has yet to be properly highlighted. This 1st Canadian Astrobiology Workshop was an initial attempt at developing a scientific community that can learn from, and build on, this heritage with the ultimate goal of developing Canada's space exploration abilities. To quote CSA president, and Canada's first astronaut, Marc Garneau: "We do not want to be mere spectators, but rather participants in the exploration of Mars".[2]

[1] Canadian Space Agency, http://www.space.gc.ca

[2] ibid.

Workshop Summary:

The 1st Canadian Astrobiology Workshop was held on June 15-16 at l'Université du Québec à Montréal. The Canadian Space Agency-funded workshop was organised and hosted by the Centre Geotop-UQÀM-McGill, a multidisciplinary bio-geoscience research centre. Nineteen invited participants, mostly Canadian university researchers, took part in the workshop, which was led by Richard Léveillé, postdoctoral researcher at the Centre Geotop-UQÀM-McGill, and Kim Juniper, director of the centre. The goals of the workshop were as follows:

1) Offer a forum to encourage communication and discussion amongst scientists of different backgrounds on astrobiology-related scientific issues.

2) Explore and identify key research projects that are being undertaken by Canadian scientists in areas of importance to astrobiology.

3) Identify Canadian experts in issues of importance to astrobiology.

4) Identify 'niche' research areas where Canadian scientists can contribute significantly to advancing scientific knowledge pertaining to astrobiology.

5) Identify key field sites in Canada where analogue studies are being undertaken, and propose sites for future studies.

6) Foster scientific collaboration, in both field-based and laboratory-based research.

7) Foster discussion and collaboration between university-based scientists and the CSA.

8) Explore possibilities for international collaboration.

The workshop also marked the first meeting of the Astrobiology Working Group (AWG), a newly-created advisory group of the Canadian Space Agency. The creation of the AWG follows the recommendations of the CSA's Space Exploration Advisory Committee (SEAC) to form Discipline Working Groups for all sectors of Space Science.

While most of the goals were successfully achieved during the workshop, some will benefit from further discussion and a continuation of the working group's activities.

1. Summary of Workshop Activities:

Day 1

The workshop began with brief introductions of participants and their research interests and experience. Many participants briefly outlined their experience with other (e.g., NASA, ESA) exo/astrobiology programs, either through current or proposed research projects, past postdoctoral fellowships or by serving on grant review panels. Surprisingly, many participants had very little knowledge of the CSA and its activities in space science and exploration.

Invited speaker Ricardo Amils of the Centro de Astrobiología (Spain) delivered the only research talk of the workshop. He briefly described the CAB, a modern astrobiology research facility funded by the Spanish government. He also highlighted the multidisciplinary nature of astrobiology and the need to bring together scientists from various disciplines, as well as engineers and technology experts. Professor Amils discussed ongoing collaborative astrobiological research on the Rio Tinto, a river in Southern Spain draining ancient metal-rich hydrothermal deposits. The river is viewed as a field analogue for studying Mars-related astrobiology and for technology development and testing. Collaborators in this research program are currently addressing a number of biogeochemical questions related to organisms that thrive in this metal-rich, and highly acidic, river system. For example, the river contains so-called iron bioformations (or stromatolites) that are believed to be precipitated by bacteria, algae and(or) fungi in a novel example of biomineralisation. Spanish scientists and engineers, in collaboration with NASA, are also focusing on the underground geomicrobiology of the Rio Tinto system. This work includes the development of new aseptic drilling techniques and technologies for sampling subsurface materials.

Following this presentation, a variety of issues were initially addressed by the working group. For example, it was agreed that the widely accepted definition of astrobiology (i.e., “the study of the origin, the nature, the evolution, distribution and destiny of life in the universe”) would be appropriate for the group. An initial group brainstorming session included a discussion of possible scientific questions that could be addressed by the group (e.g., signatures for life, limits of life and life preservation, metabolism, sample handling and analysis protocols).

A subsequent group brainstorming session focused on Canadian areas of expertise, resources and field sites of importance to astrobiology research. This highly productive activity produced three lists (see appendices) that illustrate the enormous potential for astrobiology-related science and exploration-related technology development and testing in Canada.

Curtis Suttle briefly mentioned that the Canadian Institute of Advanced Research was interested in encouraging their Cosmology and Gravity, Earth System Evolution and Evolutionary Biology groups to interact under the “umbrella” of astrobiology. Following the workshop, Mel Silverman, vice president of research at the CIAR, was contacted and informed of the AWG and the workshop. Dr. Silverman indicated that the CIAR’s interest in astrobiology was only at a very early stage and no formal plans had been made. Nevertheless, it was informally agreed that the CIAR and the AWG would keep in contact to share developments in the coming months and that a formal Canadian involvement in astrobiology should be developed in parallel with that of NASA, ESA and other groups.

Day 2

Alain Ouellet, acting program manager for Planetary Exploration and Space Astronomy at the CSA, began the second day of the workshop by presenting the CSA's organisational structure and current activities in relation to space science and planetary exploration. Funding opportunities at the CSA for science-based, technology-enabled projects were discussed. It was noted that any CSA-funded project needs to include a space-related component. It was also stressed that the CSA requires science community input, which it gathers by Announcements of Opportunities, national workshops and by science advisory committees and working groups. Mr. Ouellet also described some Canadian-led space science packages on recent (e.g., Mars-Nozomi) and future (e.g., Mars-Phoenix/MET station) space missions and he then outlined the CSA's goal of sending a Canadian-led mission to Mars in 2011. It was also noted that the CSA seeks to increase Canadian Arctic research and activities, related to a Canadian-led Mars mission, by allocating as much as $500,000, which could also be matched by NASA funds.

The group then spent the rest of the workshop discussing and developing a series of recommendations and short- and long-term goals, as well as discussing possible funding avenues. A preliminary "astrobiology timeline" (Figure 1) with respect to a mission to Mars being launched in 2011 was also produced. The issues discussed and the conclusions from these discussions are summarised in sections 2-4.

2. Key Themes:

While a number of issues and questions were addressed throughout the workshop, a small number of key themes emerged from the discussions. These themes have been identified based on the consensus of the working group, the amount of discussion they received or their apparent importance to Canadian space science and astrobiology. These themes are highlighted below, in no particular order.

2.1. Astrobiology in Canada is at an early stage.

While individual members of the AWG possess much experience and interest in astrobiology, the community as a whole has only limited experience dealing with the CSA and the wider space science community. Similarly, although the last two Canadian Space Exploration Workshops have included break-out groups and scientific presentations on exo/astrobiology, the scientific community in Canada lacks a more structured network for interacting on astrobiology-related issues. There is currently no formal astrobiology research program or network in existence in Canada. In comparison various programs and networks currently exist in the U.S., Spain, Australia, the U.K., France and Sweden, either independently or in collaboration with space agencies.

Part of the explanation of this deficiency appears to stem from the way science is funded in Canada. While NSERC and CIHR are the primary funding agencies for fundamental science in Canada, they have no mandate to fund astrobiology, or even space science directly. Conversely, the CSA does not fund fundamental science and is somewhat biased towards technology-enabled and space-related projects (e.g., flight instruments, science payloads). While this has been a successful strategy for the contribution of robotic manipulators to the NASA Space Shuttle program and the International Space Station, as well as by more recent CSA-funded research relating to LIDAR-based sensing systems and remotely-operated/autonomous drilling technologies, little scientific development has taken place in the field of astrobiology. Thus, there is currently a perceived “funding gap” in Canada that appears to hinder the development and growth of astrobiology as a scientific discipline.

2.2 Astrobiology is a multidisciplinary science.

Astrobiology is a multidisciplinary science that draws from fields as diverse as microbiology, biochemistry, planetology, climatology and cosmology, in addition to several others. While the search for life on other worlds is a primary objective of astrobiology, it is by no means the only one. Among other things, astrobiology seeks to understand the origin and evolution of life on Earth as our only known example of life. Astrobiology also deals with the future expansion of humans and other life throughout our solar system and beyond.

The multidisciplinary nature of astrobiology and the complex nature of life also means that any effort to search for extant life or evidence of past life needs to include a multidisciplinary team of bio- and geoscientists as well as planetary scientists, engineers, technologists, data specialists, modellers, mathematicians and statisticians. Such a team would need to collaborate before, during and after a mission. Individual scientists can not be expected to bear alone all the brunt of designing and building space payloads and scientific instruments, as well as acquiring all the data from such instruments.

Data analysis is very important in order to detect and interpret signals from remotely-operated and remote-sensing instruments. Data analysis tools such as principle component analysis, multidimensional analysis and interactive models need to be incorporated into data analysis protocols. These will help to extract the most information out of any data set obtained from a space mission.

If a Canadian-led mission to Mars, or anywhere else for that matter, is to have an astrobiological component, such a team of experts would need to be formed. Presently, no such group would likely be able to assume all of these responsibilities. While the members of the AWG possess a wide range of expertise and experience, a group with an even broader expertise would be required for a space mission.

2.3 The Arctic as a Mars analogue.

The Canadian high Arctic offers a number of varied environments and features that resemble in some respects environments that are known or are suspected to be found on Mars. These include a cold and dry climate, ice-related sedimentological and erosional features, and ice-related structures on various scales. These environments host novel microbiological communities, and in some cases these communities make up entire microbial ecosystems. The Arctic also offers a high potential for preservation of organic biomarkers and fossils, thus expanding axes of spatial and temporal heterogeneity.

Furthermore, the Canadian high Arctic offers a very broad range of different environmental settings, including broad liquid (in this case water) covered environments which may be of significant importance as Martian analogues, all in easily accessible localities. Canadian scientists and technologists have extensive experience with the logistics of doing research in the Arctic and they offer thorough knowledge and understanding of arctic ecosystems and environments as well as various physical, chemical, biological and geological processes and phenomena that occur there.

The Canadian high Arctic is thus an ideal astrobiology field study site. In fact, numerous on-going projects (both Canadian and International) in the Arctic already contain elements concerning Mars and (or) astrobiology. For example, two members of this AWG (Pollard, Whyte) are currently involved in NASA astrobiology-related projects exploring high Arctic perennial springs and permafrost as Mars analog sites. In addition, analog research continues at the NASA Haughton-Mars Project. Both the CSA and Canadian scientists need to build on this work and become leaders in the field of polar astrobiology.

The working group also agreed that an eventual field workshop in the Arctic (e.g., MARS) would provide essential hands-on interdisciplinary experience in this appropriate test environment and a novel perspective to a group interested in pursuing astrobiology-related research and technology-development.

2.4 Fossilisation.

Astrobiology seeks to understand life in the universe. To date, our only example of life is here on Earth, and the evidence for the history of life exists only in the ancient rock record through body and trace fossils, biomarkers and isotopic signatures. The fossil record on Earth provides essential information about the evolution and diversity of life. Thus, this information may be used in the search for evidence of past life elsewhere and provides a context for understanding any possible discovery of such evidence. Any search for preserved or fossilised ancient life, on Earth or elsewhere, also requires knowledge of the mechanisms, rates, modes and fidelity of fossilisation of both biomineralised and non-mineralising forms, and their isotopic and molecular signatures.

Canadian scientists have long been involved in the study of fossils, including some of the most ancient ones known, as well as the study of the environmental context of past life and global change. Canada also has a strong expertise in the field of geomicrobiology, specifically microbe-mineral interactions. Biomineralisation is one of the fundamental processes by which microorganisms (bacteria, algae, fungi…) may become fossilised and preserved in the rock record. Such fossils have been found in rocks that are more than three billion years old and they represent some of our best evidence of the existence of early life on Earth. Microbes also leave chemical evidence of their activities in rocks. These chemical and isotopic “fossils” are important indicators of past and extant life. Canadian scientists have demonstrated leadership and expertise in these rapidly evolving fields of research and are in a key position to pursue the combined geologic and biologic groundtruthing required to clearly understand the preservation pathways of these chemical fossils.

3. Recommendations:

The following are recommendations put forth by the AWG. They are designed to develop a strong astrobiological community in Canada that is ready to address the needs of the CSA and to guide the CSA on scientific matters pertaining to astrobiology and space exploration.

3.1. General Recommendations.

- **The CSA should maintain funding for the AWG in coming years as a way of ensuring the continued development of an active Canadian astrobiology community.**

In light of the current lack of appropriate funding sources, the financial support of the CSA is essential for the continued development of astrobiology in Canada. The CSA can also provide useful resources and experience as well as numerous international opportunities for Canadian scientists. In return, the AWG will provide valuable guidance and leadership, as well as innovative ideas to the CSA. Ultimately, the CSA and Canada will benefit by a harnessing of the diverse expertise that is already present in the country, and by the rapid positioning of Canada on the global stage of astrobiology and space exploration.

- **The CSA should help to eliminate the "funding gap" for astrobiology-related science and continue its contribution to training of highly-qualified personnel.**

The CSA should continue its efforts to provide more science-based funding in space exploration/astrobiology in collaboration with NSERC or other funding agencies. For example, CSA-NSERC research grants for university researchers in space science could greatly benefit the development of astrobiology-related research in Canada. The recently announced joint initiative between the CSA and the CIHR on "microgravity and bone cells" is a precedent to be followed.

Funding of science represents a much less risky venture than funding robotic missions, for example. At the same time, scientific research can be highly visible to Canadians and could benefit the CSA greatly by favourable national public relations, while also helping to address mission-related goals and objectives.

The CSA should also continue to promote space science research by offering scholarship and fellowship supplements. However, these programs tend to reward students and fellows already interested in space science. More needs to be done in order to attract the best and brightest young minds to space science, in general, and astrobiology, in particular. Students interested in astrobiology need to know that there will be support for their graduate research and future careers. Ideally, funding agencies, perhaps with the guidance of the CSA, need to create space science subjects for post postgraduate students and postdoctoral fellows.

More also needs to be done in educating “astrobiologists” and planetary scientists by developing astrobiology and space science educational programs. Currently, no astrobiology university program exists in Canada. In the US and elsewhere, numerous courses in astrobiology are widely offered and several undergraduate- and graduate-level programs exist. Astrobiology can be a unifying theme in science curricula. The CSA could be a driving force for instigating changes to college and university curricula.

Other areas of funding that need attention include travel funds for field work (e.g., for analogue studies), participation in astrobiology and space exploration workshops and conferences, and student exchanges in astrobiology research groups and laboratories.

- **The CSA should put out an Announcement of Opportunity (AO) directed specifically to the astrobiology community before, or in parallel with, the planned AO for mission concept studies.**

This will enable the astrobiology community to organise around a common mission-specific goal and to develop astrobiology science goals. Currently, the science community interested in astrobiology is far from being ready to address mission-related concepts. It is feared that a hastily-prepared mission (based strictly on launch opportunities) may not benefit from the best possible scientific resources. Such an AO would also be an excellent opportunity to demonstrate the CSA’s involvement in astrobiology, an area that has been poorly funded in previous CSA AOs. The AWG could provide more detailed input and direction to SEAC on the nature of the AO, if required.

- **The CSA should help to identify and develop appropriate Mars analogue and astrobiology field sites in Canada and promote collaborative astrobiology-related research at analogue sites.**

While there are currently sites where research has taken place in the past or is currently ongoing, there are likely several other sites that warrant development. A preliminary list of sites of interest is provided in Appendix 1 and these offer a glimpse at the numerous possibilities and potential for doing field-based astrobiology research in Canada. The CSA could demonstrate leadership by eventually co-ordinating appropriate field-based astrobiology research in Canada. A future astrobiology workshop could focus on the task of matching analogue field sites with scientific questions to be addressed.

In addition to providing fundamental and essential knowledge, and practice in the co-ordination of multidisciplinary teams, the exploration of these sites will enable the testing of technology and ultimately space science packages and payloads, as well as realistic field calibration and ground truthing of instruments. As well, the choice of landing sites for a lander-based mission would benefit from such studies. Ultimately, these efforts would greatly increase the chances of success of any mission.

- **The CSA and the AWG should continue to forge links with other groups in Canada, and elsewhere, that are interested in astrobiology.**

The development of astrobiology in Canada should not be limited to a small group of individuals. The AWG has already established informal links with the Canadian Society of Microbiologists, the Canadian Institute for Advanced Research, the Origins Institute of McMaster University, as well as with several American and European researchers involved with the NAI, the CAB and the EANA. Eventually, more formal relationships will help in training of highly-qualified personnel, in creating research and space exploration opportunities, and in achieving science goals.

- **The CSA and the AWG should interact with the VENUS and NEPTUNE projects.**

Opportunities for technological development, conceptual ideas for remote sensing, and autonomous scientific data collection and analysis abound with these two revolutionary marine science projects. These seafloor cabled observatories will revolutionise the way ocean science is done. In fact, the projects will force scientists to come up with new approaches and instruments for remote data collection as well as new ways of dealing with online streams of data. These two projects will provide Canadian scientists with a never-before seen opportunity to innovate. Opportunities to participate in these projects are currently available and the astrobiology community needs to act quickly to take advantage of these.

3.2 Space Exploration and Mission-specific recommendations.

- **Any astrobiology component of a Canadian space exploration mission should search for signs of extant life (novel or similar to Earth-based life forms) and evidence of past life, as well as evidence for the building blocks of life and (or) conditions required for the development of life.**

Three of the most fundamental astrobiological questions pertaining to Mars are:

1) Does life currently exist on Mars?
2) Did life ever exist on Mars?
3) Could Mars support life as we know it today, or could it have done so in the past?

Ideally, an astrobiological mission would attempt to address all three of these questions. However, such a search could be technologically and scientifically challenging, as many methods and instrumentation are not presently sufficiently developed in terms of their miniaturisation, autonomy or flight readiness. Nevertheless, a broad investigation would potentially maximise the return on investment. Both a broader understanding of the nature of life (not necessarily identical to that found on Earth), and novel methods would be developed through such a mission.

- **Any comprehensive effort to search for extant life or evidence of past life needs to include a multidisciplinary team of bio- and geo-scientists as well as engineers, data specialists, modellers, mathematicians and statisticians.**

The goal of any such effort should be to maximise the amount of information obtainable from a limited amount of raw data. Currently, no pre-existing group could assume these responsibilities.

- **The CSA should continue to provide mechanisms for networking, such as the Space Exploration Workshops (CSEWs) and the Space Exploration mailing list**. **Additional networking tools should also be explored.**

Better communication between scientists and engineers and technology experts will ultimately facilitate the development of Canadian technology in flight instruments, robotics and science payloads. Any instrument developed by Canadians using Canadian funds would likely be highly sought after by NASA (or other space agencies) as such a contribution ultimately decreases overall costs of a mission by cost-sharing. In terms of astrobiology, this is an area where Canadians have lagged behind. If Canada is to send a mission to Mars in 2011 with an astrobiology science payload, scientists and engineers need to begin discussions and create partnerships as soon as possible to meet realistic mission-related deadlines (see Figure 1).

While the CSEWs are very useful for bringing scientists and engineers together, their audience is limited and they are poorly known outside the Canadian and international space communities.

We propose that the CSA develops an online database of industries, engineers and scientists interested in astrobiology and space exploration in order to further facilitate networking. This database should include information such as areas of interest, research skills, lab equipment/instruments, and space technology experience as well as contact details. An online, voluntary sign-up form/questionnaire could be placed on the CSA website.

- **A program of Mars data compilation and analysis should be undertaken.**

The enormous amount of existing data (past and current missions) on Mars should be compiled and used as a foundation for any future mission. Pertinent information needs to be extracted from the data. What questions can we ask and attempt to answer now with existing data and information? This information may influence the scientific goals of any mission, as well as the instrument packages and choice of landing sites.

- **Any Canadian-led mission will need to focus considerable effort beforehand to select an appropriate mission-specific landing site in order to maximise the chances of success of the mission.**

Technological considerations aside, selecting the appropriate landing site can best be accomplished by compiling available information on Martian environments and surface features as well as by analogue studies here on Earth. This selection must be based on mission-specific scientific goals and technological capabilities and should not simply be "borrowed" from other groups that have worked on this in the past or that will in the near future.

- **The CSA should maintain interest in space exploration targets other than Mars (e.g., Venus, the Moon, Europa…) and longer-term missions (sample return, manned missions…).**

While Mars is an excellent near-term target for a robotic mission, other exploration opportunities of interest to astrobiology will continue to exist in the coming years. The CSA should continue its support of research and technological applications over a longer-term (i.e., post 2011) in anticipation of such opportunities.

4. Astrobiology Goals:

A number of proposed future activities of the AWG were discussed at the workshop. Many of these were retained as short-term goals for the AWG and are listed below. Long-term goals will continue to be developed and included in a Canadian Astrobiology Roadmap, which will benefit from further discussions with the broader Canadian astrobiology and space exploration community.

- **Begin the development of a field-base research program.**

We suggest an initial three-step approach. Firstly, a critical review paper on the astrobiological potential of Canadian science needs to be written. For example, this could take the form of a review of Mars analogue field sites in Canada. Such a review would cover the merits, logistics and scientific potential for the different field sites. Further group discussions will likely be required to determine the best course of action.

Secondly, a pilot study needs to be designed and undertaken at one or more of these sites that offer the most potential (tentatively in 2006). This would be an all-inclusive program where all researchers could test instruments and techniques in the field and scientific questions would begin to be directly addressed.

Finally, a full-scale field-based research program would include addressing science goals, but ultimately developing and testing flight instruments and science packages for future missions.

- **Begin the development of a multidisciplinary science payload package for Mars astrobiology.**

The Canadian astrobiology community needs to mobilise rapidly if we are interested in developing a science payload package that could be flown on a 2011 or later Canadian mission to Mars. Considering that a payload needs to be flight-ready two years before launch, the timeline leading up to such a mission is extremely short (see Figure 1). The community needs to quickly identify likely analytical methods and consider possible suites of instruments in the coming months. This could possibly take the form of an "astrobiology payload concept study" and will require extensive dialogue between scientists and engineers. This would set the stage for a more extensive feasibility and design project that would lead to the building of a laboratory prototype. Before building of a flight prototype, extensive field testing should be undertaken in various localities, possibly selected from those in Appendix 1.

- **Compile existing data on Mars into a database.**

Since Mars is the obvious near-term target for CSA, it seems only logical to compile existing information and data from what has been done in the past. Recent mission have produce a wealth of data and, in some case, continue to do so. Specific activities could include:

- Summarise past missions, observations and data, Earth-based studies

- Develop an interactive database (e.g., imagery, chemical data, atmospheric data, etc.)
- Determine what scientific questions can be answered with available (e.g. image analysis, compare with Earth analogues, etc.)

Ultimately, such an endeavour would help to develop astrobiology and Mars-related science in general, and more importantly, disseminate that knowledge to Canadian scientists and engineers. Moreover, the results will help determine:

- science questions for future missions
- appropriate landing sites
- instrument design

The ultimate nature of this compilation should be investigated further. In particular, currently available data sources and compilations need to be assessed.

- **Investigate possible funding for a collaborative, field-based astrobiology program.**

Two options discussed at the workshop are the NSERC Research Networks Programme and Special Research Opportunity Programme. The former has a poor success rate for space-related projects and the astrobiology community is likely not yet prepared for such an endeavour. The latter, on the other hand, is designed to fund high-risk, short-term projects that have an element of urgency or timeliness. This urgency could be justified by the timeline (see Figure 1) leading up to the proposed 2011 Canadian-led mission to Mars. A third option, NSERC Collaborative and Development Grants may be possible in the future by developing private-sector partnerships. Finally, it is hoped that joint CSA-NSERC and CSA-CIHR research grants will be more widely available in the near future.

- **Investigate possible collaboration on American, European or other space exploration projects (e.g., Scout missions).**

This will require ongoing networking and will benefit from CSA's current and future space exploration agreements with other international partners (e.g., NASA, ESA). As Canada's interest and expertise in astrobiology become increasingly known, opportunities for collaboration will likely arise. A dynamic community needs to be ready to take advantage of these opportunities.

- **Participate in the Canadian Space Exploration Workshop 5 (May, 2005).**

This workshop will provide a forum to interact with the wider space science community and to further develop the astrobiology community in Canada. The AWG will likely be able to come to the workshop more prepared than individual scientists have been able to do in the past. Given the focus and momentum generated by the first meeting of the AWG, it is now possible to propose focused activities in astrobiology for the workshop.

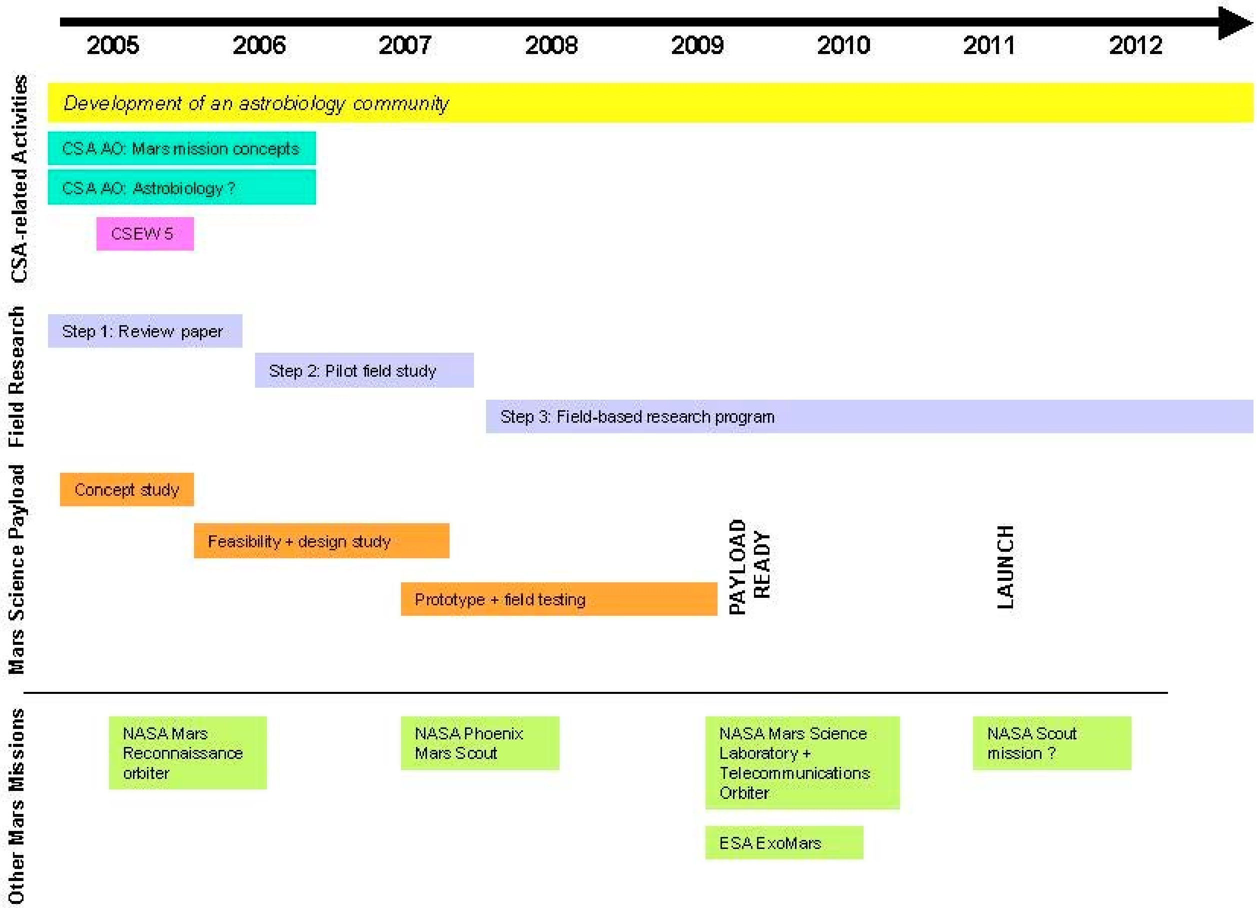

Figure 1. Preliminary Timeline for a Canadian Mars 2011 Mission

Appendix 1: Astrobiology-related field sites in Canada.

1. Precambrian rock record and the Canadian Shield.

Canada has one of the most extensive Precambrian rock records on Earth and this includes numerous well-studied fossil localities. This ancient rock record provides a broad array of spatial and temporal scales to study past biology and global change, through paleogeographic reconstruction, macrofossils, microfossils, and chemical fossils. Of particular importance to astrobiology is the fact that this rock record represents a period of time before plants and animals covered the land surface, and in fact before the evolution of multicellular organisms, and hence represents a "non-vegetated, microbial planet" analogue. This allows reconstruction of planetary-scale processes and planetary biotic evolution. Canadian scientists have extensive field experience and geological expertise in dealing with this rock record.

2. Canadian High Arctic

The Canadian High Arctic offers a number of varying cryosphere environments for studying astrobiology-related issues and acts as an analogue for martian environments. These include permafrost, ground ice, cryptoendoliths, sea ice, and a variety of cold and hot perennial springs; our fundamental knowledge of the microbial communities existing in these sites is presently severely lacking but the existence of active microbial communities in these cold environments will have significant implications for the possibility of life in other very cold environments such as Mars, and possibly Europa. Canadian experience working in the Arctic and the relatively easy access make this an ideal location for developing further astrobiology-related activities.

3. Hydrothermal systems

Deep-sea hydrothermal vents are also possible analogues of environments on Europa. Canada has some of the best-known and most-studied deep-sea vents off the coast of British Columbia, along the Juan de Fuca Ridge. Other vents also occur further North along the Explorer Ridge, as well as in the Arctic. Again, Canadian expertise and relative ease of access make this another field site that merits continued development for astrobiology-related activities. The recently-funded cabled observatory NEPTUNE will provide numerous scientific and technological opportunities for studying hydrothermal processes and related phenomena on the Juan de Fuca Ridge, and for development of novel remote data collection techniques.

A number of terrestrial hot springs are also found in Canada (e.g., Rocky Mountains, Arctic, Vancouver Island). These also offer important insights into biology adapted to "extreme" conditions and may also represent martian analogue environments. Further studies of these hot springs would therefore benefit the field of astrobiology.

4. Gas hydrates, cold seeps, hydrocarbons

Seafloor hydrocarbon deposits and cold seeps are found off the coasts of British Columbia and the Maritimes, and Canadian scientists have been pioneers in their study. These represent another example of an “extreme” environment where life is able to flourish in novel ways, and given the solid phase nature of the hydrocarbons they may provide a useful analogy to solid phase energy sources in the colder Martian environments. The Pacific sites will be partly covered by the NEPTUNE cabled observatory.

5. Subsurface mines and acid rock drainage

Scientists have become increasingly aware of a deep subsurface biosphere 100s of meters within various rock formations. This awareness has led astrobiologists to suggest that subsurface life may be found elsewhere in the Solar System. Canada’s wealth of underground mines provide excellent opportunities to access parts of this deep subsurface biosphere.

An unfortunate, yet widespread by-product of many metal mining activities is the creation of acid rock drainage due to the interaction of sulfur-rich mine wastes with air and water. The acidic run-off from such mine wastes is often devastating for the surrounding vegetation and animal communities. However, acid-loving microoganisms are commonly found in such wastes and they again reveal the adaptability of microbial life on Earth, perhaps hinting at clues to life elsewhere.

6. Other “extreme” environments:
   e.g., deserts, hypersaline cold springs, subglacial/deep ice, alkaline lakes, meromictic lakes, etc.

Limited astrobiology-related work has been done in Canada on these environments, yet scientists from Canada and elsewhere are now beginning to study them in greater detail. These environments are known to host novel microbial communities that are well adapted to the harsh conditions that prevail there.

Appendix 2. Canadian scientific expertise in astrobiology-related areas of research.

1. Precambrian geology:
   e.g., planetary evolution, paleobiology, and paleoenvironmental reconstruction: possibly the greatest density of expertise in the world for studying non-analogous conditions to the present day

2. Environmental microbial metabolism and diversity:
   e.g., Arctic and ice-related environments, hydrothermal systems, acidic environments

3. Microbe-mineral interactions:
   e.g., geomicrobiology, biomineralisation, microbial fossilisation, microbe-metal interactions, bacterial magneto-fossils, microbial biomarkers

4. Geocryology:
   e.g., geophysical sensing techniques, terrestrial/marine ice-related processes

5. RNA biochemistry/catalysis, early evolution:
   e.g., cellular organisation, “ribo switches”, “origins and evolution”

6. Fossilisation (taphonomy), preservation, traces of life and their detection
   e.g., stromatolites and microbialites, microfossils, biomarkers and chemical fossils

7. Atmospheric science, trace gases, atmospheric gases as biosignatures

8. Climate evolution

9. Planetary evolution

10. Mineral deposits

Appendix 3. Astrobiology-related resources in Canada.

1. ROPOS submersible and the CCGS John P. Tully
2. NEPTUNE-Canada and VENUS cabled seafloor observatories
3. ArcticNet and the CCGS Amundsen (icebreaking science vessel)
4. McGill Arctic Research Station (MARS)
5. Polar Continental Shelf Project
6. Northern Scientific Training Program for students
7. NSERC Northern Supplement Program for Researchers
8. Canadian Synchrotron light source
9. Origins Institute at McMaster University
10. LAMIC (Laboratoire de micoranalyse, micromanipulations et cryo-observations)
11. Other resources (widely distributed):
    - Mini fluorescence techniques
    - Environmental flow cytometry and fluorimetry
    - Geomicrobiology laboratories and related equipment (e.g., electron microscopes)
    - Mass spectrometry, isotope biogeochemistry, and radiometric dating
    - Luminescence and non-radiometric dating
    - High resolution GC-MS
    - High throughput genomics and proteomics
    - Geographical Information Systems (GIS)
    - Remote Sensing (e.g., ground penetrating radar, hyperspectral capabilities, LIDAR)
    - Micro-electrodes
    - Environmental micro-arrays (gene chips)
    - Clean drilling technologies
    - Robotics (including space applications)

Appendix 4. Workshop Participants.

Ricardo Amils Pibernat
Centro de Astrobiología
Madrid, Spain
Tel: 915206414
Fax: 915201621
ramils@cbm.uam.es

Mairi Best
Department of Earth and Planetary Sciences
McGill University
Montréal, QC H3A 2A7
Tel: (514) 398-4895
Fax: (514) 398-4680
mmrbest@eps.mcgill.ca

Grant Ferris
Department of Geology
University of Toronto
Toronto, ON M5S 3B1
Tel: (416) 978-0526
Fax: (416) 978-3938
grant.ferris@utoronto.ca

Vicky Hipkin
CSA program Scientist – Phoenix
Department of Physics
University of Toronto
Toronto, ON M5A 1A7
Tel : (416) 971-2363
vicky@atmosp.physics.utoronto.ca

Hans Hofmann
Department of Earth and Planetary Sciences
McGill University
Montréal, QC H3A 2A7
Tel: (514) 398-2769
Fax: (514) 398-4680
hofmann@eps.mcgill.ca

Kim Juniper
Centre GEOTOP-UQÀM-McGill,
Université du Québec à Montréal
C.P. 8888 Succursale Centre-Ville
Montréal, QC H3C 3P8
Tel: (514) 987-3000 (#6603)
Fax: (514) 987-3635
juniper.kim@uqam.ca

Kurt Konhauser
Department of Earth Sciences
University of Alberta
Edmonton, AB T6G 2E3
Tel: (780) 492-2571
Fax: (780) 492-2030
kurtk@ualberta.ca

Richard Léveillé
Centre GEOTOP-UQÀM-McGill
Université du Québec à Montréal
C.P. 8888 Succursale Centre-Ville
Montréal, QC H3C 3P8
Tel: (514) 987-3000 (#3572)
Fax: (514) 987-3635
leveille.richard@uqam.ca

Kathleen Londry
Department of Microbiology
University of Manitoba
Winnipeg, MN R3T 2N2
Tel: (204) 474-7199
Fax: (204) 474-7603
londryk@cc.umanitoba.ca

Nancy Martineu
Department of Geography
McGill University
805 Sherbrooke West
Montréal, QC H3A 2K6
Tel: (514) 981-6530
Fax: (514) 398-7437
martineau@felix.geog.mcgill.ca

Jay Nadeau
Department of Biomedical Engineering
McGill University
Montréal, QC H3A 2B4
Tel: (514) 398-8372
Fax: (514) 398-7461
jay.nadeau@mcgill.ca

Alain Ouellet
Acting Program Manager, Planetary Exploration and Space Astronomy
Canadian Space Agency
John H. Chapman Space Centre
6767 route de l'Aéroport
Saint-Huber, QC J3Y 8Y9
Tel: (450) 926-4773
Fax: (450) 926-4766
alain.ouellet@space.gc.ca

Wayne Pollard
Department of Geography
McGill University
Montréal, QC H3A 2K6
Tel: (514) 398-4454
Fax: (514) 398-7437
pollard@geog.mcgill.ca

Gordon Southam
Department of Earth Sciences
The University of Western Ontario
London, ON N6A 5B7
Tel: (519) 661-3197
Fax: (519) 661-3198
gsoutham@uwo.ca

Curtis Suttle
Department of Earth and Ocean Sciences
University of British Columbia
Vancouver, BC V6T 1Z4
Tel: (604) 822-8610
Fax: (604) 822-6091
suttle@eos.ubc.ca

Peter Unrau
Department of Molecular Biology and Biochemistry
Simon Fraser University
Burnaby, BC V5A 1S6
Tel: (604) 291-3448
Fax: (604) 291-5583
punrau@sfu.ca

Hojatollah Vali
Department of Earth and Planetary Sciences
McGill University
Montréal, QC H3A 2A7
Tel: (514) 398-3025
Fax: (514) 398-4680
vali@eps.mcgill.ca

Lyle Whyte
Department of Natural Resource Science
McGill University - Macdonald Campus
St. Anne de Bellevue, QC H9X 3V9
Tel : (514) 398-7889
Fax: (514) 398-7990
whyte@nrs.mcgill.ca

Vladimir Yurkov
Department of Microbiology
University of Manitoba
Winnipeg, MN R3T 2N2
Tel: (204) 474-9045
Fax: (204) 474-7603
vyurkov@cc.umanitoba.ca