A SYSTEMATIC APPROACH TO INVESTIGATIONS AT MARS ANALOG RESEARCH STATIONS

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To prepare for a Martian expedition led by a human crew and assisted by robots, a substantial amount of mission definition can emerge from Mars analog studies on Earth. A series of human Mars expeditions will rely on exploration strategies, human factors solutions, and technologies developed and tested at Mars analog bases where real field science is practised. An international, interdisciplinary research program into field operations, exploration technology, information management, habitability issues, mission support options, and crew social-psychology is needed to integrate all the components necessary for a successful expedition. A systematic approach for integrating these components is advocated. This approach relies on guiding research towards key themes progressively explored in sequential order towards a complete understanding of Martian expeditions. Investigations are organized into mission classes, and classes sorted into themes. With a progressive series of 15 Mars analog expeditions the world will be ready to go to Mars.

INTRODUCTION

A Mars analog is an environment or situation on Earth, in nature or by simulation, for which there are, or could be, analogous characteristics on Mars. This definition covers both the physical setting of Mars, as well as design considerations for technological challenges and scenarios for human activity. The complex interplay between these factors may ultimately be understood only on Mars itself, and then only in relation to the circumstances of the day in a historical sense. It is difficult to believe there is a single perfect scenario. The options, however, can be narrowed down to a set that will provide robust opportunities for humans and robots to achieve the scientific objectives of the Mars exploration program. With Mars analog studies and mission simulations, a great deal may be learned about how to structure a Martian expedition so that a set of effective strategies for living and working on Mars are available to meet particular circumstances. A Mars analog exploration program can be established to define the options. Current efforts in Mars-analog science and exploration are also providing case studies for the organization of interdisciplinary programs.

At two existing Mars analog sites, Mars Analog Research Stations are operated by Mars Society volunteers. These are two of the four intended for selected scientists,

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engineers and other professionals from a variety of institutions worldwide to support field science investigations, technology field tests, and exploration research.[*]

In July 2000, the Mars Society built its first Mars Analog Research Station (MARS) on Devon Island in Arctic Canada, near the Haughton Impact Crater.[†] In December 2001, a second Station was erected in the desert, near the town of Hanksville, Utah.[‡] A third Station was also constructed and displayed in Chicago at the Adler Planetarium, and pending funds, will be transported to a third site on a volcanic field in Iceland.[§] The Mars Society of Australia is currently seeking funds to construct a fourth station near Arkaroola in Australia.[**]

These four stations of the MARS project represent a substantial scientific resource for conducting Mars analog studies. To fully exploit the opportunity these stations present, Mars Society Canada (MSC), led by the author, in 2002 initiated a long-term research program for systematic investigations at Mars analog sites around the world. The first mission, dubbed "Expedition One" (or ExOne), was successfully accomplished in partnership with Mars Society Australia (MSA), from mid-February to mid-March 2003 at the Mars Desert Research Station (MDRS) in Utah.[1] Expedition Two (ExTwo) is planned for Australia in mid-2004 near the site where the Australian Mars Analog Research Station (MARS-OZ)[††] will be constructed once funding is acquired. ExTwo will be organized by MSA in partnership with MSC. As a young organization, the international Mars Society does not have the resources that national space agencies can provide, so it relies mainly on private donations and membership dues to carry out a research agenda which those agencies have not adequately engaged in. Over the course of many years and expeditions, a Mars analog research program of systematic investigations conducted by the Mars Society, or by other associations or agencies, will establish the metrics of science exploration to aid in Martian expedition planning.

The international Steering Committee of the Mars Society has identified the primary goals to be met by the Mars Analog Research Station project[‡‡]:

1. The Stations will serve as an effective test bed for **field operations studies** in preparation for human missions to Mars specifically. These will help develop and allow tests of:
    a. Key habitat design features
    b. Field exploration strategies
    c. Tools and technologies

[*] http://www.marssociety.org.au/library/Analogue_Stations.pdf
[†] http://www.marssociety.org/arctic/
[‡] http://www.marssociety.org/mdrs/
[§] http://www.euromars.org
[**] http://www.marssociety.org.au/MarsOZ.shtml
[††] http://www.marssociety.org.au/library/MarsOZ_Proposal-ver1b.pdf
[‡‡] http://www.marssociety.org.au/library/Analogue_Stations.pdf

   d. Crew selection protocols.

2. The Stations will serve as useful field research facilities at selected Mars analog sites on Earth, ones that will help further our understanding of the **geology, biology, and environmental conditions** on the Earth and on Mars.
3. As an operational test bed, the Stations will serve as a central element in support of parallel studies of the **technologies, strategies, architectural design, and human factors** involved in human missions to Mars.
4. The facilities will also bring to the field compact laboratories in which in-depth data analysis can begin before scientists leave the field site and return to their home institutions.
5. The Stations will help **develop** and **integrate** the capabilities needed on Mars to allow productive field research during the long months of a human sojourn. The facilities will evolve through time to achieve increasing levels of realism and fidelity with the ultimate goal of supporting the actual **training** of Mars-bound astronauts and the most effective ground support.

The program of research that Mars Society Canada advocates is to reorganize these goals into a logical, systematic roadmap with more specific questions for analog investigations to undertake.

APPROACHES TO RESEARCH ORGANIZATION

At a 2001 workshop[2], "Science and the Human Exploration of Mars", the consensus among participants was that "Understanding of the data needs can lead to the definition of experiments that can be done in the near-term that will make the design of human missions more effective"; and it was also suggested to "Define controlled experiments that quantify the productivity of humans and their robotic tools as scientific explorers, including: a. Field exploration; b. Analytical capabilities; c. Communication of findings between the planetary surface and scientists and lay people on Earth."

So far, the majority of missions to the two existing analog stations have emphasized journalistic reporting of the personal experiences of the crewmembers in holistic mission simulations with very little experimental controls. Compare this with the focus of Expedition One on deliberate investigations into specific parameters of the Mars analog experience such as work load, task analysis, and cognitive testing. To establish an effective, practical, professional and systematic program, it would be beneficial to steer away from anecdotal observations and strive for quantitative and qualitative data. An anecdote is essentially a single data point representative of non-repeatable circumstances. Thus relying on these to guide the direction of research in the early, low-fidelity stages of an analog research program would be an incremental approach unlikely to provide enough coherent information to effectively plan a Martian expedition without decades of repetition.

Anecdotes no doubt provide useful information in understanding the results of holistic simulations, but in order to prepare for high-fidelity simulations, Mars analog operational studies would profit more quickly by focusing on isolated individual parameters relevant to Martian expeditions. These need not be studied during holistic simulations at all. An analog investigation only studies the parameter in question, isolated from others factors that would obscure the distinguishing of cause from effect. With focused investigations the operational parameters for an analog expedition are optimized, then gradually, systematically integrated into the mission scenario. To start with a strictly defined simulation scenario is to embed unproven assumptions into the scenario. The circumstances of a simulation would be reflective only of that particular scenario, revealing about other options few conclusions that are not overly interpretative.

How a multi-disciplinary research program for Mars analog studies is organized is directly important to its success. The science program may be either strategically planned and active, or *ad hoc* and passive. The passive approach would be to invite scientists to a site to accomplish their individual research, or engineers, technologists and computer scientists to field test exploration technology. This is similar to the approach currently employed by the NASA-SETI Haughton-Mars Project.[3] The passive approach relies upon opportunity to discover what questions are being answered, and is particularly useful early on in learning how to plan Martian expeditions, providing a baseline for anthropological studies of scientists in the field as they would prefer to work and live[4], and also a frame of reference for contemplating which questions need further investigation. A checklist of questions that may be answered over time as opportunities are presented can be part of an effective long-term program. The checklist can be expanded as the program progresses. However, to prepare for holistic, high-fidelity simulations, an *ad hoc* program will not suffice.

The interdisciplinary nature of research typically done at Mars-analog field sites requires care in designing field methods appropriate to each type of enquiry. Studies that run in parallel, for example studies of geological scouting procedures and observations of pressurized rover operations, must be coordinated so as to not introduce factors that confuse the situation. In this example, running simulations of rover emergencies that interrupt scouting operations could contaminate studies that depend on accurate measurements of time consumed by the latter, unless accounted for properly. The problem of holistic, interdisciplinary studies, however, is in knowing which effects are due to which causes. Difficulties in drawing legitimate conclusions can be alleviated by taking care with data collection to measure factors that are strictly defined, such as the amount of field notes required to document various sites of biological significance, or by reducing the number of parallel investigations to focus them with strict experimental controls. The best strategy for learning how to conduct Martian expeditions is the scientific method itself.

An active, strategically planned approach would be to begin with a number of questions, and then bring in researchers and test subjects for studying these sequentially. This is investigative science. A single institute or expedition research council would need to guide a program of investigative science, answering those questions prior to more complex issues. Analog investigations and holistic simulations, as Expedition One has shown, benefit from research rigorously coordinated among the participants.

Coordination among various kinds of research can be effectively accomplished by understanding the requirements of the data from the perspective of the various analog investigation levels as defined below.

Level 0 : understanding what questions the research goals are to answer.
Level 1 : understanding the products of the research goals.
Level 2 : understanding the data and tasks needed to generate the research products by:
   a. investigating what data is to be collected
   b. investigating what actions are to be produced
Level 3 : understand how to generate the data and tasks by:
   a. investigating what specific human skills or knowledge are required to:
      i. obtain the data desired
      ii. deliver the actions desired
   b. investigating how to technologically
      i. obtain the data desired
      ii. deliver the actions desired

These analog investigation levels also inform which studies can run in parallel, which run in sequence, and which have no dependencies. From a more holistic perspective, the goal of exploring Mars provides a guide for establishing how Mars analog studies should progress.

The effectiveness of a Martian expedition will be judged by the quality and quantity of science data returned. The first experiments analysing exploration operations should focus on: identifying the various forms of data that an explorer can acquire in the field; observing how data sets are made on Earth by field scientists as a natural baseline for comparison; studying how to safely acquire similar data on Mars; consider to what use and how those data sets are used; and at all steps learn how to maximize the data available. Classifying the type of study based on requirements of data collection helps organize these studies into a coherent program. The application of industrial engineering analytical tools for task and work load measures can provide metrics for efficient exploration. Metrics established in analog operational studies would be valuable for comparing strategies on task-oriented and goal-oriented scales.

Mission Classification

The kinds of research conducted at and around Mars analog research stations may be classified as:

(i) Missions of discovery
(ii) Missions of opportunity
(iii) Missions of investigation

Missions of discovery employ an active approach in holistic, realistic simulations (that nevertheless may be of low fidelity), setting up the situation and discovering with qualitative observations the circumstantial problems that were not anticipated. In this case crewmembers are test subjects. Work at FMARS and MDRS have mostly been missions of this class.

Missions of opportunity employ the passive approach of having engineers and scientists bringing projects to the program. These will test technologies and pursue study of geological and biological analogs to Mars on Earth. These missions are highly dependent on collaboration with experts who are employed in their home institutions in funded research projects. Some data may be proprietary to the researcher, so data-sharing might be limited or prohibited. Work in the Haughton-Mars Project is primarily of this mission class.

Missions of investigation employ the active approach in experiments testing isolated parameters and making quantitative observations on operational problems. Disruptions are inevitable, but do not have to introduce chaos to an exploration program if managed effectively. Focusing on normal operations first will help expedition planners understand how to establish control over disruptive situations and alleviate circumstantial problems, in order to return to the desired state. Researchers study specific tasks in order to develop more effective operational procedures for conducting scientific investigations. Missions of investigation will be the prime method of defining the tasks, tools and strategies employed during missions of discovery, and therefore must be conducted prior to simulation studies. Expedition One to MDRS consisted primarily of missions of this class.

The MARS project should employ all three strategies. To do so effectively, the differences between the approaches need to be understood, and in what situations they are appropriate, and in what situations one must take precedence over the other. It is difficult to design an experiment well when the questions of interest are not first considered, weighed, and prioritized.

A LONG TERM PROGRAM

A systematic approach to Mars analog investigations is to explore options that build an effective scenario from the basis of the intended purpose of the expedition field science, to the operations that arise from pursuit of that purpose, to the human factors issues that emerge from those operations, and then to the technology needed to support the human activity of those operations and issues. Long-term planning for this projected series of analog Expeditions is necessary to guide the body of research towards directions that obtain results applicable to Martian expedition planning, or that help prepare for and understand how to conduct future analog Expeditions.

The goal of a Mars-analog program is to provide a complete understanding of how to effectively conduct the human exploration of Mars. The road to Mars may be understood by tracking backwards from Mars to Earth. Prior to a Martian expedition, to avoid unnecessary risks all the strategies for conducting it must be tried, and all the technologies employed must be tested. A 500-day Martian expedition would be preceded by a 500-day Martian expedition simulation on Earth. Over time, a high-fidelity simulation can be approached, but is not yet achievable. This is not only due to a lack of technology, but a lack of understanding of how to operate a simulation. The most effective mix of exploration strategies, field equipment, science goals, crew roles and skills needed, and individual science operations tasks have not been adequately studied yet.

Below are 100 questions that need to be answered before a Martian expedition could be successfully planned. All questions are numbered over each subsection sequentially. One overall, long-term question will be to:

1. Define the nature of a fully realistic simulation in order to:
   (a) Learn how to accomplish the selection, training and support of a crew that will actually go to Mars.
   (b) Integrate the tasks necessary to accomplish the mission, and to
   (c) Design an appropriate and effective working environment.

The holistic simulation is an experiment like an onion to grow in layers rather than to be peeled. Tasks and factors studied in short-duration missions should be limited to simulating only the properties relevant to what is being studied, in order to understand the innermost layers before building the outermost. It is obvious that all questions cannot be considered simultaneously. Intelligent observation of processes, interactions and tasks is necessary to investigate how these properties act in isolation before discovering problems when they are integrated. This is a desirable strategy for advancing the knowledge base more quickly than what would result from the pace of a holistic study. Documentation of the experiments and peer review is absolutely critical. The goals and methods of each experiment must be well understood and agreed upon in the planning phase by all those concerned.

How to conduct a 500-day simulation is not understood well enough to engage in one immediately. Therefore, shorter missions of discovery, perhaps in 90-days periods, will be needed to test options prior to a series of long-duration simulations. Similarly, before 90-day simulations can be effective, shorter missions of investigation should be undertaken, perhaps in 15-day and 30-day phases. The focus of each 15-, 30-, 90- and 500-day missions can be decided upon with regard to the data needs.

A 30-day mission of discovery would be valuable to compare with a later 500-day holistic simulation in order to assess how much science each can accomplish in those allotted time frames. Comparing the two becomes an overall mission of investigation. This would have the direct result of:

2. Evaluating the two competing classes (the 30-day quick-return Earth-Mars orbital opposition class versus the 500-day long-surface-stay Earth-Mars orbital conjunction class) of human missions to Mars in terms of possible scientific return.

This may prove important if a range limitation on the ability to explore away from the base (the exploration circle) exhausts the opportunity to conduct scientific investigations around the site long before 500 days are up. Before the parameters for (2) can be considered, the preceding short-duration missions (days to weeks in duration) must determine the priority of tasks. These short-duration missions can be either missions of investigation or opportunity, and need not be done holistically (ie. focus just on the EVA, not on habitat life, if the question is one of exploration).

Field Reconnaissance and Exploration Studies

Field geology begins with mapping. For Mars we will have maps of topographic and mineral data. Orbital spacecraft will reveal clues about the mineralogical makeup of the Martian surface, so that kind of map will need to be confirmed and expanded into maps of terrain types. Given a finite space in which to store samples, it would be prudent to limit the number of samples obtained on reconnaissance to those that fully characterize the region. Samples that are representative of the varieties of rocks present are desirable, as well as unusual samples, and positions noted on the map. Limited simulations can be used to determine how long this sort of mapping will take using a variety of systematic reconnaissance strategies, while holistic simulations can integrate the best strategy as the first step in a program of exploration. What observations need to be made; what samples need to be obtained? Studies of reconnaissance strategies should involve the:

(a) Confirmation of theories of the local geology,

(b) Mapping of features of geologic significance and biologic potential

(c) Investigations of curious or anomalous data, and

(d) Attempts to locate useful resources.

An "exploration circle" could be defined as the minimum and maximum distance range which could be thoroughly explored over the course of a long-duration Martian surface expedition.

3. How long (in EVA time) will it take to reconnoitre the exploration circle surrounding a base?

With the emphasis put upon finding the best recon strategy, with limited time in short-duration missions it is best to remove irrelevant factors from the experiment. It is important to understand how these strategies work when all the technology functions correctly, before testing crew adaptation to equipment failure or emergencies. The relevant factors would likely be local mobility (ATV or analog pressurized rover), and physical capacity of the spacesuit. A non-functioning radio, for example, would be irrelevant to testing the recon strategy except in a holistic simulation. For limited simulations, the sim is in testing the recon strategy, not crew response to emergency, circumstantial or situational factors. Continuing the testing of the recon strategy is of higher priority than maintaining communications fidelity, so for example the helmet could be removed in the case of an inoperable radio to give the crew the ability to communicate unmediated by technology in order to complete with the experiment. Given that EVA time is a quantifiable factor measured in order to assess the effectiveness of the strategy, then that information can then be used in rover and spacesuit studies in designing options for such things as duration of oxygen supply with relation to distance traveled. In that case, duration of each EVA can be varied to test effectiveness of a particular recon strategy. It would be useful to have a non-participating eyewitness present on the EVA to make investigative human factors observations. Factors that prevent the testing of the primary questions should not be part of the simulation.

Mars-Analog Science: Geology, Biology, Climate and Atmospheric Studies

There are several broad scientific questions that can be explored at Mars analog research stations, but many of these will rely on the opportunity of having specific experts as crewmembers. None of these require simulation conditions, except in the context of field operational studies, so these are missions of opportunity. This list is by no means exhaustive, but questions relevant to Mars are:

4. What is the variety of the regolith among different types of terrain in the area?
5. What can we learn regarding the stratigraphy and structure of the area?
6. What is the depositional and diagenetic history of the area?
7. What igneous processes have operated in the area?
8. How have impact processes altered the previous geology?
9. What can we learn of the age and the chronological record in the area?
10. What can we learn of the local and regional tectonic history?
11. How did the area evolve climatically?
12. What is the history of life in the area?
13. What is the biogeochemical variety of the soils in the area?
14. What are the temporal and spatial distributions of biological materials and life in the area?
15. What is the history of the fluvial and aeolian landscape?
16. What is the history of water in the area?
17. What is the water chemistry in the area?
18. What is the capacity for microbial life to thrive in the area?
19. What is the microbial diversity within microhabitats in the area?
20. What is the relationship between microenvironmental factors and water availability in the area?
21. Are there useful chemical, mineralogical and hydrological resources?
22. Can aquifers be detected in the subsurface and accessed?
23. Can carbonates and evaporites be detected?

Field Operational Studies

The best tools and methodologies appropriate for fieldwork on Mars need to be determined to answer the questions of geology, biology and climate evolution. Field operational studies are the focus of exploration planning. These can be assessed during missions of investigation under limited simulation conditions.

24. What are the tasks for each field science goal?
25. What is the science return per hour of work for each field science goal?
26. How can operational tasks be simplified for Mars?
27. What are the physical demands of each task?
28. What are the dexterity requirements of spacesuits in the field?
29. What are the resource requirements for each task?
30. What are the knowledge and skill levels required for each task?
31. How are the best samples obtained for surface and subsurface rocks and minerals?
32. How many samples are needed for each science goal, in mass and volume?
33. How should samples be curated?
34. Which methods are best for documenting where samples are obtained and their geological context?
35. How many astronauts are needed for any task?
36. Is it necessary only experts who understand the scientific basis perform each different science operation or can any of those activities be performed by well-trained non-experts?
37. Which way is best to organize work teams for each science goal?
38. Which exploration strategies are best for each science goal?
39. What are the mobility requirements of each science goal?
40. What data needs to be recorded in the field?
41. What data needs to be synthesized and amalgamated in the field?
42. What tools are needed in the field?
43. How much active monitoring and maintenance of field equipment is needed?
44. What information is needed in the field?
45. In what form (hardcopy or electronic) is information usefully available?
46. What sorts of navigational aids will be necessary out in the field?
47. Which procedures are best for drilling into various types of surface rocks?
48. Which questions can aerial reconnaissance help with?
49. Which questions can tele-operation of robots help with?
50. What hyperspectral microscopy and spectral aids would be useful in the field?
51. How will geophysical and meteorological instruments be deployed?

52. What networked instruments need to be deployed, and how?

53. How can humans, autonomous and teleoperated robots cooperate in field operations and field science?

54. How many of the science questions can be answered robotically before a human mission, and how many will be dependent on one?

55. Which science questions can robots follow up after human investigation?

Human Factors, Crew Selection & Training

Short-duration station occupancy does not approach realism in the simulation when considering questions of long-term social factors among the crew. However, how the crew uses time and space within the habitat can be studied over long or short duration missions. How different mixtures of personalities function as a team is an important question for both social interactions within the habitat, and cooperative relationships in conducting fieldwork. Selecting different personality types to study this will be necessary. Different command structures should be experimented with, for both base habitat command and field work.

To protect privacy, crew surveys will have to be handled with care. It is important to remember to choose the crew according to the experiment. Crews made up of entirely of engineers can study technologies deployed around the habitat. Crews made of geologists, geophysicists, and biologists could be used to study field operations. Crews with scientific background in social, psychological and human sciences could provide the expertise needed to minimise negative competition, stress and intolerance while answering questions related to living and working in extreme environments. Are age and gender relevant factors? The balance of occupational disciplines is another factor with which to experiment. Yet another is crew size: how would four astronauts be able to handle a mission differently that five or six?

In addition, how much and what kinds of training should be experimented with as well. Training must be general in terms of reflecting the real conditions in which they will be living, it must be specific to the missions they will be assigned and it must be focused on building cohesiveness and problem-solving among and between crews.

Finally, crew support is essential. Developing active and passive strategies of counter-measurement to the social and environmental stresses is crucial. Personal and social adaptation to life in such conditions requires attention to the lived experiences of the crews and to their preoccupations. Mission success does depend ultimately on the crew's ability to work well together and to support each other in times of stress and extreme social isolation.

A partial list of some human factors questions that should be considered are:

56. What level of adaptive capacity among the crew is needed on Martian expeditions?

57. How does crew use time and space within the habitat?

58. Do different personality mixes affect general or specific activities of the crew working as a team in the field?
59. How do different personality mixes affect the working environment and social interactions of the crew within the habitat?
60. What effects do different command structures have on habitat life, field work, EVA planning and debriefings?
61. What is the optimum crew size?
62. What is the optimum skill mix, or in what instances is particular skill mixes favoured?
63. Are age and gender relevant factors?
64. How much and what kinds of training should be provided?
65. What social and environmental stresses need to be supported remotely by telehealth professionals?
66. How does the crew adapt to the personal and social situation of extreme isolation
67. How do crewmembers support each other in times of stress?
68. How is personal conflict among crewmembers managed?
69. How are working relationships among the crew managed?
70. How are differing priorities among the crew managed?
71. What characteristics does an expedition leader need?
72. What is the most effective leadership structure?
73. What social training does an international crew need to accommodate for cultural differences?
74. How do individuals in a crew identify with the group and subgroups?
75. What are the best ways to keep the crew alert and effective?
76. How much time will crewmembers need for relaxation, entertainment and rest?

Mission Support

77. How do Mars mission crews and Earth-based scientists collaborate on research questions?

78. Which variations on interaction between mission support and the crew prove most effective for which aspects of the mission?
79. What are the strengths and weaknesses of having mission support centralized or distributed?
80. What is the optimum periodicity on non-emergency interaction between the crew and mission support? i.e. how often to report on normal operations?
81. What is the best way to obtain information from the field team?
82. How does mission support handle circumstantial problems versus operational problems?
83. What variation in report styles is effective in what situations?

Tools & Technologies

Automation, instrumentation and robotics are very important aspects to consider in a Mars mission, but for MARS habitats most of those experimented with will depend on missions of opportunity where researchers bring their tools and technologies to the program. The MARS program should focus on experimenting with how technologies are used to augment the mission.

84. What mobility options are there for exploration?
85. What are the requirements for spacesuits?
86. What instruments can extend the cognitive and sensory experience of the astronauts?
87. What are the requirements for data-logging instruments?
88. What is the volume and mass of equipment needed to be landed on Mars?

Data Analysis

89. What instruments are necessary in the habitat?
90. What instruments are necessary out in the field?
91. Where are samples analyzed?
92. How are results communicated?
93. What work can Earth-based scientists work on for sample preparation and analysis within the habitat or in the field tele-robotically?
94. Will expedition scientists complete academic papers while on Mars?

Habitat Design Features

An area to experiment with is the layout of fixed features of the habitat. Ergonomics and effective use of the lab, the EVA preparation room, the communications station, the kitchen, the airlock, and emergency exits are possible areas to study.

95. How will the forward and backward contamination issues be reflected in the habitat architecture?

96. How to mitigate dust tracking into the habitat?

97. How is the communications station set up to be most useful to the crew?

98. How to reduce risk to life in the design of the habitat?

99. What physical and environmental factors must be accommodated in the design and operation of the habitat?

100. How much active maintenance and monitoring of the habitat is needed?

MISSION THEMES

The chart below classifies each of the 100 questions into mission classes. Then each question is described at the study level, which is then numbered. Level zero studies are overall goals of the program. Level one studies are described as products. Level 2 are both data and tasks. Level 3 are skills and technology. Based of these classifications, the questions are then organized into themes, which are given an alphabetic designation.

A Theme studies are Missions of Investigation on Level 3 human factors / skills.

B Theme studies are Missions of Investigation on Level 3 technology.

C Theme studies are Missions of Investigation on Level 2 tasks.

D Theme studies are Missions of Investigation on Level 2 data.

E Theme studies are Missions of Investigation of Level 3 human social interactions.

F Theme studies are Missions of Opportunity on Level 3 technology.

G Theme studies are Missions of Opportunity on Level 1 geological goals

H Theme studies are Missions of Opportunity on Level 1 biological and environmental goals.

I Theme studies are Missions of Discovery on Level 3 human factors / social-psychology.

J Theme studies are Missions of Discovery on Level 3 technology.

K Theme studies are Missions of Opportunity on Level 1 geological goals requiring special technology like drilling, age-dating, etc.

L Theme studies are Missions of Discovery on Field Reconnaissance Strategies.

M Theme studies are Missions of Discovery about holistic Simulations.

	Mars Expedition Questions	Mission Class	Focus	Level	Mission Theme
1	How to simulate a 500 day expedition	Discovery	goal	0	M
2	30 day vs. 500 day sim comparison	Discovery	goal	0	M
3	How long to scout exploration circle	Discovery	goal	0	L
4	Variety of the regolith	Opportunity	product	1	G
5	Lithotratigraphy and structure	Opportunity	product	1	G
6	Depositional / diagenetic history	Opportunity	product	1	G
7	Igneous processes	Opportunity	product	1	G
8	Impact processes	Opportunity	product	1	G
9	Chronostratigraphy	Opportunity	product	1	K
10	Tectonic history	Opportunity	product	1	G
11	Climatic history	Opportunity	product	1	H
12	History of life	Opportunity	product	1	H
13	Biogeochemical variety of the soils	Opportunity	product	1	H
14	Temporal / spatial biological distribution	Opportunity	product	1	H
15	Fluvial / aeolian landscape history	Opportunity	product	1	G
16	History of water	Opportunity	product	1	G
17	Water chemistry	Opportunity	product	1	H
18	Microbial richness, capacity to thrive	Opportunity	product	1	H
19	Microbial diversity in microhabitats	Opportunity	product	1	H
20	Factors in water availability	Opportunity	product	1	H
21	Chemical / mineral / water resources	Opportunity	product	1	K
22	Subsurface aquifers	Opportunity	product	1	K
23	Carbonates and evaporites	Opportunity	product	1	K
24	what are the science tasks	Investigation	tasks	2	C
25	science return per hour for each goal	Investigation	data	2	D
26	operational simplification	Investigation	tasks	2	C
27	physical demands of tasks	Investigation	skills	3	A
28	dexterity demands of tasks	Investigation	skills	3	A
29	resource requirements of tasks	Investigation	tech	3	B
30	knowledge / skills for each task	Investigation	skills	3	A
31	sampling methods for each goal	Investigation	tasks	2	C
32	sample volume and mass for each goal	Investigation	data	2	D
33	sample curation for each goal	Investigation	tasks	2	C
34	sample documentation for each goal	Investigation	data	2	D
35	Number of persons for each task	Investigation	skills	3	A
36	Expertise for each task	Investigation	skills	3	A
37	how to organize work teams	Investigation	skills	3	A
38	exploration strategies for each goal	Investigation	skills	3	A
39	mobility requirements for each goal	Investigation	tech	3	B
40	what data recorded for each goal	Investigation	data	2	D
41	what data amalgamated for each goal	Investigation	data	2	D
42	tools needed in the field for each goal	Investigation	tech	3	B
43	what field equipment monitoring / maintenance	Investigation	tech	3	B
44	what info needed in the field	Investigation	data	2	D
45	what format for info in field	Investigation	data	2	D
46	what navigational aids needed	Investigation	tech	3	B
47	drilling procedures per rock type	Investigation	tech	3	B
48	what help aerial recon can provide goals	Investigation	data	2	D
49	what teleoperated robots for each goal	Investigation	data	2	D
50	what spectral aids / microscopy in field	Investigation	data	2	D

Figure 1: Part one of analysis chart of analog expedition questions.

	Mars Expedition Questions	Mission Class	Focus	Level	Mission Theme
51	how to deploy geophysical / atmospheric instruments	Investigation	skills	3	A
52	what networked instruments	Investigation	tech	3	B
53	human / robot / telerobot cooperation for each goal	Investigation	skills	3	A
54	precursor robot missions for each goal	Investigation	data	2	D
55	robotic followup for each goal after human expedition	Investigation	data	2	D
56	individual adaptive capacity	Discovery	skills	3	H
57	crew use of time and space in habitat	Discovery	tech	3	J
58	personality mixes for team work in field	Discovery	skills	3	I
59	personality mixes for interactions in the habitat	Discovery	skills	3	I
60	effects of command structures on hab and field work	Investigation	skills	3	E
61	optimum crew size	Investigation	skills	3	E
62	optimum skill mix	Investigation	skills	3	E
63	age and gender factors	Discovery	skills	3	I
64	how much and what kinds of training	Investigation	skills	3	E
65	social-environmental stresses supported remotely	Discovery	skills	3	I
66	crew adaptation to extreme isolation	Discovery	skills	3	I
67	how crew support each other in times of stress	Discovery	skills	3	I
68	personal conflict management	Investigation	skills	3	E
69	management of working relationship between crew	Investigation	skills	3	E
70	management of differing priorities among crew	Investigation	skills	3	E
71	leadership characteristics	Discovery	skills	3	I
72	leadership structure	Investigation	skills	3	E
73	social training for cultural differences	Discovery	skills	3	I
74	identification with crew and subgroups	Discovery	skills	3	I
75	strategies for keeping crew alert and effective	Investigation	skills	3	E
76	time for relaxation, entertainment, and rest	Discovery	skills	3	I
77	interplanetary science collaborations	Discovery	skills	3	I
78	which crew - support interactions are effective	Discovery	skills	3	I
79	mission support centralized or distributed	Investigation	skills	3	E
80	how often to report on normal operations	Investigation	skills	3	E
81	best ways to obtain information from the field team	Discovery	skills	3	I
82	how to support circumstantial vs operational problems	Discovery	skills	3	I
83	effective report styles for each situation	Discovery	skills	3	I
84	mobility options for exploration	Investigation	tech	3	B
85	requirements for spacesuits	Investigation	tech	3	B
86	instrument for extending cognitive / sensory experience	Opportunity	tech	3	F
87	requirements for data-logging instruments	Investigation	tech	3	B
88	volume / mass of equipment needed to be landed	Discovery	goal	0	M
89	data analysis instruments in habitat	Investigation	tech	3	B
90	data analysis instruments in the field	Investigation	tech	3	B
91	where are samples analyzed	Discovery	tech	3	J
92	how are results communicated	Discovery	skills	3	I
93	telerobotic sample prep and analysis	Opportunity	tech	3	F
94	will crew complete academic papers on Mars	Discovery	skills	3	I
95	contamination issues for habitat design	Discovery	tech	3	J
96	mitigation strategies for dust	Discovery	tech	3	J
97	comms station ergonomics	Discovery	tech	3	J
98	risk reduction, safety redundancy in habitat design	Discovery	tech	3	J
99	habitat ops design for physical / environmental factors	Discovery	tech	3	J
100	level of habitat maintenance / monitoring required	Discovery	tech	3	J

Figure 2: Part two of analysis chart of analog expedition questions.

The mission themes must be researched separately, generally in the order from A to M. A and B themes can be researched together, as can C and D, and G and H. However, there are so many questions within each of those groups that several expeditions would be required to adequately study each theme. Also, the first four themes (A-D) must be done in the context of the science goals (themes G, H, K).

Expedition One[1] was organized to study A-B investigations (exploration operations) over the first week, followed by C-D investigations (science operations) over the second week. During week three the crew studied G and H science goals, as well as E theme studies on social interactions, while in week four they experienced I and L missions of discovery.

Expedition One was the first step in what is intended as a long-term research program. Its focus was primarily missions of investigations that attempted to characterize the basic field operations needed to conduct a program of 11 geology and biology goals that could be researched at MDRS. ExOne also consisted of missions of opportunity and discovery. These studies were conducted over four phased weeks at MDRS by a crew of 26 researchers and assistants.

Based on the analysis in this paper, a roadmap for a progressive series of Mars analog expeditions can be designed. The details will depend largely on who participates in such expeditions and what the crew field scientists decide to focus on. Given at least 19 science goals (more are likely to be added), with each of the A to D themed investigations needed to be studied with them, perhaps four or five expedition could sufficiently answer those operational questions. The phasing of Expedition One also helped to study questions from other themes by integrating the lessons learned from the early phases into a mission science operations scenario. If future expeditions are similarly phased, then E, G, H, and K themed studies could be researched in the later phases of those same first five 30-day expeditions (Expedition Two to Six).

Long term strategies and social dynamics would need to be researched in missions of discovery once the basic operational questions are understood. I and J themed studies would require longer times to see results, so a series of 90-day expedition would be required, which integrated all the lessons learned from the 30-day expedition and began to see how holistic processes work. At this time there is no way to estimate how many 90-day analog expeditions would be required, but it would depend on how many variations on the social dynamic situations were set up in the crew selection process, and how many different configurations of the habitat architecture was tested. Perhaps another six expeditions would be adequate.

Finally, the entire field reconnaissance and Mars science program would need to be tested in 500-day expeditions. At least two of these is recommended, which could operate simultaneously at different Mars analog sites. In addition, in order to answer question 2 about how much science could be accomplished in 30-day conjunction class quick-return missions, compared against 500-day opposition class long duration expeditions, a 30-day high-fidelity holistic simulation would be needed. Therefore, that brings the total to at least fifteen Mars analog expeditions for a systematic long-term program.

CONCLUSIONS

A long term program of Mars analog studies can be progressively designed. The analysis of questions herein, defined into mission classes and themes, will help researchers to structure the program and understand the sequence in which investigations must proceed. Without this organization, the time it will take the international community to be ready to go to Mars will likely be considerably more. In about 15 Mars analog expeditions that research could be accomplished.

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