ROBOTIC MAPPING AND EXPLORATION OF A TERRESTRIAL LAVA TUBE: A STRUCTURED PLANETARY CAVE MISSION SIMULATION WITH A REMOTE ASTROBIOLOGY SCIENCE TEAM

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Introduction: Volcanic caves are compelling targets in the search for extant and past life on Mars (e.g., Boston et al., 2001; Cushing et al., 2007; Léveillé & Datta, 2010; Blank et al., 2018). A recent survey using data from the Mars Reconnaissance Orbiter's Context and High Resolution Imaging Cameras has identified more than 1,000 candidate cave entrances on the surface of Mars (Cushing et al., 2017).

BRAILLE (Biologic and Resource Analog Investigations in Low Light Environments) is a NASA-funded analog Martian cave mission project centered around field research at Lava Beds National Monument (Northern California, USA). The BRAILLE Team's objectives are to (1) characterize microbial life and microbial community structure in terrestrial lava caves and the nutrients in rock and water that sustain them; (2) distinguish secondary minerals associated with microbes in the caves – macroscopic, putative signatures of life and a geochemical record of life that could persist long after any life died away; and (3) practice robotic life-detection and mapping mission operations by directing remote rover activities in one of the caves, Valentine Cave, from a surface command center located at park headquarters. The first two of these objectives are independent of the mission simulation but provide valuable ground truth information that aids in the interpretation of remote observations collected using the rover. Here, we will focus on the mission simulation and its relevance to future planetary cave mission efforts.

Astrobiology Investigations at Lava Beds: Our interdisciplinary science effort at Lava Beds focused on 9 caves selected to encompass a range in flow age, length, depth, number of entrances, and human visitation. While our team conducted individual disciplinary studies of the microbial community, geochemistry, and secondary mineralogy, our collective goal was to correlate in situ photographic imagery with laboratory analytical probe results, moving from apparent "bare rock" (basalt) surface, through mineral crusts and coatings, secondary mineral products with small (several mm to cm), coral-like morphologies coating the cave walls, and on to biofilms and, finally, oozes. Compositionally, the mineral features consisted primarily of several forms of amorphous silica, which enhances their preservation potential. Details of this "ground truth" work is being reported elsewhere.

Robotic Operations and Mars Mission Simulation: The cave environment presents several challenges for scientific investigation that will need to be overcome through mission design or the development of novel technologies. Not least of these are ingress, maneuvering inside a cave, and operational and data uplink and downlink with out-of-line-of-sight communication paths. BRAILLE's simplified mission simulation focused on science activities and relied on out-of-sim assistance for out-of-line-of-sight communication relays (which NASA and others have developed elsewhere) and refinements in rover positioning within the cave.

The robotic operations aspect of our project used the NASA Ames testing rover, CaveR, which was modified for our use. The rover's mast was removed, reducing the rover height to 1m. The scientific instrument payload, consisting of cameras and spectrometers including the NIRVSS suite optimized for water detection on the moon, were housed in a rectangular pod mounted to one side of the rover and aligned with the top of the rover platform. This pod, able to tilt 45°, was aimed at one side of the cave as the rover moved downslope during mission activities. Its orientation maintained a roughly constant focal length for the instruments of 0.75m from the cave wall.

Prior to mission simulation activities, the rover was transported via truck from NASA Ames to Lava Beds, where we could park within 10m of the cave entrance. To avoid damage to the point of ingress, the rover was disassembled partially and ported manually into Valentine Cave.

The concept of our mission operations is summarized in Table 1. CaveR mapped 20m segments of one side of the cave wall autonomously using a laser scanner, collecting images every 2 seconds and recording time stamp and distance from the starting point. These images were stitched together to form a mosaic, with resolution to ~0.3 mm, which was delivered to a remote science team. The science team worked individually and then as a group to select priority targets of interest on the mosaic, developed an operations plan, and returned that to the rover operators via a human runner. CaveR then returned to interrogate the targets of astrobiological interest, as directed by the remote team. These activities were conducted under a mission timeline constraint. These same transects were examined by a separate group of astrobiology scientists, in the cave, in similar, timed exercises. We will report correlations between the groups in and out of the mission simulation and initial lessons learned from this planetary mission operations concept.

Table 1. BRAILLE Operations: 4-5 Phases of Cave Exploration.

		Phase	*Activity (location)*
BRAILLE Mission Operations	I	Exploration & Mapping	**Scouting pass** (Rover Transect, in cave)
	II	Science Planning	**Data review and science task planning** (Mission Control, LBNM Park Headquarters)
	III	Science Sensor Deployment	**Execution of science tasks by rover as defined in (2)** (Rover Reverse Transect, in cave)
	IV	Science Interpretation	**Data review & creation of follow-up task plan** (Mission Control, LBNM Park Headquarters)
	V	(Optional) Ground Truth Assessment	**ATP Swab and in-person target evaluation** (Out-of-Sim Scientists, in cave)

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