DETERMINING EFFICIENT ROVER SCIENCE PROTOCOLS FOR ROBOTIC SAMPLE SELECTION.

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Introduction: On a science-driven sample-return or caching mission such as Mars 2020, use of resources will be tied to the number of samples collected and stored. A central point of tension among science team members is likely to revolve around the competing philosophies of immediate, rapid collection, and continued exploration to locate the ideal sample. Thus, the way the science team chooses to interrogate a site will be an important component in determining whether Mars 2020 will be able to meet its engineering requirements and mission goals.

The GeoHeuristic Operational Strategies (GHOST) field tests are designed to isolate and test science-driven landed and rover operations scenarios, in order to determine best practices in maximizing the science return from planetary missions. In a recent field test at a potential Mars 2020 landing site analog, we tested two science operations methods for data acquisition and decision-making protocols currently used by Mars Science Laboratory (MSL) to assess the quality of chosen samples and associated resulting science conclusions. These were: (1) a "linear" scenario, where all sites are examined as they are encountered [e.g., 1-3]; and (2) a "walkabout-first" approach in which a smaller, defined subset of the field site is examined with remote rover instruments, to gain an understanding of context prior to deploying time- or power-intensive contact and sampling instruments [4,5].

Field Site: Our field site was a 1 km^2 area located on semi-arid land administered by the Bureau of Land Management (38.851°N, 109.985°W) in the Greater Canyonlands area southeast of the town of Green River, Utah. In this area, erosive processes are dominated by running water (primarily from torrential rains that occur sporadically during summer storms) and mass wasting along cliff faces. Mesozoic-aged sedimentary units were deposited on river floodplains and during transgressive-regressive events within an epeiric sea setting. This resulted in intermingled deposits that reflect a combination of potential marine, fluvial, and terrigenous deposits. Subsequent tectonic forces uplifted and exposed ~100 million years of this diverse geologic history [6], including units containing micro and macroscopic biosignatures (chemical and fossil records) [7]. Lacustrine deposits, travertine deposits, and exhumed curvilinear fluvial channels are common in these units [8,9], similar to features documented on Mars [10,11]. Additionally, if the northern ocean hypothesis is viable (e.g., [12,13]), this field site is a reasonable analog for martian intermittent sea incursion.

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 more cleanly isolates science-driven protocols from those driven by the needs of the engineering or operations systems [14-16]. We use a generalized suite of commercial, off-the-shelf instruments that provides visual, compositional and geochemical data similar to flight-ready instruments, while humans provide mobility and run the instruments. 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 resulting 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 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 known 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 [17,18] and MAHLI/WATSON [19,20] images (the SHERLOC/PIXL instruments [20,21] 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. Finally, when requested, the rover crew removed mantling dust by hand, mimicking a Dust Removal Tool (e.g., [22]).

Field work: Our science team divided into two Rover Science Teams, a Tiger Team, 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. He 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 resolution visible-wavelength images, CRISM spectroscopic images). Using these data, one Rover Science Team planned a traverse based on a linear approach, while the other created a notional traverse based on a walkabout-first approach. The Tiger Team, using traditional field methods, also pre-planned field work using the orbital data. All teams developed hypotheses for the depositional history of biologically relevant units. Teams followed their traverses, and data acquired at each traverse stop was used in the decision-making process for choosing and prioritizing samples. Each team was limited to 5 samples.

Assessment: The ultimate goal of testing various science operational strategies is to derive the highest-quality science out of field work on another planet. However, quantifying "science return" is not straightforward, because 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. Instead, science operations scenarios must permit characterization of the expected or hypothesized, and discovery of the unexpected. We thus assess our results in terms of what would constitute best practices in a given situation. 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 much 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 56 sols to execute compared to the 69 sols required by the linear approach. Additionally, while the amount and extent of contextual information provided by each method was similar, since that contextual information was acquired earlier in the process for the walkabout-first approach, team members had sufficient time to discuss results and come to robust conclusions, leading greater confidence in sample selection. By contrast, the Rover Team executing the linear approach took more time at each site, and was under significant pressure to decide immediately whether or not to sample, leading to less optimal samples being acquired in lieu of additional information. The Rover Team executing the linear method would have ejected two samples they acquired in favor of others, had they had that option.

Finally, in addressing their hypotheses, both teams quickly focused on acquiring broad imaging coverage rather than spending time and resources on fewer, more targeted high-resolution images. This indicates that greater data coverage at coarser resolution provided better context information than less data coverage at higher-resolution (spatial, spectral or otherwise).

Conclusions: Our results indicate that (1) geologic context, provided as early as possible, will save mission time and resources; and (2) science must be given time and space to occur. 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. We also conclude that significant science-related time could be saved if Mars 2020 returns to a site that has been previously reconnoitered.

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