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Conducting Rock Mass Rating for tunnel construction on Mars

Heidi D. Beemer [a], D. Scott Worrells [b,*]

[a] U.S. Army, Fort Leonard Wood, MO, 233 Saint Robert Plaza Dr., Saint Robert, MO 65584, USA
[b] Graduate Studies, Embry-Riddle Aeronautical University-Worldwide, 33 LittleJohn Lane, Rockledge, FL 32955, USA

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ABSTRACT

Mars analogue missions provide researchers, scientists, and engineers the opportunity to establish protocols prior to sending human explorers to another planet. This paper investigated the complexity of a team of simulation astronauts conducting a Rock Mass Rating task during Analogue Mars missions. This study was conducted at the Mars Desert Research Station in Hanksville, UT, during field season 2015/2016 and with crews 167,168, and 169. During the experiment, three-person teams completed a Rock Mass Rating task during a three hour Extra Vehicular Activity on day six of their two-week simulation mission. This geological test is used during design and construction of excavations in rock on Earth. On Mars, this test could be conducted by astronauts to determine suitable rock layers for tunnel construction which would provide explorers a permanent habitat and radiation shielding while living for long periods of time on the surface. The Rock Mass Rating system derives quantitative data for engineering designs that can easily be communicated between engineers and geologists. Conclusions from this research demonstrated that it is feasible for astronauts to conduct the Rock Mass Rating task in a Mars simulated environment. However, it was also concluded that Rock Mass Rating task orientation and training will be required to ensure that accurate results are obtained.

1. Introduction

The focus of this study was long duration habitation of planet Mars. The researchers fully recognize the paramount task of exploring Mars begins with getting there. This study assumes the problems of getting to and from Mars have been solved. This research then, deals with how space explorers will establish and sustain long-term habitation that will enable long duration exploration of Mars. It is believed, for a number of reasons that will be disclosed throughout the research, that long duration exploration of Mars should be supported by a subterranean habitation system. The hostile environment of planet Mars presents a myriad number of obstacles and problems that threaten human life, restrict mobility, and impose physical and psychological stress. In order for long duration space exploration of Mars to be successful we must first provide for the physiological needs (i.e., food, water, shelter) of the explorers. Until those needs are met and also sustained, long duration human exploration of Mars is not feasible.

This research is the first of a two-part study conducted at the Mars Society's Mars Desert Research Station (MDRS) in Hanksville, UT. The study explored the effects of stress, isolation, and team efficacy on performance while completing a geological task. Three teams, consisting of three simulation astronauts, were isolated in a simulated Martian environment for a two-week period of time.

1.1. Part I Rock Mass Rating task

Rock Mass Rating (RMR) is a geomechanical classification system for rock layers used to identify the most significant parameters that influence rock mass behavior [1]. Rock Mass Rating is a critical aspect to site investigation and can help determine the suitability of a rock mass when considering building a specific structure within that mass. This system has been applied to tunneling, mining, rock slopes and foundations, and it is a simple, inexpensive, and reproducible manner of determining rock quality. On Mars, the RMR system could be used as a preliminary test for building subterranean habitats that would provide Mars explorers with shielding from radiation. The RMR system consists of six geologic tasks which include investigation into the rock layers by testing uniaxial compressive strength of rock material, rock quality designation, spacing of discontinuities, condition of discontinuities, ground water condition, and orientation of discontinuities. Geological engineers on Earth collect quantitative and qualitative information about rock layers using geological tools to calculate the RMR of a specified rock layer. Results are best obtained by using core sampling or borehole equipment, however measurements can also be made using a ruler on exposed rock outcrops to

* Corresponding author
E-mail addresses: Hdbeemer@gmail.com (H.D. Beemer), worrelld@erau.edu (D.S. Worrells).

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measure fractures or jointing if core sampling equipment is not available. This paper will focus on the RMR task and its importance for future Martian exploration and habitation.

1.2. Part II impact of human factors on the Rock Mass Rating task

Three person teams completed a pre- and post-task survey, compiling Cohen's Perceived Stress Scale [2], Friendship Scale [3], and the Team Confidence Measure [4] to measure stress, isolation, and team efficacy respectively. Each team completed the pre-task survey on the third day of simulation. Teams then completed the Rock Mass Rating task. A post-task survey was completed on the sixth day of simulation. Results of the human factors effects on task performance will be published in a separate paper.

2. Literature review

2.1. Radiation

Ionizing radiation on Mars is a known risk of exploring the planet. Today, when the public and academics discuss the feasibility of planetary missions, radiation exposure is a limiting factor [5]. Radiation can cause biological damage at the cellular level causing cell death, cell mutation, and neoplastic transformations or tumors [6]. Depending on the amount of radiation exposure, health effects are either acute, accruing within hours, days or weeks, or delayed, occurring months or years after exposure [6]. It is important to investigate and understand the levels of exposure that astronauts will encounter while living and working on the surface of Mars.

The Martian atmosphere minimally shields the surface of the planet from cosmic radiation [7]. The composition of the Martian atmosphere is predominantly Carbon Dioxide (CO_2) and Nitrogen (N_2) [8]. The radiation that does penetrate the atmosphere of Mars is Galactic cosmic radiation (GCR) particles and solar particle events (SPE). Both types of radiation are energetic enough to pass through the atmosphere and be absorbed into the Martian regolith. When this occurs neutrons and gamma (γ) rays can be created, becoming a part of the ionizing radiation environment of the planet. “Hard” spectrum events also produce secondary neutrons in the atmosphere of Mars which are capable of reaching the surface of Mars [7].

2.2. Permeant habitation

The most cost effective way to initially shield a Martian habitat would be to use the natural shielding properties of the Martian regolith to cover living quarters [9]. As the Martian colony expands there will be a need for a more permanent residence than habitats brought from earth. One location to construct a Martian base would be in preexisting caves or lava tubes which would provide protection under several meters of regolith, rock, and ice [10]. Preliminary research has been conducted on methods for using robotics to locate caves; however, due to existing technological barriers these structures cannot be remotely mapped from earth [10]. On Earth, a vertical descent is often required to access cave networks. Cranes, escalators, ropes with pulleys, and tethered balloons may be needed to enter the cave system adding to the difficulty of the task on Mars [11]. An alternative way of providing explorers a permanent habitat would be to create man-made tunnels. These tunnels would provide colonists the same radiation shielding as a natural cave, but it could be built in any supporting rock structure. In order to create tunnel structures current engineering methods used on earth will need to be adapted to be used on Mars. On Earth, engineers have relied on the RMR system for the design and construction of excavations in rock, such as tunnels, mines, slopes, and foundations. The RMR system derives quantitative data for engineering designs that is readily communicated between engineers and geologists [12].

In a Geophysical Research Letter, Nahm and Schultz [13] discussed the procedures for calculating a RMR for a Martian outcrop located within the Vostok crater at Meridiani Planum, Mars. Remote sensing instruments from National Aeronautics and Space Administration's (NASA) Mars Orbiter Camera (MOC) and Opportunity's navigation camera (NAVcam) were used to successfully determine the RMR of the exposed rock outcrop [13]. Remote sensing techniques may be used to initially determine feasible sites for tunnel construction before committing a Martian colony to one site. However, verification must occur once astronauts are on the surface to ensure the site remains suitable for constructing a tunnel.

2.3. Mars analogue missions

Earth-based, Mars analogue simulations give engineers and scientists the opportunity to establish protocols. Fidelity of the analogue is an important factor to consider and is determined by the similarity of the selected site to its counterpart planet, in this case Mars, or the mission architecture. Analogue similarities can be defined as either the physical processes, such as morphology, chemistry, and geology of the site, or situational and logistical similarities experienced by the crew, specifically isolation, stress, confinement, and limited access to internet and communication [14]. The MDRS is a prototype research facility used by scientists and academics to demonstrate the ability to live and work in a manner similar to astronauts living in a remote base on Mars [15]. The station is located in the San Rafael Swell among red-colored hills, soils, and sandstones similar to the iron oxides rich deserts of Mars, making the physical fidelity of MDRS very high [16]. In this paper, MDRS was used as a high-fidelity analogue to test RMR task procedures during a Mars surface exploration mission.

3. Methodology

The RMR task was conducted on the sixth day of the two-week simulation. Participants were randomly assigned task roles using sealed task packets assigned to MDRS sleeping quarters 2, 3, and 4. Each team completed the following six geologic tasks used to classify the rock mass:

1. Testing uniaxial compressive strength of rock material
2. Rock quality designation
3. Spacing of discontinuities
4. Condition of discontinuities
5. Ground water condition
6. Orientation of discontinuities

Each team was provided a tool kit with the appropriate equipment to conduct the RMT task. This kit included a rock hammer, a geological compass, a tape measure, a 12-inch ruler, a 6½ inch core sampling tube, and a local United States Geological Service map.

3.1. Participants

Research conducted at MDRS is limited by the two-week, six-to seven-member crew cycle set forth by the Mars Society. While in Martian simulation at MDRS, participants conduct experiments in geology, astrobiology, chemistry, as well as, technology demonstrations, and human factors. These MDRS experiments frequently involve Extra-Vehicular Activity (EVA) throughout the San Rafael Swell. Results are generally presented in a manner in which future scientists can benefit from lessons learned by MDRS crew members. Lessons learned from each experiment conducted at MDRS adds to the body of knowledge for future Martian exploration missions.

Crews at MDRS have various academic, professional, and social backgrounds. Teams apply through the Mars Society to conduct a two-week Martian simulation mission and are often sponsored by universities, academic societies, and/or space programs of other nations.

Participation in the study was completely voluntary. Each participant