IS A LINEAR OR A WALKABOUT PROTOCOL MORE EFFICIENT FOR ROBOTIC SAMPLE SELECTION IN A SMALL REGION OF INTEREST?

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Introduction: The GeoHeuristic Operational Strategies (GHOST) field tests are designed to isolate and test science-driven landed and rover operations scenarios, to determine best practices in maximizing the science return from planetary missions. Here we make a preliminary report on a GHOST field test at a potential Mars 2020 landing site analog, where we tested two science operations methods for data acquisition and decision-making protocols currently used by Mars Science Laboratory (MSL). These methods were: (1) a "linear" approach, where all sites are examined as they are encountered [e.g., 1-3]; and (2) a "walkabout" approach in which the field site is first examined with remote rover instruments, to gain an understanding of context prior to deploying time- or power-intensive contact and sampling instruments on a smaller subset of locations [4,5]. The goal was to provide field-tested insight into planning for missions such as Mars 2020, where science operations must facilitate efficient choice of sampling locations.

Field Site: Consistent with the current goals of the NASA Mars Exploration program, we chose a Mars analog site with evidence of past habitability (e.g., rivers and lakes) detectable from *in situ* measurements. Our field site is located in the Uinta Basin of the Colorado Plateau province in northeastern Utah on land administered by the Bureau of Land Management (39.8058°N, 109.0759°W). Having a modern semi-arid climate, sparse vegetation and a canyon incised through the 500 m x 500 m study region, rock layers are well exposed at the field site with some outcrops in three dimensions.

The Eocene Green River Formation in the Uinta Basin is the record of ancient Lake Uinta, which occupied portions of northeastern Utah between 57 and 43 Ma. The GHOST exercise examined rocks in the upper Green River Formation, from the top of the Douglas Creek Member, which includes fluvial-deltaic and carbonate facies [6,7].

Approach: Rather than adding risk to the field test and limiting its results by relying on a rover mock-up equipped with a suite of instruments meant to be analogous to a specific mission scenario, GHOST adopts a "roverless roving" approach that cleanly isolates science-driven protocols from those driven by the needs of the engineering or operations systems [8-10]. We use a generalized suite of commercial, off-the-shelf instruments that provides visual, compositional and geochemical data similar to flight-ready instruments. Humans provide mobility and run the instruments, but do not inject their geologic knowledge into data acquisition. Although low-fidelity in terms of engineering, it is high-fidelity in terms of the data acquired and the process of acquisition used to acquire it. Specifically, testing science decision-making protocols (which instruments to use, when and how often to use them), and assessing the science results, require as input only the data gathered by those instruments, not the hardware or the instruments themselves.

Methodology: Limited power, time and data volume constrain the number and type of science observations that may fit into a single rover planning cycle ("sol"). We used the average resources employed by the MSL mission (as averaged over the last 5 years of operations [5]) to execute common observations and mobility commands. For most sols we assumed approximately 1 hour of active remote data acquisition (imaging, whole-rock multispectral data from Mastcam or ChemCam) and one choice of either a drive (50-100 m was considered a sol's drive) or multiple observations using the instruments mimicking those that come into contact with the surface (e.g, MAHLI, APXS; also referred to as contact science).

Instruments. We used instruments that could produce data generally similar in type and resolution to those produced by current or future Mars missions. This included a digital SLR camera with a macro lens to cover the range of resolutions produced by Mastcam/Mastcam-Z [11,12] and MAHLI/WATSON [13,14] images. The SHERLOC/PIXL instruments [14,15] were assumed to be crucial to the actual sampling process, rather than the process of choosing samples. A handheld spectrometer (generously furnished by Analytical Spectral Devices) yielded multispectral whole-rock data in the visible-near infrared wavelengths, and a field XRD produced mineral abundances. When requested, the rover crew removed mantling dust by hand, mimicking a Dust Removal Tool. Finally, as a technology demonstration for future tests, we used a small commercial drone to test potential operational strategies of a small scout rotocopter, which could provide traverse reconnaissance or follow-on science analysis to a surface rover mission.

Field work: Our science team divided into three teams and a Site Expert. The Site Expert reconnoitered the site prior to fieldwork, to allow the rest of the team to approach the site blind. She then provided the rest of the field team with "orbital" data similar to what might be produced for a rover mission (e.g., Mars Reconnaissance Orbiter CTX and HiRISE resolution visible-wavelength images, CRISM spectroscopic images). Using these data, one team planned a traverse based on a linear approach, while another created a notional traverse based on a walkabout-first approach. The third team also pre-planned field work using the orbital data, but examined the site using traditional field methods, thus providing a direct comparison between results using rover-driven methods and those achieved by a "standard" terrestrial field exercise. All teams developed hypotheses for the depositional history, to be tested during field work. Teams followed their traverses, and data acquired at each stop was used in the decision-making process for choosing and prioritizing samples. Each team was limited to three samples.

Assessment: To balance the need for an objective assessment of the efficiency of each science operations method against the fact that science itself is a process and the most common science-related goals (e.g., characterize the geology of a site) tend not to have clear, defined end points, we measured the time spent on each method, and then assessed how well that time was spent. In this context, we found that the walkabout-first method was superior in terms of (1) less time required to execute; and (2) greater confidence in results and interpretations. This superiority stems from the fact that the walkabout-first method provided broad geologic context earlier in the science analysis process.

Both methods allowed similar characterization and interpretation of the general geologic history of the site. However, the walkabout-first method yielded a >25% savings in sols, taking 37 sols to execute compared to the 50 sols required by the linear approach. Additionally, while the amount and extent of contextual information provided by each method was similar, that contextual information was acquired earlier in the process for the walkabout-first approach, so team members had more time to discuss results before having to make sampling decisions, leading to greater confidence in choosing when to acquire a sample. By contrast, the team executing the linear approach was hard-pressed to make sample/no-sample decisions with the data in hand. For example, both the linear and walkabout-first teams encountered a shale bed early in the traverse. While the linear team spent several sols debating how to spend resources on this unit before moving on, the walkabout-first team was able to gather imaging and compositional data and study it while moving to the next stop, knowing that they would be able to return later if a return was warranted by the data at all stops. This supports the results from similar previous tests [9,10]. In this case, however, the region of study was half the size of the previous site. We surmise that this is the reason the ratio of walkabout-first to linear sols is even lower for this test (0.74) than for the previous test (0.81); the smaller area meant that the walkabout-first team spent fewer sols retracing steps in multiple loops.

Conclusions: Early results indicate that geologic context, provided as early as possible, will save mission time and resources. Using this method in smaller ROIs may improve science return even further, since they would require fewer sols to traverse in multiple loops or to survey initially. We suggest that the walkabout-first approach be used where possible to provide early context and time for the science team to develop reasonable hypotheses and robust ways to test them.

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