CANMOON ANALOGUE MISSION TACTICAL SCIENCE TEAM: SCIENTIFIC INSTRUMENTATION AND DECISION MAKING DURING A HIGH FIDELITY REALTIME LUNAR ANALOGUE MISSION.

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Introduction: As part of its Lunar Exploration Analogue Deployment (LEAD), the Canadian Space Agency (CSA) is carrying out a series of field tests and analogue missions to test technologies, develop mission operations architectures, and provide training for students and young professionals. The CanMoon lunar sample return analogue mission was a joint endeavor of the University of Western Ontario and the University of Winnipeg run for two weeks in August of 2019. This analogue mission was designed to accurately simulate near real-time communication between an Earth-based mission control station and a scientific rover platform operating on the lunar surface. The goal of this analogue mission was to assess the decision-making abilities of the mission control team and document the approaches undertaken to complete remote scientific analysis. For a full overview of the 2019 CanMoon analogue mission see Marion et al. [1].

Mission Overview: The locations used as analogue lunar terrains for the CanMoon mission were located on the volcanic island of Lanzarote in the Canary Island group. Lanzarote hosts several geologically young lava flows that date to the 1700's [2]. These well-preserved volcanic deposits have been used as lunar analogues in the past by groups from the European Space Agency (ESA) including the PANGEA astronaut training simulation [3,4].

The primary scientific goal of the CanMoon analogue mission was to obtain data and collect a suite of samples that met 4 scientific objectives: 1. Characterize the geologic diversity of the field site; 2. Identify and obtain a sample containing volatile content; 3. Identify and obtain a sample bearing mantle derived material such as a mantle xenolith; and 4. Analyze and return the best possible sample for post-mission age dating analysis. These 4 objectives largely shaped the mission decisions made by the in-simulation teams.

CanMoon Science Team Structure: Participants in CanMoon served on one of three teams: the *Field Team* responsible for logistics and instrument operation in the field, the *Planning Team*, responsible for composing and sending specific commands to the analogue rover [5], or the *Science Team*. The *Science Team* was broken down into two sub teams, a *Tactical Science Team* responsible for targeting the individual instruments onboard the analogue rover, and a *Science Interpretation Team* responsible for analyzing the constant flow of data being generated and downlinked from the rover platform. The full *Science Team* structure is presented in Figure 1. The primary focus of this abstract will be the structure of the CanMoon *Tactical Science Team* and its role in analogue missions operations. For additional information on the *Science Interpretation Team* and the analysis of both in-simulation and post-mission data analysis see Hill et al [6].

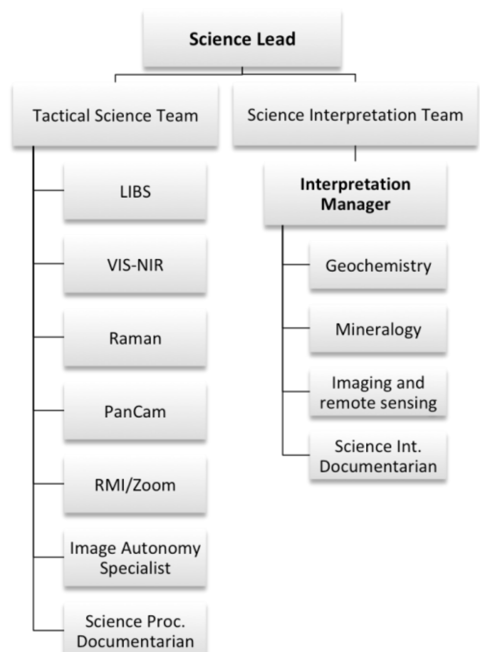

Figure 1: CanMoon Science Team structure including the Tactical Science and Science Interpretation Teams

Science Instrumentation: The CanMoon analogue rover platform included a suite of scientific instruments for analyzing the composition and morphology of the local geology in the immediate vicinity of the chosen landing sites. This instrument suite included 3 different visible light still image cameras, a real-time color video camera, and three spectrometers. For additional details on each of the scientific instruments see Marion et al. [1].

All of the included instrumentation was purposely selected to be fully standoff. This eliminates the need for a robotic arm and all the associated time consuming repositioning maneuvers to contact instruments. Indeed, one of the operational objectives of CanMoon was to assess the scientific return of a rover equipped solely with stand-off instrumentation. The intention of making the rover more versatile and mobile, able to cover a large area quickly before carefully positioning to collect the most scientifically pertinent and geologically representative sample in a given area.

The instrument suite also included four analogue sampling devices. A scoop tool was included for collecting loose regolith samples or a collection of small unconsolidated rock samples. A sieve option was included should the *Tactical Science Team* decide to sample only small rock fragments from a loose unconsolidated surface. A claw tool was included for collecting small rock samples from hard surfaces where the scoop or sieve would be ineffective. Finally an analogue representation of a percussive drill was included in order to allow the *Tactical Science Team* to break off a small piece of a larger in-situ country rock that could otherwise not be sampled.

Science Procedures: During Mission operations the *Tactical Science Team* worked closely with the *Science Interpretation Team* and *Planning Team* to decide where to navigate the rover. Once the rover reached a new waypoint, the *Tactical Science Team* would first collect a panoramic image in order to both situate the rover in its new position and target additional higher resolution images of particular targets. These zoom images were targeted by annotating the downlinked panoramic image and completing a specific sequencing document, which included details such as angle and zoom level for the new images [5]. Once the zoom images were obtained the Camera Team would verify that complete and uncorrupted files were received before passing the images along to both the *Science Interpretation Team* and the compositional instrument sub-teams. If the targets warranted further investigation, one or more of the compositional instruments would be targeted by annotating the corresponding zoom images and completing additional sequencing documentation. Once the raw data was collected and downlinked, the compositional instrument sub-teams would verify the quality of the data before passing it along to the *Science Interpretation Team* for further analysis. This method of relying on the Tactical Science sub-teams to only target and quality check the incoming data, enabled quicker data collection and more efficient real-time data management.

Use of VR and Immersive Technologies: In addition to the standard methods of view data on screen in the CanMoon mission control room, a set of Oculus Rift Virtual Reality (VR) headsets were employed to provide members of the *Science* and *Planning Teams* with a more immersive view of the analogue terrain. The two mission datasets integrated into the immersive VR system were the panoramic images obtained by the rover and a digital terrain model generated using pre-mission remote sensing data [7]. The panoramic images were uploaded to a www.roundme.com, a 360 image hosting site that which not only enabled easy immersive viewing through the use of WebVR, but also allowed the collection of panoramic images to be accessed by any phone, tablet, or computer with an internet connection. The terrain model was saved as a Virtual Reality Media Language (VRML) file and uploaded to www.sketchfab.com, an online repository for 3D objects and terrains that enabled easy access and quick immersive viewing through the use of WebVR.

Mission Results:

Week 1. The first week of CanMoon operations took place at a field site dubbed “Janubio”. The first in-situ images returned by the rover revealed the presences of numerous boulders that were below the size detectable from pre-mission remote sensing images, but large enough to be significant obstacles to rover traverses. As a result, the rover was only able to traverse ~100 m rather than completing the pre-planned 650-720 m traverse [8]. Despite the difficult terrain, the in-simulation teams managed to collect 2 representative samples from this site which met all four main science objectives. For additional detail on the analysis of this site and the collected samples see Hill et al. [6].

Week 2. The second week of operations took place at site “Nuevo Ortiz”. This site hosted far fewer obstacles allowing for a greater amount of rover movement. Overall the rover traversed ~300 m mostly along a portion of the pre-planned traverse path [7]. The in-simulation teams collected a total of 5 samples from this site which collectively met all four of the main science objectives [6].

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