SCIENCE SUPPORT FOR ARTEMIS CREWED OPERATIONS ON THE MOON: LESSONS FROM THE HAUGHTON-MARS PROJECT, DEVON ISLAND, ARCTIC, AND A MARS FORWARD STRATEGY.

Pascal Lee[1], [1]Mars Institute, [2]SETI Institute, [3]NASA Ames Research Center, MS245-3, Moffett Field, CA 94035-1000, USA. Email: pascal.lee@marsinstitute.net.

Summary: Science support for Artemis crewed operations will build on, but must also evolve away from, Apollo, as lunar sortie missions make way for a fixed base approach and Mars crewed missions.

Introduction: Science support for Artemis [1] crewed operations are anticipated to evolve over time, from Apollo-style science backrooms ideal for one-time sortie missions to a given location, to approaches progressively better adapted for field science from a fixed base - the Artemis Base Camp - and eventually human missions on Mars, also from a surface base.

We identify several key considerations that will drive this evolution based on our experience with 25 field seasons of field science and exploration operations at the NASA-supported Haughton-Mars Project (HMP) analog site on Devon Island, High Arctic. The HMP analog experience is particularly relevant to planning science support for Artemis, as HMP is a field science project which has had to evolve rapidly from early sortie missions to a fixed base operation (HMP Base Camp). The HMP is also a field research project in which science and exploration excursions are conducted via extensive use of all-terrain vehicles (ATVs), side-by sides, and/or small habitable rovers, as Artemis lunar operations will/should include over time. The anticipated trend and requirement in science support is a progressive increase in crew autonomy and tactical responsibility over time, and an evolution of Earth-based science support towards focusing on science strategy, problem solving, targeting, tasking, and synthesis of findings.

Importance of Phased, Iterative Science Ops: Fieldwork exploration experience on Earth, the Moon, and Mars shows that effective and efficient field science is often accomplished by allowing extended investigation time to be spent at a small subset of locations with a Science Region of Interest (ROI), rather than requiring that an equal amount of time be spent at every location within an ROI. In Antarctica, and also at HMP in the Arctic where field science and exploration are conducted from a fixed, permanent or temporary base, opportunities to revisit a few sites repeatedly has been critical to allowing the best samples to be collected and geologic hypotheses to be thoroughly tested.

At HMP for instance, very early on in the reconnaissance of each new sector at and around Haughton Crater, a finite number of sites were identified as being the best features or locales for sampling (e.g., outcrops,

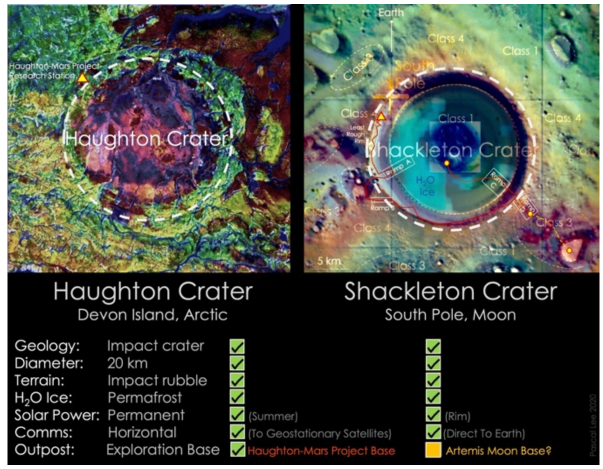

Figure 1. Haughton Crater *vs* Shackleton Crater. Haughton Crater on Devon Island, High Arctic, presents some aspects that are analogous or of unique relevance to exploring the polar regions of the Moon. Lessons learned from the Haughton-Mars Project (HMP) may help planning (and train for) Artemis crew science operations and their support.

megablocks, ejecta blocks, hydrothermal vents), and over the course of subsequent days, weeks, campaigns, and even decades, the same sites would be productively revisited repeatedly to yield additional valuable samples and information. As a consequence for structuring real-time science support for Artemis crewed missions where, contrary to Apollo, longer-term exploration is contemplated from a fixed base, we should anticipate, and indeed plan, for crews exploring any region to have opportunities to *revisit* the best sites nearest to their base multiple times, and allow enough time between each visit (during the same mission, or over successive missions) for the science backroom, as well as the crews, to *iterate* on the science. This ability to iterate is critical to conducting productive field science, as it allows science operations to be phased with adequate pauses between each visit to the same site: field reconnaissance by robot or crew, then pause to formulate/revise hypotheses, define new questions/plans/observations/tasks, brief crew, then revisit site, etc.. Iterations between hypotheses and tests is afterall the root process of the scientific method.

For Mars, the need for time to iterate between each set of new observations is well understood from our experience with both lander and rover missions. Although EM signal travel time delay between the Earth and Mars for interfacing with surface assets is sometimes perceived as the greatest barrier in directing surface operations on Mars in real time, the actual bottleneck in real-time science operations is the time needed by the science backroom to examine and "digest" new data, and formulate the next iteration in plans and commands. Actual command upload and data download time delays are a relatively minor issue in that perspective.

Similarly, when human crews will explore Mars, while the lack of ability to have real time dialogs with Earth will be a significant safety concern, its impact on science operations can be minimized if a phased and iterative approach is adopted in the fieldwork, allowing for multiple visits of the best sites and ample time between site revisits for the science backroom to examine and digest the latest visit's data (including crew reports), formulate new questions/plans/tasks for the next visit, and brief the crew.

Time Delay and Increased Autonomy For Mars: Two-way EM signal travel time delays between the Earth and Mars range from 7 to 44 minutes. It is already understood that such time delays will mean that traditional real-time "Mission Control" will not work and have to be replaced by time-delayed "Mission Support", with all aspects of real-time support required by crew operations needing to be provided on site, by the crew itself and/or an on-site AI (artificial intelligence) system. Because Artemis is intended to enable "Moon To Mars", it is essential that the Artemis science operations experience not be singularly focused on maximizing lunar science alone, but include, perhaps at progressive levels of fidelity and relevance, approaches that will optimize future Mars crewed science operations as well. For instance, it would be worthwhile to invest in developing (training) AI technologies for crew science support to be tested with Artemis astronauts on the Moon, so that such systems could be matured for longer term crewed science missions on the Moon and Mars.

The extended light travel time delay between the Earth and Mars will, in any case, mean that crews on Mars will need to have significant autonomy. The strongest requirement for this comes from not from science operations, but from safety. However, because field safety considerations are such drivers in the conduct of field operations in extreme environments, real-time tactical aspects of science operations will largely have to be left to a highly autonomous crew to decide on and carry out, without much input from a science backroom on Earth that could affect ongoing EVA or even habitable rover traverse operations. Under such conditions, the science backroom's real-time support will be limited to top-level strategic decisions at best (requesting that the crew stay at one location at the cost of scrapping the next, for instance), with no practical possibility to steer science operations tactics "live" (for instance requesting that the crew collect a specific sample noticed in the (time-delayed) imaging stream). However, if a phased/iterative approach is adopted, then exploration strategies and specific tactical tasks can be directed by a science backroom from one EVA to the next.

In Situ Science Backroom on the Moon or Mars: On Mars, and possibly even on the Moon in the case of larger crews stationed at a base, it is likely that any scientist crewmember will not be the sole implementer of his/her area of science. A human crew will likely be multidisciplinary and include redundancies in its core competencies/expertises. For instance, a geologist on a crew will likely not be only one trained and engaged in conducting field geology on the mission, and indeed, due to the vagueries of EVA opportunities and scheduling, there could be many EVAs with important geologic scope which might not involve the lead geologist as an EVA crewmember. In such instances, the geologist(s) remaining in IVA (intra-vehicular activity) could staff an in-situ science backroom to provide real-time science support to the EVA crew during its excursion. The scientist crewmembers in the in-stu backroom would then both play the role, and represent the interests of, the science backroom (presumably a large community) on Earth.

Such in-situ or proximal operations support are frequently used in a wide variety of extreme environment operations, from deep-diving submersible operations to mountaineering climbs, to polar expeditions.

Conclusions and Recommendations: Science support for Artemis crewed operations should be established to evolve flexibly over time, beginning with Apollo-like science support approaches (only enhanced by state-of-the-art technology such as astronaut body cams, etc.) for initial Artemis sortie missions, then segueing towards approaches more suitable for fixed based crewed operations in which science support is more "relaxed", i.e., better-adapted and more sustainable for longer-term operations in which multiple visits to targets of interest within local ROIs will be possible, then towards approaches in which crews are given maximum in-situ science operations autonomy, perhaps with AI in the loop.

References: [1] NASA (2020). Artemis Plan. NASA's Lunar Exploration Program Overview. NP-2020-05-2853-HQ.

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