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Field geology on the Moon: Some lessons learned from the exploration of the Haughton impact structure, Devon Island, Canadian High Arctic

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ABSTRACT

With the prospect of humans returning to Moon by the end of the next decade, considerable attention is being paid to technologies required to transport astronauts to the lunar surface and then to be able to carry out surface science. Recent and ongoing initiatives have focused on scientific questions to be asked. In contrast, few studies have addressed how these scientific priorities will be achieved. In this contribution, we provide some of the lessons learned from the exploration of the Haughton impact structure, an ideal lunar analogue site in the Canadian Arctic. Essentially, by studying how geologists carry out field science, we can provide guidelines for lunar surface operations. Our goal in this contribution is to inform the engineers and managers involved in mission planning, rather than the field geology community. Our results show that the exploration of the Haughton impact structure can be broken down into 3 distinct phases: (1) reconnaissance; (2) systematic regional-scale mapping and sampling; and (3) detailed local-scale mapping and sampling. This break down is similar to the classic scientific method practiced by field geologists of regional exploratory mapping followed by directed mapping at a local scale, except that we distinguish between two different phases of exploratory mapping. Our data show that the number of stops versus the number of samples collected versus the amount of data collected varied depending on the mission phase, as does the total distance covered per EVA. Thus, operational scenarios could take these differences into account, depending on the goals and duration of the mission. Important lessons learned include the need for flexibility in mission planning in order to account for serendipitous discoveries, the highlighting of key "science supersites" that may require return visits, the need for a rugged but simple human-operated rover, laboratory space in the habitat, and adequate room for returned samples, both in the habitat and in the return vehicle. The proposed set of recommendations ideally should be tried and tested in future analogue missions at terrestrial impact sites prior to planetary missions.

1. Introduction

It is hoped that humans will return to the Moon at the end of the next decade and then eventually on to Mars. Current NASA plans are evolving but many envisage a series of 7-day sortie missions—the number of which remains to be determined—followed by one or more intermediate stays ranging from 14 to 90 days, before moving on to regular 180-day missions (NASA, 2007). Significant progress has been made in developing the necessary technologies required to transport astronauts and equipment to and from the lunar surface. The question of if, and how rapidly, an outpost will be established, and if sortie missions will continue to different regions of the Moon once an outpost has been established, has not yet been answered. Irrespective of the timelines involved, what we plan to do on the Moon has only recently been addressed by groups including the National Research Council and the Lunar Exploration Analysis Group. The techniques and strategies required to accomplish these objectives remain to be determined. This is timely and critical as important design requirements—such as the amount of laboratory space in the habitat and mass of samples to be returned to Earth—are currently being defined. Progress has been made with the establishment, by NASA, of the Optimizing Science and Exploration Working Group (OSEWG). An objective of a sub-group of

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OSEWG, the Surface Scenarios Working Group, is to develop science scenarios for different mission types and sites. So far, the first steps have been taken towards developing science-driven scenarios for sortie missions with "Apollo-like" mobility at a handful arbitrary sites (e.g., the Tsiolkovsky and Alphonsus impact craters, Marius Hills, Olivine Hill, and the Nectaris Basin) (Bleacher et al., 2008, 2009).

The study of science activities and requirements for longer duration missions is only just the beginning (Clark et al., 2008). The experience gained during the six Apollo lunar landings is invaluable and remains the only ground-truth data regarding manned planetary missions. However, the world has dramatically changed since the last lunar landing in 1972. Substantial technological developments—such as digital data capture, hand-held field instruments, high-resolution remote sensing datasets, pressurized rover platforms, and increased use of robotics—will change the way in which fieldwork is conducted on the Moon. The length of future missions may, however, be the most profound difference with respect to the Apollo missions. Interviews with 8 of the Apollo astronauts suggest that the extended duration of future missions will have a major influence on mission approach and planning, with the need for increased crew autonomy and reduced scheduling (Conners et al., 1994).

Various approaches can be taken towards planning for the future field geology component of lunar surface operations (Carr et al., 2003; Bleacher et al., 2008; Clark et al., 2008), but all require knowledge of how field geology is conducted. This is not easy given the highly exploratory nature of field geology in which an iterative, often real-time approach is taken to gathering data and developing and testing hypotheses. One important method to help plan future lunar surface operations is to study how scientists conduct science on Earth, particularly field geology, which will be the dominant scientific endeavour on the Moon. Essentially, by conducting geology in an "analogue" environment on Earth, we can learn how to take fieldwork beyond the Earth. There are lessons to be learned from any field geology activity, but as noted by Snook and Mendell (2004), the fidelity of an analogue activity is critical. Fidelity aims to relate various factors in an analogue activity, from the geological terrain (i.e., the geology of the site is a close geological analogue for the planetary body in question), and the environment (temperature, vegetation coverage, and degree of isolation), to the logistics and corresponding mission operations infrastructure, both in the field and at mission control front and backroom.

In this contribution, we use the systematic exploration of a terrestrial impact crater—the 23 km diameter Haughton impact structure, Canadian High Arctic—as an analogue for the geological exploration of cratered terrains on the Moon and Mars. Scientifically, the Haughton structure is a valuable lunar analogue as impact cratering is considered the most important surface process on the Moon (Hiesinger and Head, 2006) and many of the highest priority science goals for lunar exploration revolve around understanding the impact cratering processes, products and the impact flux, particularly in the first several hundred million years (NRC, 2007). In addition, Haughton crater lies in a polar desert environment that is largely devoid of vegetation (Figs. 1 and 2) and it is relatively easily accessible through the infrastructure and logistics provided by the Haughton–Mars Project (HMP) and the Polar Continental Shelf Project (PCSP) operated by Natural Resources Canada. Previous work at this site focused on field science ethnography (Clancey, 2001) and short-duration operations focused on astrobiology laboratory requirements (Cockell et al., 2003). Here, we provide a series of lessons learned based on the geological exploration of the Haughton impact structure that it is hoped will provide a guide for the development of surface scenarios and mission operations requirements, particularly for longer duration missions (weeks to months). This contribution is primarily aimed at informing the engineers and managers involved in mission planning, rather than the field geology community.

2. Exploration of Earth as an analogue for the exploration of the Moon

2.1. Terrestrial analogues for space environments

Terrestrial analogues may be broadly defined as locations on Earth—either field or laboratory-based—that approximate, in some respect, the geological, environmental, and putative biological conditions and/or setting(s) on a planetary body, either at the present-day or sometime in the past (Farr, 2004; Osinski et al., 2006). Current terrestrial analogue research activities typically focus on three main areas (Osinski et al., 2006): (1) comparative planetary geology, including process studies and the characterization of analogue materials; (2) astrobiology of extreme terrestrial environments; and (3) exploration science. The latter is a term that covers a broad range of disciplines and topics and includes, but is not limited to, studies of the following: instrument testing and development, astronaut training, human–robot interactions, mission control operations, surface operations (which includes crew scheduling, mobility, navigation, communications, sample acquisition, sample storage, etc.), psychology and group dynamics, and telemedicine (Osinski et al., 2006). It is worth noting that historically, studies in analogue environments have focused largely on psychological studies on the effects of isolation and confinement (e.g., Antarctic winter over stays, submarine missions, Skylab, and International Space Station stays). Very few studies have been conducted related to understanding the surface exploration.

Terrestrial analogue sites are increasingly being used to carry out analogue missions, which integrate various features of the target mission to gain an understanding of the system-level interactions. Examples include the Desert Rats campaigns (Kosmo et al., 2007) and the 2008 Moses Lake Sand Dunes field test (Fong et al., 2008). With respect to astronaut training, it is notable that during the Apollo era geological training of astronauts often involved fieldwork at impact craters, such as Meteor Crater, USA, and the Sudbury impact structure, Canada (Margolin, 2000). Thus, terrestrial analogue environments provide a critical, low-cost (relative to space) test-bed for optimizing exploration requirements and strategies for future planned human missions to the Moon and Mars. Of particular interest are high-fidelity environments such as Antarctica and the Arctic, where "human beings are in constant peril from the environment and must be supplied with the necessary logistical support in order to survive and carry out useful work" (Eppler, 2007).

2.2. The Haughton impact structure

The Haughton impact structure is a well-exposed and well-preserved 23 km diameter, 39 Myr. old impact structure situated on the western Devon Island, Canadian High Arctic (Osinski et al., 2005a). The Haughton structure is well-known as a Mars analogue site (Lee and Osinski, 2005) and detailed and systematic geological and biological investigations have been carried out at this site each summer since 1997 (Lee and Osinski, 2005), following earlier studies in the 1980s (Grieve, 1988). These studies show that Haughton is a complex impact structure, with a well-developed central uplift and faulted crater rim and that it possesses a series of impactites (impact-modified and generated