TERRESTRIAL ANALOGUES OF MARS: A REVIEW AND OUTLINE OF THE CANADIAN ANALOGUE RESEARCH NETWORK. G. R. Osinski and A. Berinstain, Canadian Space Agency, 6767 Route de l'Aeroport, Saint-Hubert, Quebec, J3Y 8Y9, Canada. E-mail: gordon.osinski@space.gc.ca Tel: +1 450 926 4478.

Introduction: The world of planetary exploration is rapidly evolving. More than ever before, the international scientific community is attempting to answer fundamental questions on the origins of life and of the Solar System, by exploring other planets. Humans will one day explore Mars and use the Moon as a stepping-stone to demonstrate technologies and to do science. Currently, the only way we can "explore" Mars is via data sent back from unmanned orbiting spacecraft and rovers, and through the study of martian meteorites. Interpretations of Mars must, however, begin by using the Earth as a reference. We are very fortunate in Canada to have the geography and climate that we have. Much of the remote, harsh, and often unexplored regions of the Canadian north, and elsewhere, can serve as analogues for the Moon, Mars, and possible other planetary bodies.

Under the theme of "Exploring other worlds begins with exploring our own", the Canadian Space Acency (CSA) is using a multi-disciplinary approach to use Mars analogue sites in Canada to further our scientific understanding of Mars and Earth, to develop and test specific technologies, and to understand how to explore and live in a safe manner on other planets. Some of the technology developed and the infrastructure deployed at these remote field observatories will directly benefit northern communities.

The aim of this paper is to present an up-to-date review of analogue science in its many forms and to outline the CSA-led Canadian Analogue Research Network.

Terrestrial analogues of Mars: Terrestrial analogues are places on Earth that approximate, in some respect, the geological and environmental conditions on Mars and other planetary bodies, either at the present-day or sometime in the past.

Why Mars? Mars is the most Earth-like planet in the Solar System. It has seasons, days similar in length to the Earth day, it has an atmosphere, and it has polar caps that change with the seasons. No other planet has these characteristics. Even more importantly, it is the only body in the solar system, besides the Earth, where water is known to have flowed across the surface [e.g., 1, 2]. Furthermore, the exploration of Mars is a high priority target of the Canadian scientific community (see results of the 4th Canadian Space Exploration Workshop: http://www.space.gc.ca/asc/eng/events/2002/csew4_report.asp).

A review of Mars analogues: Mars analogue research activities focus on three main areas: (1) Geomorphological processes; (2) Geological materials; (3) Exploration science.

Geomorphological processes. One of the main goals of martian science is to understand the origin and temporal evolution of landforms and physical features of the martian surface, and the relationship of these to underlying geological structures. As such, many aspects of analogue studies focus on investigating geological processes that modify the Earth's surface and extrapolating them to Mars.

Figure 1 outlines the main geological processes that modify the Earth's surface, and a comparison with the Moon and Mars.

	Earth	Moon	Mars
Aeolian	Yes	No	Yes
Fluvial	Yes	No	Yes
Glacial	Yes	No (?)	Yes
Groundwater	Yes	No	Yes
Hydrothermal	Yes	No (?)	Yes
Impact cratering	Yes	Yes	Yes
Lacustrine	Yes	No	Yes
Marine	Yes	No	Yes
Mass wasting	Yes	Yes	Yes
Periglacial	Yes	No (?)	Yes
Rock weathering:			
Physical	Yes	Yes	Yes
Chemical	Yes	No	Yes
Tectonic	Yes	Yes	Yes
Volcanic	Yes	Yes	Yes

Figure 1. Summary of the main geological processes that effect the geomorphology of the Earth's surface and a comparison with the Moon and Mars.

Several aspects of the geological processes outlined in Figure 1 can be explored at any location where the suitable geology exists (e.g., characteristics of flood basalts, extensional tectonic terrains, effects of impacts into volatile-rich [i.e., sedimentary] target rocks, etc.). However, a complete understanding of many surface-modifying processes requires that terrestrial sites be chosen based also on similarities to the known and/or suspected environmental conditions on Mars at the present day and in the past (i.e, cold and/or dry, arid locations).

Geological materials. The physical properties (e.g., strength, density, thermal properties, etc.) of rocks and minerals affect the efficiency, rate, and outcome of many geomorphologial processes. The properties of martian rocks and minerals are currently studied using two main methods:

- Laboratory-based studies of the SNC (shergottite, nakhlite, and chassigny) group of meteorites, which number 34 at the time of writing. These are the only samples we currently have from Mars.
- Spectroscopic techniques using remote science instrumentation mounted on orbiting spacecraft (e.g., the Thermal Emission Spectrometer on Mars Global Surveyor), or in-situ instrumentation on rovers and landers (e.g., the Moessbauer Spectrometer and the Alpha Particle X-ray Spectrometer on the Mars Exploration Rovers).

However, interpretation of spectroscopic data sent back from unmanned orbiters and rovers involves comparisons with spectral libraries of terrestrial rocks and minerals. Thus, spectra must be collected from a wide variety of terrestrial materials. In addition to the igneous martian meteorites, many other rocks and minerals are suspected of being present on the martian surface or in its interior. For example:

- Ices, clathrates.
- Evaporites, carbonates, and clays.
- Other volcanic and magmatic rocks not represented by the SNC meteorites.

In addition, little is known about the spectral signatures of chemically and hydrothermally altered and shock-metamorphosed rocks and minerals.

Much of this analogue work focusing on geological materials will be laboratory-based; however, suitable samples are required from a variety of field sites. Furthermore, in-situ, field-based studies are also important for ground-truthing data collected from orbit.

Exploration Science. The human exploration of the Moon and Mars is now in the long-term plans of the US National Aeronautics and Space Administration (NASA) and the European Space Agency (ESA). Space exploration is now being driven by exploration and the task of conducting fieldwork on other planetary bodies. Exploration science is motivated by the need to understand and answer fundamental questions about how we will explore other planets. For example, how will exploration be conducted and what technologies will be required? How many people will it take? How will the missions be supported from Earth? How will the missions be planned and managed?

Exploration science covers a broad range of disciplines and topics and includes, but is not limited to, the following:

- Communications and computing for planetary exploration:
  - Personal (i.e., spacesuit).
  - Internal base station and/or spacecraft.
  - Interplanetary (i.e., Earth–(Moon)–Mars).
- Robotics.
- Telemedicine.
- Mission Control operations.
- Field operations.
- Remote sensing technologies.
- Instrument and technology testing.

Canada is a leader in exploration science. At the forefront is a group led by Dr. Steven Braham from Simon Fraser University, British Columbia (http://polylab.sfu.ca/spacesystems/HMP/). Dr Braham and collegues have been working on exploration system integration and utilization models, based on supporting planetary exploration traverse requirements. This group has been working on new analogue mission concepts that are driven by "utilizing knowledge gained by supporting and managing real explorers in the field to help better understand what exploration actually is, and needs" [S. Braham 2005, personal communication].

Current field-based analogue activities in Canada: The Canadian Arctic offers a plethora of potential analogue sites, including vast regions of continuous permafrost, polar deserts, meteorite impact craters, glacial landscapes, perennial springs, ice-covered lakes, and unique biological habitats. In particular, the polar deserts of the Arctic (and Antarctic) represent one of the closest analogues to Mars, on Earth: they are cold, windy, rocky, and in the summer, drenched in ultraviolet radiation [e.g., 3]. By studying how life survives in such harsh regions on Earth, we can gain a better understanding of how life may have developed on other worlds and in what niches it may be found. While much of the past analogue research in Canada has focused on sites in the Arctic, there are many other sites throughout Canada that may also be suitable candidates for incorporation into the Canadian Analogue Research Network.

Analogue activities have been carried out at several sites around Canada. Four examples are given below:

Expedition Fiord, Axel Heiberg Island, Nunavut. McGill University's Axel Heiberg Island Station was founded in 1960 and is located at 79°26' N, 90°46' W, on Axel Heiberg Island in the Canadian High Arctic (Fig. 2). A research team led by Dr. Wayne Pollard has spent a number of seasons conducting field research on various topics, including:

- The search for water: Perennial springs as analogues for hydrothermal systems on Mars [4, 5].

- Water-related landforms: Gully and valley formation [e.g., 6]
- Drilling technology and sampling.
- Life in extreme environments.
- Mars rover and instrumentation studies.

For further details see:
http://www.geog.mcgill.ca/mag2/fieldstations.htm

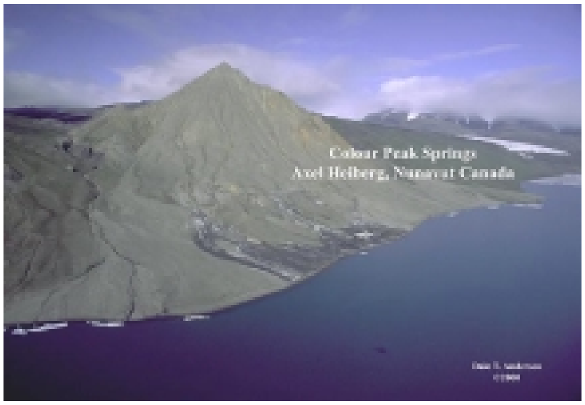

Figure 2. Photograph of the Colour Peak Springs on Axel Heiberg Island, Canada. Photo: Dale Anderson.

Haughton impact structure and surrounding terrains, Devon Island, Nunavut. The Haughton impact structure is situated in a polar desert environment (Fig. 3) that is similar in many respects to conditions that may have existed on Mars in the past [3]. Investigations at Haughton have been carried out under the auspices of the Haughton–Mars Project. This is an international, multi-disciplinary project started by Dr. Pascal Lee (NASA Ames Research Center) in 1997. Science investigations include:

- Impact cratering studies [e.g., 7].
- Biology of impact craters.
- Microbial colonization of impact-generated and impact-modified materials [e.g., 8].
- Gully and valley network formation [e.g., 9].
- Periglacial and glacial geology.
- Limnology of ponds and lakes [e.g., 10].
- Life in extreme environments.
- Remote sensing and geophysical studies.

For further details see:
http://www.marsonearth.org/

Pavilion Lake, British Columbia. The Pavilion Lake Research Project started in 2004 and is being led by Dr. Darlene Lim (NASA Ames Research Center) and Dr. Bernard Laval (University of British Columbia). The main research themes are:

- Understanding microbialite and carbonate formation in alkaline freshwater lakes [11].
- Instrument and experiment deployment in fragile environments.

For further details see:
http://supercritical.civil.ubc.ca/~pavilion/

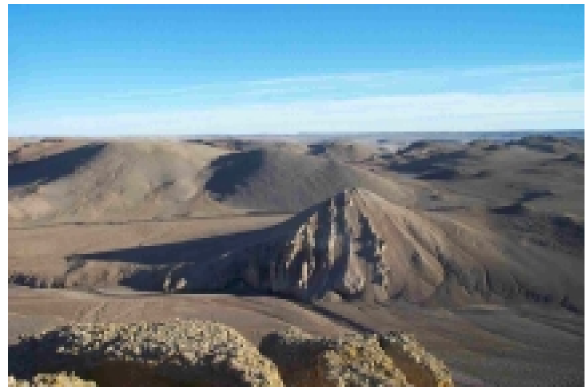

Figure 3. Photograph looking in towards the interior of the Haughton impacts structure, Devon Island, Canada. Photo: GRO.

Tuktoyaktuk Peninsula, Northwest Territories. The geomorphology of this region of northern Canada is dominated by periglacial processes and is host to the greatest concentration of pingos (ice-cored hills) in the world (Fig. 4). A research team led by Dr. Richard Soare from Concordia University has been studying the periglacial features of the Tuktoyaktuk Peninsula and comparing them to similar features seen on Mars [e.g., 12, 13].

Figure 4. Photograph of two large pingos in the Tuktoyaktuk Peninsula, Canada. Photo: Earth Sciences Information Centre, Natural Resources Canada (NRCan).

The Canadian Analogue Research Network: Analogue studies are deemed a high priority area of interest by the Canadian science community and represent a niche area where Canadian scientists can contribute significantly to our understanding of Mars and other planetary bodies. Canada is ideally suited as a focal point for analogue studies for several reasons, including:

- Ideal geography and climate (e.g., Figs. 2–4).
- A wide variety of Mars analogue environments.
- A history of analogue science activities, including exploration science (see above).
- Relative ease of accessibility unlike, for example, Antarctica.
- Pre-existing logistical framework (e.g., NRCan Polar Continental Shelf Project).

Furthermore, large regions of Canada are still being actively explored. In addition, there is currently an unprecedented interest and activity in space (e.g, Mars Exploration Rovers, Cassini, Deep Impact, etc.), which we can build upon.

The Canadian Space Agency is, therefore, leading the creation of a Canadian Analogue Research Network that will enable scientists from Canada and elsewhere to carry out field-based analogue research studies anywhere in Canada. This network will include many of the pre-existing analogue field programs, infrastructure, and experience, and combine them into a coordinated network. In addition, it is likely that several other, as yet unidentified sites, will be chosen and incorporated into the network. Funding (to be announced) will be available to support infrastructure development and science at these sites.

Goals of the Canadian Analogue Research Network. The main goals of this project are to:

- Establish a coordinated network of Moon–Mars analogue sites in Canada.
- Enable scientists to carry out field-based analogue and exploration-related research studies in the Arctic and elsewhere in Canada.
- Enhance the use of spaceborne and airborne remote sensing data sets in analogue studies.
- Foster collaboration between the CSA, other Canadian government departments (e.g., Natural Resources Canada), universities, industry, and international partners.
- Increase the competitiveness of Canadian scientists in the few opportunities that exist for participation in planetary missions.
- Provide field laboratories to test technology of use to industry and northern communities.
- Enhance the use and enable greater access of the Canadian Arctic by the scientific community.

Activities of the Canadian Analogue Research Network. Analogue sites provide unique opportunities to further our scientific understanding of Mars and other planets by studying and investigating geological and biological processes on Earth. A variety of activities are planned under the auspices of the Canadian Analogue Research Network:

- Conduct scientific research to further our understanding of the Moon, Mars, and Earth.
- Connect the remote science site(s) to the scientist in the field and to their support teams.
- Develop and test technologies and instrumentation.
- Learn how to keep astronauts healthy and how to work in extreme environments
- Utilize Geographic Information System (GIS) software to synthesize remote sensing database, field observations, laboratory data, etc.
- Apply the expertise and knowledge learned to benefit remote communities.
- Other activities (e.g., astronaut training, field workshops, etc.).

The Space Science branch of the CSA is working with the Canadian scientific community, in conjunction with various community and government groups, to select a few analogue sites in that will form the Canadian Analogue Research Network. Funding announcements and further details can be found at: http://www.space.gc.ca/asc/eng/csa_sectors/space_science/space_science.asp

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