EXPEDITION ONE:
A MARS ANALOG RESEARCH STATION 30-DAY MISSION

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Expedition One was the first of a series of expeditions by a single crew to Mars-analog research sites around the world. Interdisciplinary studies in human factors, geology, biology, operations, and exploration technology required careful coordination among diverse groups and individuals. Research over the thirty days of the mission was organized into four Phases, which progressively linked to develop an integrated mission science scenario. Mars-analog rover, datalogger and suit technologies were tested while studying group processes and conducting task analyses to optimize extra-vehicular activity field work for an intensive geology and biology research program. Mars-analog studies classified according to three mission types are discussed, with examples. A description of the complete Expedition One program is given, with inclusion of the decisions made for the way the mission was organized and conducted, and preliminary conclusions are provided pending further analyses of accumulated data.

INTRODUCTION

The Mars Society of Canada and the Mars Society of Australia have initiated an international, interdisciplinary program to exploit the Mars Society's investments in Mars-analog research stations around the world.[1] The first step in this program, *Expedition One*, was to the Mars Desert Research Station (MDRS) in Utah, from February 15th to March 16th in 2003. Expedition One (ExOne), the 14th crew rotation at MDRS, was undertaken with the goal of expanding the scope and enhancing the thoroughness of Mars-analog studies, with an emphasis on improving the methods of field investigations and the fidelity of simulations at MDRS. From a science management perspective the strategy was to focus on factors and issues not previously studied, to do it in a manner that maximizes scientific results, and use the experience gained to build up a better mission science scenario in order to develop, in the long-term with further analog-expeditions, more realistic mission simulations.

MARS ANALOG INVESTIGATIONS

There are three classes of analog missions that can be done at any of the research stations. As defined by Persaud[1], they are: missions of discovery, missions of opportunity, and missions of investigation. The latter two are similar in that these both are investigative, but missions of opportunity typically focus on field science research or exploration technology assessments, and are usually funded separately from the institution managing the mission by outside research groups; while missions of investigation can be quantitative and/or qualitative studies, focusing on normal operations, and can be accomplished in short times within a long-term program establish by a single research group. Missions of discovery tend to be more anecdotal and circumstantial, focusing on interruptions, emergencies, stress, social-psychology, and off-normal operations, with the most significant results from studies conducted over several months or years.

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The 30-Day Expedition One was an intensive mission of investigation to pursue a specific suite of research. The research philosophy for Expedition One focused on science-driven expedition planning rather than technology-constrained exploration. This approach argues for the needs of science and scientists conducting field research to determine the characteristics of technology such as spacesuits, rovers and field equipment. For instance, for operational studies no assumptions were made about imaginary oxygen supplies determining how long an extra-vehicular activity (EVA) could be, and thus determining how much science could be accomplished. Instead, science operations were studied parametrically to develop improvements to the field science mission scenario, which once developed would inform the choices made for technological development. Parametric studies require focusing on operational factors independent from circumstantial conditions. Available oxygen supply or the use of suit to suit radios is circumstantial to the technology employed, reliant on the performance of a specific engineering design. A determination of how long an astronaut-scientist must be in the field to get a task done will properly determine the quantity of oxygen required. Science must drive the technology, not the other way around. With quantitative and qualitative investigations of what is needed for reaching science objectives, task analysis and work load studies will provide the operational metrics to which technology will be driven. Establishing the metrics of exploration is one of the chief objectives of Expedition One.

Other crews[*] have focused on holistic mission simulations in order to understand relationships and circumstantial factors that develop between and among crewmembers and processes as time, space, materials and energy within the habitat is used. Holistic mission simulations, as done during the past field seasons at the Flashline Mars Arctic Research Station[2] and MDRS (missions in which several ExOne crewmembers have previously participated), are missions of discovery. The goal is to discover what insights unexpected situations and unreliable technology can provide, and incrementally improve the fidelity of simulations. These scenarios have allowed research on human factors issues and habitat systems design, but despite some science objectives having been directed towards EVA field work, little long-term planning or coordination of geological and biological field investigations has occurred. Assumptions about technological constraints, operational procedures and protocols may be limiting conclusions in these types of holistic studies without any mission-to-mission situational controls or insights first obtained through parametric investigations.

On Devon Island with the NASA-SETI Haughton-Mars Project (HMP), the research program has been directed at several kinds of questions among Mars-analog sciences (geology, biology and geophysics).[3] “The opportunity of scientific field studies at Haughton is also used to support studies in exploration research, to investigate the technologies, strategies, human factors and hardware designs relevant to the future exploration of Mars by robots and humans.”[†] These may be classified almost entirely as missions of opportunity, for these depend on an annual ad-hoc conjunction of participants selected at the discretion of the PI, with funded projects from research institutions all over the world. The Haughton-Mars Project evolves from year to year, but does not appear directed towards or structured for integrating developed exploration strategies into a science mission scenario which may lead to dress-rehearsal expedition simulations.

The goal of Expedition One is to try a third approach, blending the best aspects of holistic mission simulations at MDRS and the investigative field science opportunities of the HMP, and to go beyond them by discovering what benefits a strongly coordinated set of focused missions of investigations might provide for increasing the fidelity of mission simulations. Each week was a distinct but progressively linked Phase of Expedition One.

DESIGNING THE EXPEDITION ONE RESEARCH PROGRAM

The NASA Reference Mission[4] describes plans for science EVAs on Mars to be performed every other day at most, with days between for planning, analysis, and reporting, and habitat systems maintenance. “Current NASA planning envisions sending a crew of six people to Mars… to conduct a

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[*] http://www.marssociety.org/mdrs and http://www.marssociety.org/arctic
[†] http://www.marsonearth.org

long-term expedition. The crew will spend a year and a half on Mars and will have considerable mobility, along with sampling and analytical capability, in an area of high scientific interest."[5] It is not necessary to apply these conditions (six crewmembers, EVAs every two days) to Mars-analog missions unless a mission of discovery was conducted to assess that specific scenario. For missions of investigation or opportunity, the program can be quite different. Even for a mission of discovery, the assumption that a crew of six is optimum and scheduling of EVAs should be limited to every two days at most can be tested and compared against many alternatives. A crew of six likely would consist of three or four field scientists at most, each of whom would have to be cross-trained to perform additional habitat maintenance duties.

For Expedition One, responsibilities were divided between a Field Research Crew and a Mission Systems Crew. There were at times as many as six field scientists present (including the Commander / Principal Investigator), allowing the EVA frequency to be increased to three or four per day, with time scheduled for lab work, communications and rest between simulated EVAs. These three geologists and three biologists were joined by four engineers, two human factors researchers, an Executive Officer (to manage the station as a base of operations) and a videographer for a total of fourteen crewmembers. The Mission Systems Crew had primary responsibility for maintaining the habitat and the equipment necessary for the Field Research Crew to be able to keep up with a hectic pace of EVA operational studies. These roles were not meant to be representative of an actual Mars expedition crew, but designed to accomplish the science program of ExOne. As such, holistic simulation studies within the habitat with this large crew were not appropriate in Phases One or Two, but as the number of participants were reduced to fewer crewmembers in later Phases, useful habitat simulations became possible.

Simulations of EVAs conducted by subgroups of the crew were studied throughout all four Phases. EVAs were studied on a task basis rather than holistically, in order to make observations such as measurements of the time required to explore an area, regardless of how many EVAs it took. Work efficiencies of EVA teams were investigated for two to five participants. Crew combinations were typically two geologists, two biologists or geologist / biologist pairings, usually with additional EVA team members, typically an engineer or two, to serve as field assistants, pilots, and safety officers. Once a realistic assessment of how much EVA-time it would take to explore an area within a 500-day mission is accomplished, combined with studies of optimized EVA crew mixtures, task loading and optimized science operations, only then a total expedition crew could be efficiently designed. The baseline for Martian expeditions that needs to be established is the conduct of EVAs, not work life in the habitat. This baseline will be established over the course of many seasons of Expedition-One-style missions of investigation. ExOne served as a useful trial of field methods to validate the approach.

After the crew was selected in August 2002, the geologists and biologists established a number of program goals relevant to the Mars analog region of Utah, and around these operational studies, human factors studies, and technology studies were planned by the human factors researchers and engineers. Operational investigations were structured to try different combinations of scouting strategies, mobility options, and exploration strategies for different terrain types, driven by the field science goals. Sampling methods, data-logging requirements, dexterity requirements, and level of expertise required in the field were assessed. Operational data was collected by non-participating observers using digital video cameras and personal digital assistants (PDAs) using TimerPro software[*]. Operational data is also obtainable from the EVA team's use of digital audio recorders, GPS units, data-loggers, digital cameras, and field notes. These EVAs were modular, kept to four-hour blocks of time, and could be rescheduled or cancelled due to circumstances such as poor weather.

A daily routine was tested: wake-up by 6 AM; crew briefing at 7 AM; morning scouting EVA teams out the airlock by 8 AM, returning by noon; midday lunch and EVA debriefings; afternoon science EVA teams out the airlock by 2 PM, returning by 6 PM; dinner and debriefings by 8PM, and the evenings reserved for personal time, with lights out by 11 PM. The crew was not confined to the habitat during the

[*] http://www.acsco.com/timerpro.htm

first two Phases, due to the lack of habitat simulation studies. For Phase Three, simulation protocols were established for the habitat, and in Phase Four these became strict.

The first two weeks of ExOne were entirely missions of investigation. During Phase One, the research crew experimented with EVA exploration technology, scouting operations, and field science. The primary aim was to identify the field exploration tasks that are needed to be accomplished during a mission, narrow those down to what is practical, and then integrate them into a holistic expedition simulation for the final rover-based week-long mission. Phase Two continued investigation of scouting operations, but also focused on science operations localized to sites identified by the field research crew to be of interest to the geology and biology programs. Phase One and Two were commanded by Rocky Persaud, the Principal Investigator for Expedition One, from the perspective of a cross-trained geologist and engineer. The desire to test alternative command styles led to the choice of switching commanders for successive Phases.

The third week consisted of missions of opportunity. Phase Three focused on field science itself, without further study of field operations, except for during the rover comparison study that took advantage of the presence of three analog pressurized rovers present at MDRS that week. Field science was accomplished using preliminary conclusions regarding the best exploration strategies and science operations tested during the previous two Phases. Phase Three was commanded by Shannon Rupert Robles, the Chief Biologist for Expedition One.

The fourth and final week, Phase Four, was comprised of two specific missions of discovery, one being based on crew activities in the habitat exploring alternative command styles, partly to train crewmembers for leadership responsibilities in future analog-expeditions, and partly to study was how the station crew relates to those operating on EVA in a variety of social situations; and the second being based on science operations conducted by a subset of the crew during a 5-day expedition in an analog pressurized rover.

Missions of discovery usually require long durations for significant results, at least for crew social-psychology studies, but by preceding Phase Four with a series of investigations, the short duration of this Phase could provide several generally useful insights. The daily routine at the station was made stricter for Phase Four, and a rotating commander or "crew nag" was chosen for a few days each: Chief Geologist Jonathan Clarke, Communications Engineer Stan Piechocinski, and finally Rocky Persaud once again for shut-down operations of Expedition One and preparing for the next crew to occupy the station. Each pursued a more consensus-based planning scenario, though each tended to emphasize different factors and protocols according to their personalities.

The 3-person week-long rover mission consisted of geologist/engineer Rocky Persaud, biologist Shannon Rupert Robles, and a rover-pilot / engineer / field assistant. The third rover crewmember was Jennifer Knowles for three days, and Matt Bamsey for two. These combinations of crewmembers were the most cross-trained and experienced of MDRS veterans available for the rover mission using the Everest vehicle[6] provided by the University of Michigan Manned Rover Project. Even though this was the first such week-long Mars-analog rover mission it was not held back by inexperience, as pre-Expedition training and the experience during prior Phases made possible the familiarization of crewmembers with the equipment and the optimization of exploration strategies. This allowed study of an integrated exploration strategy developed over the prior weeks.

EXPEDITION ONE GEOLOGY PROGRAM

Geology Goals

The following six goals were established prior to the expedition and provided the basis for exploration of the region surrounding the Mars Desert Research Station.

1. ***Develop an understanding of the variety of regolith in the area.*** Regolith is the surface material of the terrestrial crust and can be described as everything between fresh rock and fresh air. It includes

weathered rock, surface sediments, and volcanic materials. Regolith forms the surface of all the rocky and icy bodies in the solar system. Terrestrial and Martian regolith also contains ice and shallow groundwater. On earth (and perhaps Mars) biota also forms part of the regolith, and this, together with physical and chemical processes, forms soil. On both Earth and Mars understanding the regolith is vital because it is the material that is recording in remote sensing, hosts a range of resources, including water and ores, and provides the substrate for construction and mobility. On earth regolith is also the basis of plant growth and food production. The aim of the regolith study goal in Expedition One is to produce a regolith terrain map of the region. This map will be based on remote sensing, field observations, and use of the Portable Infrared Mineral Analyzer (PIMA)[7]. The map will document the distribution of regolith and landforms provide a basis for further research in geosciences and biology.

2. ***Develop a detailed understanding of the stratigraphy and structures of the region.*** The Jurassic and Cretaceous sediments of the MDRS field area contain a succession of non-marine to marine rocks whose architecture (stratigraphy and structure) are of considerable interest to both sedimentologists and economic geologists. The basin architecture is an important control of the distribution of rock types in three dimensions and is an important tool in understanding the distribution of coal, petroleum, uranium, and groundwater. Understanding the sedimentary architecture also provides important insights into the evolution of the basins in which these sediments were deposited. Basin architecture studies on Mars will likewise provide important insights into the evolution of Martian depositional basins. Data pivotal to understanding the basin architecture of the MDRS study area will be collected by mapping of the lithologies and structures and measuring stratigraphic sections through the succession. This data will provide a basis for more detailed geological investigations and analysis. A paper and a map of the geology of the area are the main products aimed for in this goal.

3. ***Develop an understanding of the depositional and diagenetic history of the succession.*** Previous missions have reported a diversity of sedimentary and diagenetic indicators, including vertebrate, invertebrate, and plant fossils, cross bedding, ripple marks, fossil soils, and abundant gypsum. Our goal during Expedition One was to systematically collect this information to determine information on the depositional environments responsible for the sediments, the flow directions of the currents responsible for their deposition, and the biotic communities extant on the surface during deposition. We also intended to understand the diagenetic processes that have affected these sediments, that is, those processes that have operated subsequent to deposition and prior to weathering. Of particular interest in this regard is the distribution of the calcium sulphate mineral gypsum, which is quite common in the area. Previous observations have described gypsum as occurring as bedded horizons, crosscutting veins, and as surface crusts. It will be an important part of understanding the depositional and weathering history to know which gypsum occurrences were deposited with the sediments, those that are the result of movement of subsurface brines or hydrothermal fluids, and those that are the result of modern, near surface processes. On Mars such detailed sedimentary and diagenetic studies will be an integral part of understanding the formation and history of sedimentary rocks.

4. ***Develop an understanding of igneous processes in the region.*** A number of igneous dikes have been reported in the region by previous explorers. As the opportunity arises, these will be mapped and sampled to determine their chemistry, distribution, and intrusion depth. Map and sample igneous dikes in the region, and determine if they are shallow or radial. Samples will be collected by all geoscientists as required, to be analyzed post-mission. The analyses will allow determination of the relationship of these rocks to various igneous complexes in south-eastern Utah, such as those of the Henry Mountains. Such studies provide a useful comparison to Martian exploration where samples collected on the planet by observers will be analyzed by others back on earth and provide information on the magmatic history and crustal and mantle evolution of the planet. At this stage the data will be kept in a database, pending for complete sample coverage from future expeditions.

5. ***Develop an understanding of the landscape history.*** Preparation of the regolith terrain map (geology goal 1) will also provide information valuable for the determining of the landscape history of the region. Of particular interest are the products of fluvial processes, such as channels, flood plains, and

gullies, which have extensively shaped the landscape. Also of interest are past and present aeolian processes and the resultant deposits of windblown sand and dust. The expedition aims to document occurrences and orientations of sand dunes, collect dust samples for both geological and microbiological study, perform granulometry on wind blown sand, and document with still and video photography the activities of dust devils. Both fluvial and aeolian activities are believed to be important shapers of the surface of Mars, past and present. Studies of terrestrial analogues will develop tools appropriate for their investigation on Mars and provide baseline data against which their Martian counterparts can be compared. All researchers will collect data into aeolian processes as the opportunity arises, and will be analyzed post-mission. Fluvial data will be incorporated, along with geomorphologic information, into the regolith paper.

6. ***Develop an understanding of water chemistry in the area.*** Groundwater is a key component of the MDRS environment. Seeps and springs are believed to have shaped the landscape through sapping, while the distribution of shallow groundwater and ephemeral surface pools are very important controls on the local ecosystems. Collecting preliminary salinity and pH data on such occurrences using hand held meters is the last goal for geological research. The data will be important for current research in both geology and biology. The resulting database will also be a precursor to later, more intensive hydrogeological studies.

Geology Research Classification

Investigations for the geology program of Expedition One were classified into different levels as follows:

Level Zero: the geological goals.
- Level One: products of the geological goals.
  - Level Two: investigating what data are we collecting, and what actions we need to produce.
    - Level Three: investigating what specific human skills are required to obtain the data desired and to deliver the actions desired; and how to technologically obtain the data desired and how to deliver the actions desired.

This classification scheme imparted structure to the program and determined during which Phase of the expedition a specific investigation should be studied. Below are the classified geology operational investigations up to level two. Level Three geological exploration operations goals are discussed in the Human Factors section. These were mainly studied in Phase One, but did extend into Phase Two at a lower priority. Level Two goals were studied mainly in Phase Two. Level One goals were given priority in Phase Three. Level Zero goals were to be achieved by the end of Phase Four.

Geology Program Operational Studies

1. Develop an understanding of the variety of regolith in the area
   - i. Produce regolith-landform maps of the area
     - a. Investigate the operational requirements of verifying each site for accuracy of regolith and landform interpretation – what observations need to be made, what samples collected, what measurements to be taken?

2. Develop a detailed understanding of the stratigraphy and structures of the region.
   - i. Map the structures and lithofacies in the region
     - a. Investigate the operational requirement for mapping structures and lithofacies – what observations need to be made, what samples collected, what measurements to be taken?

   - ii. Develop a structural model of the sedimentary basin in the region
     - a. Investigate the operational requirements for laboratory construction of a structural model – what observations need to be made, what samples collected, what measurements to be taken?

iii. Obtain measured stratigraphic sections
    a. Investigate the operational requirements for obtaining sections of strata – what observations need to be made, what samples collected, what measurements to be taken?

3. Develop an understanding of the depositional and diagenetic history of the succession.
    i. Study gypsum deposits to determine their origin
        a. Investigate the operational requirements for studying gypsum deposits – what observations need to be made, what samples collected, what measurements to be taken?

    ii. Obtain paleocurrent measurements from cross bedding, ripples, imbrication, tool marks, and flute casts.
        a. Study the operational requirements for obtaining paleocurrent measurements from each type of geological feature – what observations need to be made, what samples collected, what measurements to be taken?

    iii. Interpret paleoenvironments from the bedrocks
        a. Study the operational requirements for interpreting paleoenvironments from the bedrocks – what observations need to be made, what samples collected, what measurements to be taken?

    iv. Investigate the nature of weathering horizons and paleosols in the stratigraphic succession.
        a. Study the operational requirements for determining the nature of weathering horizons and paleosols in the strata – what observations need to be made, what samples collected, what measurements to be taken?

4. Develop an understanding of igneous processes in the region
    i. Map and sample igneous dikes in the region, and determine if they are shallow or radial.
        a. Study the operational requirements for mapping and sampling igneous dikes – what observations need to be made, what samples collected, what measurements to be taken?

    ii. Collect a representative suite of igneous rocks in the region.
        a. Study the operational requirements for collecting a suite of igneous rocks – what observations need to be made, what samples collected, what measurements to be taken?

5. Develop an understanding of the landscape history
    i. Study the geomorphology of the region.
        a. Study the operational requirements for performing geomorphology studies – what observations need to be made, what samples collected, what measurements to be taken?

    ii. Study fluvial processes – channels, flood plains, etc.
        a. Study the operational requirements for fluvial studies – what observations need to be made, what samples collected, what measurements to be taken?

    iii. Study past and present aeolian processes – dunes, dust mantles, and dust devils.
        a. Study the operational requirements for aeolian studies – what observations need to be made, what samples collected, what measurements to be taken?

6. Develop an understanding of water chemistry in the area
    i. Create a database of salinity and pH of the surface water and groundwater seeps.
        a. Study the operational requirements for water chemistry studies – what observations need to be made, what samples collected, what measurements to be taken?

EXPEDITION ONE BIOLOGY PROGRAM

Biology Goals

While the goals of the overall mission would change with each Phase, the biology program was designed to complement these goals while maintaining a focused experimental microbial ecology program throughout the four weeks of the expedition. The overall problem statement for our program was: *What is the capacity for microbial life to thrive in the area around the Mars Desert Research Station and what is the relationship between microenvironmental factors and water availability to the distribution of microbial life in a temperate desert?*

To answer this question, we developed five experimental goals. These goals were broadly defined in a program of dual focus, the diversity and the richness of microbial life around MDRS. For both, we looked at distribution and availability of water in the area for patterns of microbial life. The goals are listed here in no order of importance.

1. ***Determine the microbial diversity of microhabitats.*** Most Mars analog microbiological studies to date have focused on the search for extremophiles, and this is not without justification. Should there be life on Mars, it will most likely take the form of small, isolated microbial communities hidden either beneath the planet's surface or shielded in ice, remnant populations from an era when the planet was wetter and warmer. Evolutionary mechanisms such as natural selection and genetic drift should work on these populations and communities much as they do here on Earth. Populations separated in time and space should diverge into separate species and community composition should be altered due to microhabitat conditions. For this reason, we are interested not only in extremophiles, but also in the biodiversity of common bacteria and fungi surrounding MDRS, in order that we may understand what will be required on Mars to answer these complex evolutionary questions if the planet has maintained life. It is also important to analyze microorganisms in a terrestrial analog for comparison to a Mars with life. For this goal, we will look at the microbiology of the area using traditional methods, such as microscopy, gram staining and incubation and growth of cultures. We have developed a series of experiments to test sampling methods in order to determine the best approach for detection and collection of microbes both here and on Mars. The aim of this goal is to produce a snapshot classification of microbial life over the four week expedition in the form of a database identifying the differences in microbial communities of varying regolith types and based on our assumptions for water availability in each microhabitat we identify.

2. ***Determine the capacity for microbial life to thrive in the areas around MDRS.*** Richness is an ecological measure that determines the amount of life present at a given area on a quantitative level, rather than trying to identify the types or individual species of microbes present in a sample. When richness and diversity are both assessed, a biodiversity index can be produced which will illustrate the patterns of microbial biodiversity across a landscape. For this goal, we will determine the richness of microbial communities around MDRS using carbon dioxide output as a measure of respiration in a sample. Higher carbon dioxide output in a sample indicates greater richness, meaning a higher number of microorganisms present. Carbon Dioxide output is used as a measure of biological richness in the arctic for Global Carbon Models, and this technique is also utilized in desert ecosystems and so is applicable as a method of measuring respiration in Mars analogs. The protocols for this goal were developed and tested in 2002 at MDRS[8]. These data will be compared to last season's and included in the database referenced in biology goal number one. A comprehensive method's paper and an analysis of these data are the main products aimed for this goal.

3. ***Determine the relationship between microenvironmental factors and water availability to the distribution of microbial life in a temperate desert.*** We believe water will be the key component for finding life on Mars, just as it is here on Earth. For both richness and diversity, we use water availability to characterize the microbial communities that we study. Communities will be classified as either coming from a "wet" or "dry" area. Wet areas are those where water, when it becomes available, will linger and dry areas are those areas which receive minimal benefit from any available water. This will be important on Mars, where any water that may have historically been in the regolith has long since disappeared. The ability to determine the past history of water over a landscape will be necessary in order to understand the history of any microbial life we discover, both here and on Mars. The ability to trace water patterns will also assist in the search for possible life on Mars. We need to be able to "follow the water" and methods for this technique should be developed on Earth. The aim of this goal is to gather enough data to demonstrate that the area's microbial distribution is dependent on water resources and to produce a paper with this conclusion.

4. ***Determine the biogeochemical variety of the area.*** We will be working on ways to incorporate soil chemistry and composition into our study. We acknowledge that our assumptions of water availability over a dry landscape must be dependent not only on terrain features but also on regolith type. Only in this way will we have a clear idea of microhabitat characteristics. We will collaborate with Dr. Jonathan Clarke, ExOne's Chief Geologist, to define site characterization terms that will be used by both scientific teams. This will include regolith types and terrain features, in particular those which are related to the ability to utilize water. While the geologists are studying the environment around MDRS at the landscape scale and the biologists at a site-specific scale, these common descriptors allow us to use each other's data in a consistent manner. A photo dictionary of these common terms, along with the development of symbols for use by all scientists in the field, will be the main product of this goal and will be used by science teams in future expeditions.

5. ***Identify both temporal and spatial biological distributions.*** The National Science Foundation has acknowledged the value of studying microbial ecology, and to that end, has instituted a program of research devoted to the development of microbial observatories[9]. This program is designed to develop a network of sites all working toward the discovery of unique microorganisms, as well as studying the diversity and ecological processes of microorganisms in diverse microhabitats. In addition, these microbial observatories follow a LTER (long-term ecological research)[*] program while allowing for additional research specific to the environment of the study. The Mars Desert Research Station and the other Mars Analog Research Stations give us the unique opportunity to develop a worldwide microbial observatory based on ecological principles using the same research criteria as other LTER microbial observatories[†], within the framework of Mars Analog environments. We are collecting all of our data based on the requirements used to assess the long-term distribution patterns of microbial life at established microbial observatories around the world, and are applying those requirements to our study at MDRS. Continued collection of these data and development of a database for this purpose will be the outcome of this goal. We will use the database to demonstrate the value of designating MDRS, and possibly other analog stations as well (MARS-OZ[‡], FMARS[§], and EuroMARS[**]), as a recognized microbial observatory for Mars Analog studies.

Biology Research Classification

The investigations of the biology program for Expedition One were classified similarly to the geology program. Again, Level Three goals for biology fieldwork operations are discussed with the Expedition One Human Factors program.

Level Zero: the biological goals.

Level One: products of the biological goals.

Level Two: investigating what data we are collecting, what actions we need to produce.

Level Three: investigating what specific human skills are required to obtain the data desired and to deliver the actions desired; and how to technologically obtain the data desired and how to deliver the actions desired.

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[*] LTER Research in Microbial Ecology: A synopsis of microbial studies at LTER sites. J.R. Vande Castle, Editor. 2002. http://intranet.lternet.edu/archives/documents/reports/microbial_ecology/

[†] L. Blum, P. Groffman, J.Hobbie, C. Hopkinson, G.P. Robertson, J. Vande Castle. A Research Agenda for Microbial Observatories: A 1999 Perspective from Intensive LTER Projects. 1999. http://intranet.lternet.edu/archives/documents/reports/microbial_ecology/lter_me_whitepaper.html

[‡] http://www.marssociety.org.au/library/MarsOZ_Proposal-ver1b.pdf

[§] http://www.marssociety.org/arctic

[**] http://www.marssociety.org.uk/Downloads/pdf/euro-mars-europe.pdf

Biology Program Operational Studies

1. Determine the microbial diversity of microhabitats.
    i. Produce a survey/database of microbial diversity.
        a. Investigate the operational requirements for scouting and surveying for microbial diversity – what observations need to be made, what samples collected, what measurements to be taken?

    ii. Produce a survey/database/map of desert microhabitats in a variety of geological settings.
        a. Study the feasibility of effectively communicating geological information from the hab to the biology field scientist, and study what information must be supplied by the geology team to establish the proper context for biological investigations as requested by the field biologist.

2. Determine the capacity for microbial life to thrive in the area around MDRS.
    i. Produce a map/analysis of biological richness in the area around MDRS.
        a. Investigate how to measure the biological richness of a site.
        b. Study in situ and laboratory techniques for data analysis of microbial richness.
        c. Study to find the most effective means of measuring CO2 respiration in situ and in lab.

3. Determine the relationship between microenvironmental factors and water availability to the distribution of microbial life in a temperate desert.
    i. Discovery and characterization of microbial ecosystems in the desert environment.
        a. Study methods to effectively survey the past and present water distribution.
        b. Study sampling methods for microenvironments.

4. Determine the biogeochemical variety of the area.
    i. Map the biogeochemical variety of the area.
        a. Study what soil analysis procedures are the most effective in the lab.
        b. Study to discover most effective way of soil typing in the field. What data can only be obtained in the lab?
        c. Integrate area geology (escarpments, regolith, washes, and ephemeral basins) with geochemical analysis of soil types in order to determine the best sampling sites. Determine the best method of documenting samples collected for soil analysis. Determine locations to insert sampling devices.

5. Identify both temporal and spatial biological distributions.
    i. Map the temporal and spatial biological distributions.
        a. Study effective procedures for mapping temporal and spatial distributions.

Post-Mission Analysis of the Expedition One Biology Program

The following questions will be considered in evaluating the success of the ExOne biology program.

a. Did the sites selected adequately represent the biogeochemical variety of the area?
b. Did the sites selected adequately represent the microhabitat diversity of the area?
c. Construct profiles of biological activity in relation to geology
d. Identify both temporal and spatial biological distributions
e. Evaluate all methodology.
f. Evaluate the integration of biology with the science mission, and with Expedition One as a whole.

EXPEDITION ONE HUMAN FACTORS PROGRAM

The Human Factors program consisted of field science operational investigations; crew social-psychology studies based around group processes; an evaluation of various neuro-cognitive measures for determining crew performance; and numerous additional human factors questions as time and opportunity permitted.

Field Science Operational Studies

The goal of the field operational studies is to conduct basic work-study analyses using a combined approach of different job design methodologies.[10,11,12,13,14,15] These methodologies primarily being the use of methods engineering or work simplification to define how tasks are performed, work measurement to determine how much time is taken to perform tasks, ergonomic analysis to determine the physical demands of performing tasks, job analysis to determine inputs, outputs, resource requirements, and knowledge and skill levels for tasks. Additional research maybe conducted on the utility of temperament theory in the organization of work teams. This maybe combined with other socio-metric techniques to determine the best way to organize work teams. Information gathered from the work study are intended to lay the foundation for job design of MDRS crew members, organizational structure, and a systems view of MDRS core work processes.

Work measurement and methods engineering information was collected through the use of electronic time study equipment and videotape. Ergonomic data is to be collected through the use of heart rate monitor to determine work capacity. This information combined with work measurement data will be used to estimate the physical demand and fatigue for tasks. Job Analysis and the development of task inventory will be conducted through interviews with crewmembers, both collectively and individually. Identification of the knowledge, skills, and abilities required for each task is to be identified from the job analysis. Questionnaires concerning job design will also be employed while conducting the work-study.

Myers-Briggs Type Indicator questionnaires will be used to understand individual crewmember behaviour, and develop a team profile, the purpose of which would be to develop strategies to improve team performance.

Work measurement data is used to determine the time to perform various tasks. Times would be determined for specific tasks and their elements/ work steps. This information would be also be presented in terms of standard work simplification or methods engineering format to determine the breakdown of value-added and non-value-added work steps. Examination of the non-value added work steps would be used to devise means of improving work methods. The work measurement data would also be presented in ergonomic data format to determine which body positions, strength/motions, and muscle groups are used in performing tasks. The heart rate monitor data would provide the means of calculating oxygen demand and combined with the work measurement/ergonomic data a means of estimating fatigue for the tasks performed.

Group Processes

Over 25 years of research in social psychology has revealed that people function most cohesively and cooperatively in a group when they identify with that group.[16,17,18.] To identify with a group means that people internalise as their own the values, norms and beliefs that define the group. The degree to which an aggregate of individuals actually functions successfully as a group is dependent on the existence of a shared group or social identity.[19] The situation becomes more complex where the achievement of overall goals relies on cooperation between a number of isolated sub-groups.[20,21.] Positive group outcomes depend on the alignment of sub-group goals and those of the broader mission. Expedition One provides a unique and rich environment in which to examine these social relationships. In this research we will investigate the impact of group and sub-group identity and goal alignment on motivation, effort to achieve group goals, and effective communication both within a particular group and between subgroups (including "mission support"). In addition, a number of personal well-being measures will be included (e.g., stress, mental health). Participants will complete a regular (e.g., daily) on-line survey log incorporating measures of the variables of interest (all of which are part of our ongoing research program). The instrument will require approximately 10 minutes to complete. The main analysis will explore the statistical relationship between identification, group goals and group and personal functioning.

Human Factors Research Classification

For the purpose of uniformity the following goals are structured in a way similar to those for the Geology and Biology program.

Level Zero: the human factors goals.

Level One: products of the human factors goals.

Level Two: investigating what data we are collecting, what actions we need to produce.

Human Factors Studies

1. Develop a greater understanding of group processes at work in a Mars analogue setting.
   i. Produce a visual representation and data analysis of group function in Expedition One.
      a. Study & characterize *identification* by team members with sub-groups (eg. geologists, biologists), groups (eg. field science team; system team) and the superordinate group (the broader mission)
      b. Study & characterize *group goals* and *goal alignment* between sub-groups and those of the broader mission
      c. Study & characterize *group goals* and *goal alignment* between sub-groups and those of the broader mission

   ii. Produce a visual representation and data analysis of the impact of group functions on 'positive group outcomes'*, individual performance† (and optionally, stress‡) at Expedition One.
      a. Study & characterize the impact of group function on positive group outcome
      b. Study & characterize the impact of group function on individual performance (neurocognitive functioning)
      c. (Study & characterize the impact of group function on perceived individual stress)

   iii. Produce a visual representation and data analysis of the differences in group function between non-simulation (Phase 3) and full simulation (Phase 4) experiences in a Mars analogue setting
      a. Determine differences in group function between Phases 3 and 4
      b. Identify factors associated with differences in group function between Phases 3 and 4 (e.g. strength of identification with group/ sub-group
      c. Characterize possible linkages between a. and b.

2. Develop an understanding of the relative effectiveness of different neurocognitive measures for determining crew performance in a Mars analogue setting
   i. Produce profiles of crew neurocognitive function using WinSCAT[22], an established computerized battery used by crew on the ISS
      a. Collect data on working memory, divided attention & other neuropsychological functions

   ii. Produce profiles of crew neurocognitive function using CogState[23], a more recently developed computerized battery sensitive to subtle changes in cognitive function
      a. Collect data on working memory, divided attention & other neuropsychological functions

   iii. Produce a table and data analysis outlining the relative strengths and weaknesses of the instruments above as measures of crew neurocognitive performance

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* In operational terms **positive group outcome** is defined as perceived effectiveness of relationships and accomplishment of mission goals. Specific measures will be used for each of these.

† In operational terms **individual performance** is defined as performance on neurocognitive tests

‡ In operational terms **stress** refers to any challenge or condition that forces the regulating physiological and neurophysiological systems to move outside of their normal dynamic activity.

3. Develop an understanding of the human factors implications of operational methods for the geology, biology, engineering & other science teams.*
   i. Produce reports regarding how team members *work together* in the field as they perform the following investigations.
      a. Different traverse strategies for efficient scouting / surveying specific to each field science goal.
      b. Vehicle mobility options for scouting / surveying specific to each field science goal.
      c. Data-logging options for scouting / surveying specific to each field science goal.
      d. Spacesuit dexterity requirements for scouting / surveying specific to each field science goal.
      e. Options for sampling and measuring instruments specific to each field science goal.
      f. The level of expertise that is necessary in the field for each field science goal.

   ii. Produce reports regarding *workload* on science team members in the field as they perform the following investigations.
      a. Different traverse strategies for efficient scouting / surveying specific to each field science goal.
      b. Vehicle mobility options for scouting / surveying specific to each field science goal.
      c. Data-logging options for scouting / surveying specific to each field science goal.
      d. Spacesuit dexterity requirements for scouting / surveying specific to each field science goal.
      e. Options for sampling and measuring instruments specific to each field science goal.
      f. The level of expertise that is necessary in the field for each field science goal.

   iii. Use NASA TLX software[24], direct observation, video records and post EVA debriefs to inform the reports above.

4. Using data collected from HF goals 1-3 above as well as other methods, where time permits, contribute to answers to the following questions (from Persaud[1])

- How can humans, autonomous and tele-operated robots cooperate in field operations and field science?
- Do different personality mixes affect general or specific activities of the crew working as a team in the field?
- How do different personality mixes affect the working environment and social interactions of the crew within the habitat?
- What effects do different command structures have on habitat life, field work, EVA planning and debriefings?
- What is the optimum crew size?
- What is the optimum skill mix, or in what instances is particular skill mixes favoured?
- Are age and gender relevant factors?
- How much and what kinds of training should be provided?
- What social and environmental stresses need to be supported remotely by telehealth professionals?
- How does the crew adapt to the personal and social situation of extreme isolation, and how do they support each other in times of stress?
- How do Mars mission crews and Earth-based scientists *collaborate* on research questions?
- What variations on interaction between mission support and the crew prove most effective for which aspects of the mission?
- What are the strengths and weaknesses of having mission control centralized or distributed?

* These Level Two Human Factors investigations also comprise the Level Three Science Operations investigations for each goal of the ExOne Geology and Biology programs. They typically involve the technologies of spacesuits, rovers and dataloggers which were the focus of the ExOne Technology program. It is these interdisciplinary Human Factors studies which were most carefully coordinated, involving the interests of all researchers involved in Expedition One.

- What is the optimum periodicity on non-emergency interaction between the crew and mission support?
- What is the best way to obtain information from the field team?
- How does mission support handle circumstantial problems versus operational problems?
- What variation in report styles is effective in what situations?

Pre-Expedition Operational Factors Analysis

Before the expedition, an analysis of the operational factors (HF goal 3) was conducted for the geology and biology programs. Below are tables for five or the six operational factors. The sixth, the level of expertise required in the field, was intended to be observed in the field and pursued with questionnaires. The numbers heading each column corresponds to the numbered science goal. An "x" indicates that option or strategy needed to be studied for that science goal.

Table 1: Analysis of operational factors for program goals corresponding to HF goal 3a, 3b, and 3c.

Expedition One - Operational Investigations

	Geology Goals						Biology Goals				
	Regolith	Strata	Deposition	Igneous	Landscape	Water Chen	Diversity	Richness	Water Avail	Soil Studies	Time/Spatia
a. Traverse Strategies for scouting or surveying	1	2	3	4	5	6	1	2	3	4	5
Start from hab as base and use ATV to traverse	x	x	x	x	x	x	x	x	x	x	x
Start from rover as base and use ATV to traverse	x	x	x	x	x	x	x	x	x	x	x
Start from hab as base and use rover to traverse	x	x	x	x	x	x	x	x	x	x	x
Start from ATV as base and pedestrian traverse	x	x	x	x	x	x	x	x	x	x	x
Start from rover as base and pedestrian traverse	x	x	x	x	x	x	x	x	x	x	x
Start from hab as base and pedestrian traverse	x	x	x	x	x	x	x	x	x	x	x
Move swiftly between mapped points of interest without distraction		x				x			x		x
Leisurely wander between mapped locations of interest	x	x	x	x	x	x	x	x		x	
Systematically sweep area for interesting features	x	x	x	x	x	x	x	x	x	x	x
Follow topographic controls	x	x	x		x		x	x	x	x	x
Avoid or navigate around topographic controls		x	x		x		x	x		x	x

	Geology Goals						Biology Goals				
b. Mobility options for terrain to be scouted or surveyed	1	2	3	4	5	6	1	2	3	4	5
Allows broad coverage	x	x	x	x	x	x	x	x	x	x	x
Allows access to gullies	x	x	x			x	x	x	x	x	x
Allows access to soft sand	x	x	x		x		x	x	x	x	x
Allows access to steep hills	x	x	x				x	x	x	x	x
Allows access to cliffs	x	x	x				x	x	x	x	x
Allows access to channels					x		x	x	x	x	x
Allows access to floodplains					x		x	x	x	x	x
Allows access to salt pans			x			x	x	x	x	x	x
Allows access to exposed strata		x	x				x		x	x	x
Low speed for discovery (ie. of sedimentary structures)			x				x	x		x	

	Geology Goals						Biology Goals				
c. Data-logging options for scouting or surveying	1	2	3	4	5	6	1	2	3	4	5
Record location	x	x	x	x	x	x	x	x	x	x	x
Record altitude	x	x	x	x	x	x	x	x	x	x	x
Record orientation	x	x	x	x	x	x	x	x	x	x	x
Photograph site before sampling	x	x	x	x	x	x	x	x	x	x	x
Photograph site after sampling	x	x	x	x	x	x	x			x	
Record environmental conditions (temperature, pressure, wind speed)					x	x	x	x	x	x	
Record time	x	x	x	x	x	x	x	x	x	x	x
Record traverse path / profile	x	x	x	x	x	x	x	x	x	x	x
Record audio comment	x	x	x	x	x	x	x		x	x	
Record when/where task performed (sample taken, picture taken)	x	x	x	x	x	x	x	x	x	x	

Table 2: Analysis of operational factors for program goals corresponding to HF goal 3d.

	Geology Goals						Biology Goals				
	Regolith	Strata	Deposition	Igneous	Landscape	Water Chem	Diversity	Richness	Water Avail.	Soil Studies	Time/Spatia
d. Spacesuit dexterity requirements for scouting or surveying	1	2	3	4	5	6	1	2	3	4	5
Walk 100's of meters over rough terrain	x	x	x	x	x	x	x	x	x	x	x
Handle geology hammer	x	x	x	x	x		x	x	x		
Handle sledge hammer				x	x						
Handle shovel	x	x	x	x	x	x					
Handle mattock	x	x	x	x	x	x					
Handle scraper	x	x	x	x	x	x					
Handle soil corer								x	x		
Handle variety of sampling devices							x		x		
Handle scoopula								x			
Use thermister							x	x			
Use GPS unit	x	x	x	x	x	x	x	x	x	x	
Use photographic camera	x	x	x	x	x	x	x	x	x	x	
Use video camera	x	x	x	x	x	x	x			x	
Use audio recorder	x	x	x	x	x	x	x		x	x	
Use suit radio system	x	x	x	x	x	x	x	x	x	x	
Use PIMA	x	x	x	x	x	x					
Use Geiger counter	x	x	x	x	x	x					
Use gamma-ray spectrometer	x	x	x	x	x	x					
Use magnet susceptibility meter	x	x	x	x	x	x					
Use pH meter						x	x	x	x	x	
Use salinity meter						x	x	x	x	x	
Use Soil Charts							x	x	x	x	
Use hand lens	x	x	x	x	x	x	x	x		x	
Use acid bottle	x	x	x	x	x	x					
Use scratch tester	x	x	x	x	x	x					
Use field magnet	x	x	x	x	x	x					
Use compass/clinometer		x	x	x	x	x					
Record written observations	x	x	x	x	x	x	x	x	x	x	x
Record spoken observations	x	x	x	x	x	x	x	x	x	x	x
Collect samples and place them in sample bags or jars.	x	x	x	x	x	x	x	x	x	x	
Carrying capacity and load handling	x	x	x	x	x	x	x	x	x		

Table 3: Analysis of operational factors for program goals corresponding to HF goal 3e.

	Geology Goals						Biology Goals				
	Regolith	Strata	Deposition	Igneous	Landscape	Water Chem	Diversity	Richness	Water Avail.	Soil Studies	Time/Spatia
e. Instrument options for sampling and measuring	1	2	3	4	5	6	1	2	3	4	5
Shovel	x	x	x	x	x	x					
Mattock	x	x	x	x	x	x					
Scraper	x	x	x	x	x	x					
Geology hammer	x	x	x	x	x	x	x		x	x	
PIMA	x	x	x	x	x	x					
Geiger counter	x	x	x	x	x	x					
Gamma ray spectrometer	x	x	x	x	x	x					
magnet susceptibility meter	x	x	x	x	x	x					
GPS	x	x	x	x	x	x	x	x	x	x	x
Colour scale for images	x	x	x	x	x	x					
Photographic camera	x	x	x	x	x	x	x	x	x	x	x
Video camera	x	x	x	x	x	x	x			x	
Hand scale	x	x	x	x	x	x					
Jacob's staff	x	x	x	x	x	x					
Zip locks for hand samples	x	x	x	x	x	x	x		x	x	
Jars for samples	x	x	x	x	x	x	x	x	x		
Tear off Sample tags	x	x	x	x	x	x					
Compass/clinometer or Brunton compass		x	x	x	x	x					
100 m measuring tape		x	x	x	x	x					
Sledge hammer				x	x						
Zip locks for large samples				x	x						
Dust collectors					x						
pH meter						x	x	x	x	x	
Salinity meter						x	x	x	x	x	
Soil Corer								x			
Collection box							x	x	x	x	
Scoopula								x			
Robotic sampling									x		

The basic geology and biology goals explored during Expedition One were picked for their relevancy to the region surrounding MDRS. There is enough variation among the goals such that the science operations for each, as analogs for other science goals not studied but which have similar field operations (mobility requirements, terrain traverse strategies, dexterity requirements, data-logging needs and tools employed), can be extrapolated to the pursuit of most any question on Mars.

EXPEDITION ONE TECHNOLOGY PROGRAM

The engineers of Expedition One designed a technology program based around working prototypes of Mars-analog technologies: rovers, dataloggers and suits.

Comparative Rover Studies

The availability of three analog rovers - the Queen's University ARES[*], the University of Michigan Everest, and an SUV dubbed the "Aonia PEV" by a previous crew[25] - plus research crews at Expedition One offered an unprecedented chance to evaluate these human-machine systems in realistic exploratory settings.[26] During EVA scenarios in Phase Three, these systems were decomposable into a set of task requirements involving one or more human-machine subsystems (*task-subsystem pairs).* These were exercised during simulated sampling missions, in which the same crew performs the same tasks using each rover in turn. Associated with each pair will be task-related measures, including time to completion, a set of ten-point usability scales and the NASA Task Load Index (TLX)[24]. Tasks were repeated to improve the reliability of these measures. This is not a competition between rovers or crews resulting in a winner, but rather an effort to take advantage of the natural design variations in independent rover projects, to learn what does and does not work for such vehicles in the field. In the case of a subsystem not being available on all rovers, descriptive observations of the task-subsystem pair will have to suffice. If the same methodology is later applied to the Starchaser Marsupial rover in Australia[27], it will become possible to write the world's first comparative assessment of four Mars analogue vehicles - essential reading for the future designers of real flight hardware.

Data-logging Studies

In the field, scientist-astronauts will have to gather information for a wide variety of scientific questions for relay back to Earth. Given the restrictive conditions of Mars regarding radio time-delay back to Earth, and lack of an atmosphere conducive to traditional field note-taking, a device such as the Astronaut EVA Datalogger[28] produced by the Mars Society of Canada will be needed to acquire, archive and transfer a variety of scientific and operational information.

Expedition One data-logging investigations aim to gather evidence for/against the hypothesis that an integrated data-logging system will benefit the EVA aspect of a human Mars exploration mission by:

1. Reducing astronaut time required to write reports detailing EVA activities due to the integration of audio, photo and GPS records available from the data logger.

2. Providing a single interface for recording multiple data streams.

3. Easing management of data gathered during an EVA due to its single point of access for archives of multiple streams of information.

4. Increasing astronaut time available during EVA for scouting/science by automatically recording certain data types (e.g. GPS)

5. Allowing better decisions to be made regarding priorities for revisiting scouted sites (due to more, integrated information about each site).

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[*] http://engsoc.queensu.ca/ares/

6. Keeps EVA records in a standard format (benefiting both mission supporters who will receive this data as well as others who may scan through this information at a later date).

Space Suit Studies

Space suits are a vital aspect of every EVA. As such, the performance of the suit is essential to a successful manned mission to Mars. Current spacesuits may not be used on Mars due primarily to flexibility and weight issues. Mechanical Counter-Pressure suits[29], however, may be used due to their superiority in these and other areas. While new MCP developments have produced effective gloves, the practical advantage over conventional gas-filled gloves is yet to be explored. Expedition One offers the chance to study a new MCP glove and simulation MCP suits in a Mars-analog context. It also offers the chance to analyze suit function as a stand-alone product and as an element which must integrate into other technologies of the mission.

1. Current MCP developments have produced a functioning glove, one of which is available. The ability to perform tasks with the MarsSkin glove and the Honeywell glove can be compared to determine the success of the analogue glove. Some experiments will be carried out beforehand, such as mobility, dexterity and finger deflection studies, but this mission offers the chance to explore the glove function in very realistic tasks. The glove, of course, is the most vital aspect in providing functionality to an astronaut and so the focus on hand studies is highly relevant and a key indicator for the whole suit.

2. Every aspect of suit usage should be understood, and data formed on how the suit affects the astronauts abilities. From the mo ment of donning, through mission activities, until doffing and stowage, the suit is an integral and vital aspect of EVA. Hundreds of questions can be raised, covering topics of glove flexibility, suit flexibility, data logger issues, suit durability, helmet visibility and performance, Personal Utility Life Support System (PULSS) backpack performance etc. Through first and third person experience, these aspects can be attained.

3. With gathered data/knowledge/opinion, improvements can be analyzed in both the suit and other technologies. This step is designed to optimize the suit, and optimize the interaction of the suit with other technologies. For example, what minimum diameter should all handles be on tools? What size buttons should be used (on the suit and other EVA devices), and what spacing should be allowed between each? These extrapolations can then be used to create a database of knowledge for future suit and mission design.

The Integrated Technology Program

The ExOne technology program consists of suit, datalogger and rover investigations integrated with human factors studies of field scientists using these technologies in the context of the geology and biology research programs. The following were the stated goals of technology investigations:

1. Understand how the set and configuration of systems on the Aonia, Everest and ARES rovers aids or inhibits the identification, collection, labelling and storage of regolith samples.
    - ii. Comparative tables of qualitative and quantitative sampling performance outcomes for the two vehicles, with the same crew, performing the same sampling tasks.
        - b. Which sampling performance measures (number, volume per unit time; accuracy of labelling bagging; assessed areo/biological value over all samples) form the best index of technological sampling support? How many sampling acts are needed to produce a useful measure?
            - i. Study how different sampling strategies interact with this comparative study (no more than three).
            - ii. Study ease/difficulty of use associated with rover equipment layout and design by post mission survey
            - iii. Study spacesuit dexterity requirements for sampling of this kind.
            - iv. Investigate options for sampling tools and containers for this kind of sampling activity.

2. Determine the benefit of data-logging to site scouting by having different EVA teams visit the same site with 0, 1, or 2 data loggers. Evaluate each scenario for:
    a. The datalogger interface
    b. Data management convenience
    c. Report writing times
    d. EVA time available for scouting and site science
    e. Usefulness of datalogger records for future site selection
    f. Usefulness of EVA records for site evaluation by field scientists and mission support

3. Study the MarsSkin suits and compare them with the existing MDRS analogue suits in detail. Four elements were examined during the Ex-One mission:
    a. the accuracy of the MarsSkin analogue suit in comparison to actual MCP garments
    b. the degree to which the suit can impact and assist geologist/biologist/engineer astronaut performance
    c. the comparison of the MarsSkin suits with the MDRS suits (qualitatively and quantitatively)
    d. and, by analyzing all the above, improving the suit design and effectiveness during EVA.

DISCUSSION

Phases One and Two – Operational Investigations

The first Phase of Expedition One was successfully launched on Feb. 15th with the arrival of the crew at the Mars Desert Research Station. Two days of training ensued in the various systems of the habitat, the field equipment, and field science protocols. MDRS is a work in progress, gradually being upgraded from season to season, even mission to mission, as inadequate or worn-down equipment is replaced and the habitat is improved. Despite not having the previous crew on hand to help familiarize the ExOne crew with current hab systems, training went well as we did have several experienced crewmembers who have been to MDRS before to tutor the rest on use of the MDRS spacesuits, ATVs, safety protocols, and most habitat systems such as water, power, and plumbing. The Expedition One crew was probably the most well-prepared group to ever use any Mars analog research station. The unusually large size of the crew required additional considerations that other crews have not faced.

On Monday, February 17th, the ExOne research program was initiated with studies in scouting strategies, tool use, geologist-biologist-engineer work relationships, comparative spacesuit studies, data-logging and information management, and crew psychology research. On Saturday, February 22, 2003, Phase One ended in the evening with a 3-hour debrief after dinner, and finally with the excitement of the arrival of the ARES, one of the two analog pressurized rovers to be tested during ExOne.

Phase One had 24 EVAs planned for a six-day period, with 2 EVAs every morning, and 2 EVAs every afternoon. With a field crew of six scientists, this allowed each of them to have one EVA per day, except every third day on which one would have two EVAs. Before research began, the joint Commanders of Rocky Persaud (Phase One and Two) and Shannon Rupert (Phase Three) decided to switch to a schedule of just 3 EVAs per day, to account for the learning period it took to become efficient at preparing for EVAs, as well as for the lack of the two Mars-analog rovers that were expected to arrive on the first weekend of the mission. It was foreseen that pre-planned EVAs could be rescheduled on an *ad-hoc* basis during Phases 3 and 4. Such a managerial strategy will be needed on Martian expeditions to minimize disruption to carefully planned research. The modular nature of our EVAs allowed an easy adjustment to the new schedule, and the crew appreciated the extra time to process data after their EVAs and perform laboratory analysis. Of the 24 planned EVAs, the eight rover-dependent EVAs were cancelled or moved to later Phases, leaving just 16 EVAs performed during the first week.

All EVAs were video-recorded by the videographers, and work analysis and tool use analysis was performed by the human factors officers to measure the frequency and time of certain tasks and procedures in the context of scouting and science operations. All this data will be analyzed over the next several months.

The scouting strategies that we investigated included variables such as the geologist/biologist pairings, mobility options such as pedestrian, ATV and rover mobility, terrain types, spacesuit dexterity requirements, and data-logging requirements. It was found to be more effective to have a geologist and biologist paired together to scout for sites, as they can work together and share their expertise, but when settling on a site for detailed study, it was better to use a geologist-geologist pair, or a biologist-biologist pair, but not mix the two disciplines, as the goals of these typically did not provide similar operational strategies for surveying an area. The geologists and biologists had fundamentally different ways of collecting data. Since many of the protocols for the biological experiments had been developed during the prior year's field season at MDRS, many of the biology protocols were established before the start of the expedition, making operational studies for them straight-forward, while the nature of geological field work did not allow for immediate conclusions to be made about geology operations. In the coming months careful analysis of human factors data from the work measures studies, the EVA videos and the available datalogger records should reveal unanticipated insights. Several papers will result from analysis of the human factors and operational science data.

Expedition One allowed for the comparison between 2 different analogue suits: the standard MDRS suit (which simulated current gas-bag technology) and the MarsSkin 2 suit (which simulated elastic skin suit technology, or mechanical counter-pressure). The MarsSkin suits were found to be less bulky and more comfortable to wear. The visibility afforded by the helmets was also far greater than the MDRS helmets due to the fact that the helmet (and therefore the visor) moved with the head and eye-line. The pockets on the MarsSkin were easily viewable by the wearer - impossible in the MDRS suits. Overall, these factors allowed EVA astronauts to walk, climb and ride the ATVs more effectively (and safely) than the standard suits, while also allowing sampling and scouting to be easier and more efficient. The MarsSkin backpack was much smaller than the MDRS suit, primarily because it did not have a ventilation system to the helmet and a suitably sized analogue breathing system. Backpack weights between the MDRS and MarsSkin suits were similar, however, due to the laptop computer datalogger systems carried by the MarsSkins. The helmet ventilation deficiency of the MarsSkins caused breathing troubles with some wearers despite some natural airflow through the helmet as they were not perfectly air-tight. The helmet, while offering much better visibility, was deemed unrealistic due to the fact that it relied on a flexible (but gas-pressurized) neck section. Gas-pressurization would of course make such a section stiff. Future MarsSkin versions will require the traditional fishbowl style helmet, which will also increase the perception for the wearer of donning a true pace suit style garment. Improvements to the accuracy of the backpack will also need to be made.

The gloves were a particular issue to the EVA astronauts: the MDRS gloves were big and bulky, while the MarsSkin gloves were more form-fitting. A study was performed to measure the performance of these gloves and others to attempt to quantify the difference. Simple repeatable tasks in biology, engineering, typing and geology were performed (with prior familiarization) by at least 6 subjects with the naked hand, the MDRS gloves, the two versions of MarsSkin gloves (wetsuit style and liner/outer) and actual MCP gloves and outer. The MDRS gloves were found to be about 2.7 times slower than the naked hand (average for all tests), while the actual MCP gloves were about 1.6 times slower. Of the two MarsSkin gloves, the liner/outer combination was found to be the better mimic at about 1.5 times slower than the naked hand. Of the four tests, the geology test of picking up and bagging rock samples was impacted the most by glove type, while the biology test of scooping soil into a beaker was found to offer the least variation.

Phase Two was intended to focus more on science operations rather than exploration operations or tools. About 10 of the 24 pre-planned Phase Two EVAs were successfully accomplished, as well as several additional "EarthSkin" EVAs that had not been planned prior to the launch of the expedition. The weather was a major contributor to the lack of opportunity for EVAs, negatively impacting the progress of research into science operations. No immediate conclusions about science operations can be made until the operational data is assessed. We caught up with the studies on science operations during Phase 3 and Phase 4, focusing on just science operations in relation to use of the two rover vehicles. By the end of the expedition, 38 of the 48 operational investigation EVAs from the first two Phases were completed. Full details of the results will be presented elsewhere after analysis of the video, PDA, datalogger, GPS, photo and audio data is concluded. An estimate of the quantity of data available for study is on the order of 5000 gigabytes, mainly video in digital form.

The use of a crew much larger than what would be realistic for an actual Martian expedition (for reasons stated above) offered several advantages. By having a Field Science Crew to do research and the Mission Systems Crew to take care of daily maintenance and engineering support, for every EVA we did during first two weeks of the expedition, we might consider it the equivalent of two days on Mars. With three to four EVAs per day, in some respects (like science return) one day on the Expedition might be argued to be the equivalent to one week of a holistic mission simulation. Phases One and Two could have gathered about the same information in EVA field work as a 15-week simulation, or 150 days on Mars. In reality though, inclement weather did force a cancellation of some of the scheduled EVAs. Nevertheless, if a Mars mission is on the order of 500 days, then after our Expedition via extrapolation from the operational data we will have some idea about how much can be accomplished during a long surface stay by a crew of a similar skill complement.

Phase Three – Mars Analog Science and Missions of Opportunity

The handover of command from Rocky Persaud to Shannon Rupert Robles was accomplished on Sunday, March 2nd for the beginning of Phase Three. It was an unqualified success in terms of the crew setting their own goals and accomplishing them. Pre-planning for Phase Three was not as extensive as it was for Phases One and Two. The intent was for individual researchers to come up with their own research objectives prior to the start of the expedition. Those goals were then shared between crewmembers and used as an planning tool. Once we were at MDRS, the crew, in daily planning meetings, determined how to meet these goals. This task driven approach was used in contrast to the heavily structured first Phases in order to best implement the lessons learned during the first two weeks. Flexibility in both research and approach to research was required. There was very little conflict over how to accommodate each crewmember's goals in terms of EVA scheduling. Two EVAs per day were planned each evening for the following day. In most cases, while a single crewmember's goals were given priority for an EVA, we were able to accommodate another's goals as well, by slight adjustments in site selection, transportation/equipment used and/or participants involved. The experience gained in the first two phases was critical here, as the crew was able to quickly organize and execute successful EVAs. Also critical was the use of a pre-planning document. Being able to refer to the pre-planned goals reduced the minimal conflict that resulted from crewmembers wanting to plan EVAs based on goals that were not disclosed prior to the expedition. One additional task was to produce a short report after each EVA, something that had not been necessary before Phase Three. This addition to the workload was compensated by the flexibility of this approach to EVA planning, which increased productivity in the field and also allowed for last minute changes due to new discoveries and weather effects.

The comparative rover test of three analog pressurized rover vehicles was completed and is reported elsewhere.[26] The datalogger studies were also completed this Phase, and a paper has been produced.[28]

The techniques of regolith-landscape mapping[30] have been developed in Australia in recent years proved readily applicable to the landscape at the Mars Desert Research Station in Utah. The study clarified the origin of much of the gypsum in the landscape noted by previous teams at MDRS, showing that, apart from that occurring in the Summerville and Morrison Formations, the gypsum is of weathering origin. An understanding or regolith processes and especially the mineral identification provided by the Portable Infra Red Mineral Analyser (PIMA) was of considerable value in documenting the environments for the biological program. Other results include confirmation of widespread sapping processes, as well as runoff, in the shaping of the landscape, and the very high salt content of the Brushy Basin member being responsible for the unusually barren aspect of the immediate environs of the MDRS hab. A detailed regolith landform map of the field area is in preparation.[30] As well as the science aspects, the regolith program demonstrated that the abundance of swelling clays in the regolith at the hab site itself is the cause of the extensive drainage problems associated with the waste water disposal system.

Enough data were obtained to complete a study of the Dakota sandstone formation for Melissa Battler's senior year undergraduate research project. A full assessment of the geological data for the other goals is yet to be completed.

A realistic estimation over the entire expedition for the productivity of the biology team, which consisted of seven biologists and one geologist, would be equivalent to a four-month field season for a single researcher, given that on-site participation by each scientist varied from one to four weeks. This productivity measure does not include the lab work and analysis done by crewmembers after the expedition and does not take into account the productivity values mentioned above. For examp le, while Phase One and Two had more scheduled EVAs than Phase Three and Four, the possibility that our techniques and methodology were much improved over the course of the expedition can not be discounted. Earlier crewmembers tested and refined methods that later crewmembers used to increase overall productivity of the research.

An incidental goal of the biology program was to look at ways a team as large and diverse as ours could implement our unified goals. There was a single set of protocols for the entire expedition, based mainly on ecological methodology, but including microbiology, soil chemistry and tentatively, molecular biology. While we had team members who specialized in each of these, none of us was an expert in all disciplines and so we learned the skills we needed from each other. In addition, the team was set up so that there was a lead biologist for each phase, generally someone who had been on site for the previous phase and who could in turn instruct new team members. Overall, this approach was successful and the larger, more diverse team encouraged an increase in the scope of our research, the result which was the collection of more varied data than anticipated at the beginning the expedition. One geologist, J. Clarke, was included as a member of the biology team due to his expertise in regolith terrain mapping. His assistance, and ultimate documentation, of the soils around MDRS proved invaluable in our research.

A full assessment of the biology data for all goals is yet to be completed. These results will be reported elsewhere.

Phase Four – Missions of Discovery and Science Operational Scenario Integration

One interesting issue in the human factors of Mars missions is whether or not the traditional rigid command structure with its military heritage is both relevant and suitable on a long duration space mission involving a small number of crew who have worked together and cross trained for several years before hand. Alternative paradigms of decision making should be investigated in places such as MDRS. This approach was recommended by researchers at the Australian National University's psychology department and Dr Steve Dawson who carried out social psychological research during Expedition One.

With the full agreement of all Phase 4 personnel, we conducted such an experiment. In addition to trying to employ the consensus approach used by some other crews and Phases, we have also rotated the position of "commander" to create a broader leadership base and to reduce the responsibilities placed on any one person. Rather than a traditional commander role this person (irreverently called the "hab nag") facilitated discussion and ensured that tasks were begun on time. The fact that the experience worked very well bodes well for the utility of this approach for future crews and expeditions.

Another issue on long duration missions is workload. Previous Phases of ExOne, as have previous crews, experienced heavy workloads, with people working well into the small hours. This soon leads to reduced performance and irritability and can endanger not only performance but health and safety. Experience on a succession of space stations such as Skylab, the Salyut series, Mir and now the ISS has shown the importance of keeping workload within reasonable limits. Since Phase 4 was a holistic simulation mission we attempted to do likewise. We have endeavoured - and generally managed, to rise by

7am and to complete work by 10pm each night, as well as schedule recreation time. Despite this we averaged two EVAs per day for science and engineering purposes. Less work can lead to more productivity, and we believe that this approach, which requires planning and self discipline, is worth following on future missions.

The 5-Day Everest rover mission was judged to be very successful by the participants. A geologist-biologist-engineer team of three can efficiently scout out a large area at some distance from the main habitat to accomplish a science program limited to a few goals: stratigraphy and microbial richness studies. The mission scenario tested was for long-ranging rover-based scouting over hilly terrain (on pathways graded by the U.S. Bureau of Land Management), with several EVAs conducted for surveying sites identified for their geological and/or biological features of interest. Under EVA simulation conditions, a stratigraphic section of the Salt Wash region was partially completed, and several sites were sampled for microorganisms. Hundreds of photographs (of varying quality) of the terrain scouted, focusing on signs of water, biological life, and geological structures, was obtained for assembly into a visual reference from which further site selection could be accomplished. The results are reported elsewhere.[31]

CREW SOCIAL-PSYCHOLOGICAL ISSUES

During Expedition One a range of psychological measures, informal observation, crew discussion and other means were used to collect information about crew psychological issues. The overall goal of the psychological studies was to gain insight into crew individual and group issues that may be relevant to a human mission to Mars or other prolonged human spaceflight. Another goal was to gather information relevant to improved functioning for future MDRS crews. Most of the comments below relate to Phases Three and Four, when the majority of data collection took place, but some is relevant to the entire mission.

Major psychology research findings from ExOne will be reported in future publications once data can be properly analyzed. The purpose of the current document is to summarize the measures used, impressions regarding outcomes of the studies and recommendations/implications for the future.

Formal Measures - Social Psychological Measures

All crew members completed a questionnaire entitled "Personal and Group Functioning Survey". This instrument was developed by social psychologists Dr Kate Reynolds & Dr Rachael Eggins at the School of Psychology, Australian National University. It is based on an extensive literature and research on issues of group identity and goal alignment conducted by the Social Psychology Research Unit at ANU. It aims to help determine the extent to which crew members on ExOne identified with ExOne overall as well as with subgroups such as Field Science and Mission Systems. In turn it aims to measure the degree to which crewmembers aligned their personal goals with the overall ExOne group and it's subgroups. Crewmembers in Phases Three and Four completed the questionnaire three times each week. The data will be analyzed back at ANU and results published.

Neurocognitive Measures

All crewmembers also completed a brief, computerized measure of cognitive performance called CogState.[23] This measure was developed by a team of neuropsychology researchers in Melbourne (now incorporated as CogState -- see cogstate.com) who sought to provide sensitive measures of changes in neurocognitive status. Crewmembers in Phases I and II completed CogState one or more times while those in Phases Three and Four completed it several times per week. Data will be analyzed as a separate neuropsychological study as well being incorporated into the social psychology study.

Personality Measures

To supplement measures of group and individual function, all crewmembers from Phases Three and Four completed the AstroPCI personality battery. This battery has previously been administered at MDRS by Ephimia Morphew in collaboration with Assoc. Prof. Sheryl Bishop of University of Texas Medical Branch. Prof Bishop kindly agreed to also collaborate on ExOne personality measures. The measures are currently used to assist in the "select in" phase of astronaut selection for NASA.

Observed Issues for MDRS - Adaptive Capacity

During Phases Three and Four, Dr. Dawson reported his amazement of the adaptive capacity of this large and diverse crew. In Phase Three there were 13 people living and working together in the confines of MDRS, part of that Phase involving full simulation conditions. The crew managed to adapt quickly to these conditions, work effectively and largely with good cheer. This says a great deal about the quality of the individuals who participated on ExOne and also about the benefit of extensive preplanning in preparing people to work effectively in difficult conditions. The clarity of goals achieved both as a group and individually prevented what would have almost certainly been an otherwise chaotic start to ExOne.

Initial Bonding

Also impressive was the unusually rapid development of rapport and friendship between crewmembers at the beginning of each Phase of ExOne. After discussion with crew, it seems this was largely due to the extensive planning by Rocky Persaud and the frequent interaction between crewmembers by internet and phone during the planning stages. It would seem there was already a strong sense of shared identity and goals before people met each other in person.

Factors in Interpersonal Conflict

Despite the best intentions some conflict occurred on occasions although it was generally mild in nature and quickly resolved. Most interpersonal conflict occurred late in the day when crew were tired, very busy and hungry. On occasions when conflict occurred, careful debriefing was carried out during the regular team meetings. The debriefings revealed that, on most occasions, conflict was due to failure to communicate each others' intentions or perspectives. In turn effective interpersonal interaction was undermined on occasions by problems in communication, usually due in turn to technical difficulties with communications equipment.

Where the problem was not specifically communication as such, tension seemed to be due to difficulty for crew in being able to understand the needs and priorities of other crew. This was particularly apparent during transition times eg. rover arriving back at the hab. On some occasions, including one following an extended rover mission, there appeared to be a sense of "us" and "them", a sense for those in the hab of their space being intruded upon and for those in the rover of their needs not being appreciated. Again, detailed debriefing generally resolved the problems but these are issues for further research.

Leadership

ExOne generally followed the traditional command structure employed by MDRS crew, but at the beginning of Phase Four a meeting was held to allow consensus on the leadership style to adopt for this Phase. A separate report on the MDRS website by Steve Dawson & Jon Clarke details the background and outcome. Essentially a consensus style was adopted with a rotating coordinator whose job it was to remind crew of the timetable, chair meetings, etc.

As the week developed, informal interviews with crew suggested a mixed response. Some strongly preferred this consensus style, felt much more able to "have their say", felt more a part of the mission, etc. Some, however, felt that decision making was overly dominated by strong personalities who were highly outspoken and that there was considerable pressure upon them to fall into line with the wishes of those people. More information regarding the relative effectiveness of different leadership styles should emerge once the formal psychological data is analyzed.

More research is needed to find the best model for MDRS crew and Expedition Two as well as for future human Mars missions. It seems reasonable to assume that the crew for a Mars mission would have a considerable time working and living together prior to the mission and that there will be time to both adopt and refine the best leadership style. Further analogue research, however, particularly involving more lengthy missions in a specifically Mars analogue setting should go a good way towards developing the most helpful leadership style.

Individual Crew Performance

Throughout ExOne, but particularly in Phases Three and Four, the psychological measures described above were employed to both monitor and study crew performance and it's impact on mission goals. The data is yet to be analyzed. Impressions, however, from Dr. Dawson's observations and his discussions with crew, highlighted the impact of sleep and leisure (or lack of these) and stress.

In earlier weeks of ExOne there was a great deal to do in confined conditions. As a result crew tended to stay up late to finish tasks with some impact evident on their individual performance as well as group interaction. In Phase Four a consensus decision was made to "lock in" set sleep hours from 11pm to 7am, with lights to be dimmed from 10pm. Crew reported not only feeling better, less stressed, but also being more alert and effective in their tasks, consistent with findings on the ISS and other space programs. Established programs, working with results of earlier research, seem quite able to not only allow but also require good sleep opportunity, reasonable leisure time, etc.

It may therefore be a function of the relative youth of the MDRS and the felt need to "prove oneself" which has allowed a culture of overly long work hours to permeate the practices of past crew. The current "experiment" suggests that this culture can be changed but will require crew to be psychologically stronger as a group in order to resist the overwork/burnout culture so prevalent in Western society.

CONCLUSIONS

As an experiment in mission management, Expedition One was a terrific success. Particularly valuable for future expeditions will be the use of a trained core group of individual scientists, engineers, and support officers to carry out a long-term research program now familiar with interdisciplinary field protocols, observational methods, equipment, and mission scenarios. The research accomplished has produced a vast wealth of information for understanding Martian expedition planning. With the experience of ExOne, research planning for ExTwo can be accomplished more quickly. It will build on a solid foundation in geology, biology, human factors, operations, and technology investigations established here. The phasing of the expedition over four weeks to focus on different aspects of an expedition, gradually widening the perspective from the tools and tasks, to field science operations, and then to exploration strategies in an integrated mission scenario in the context of an ambitious field science program, has proved a successful approach. An adoption of this manner of organizing interdisciplinary investigations by other research groups is strongly advocated.

Full analysis of the data acquired during the expedition and further detail for each investigation will be presented elsewhere.

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