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Synchronous in-field application of life-detection techniques in planetary analog missions

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ABSTRACT

Field expeditions that simulate the operations of robotic planetary exploration missions at analog sites on Earth can help establish best practices and are therefore a positive contribution to the planetary exploration community. There are many sites in Iceland that possess heritage as planetary exploration analog locations and whose environmental extremes make them suitable for simulating scientific sampling and robotic operations.

We conducted a planetary exploration analog mission at two recent lava fields in Iceland, Fimmvörðuháls (2010) and Eldfell (1973), using a specially developed field laboratory. We tested the utility of in-field site sampling down selection and tiered analysis operational capabilities with three life detection and characterization techniques: fluorescence microscopy (FM), adenine-triphosphate (ATP) bioluminescence assay, and quantitative polymerase chain reaction (qPCR) assay. The study made use of multiple cycles of sample collection at multiple distance scales and field laboratory analysis using the synchronous life-detection techniques to heuristically develop the continuing sampling and analysis strategy during the expedition.

Here we report the operational lessons learned and provide brief summaries of scientific data. The full scientific data report will follow separately. We found that rapid in-field analysis to determine subsequent sampling decisions is operationally feasible, and that the chosen life detection and characterization techniques are suitable for a terrestrial life-detection field mission.

In-field analysis enables the rapid obtainment of scientific data and thus facilitates the collection of the most scientifically relevant samples within a single field expedition, without the need for sample relocation to external laboratories. The operational lessons learned in this study could be applied to future terrestrial field expeditions employing other analytical techniques and to future robotic planetary exploration missions.

1. Introduction

Extreme environments on Earth are used as analogs to inform both the science and operations of future planetary exploration missions (Amils et al., 2007; Amato et al., 2010; Billi et al., 2013). In particular, Icelandic lava fields have an especially good heritage as Mars analog sites (Farr, 2004; Warner and Farmer, 2010; Cockell et al., 2011; Cousins and Crawford, 2011; Mangold et al., 2011; Ehlmann et al., 2012; Cousins et al., 2013). Lava fields are relevant for astrobiological science due to the presence of extreme conditions, including desiccation, low nutrient availability, temperature extremes (*e.g.* due to high elevation or close proximity to fumaroles), relatively young ages, and their isolation from anthropogenic contamination (Allen et al., 1981, Bagshaw et al., 2011). From an operational perspective, many Icelandic lava fields are remote enough to require that field expeditions address several sampling operational constraints that are also experienced in robotic planetary exploration (Arena et al., 2004; Preston and Dartnell, 2014).

Abbreviations: ATP, adenosine triphosphate; Cq, quantification cycle; DNA, deoxyribonucleic acid; EDTA, ethylenediaminetetraacetic acid; FIM, Fimmvörðuháls; FM, fluorescence microscopy; HEI, Heimaey; qPCR, quantitative polymerase chain reaction; RLU, relative light units; Tris, tris(hydroxymethyl)aminomethane; UV, ultraviolet

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Terrestrial field campaigns designed to conduct scientific studies of planetary analogs can also serve as operational analogs for robotic planetary missions. Field campaigns typically involve *in situ* sampling, followed by preservation of any collected samples and subsequent return to an institutional laboratory where the samples can then be analyzed, analogous to planetary sample return missions. However, some field expeditions may carry limited instrumentation for *in situ* analysis (Ehlmann et al., 2012), and like robotic planetary missions, these instruments must be chosen ahead of time. Limited on-site consumables further constrain the amount that can be accomplished in the field by both terrestrial field expeditions and planetary exploration robots. Furthermore, sending samples to an institutional laboratory with a delay of potentially several months before full scientific analysis is possible. This may prevent results of prior sampling being available to influence sampling strategy throughout the expedition, and this applies to whether on Earth or elsewhere in the solar system. Although the results obtained might be available to assist in the planning stages of future field campaigns or missions, such follow-up expeditions might be weeks, months, years or decades in the future. The ability to maximize science return from limited in-field planetary exploration analyses is far more critical given that a sample return mission from Mars, or other astrobiologically relevant planetary bodies, is still decades away (McLennan, 2012), and raises significant planetary protection issues (Bridges and Guest, 2011).

The capacity for rapid sample analysis and interpretation can alleviate the problems posed by terrestrial or planetary expeditions. Firstly, it allows for the down-selection of sampling sites in the field. Rather than being dependent solely on previous mission data or remote sensing provided by partner programs, sampling choices can be made in the field based on near-real-time results. Secondly, it allows for ‘tiered analysis’, in which a single sample may be subject to a faster or lower-cost analysis (either non-destructively or by partitioning) to determine whether it is sufficiently interesting to warrant a second, more resource-intensive or more limited-capacity analysis. These features can be combined to maximize science return if a balance is struck between the cost of carrying additional resource-light ‘pre-sampling’ instruments and the increased science return from more resource-intensive instruments.

Choosing the exact locations and samples that a field team, rover, or lander will analyze is critically important given the operational constraints. The planetary mission team must select a location to sample using the vehicle's remote sensing instruments (*e.g.* the ChemCam instrument on the Mars Science Laboratory (Meslin et al., 2013)) and assume that this site is representative of the area of interest. If a difference in sampling location of a few meters, centimeters, or even hundreds of microns could make a significant difference in the results, it may mean that science objectives are not met. This will be especially critical when life-detection is the primary goal, given the inherent variability in the distribution of living things as we know them on Earth. Successfully characterizing multiple parameters across the multiple scales of a field site will help to reduce the number of initial sampling rounds needed.

We conducted a planetary exploration analog expedition to two recent Icelandic lava fields, Fimmvörðuháls (2010) and Eldfell (1973), with a specially developed field laboratory. Our main goal was to prove the feasibility of real-time sampling and site down-selection in a life detection robotic exploration context through quick-turnaround ‘pre-sample’ analysis and extrapolation of the likely presence of biomarkers. To inform the development of current and future *in situ* planetary missions, this was broken down into three interrelated operational sub-goals:

1. Demonstrate the feasibility of performing multiple rapid cycles of sample selection, sample analysis and interpretation in-field under simulated robotic exploration constraints.
2. Demonstrate the synchronous application of multiple life detection techniques within these multiple cycles.
3. Demonstrate the potential of fluorescence microscopy (FM), adenosine triphosphate (ATP) bioluminescence, and quantitative polymerase chain reaction (qPCR) assays as quick-turnaround terrestrial life detection techniques.

Here, we report upon the operational and logistic lessons learned during the expedition, which could influence the design of future field studies. Scientific results of the expedition will be reported separately (manuscript in preparation). Follow-up expeditions are planned and will be reported upon in relation to this work.

2. Methodology

The expedition consisted of cycles of sampling, rapid preliminary analysis, and follow-up based on the results from the previous sampling and analysis cycle. The expedition personnel were split into two teams, allowing two of these repeated sampling and analysis cycles to be run in staggered parallel, thus increasing the expedition's throughput and ensuring that the field lab was neither idle nor acting as a bottleneck. After sampling cycles were completed all samples were more extensively analyzed over three additional days in the field lab to address the more detailed question of sample site homogeneity.

2.1. Field sites

Two lava fields were chosen for our expedition: Fimmvörðuháls (63° 38' 12.30'' N, 19° 26' 49.20'' W) and Eldfell (63° 25' 08.30'' N, 20° 14' 38.70'' W) (Fig. 1). The Fimmvörðuháls lava field formed between 20 March and 12 April 2010, from a basaltic effusive eruption associated with the 2010 Eyjafjallajökull eruption located approximately 7.5 km away. The field site is located in a saddle between the larger Eyjafjallajökull and Myrdalsjökull volcanic structures (Fig. 2) (Edwards et al., 2012). The Eldfell volcano, associated with the Vestmannaeyjar volcanic system, began erupting on 23 January 1973 on the island of Heimaey. The Eldfell eruption had both effusive and explosive alkali basalt eruptions and lasted for 5 months, producing ~0.23 km^3 of volcanic material (Fig. 3) (Thorarinsson et al., 1973; Higgins and Roberge, 2007). Both field sites have very

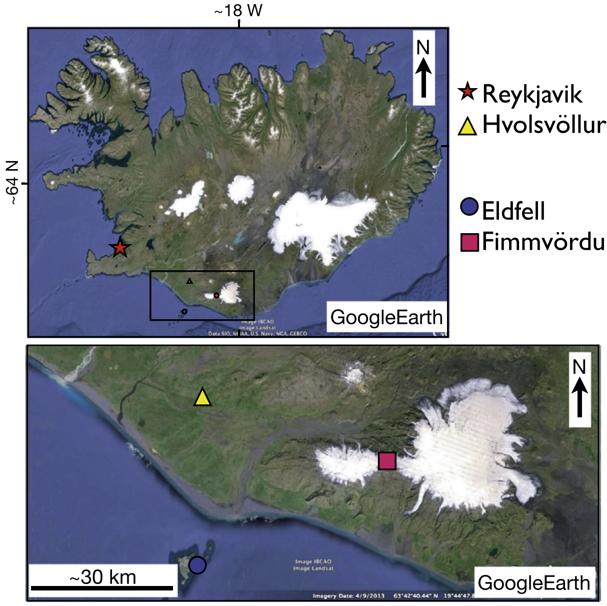

Fig. 1. A map of Iceland with the expedition's field sites marked.