ROVER–AERIAL VEHICLE EXPLORATION NETWORK (RAVEN): MISSION PLANNING, IMPLEMENTATION, AND RESULTS FROM THE 2022 ROVER-ONLY FIELD CAMPAIGN AT HOLUHRAUN, ICELAND.

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Introduction: With the successful deployment of the Mars 2020 robotic helicopter *Ingenuity* [1] and the planned future *Dragonfly* mission [2], understanding the potential of unoccupied aircraft systems (UAS) to increase the scientific return of future planetary missions has never been more critical. The ongoing Rover–Aerial Vehicle Exploration Network (RAVEN) project aims to develop optimal strategies for mission operations by conducting two field campaigns in a Mars analog environment: (1) UAS- and rover-only missions to establish baseline capabilities and science return for each mission architecture; and (2) a combined UAS-rover campaign. This study describes the results of the 2022 RAVEN rover-only mission at the Holuhraun lava field, a Mars analog environment in Iceland [3].

Field Site: The Holuhraun lava field was chosen for the RAVEN mission for several scientific reasons: (1) The 2014–2015 eruption of the Holuhraun lava flow-field is the largest flood lava eruption to take place in Iceland over the last 230 years and therefore provides an opportunity to study the development of large effusive eruptions that potentially inform the emplacement of larger flood basalt eruptions [3]; (2) The eruption emplaced lava over a large sand sheet, which may be analogous to lava flows deposited over sedimentary substrates on Mars [4]; and (3) The generation of a lava-induced hydrothermal system on the northern outwash plain of Vatnajökull [5] provides the opportunity to study microbial processes potentially analogous to past biological activity on Mars.

Rover payload: The Canadian Space Agency's Mars Exploration Science Rover (MESR) was utilized [6, 7] along with several handheld instruments to simulate the capabilities of a *Curiosity*- or *Perseverance*-class Mars rover. The total payload approximated a suite of instruments analogous to: (1) MSL Mastcam; (2) Mars 2020 SuperCam's VIS–IR spectrometer; (3) MSL ChemCam and Mars 2020 SuperCam Remote Micro-Imager (RMI); (4) MSL MAHLI, Mars 2020 SHERLOC WATSON, and ExoMars CLUPI; (5) MSL APXS; (6) MSL ChemCam and Mars 2020 SuperCam Laser Induced Breakdown Spectrometers (LIBS); and (7) Mars 2020 Navcam. The rover also simulated Mars 2020-like abrading and sampling capabilities with hand-held tools in the field.

Mission: Based on mapping and geomorphologic assessments of the region, the field site was subdivided into three components: (1) an older, underlying lava flow or flows; (2) active sand sheets; and (3) a younger, main lava flow-field (i.e., Holuhraun; Fig. 1). Primary goals of the rover mission involved identification, documentation, collection, and deposition of a cache of samples that fulfilled the RAVEN science objectives of characterizing habitability, understanding the modern aeolian environment, and understanding the nature and style of volcanism. At waypoints of interest, images and compositional data were acquired on bedrock exposures and modern sediment to provide contextualization for sample selection, facilitate scientific interpretation of the region, and form a basis for comparison of mission science metrics with the 2022 UAS field campaign and future combined UAS–rover mission campaign.

Sol Path: The rover campaign involved 13 sols (Martian day) of data acquisition and sample collection and one depot sol to simulate the drop-off of the sample cache, all along a predetermined sol path (Fig. 1b). The initial phase of the mission involved investigation of the modern sand field and sampling of the older lava flow (Fig. 2a, b; Sol 101–104), followed by an ~86.5-m traverse toward the Holuhraun flow margin, during which continued data collection was done on the older lava flow and the overlying sand sheet was sampled (Sol 105–107). Following an assessment and sampling of the Holuhraun lava flow margin (Fig. 2c; Sol 108–111), the rover acquired a second sediment sample (Sol 112–113) prior to traversing to the depot site (Sol 114).

Planning: Planning was done remotely and approximated the structure of daily mission operations for *Curiosity* and *Perseverance*. Science operations roles included a Science Lead, Science and Rover Planner, Support Scientist, and Documentarian. Activities were planned around predetermined daily constraints on duration, data volume, and energy that approximated typical constraints experienced by Curiosity and Perseverance. Standard science planning sols involved remote sensing (e.g. LIBS, Mastcam), contact science, and pre- and post-drive imaging activities. Sampling sols involved remote and contact science of the sample site prior to sample acquisition and subsequent imaging of the acquisition site.

Results:

Data acquired: The rover's sample cache included four samples: (1) older lava flow; (2) light-toned sediment; (3) dark-toned sediment; and (4) Holuhraun lava flow-field. Additional scientific observations and measurements acquired throughout the mission included 19 LIBS targets, 14 VIS–IR targets, 22 RMI observations, 4 APXS targets, 6 MAHLI targets, and 39 Mastcam observations.

Mission metrics: The planned total distance traversed by the rover mission was 238.7 m, with an average drive distance of 34.1 m. Of the 13 planning sols, 2 sols were limited by duration, 6 sols were limited by data volume, and 5 sols were limited by energy. Engineering activities required the most total time and energy during the mission simulation, and science imaging observations comprised the largest data volume. During the four sampling sols (Sols 104, 106, 110, and 112), the most energy was allocated to engineering, whereas driving required the most energy and duration during the long drive sols (Sols 105, 107, and 113). Of the two categories of science data (imaging and compositional), imaging involved the most data usage overall, whereas geochemistry measurements required the most duration.

Scientific interpretations: The modern sediment (Fig. 2a), older lava flow (Fig. 2b), and younger lava flow (Fig. 2c) were identified in rover-scale images, corroborating analog orbital-scale observations. Ripples and sand shadows visible in landscape images were interpreted as aeolian (Fig. 2a). Two types of sediment were identified: (1) light-toned medium sand comprising most active bedforms; and (2) a dark-toned substrate comprised of fine sand (Fig. 2a).

Outcrop-scale morphological differences were observed between the older and younger basaltic lava flows. The older flow is characterized by rounded protrusions and a rough surface texture. The younger flow exhibits a tabular expression and consists of coarse, drapey layering that appears highly disrupted. Both flow types exhibit a "spiny" texture with voids expressing of variable size and shape. Whereas exposures of the older flow lack visible phenocrysts, light-toned phenocrysts were observable in the younger Holuhraun flow-field. Overall, the older and younger lava flows were found to be geochemically and mineralogically similar.

The most astrobiologically compelling target identified was the dark-toned fine sand, which showed deep hydration bands in VISIR data (though this was likely due to recent rain fall). Small veins within the younger flow may have also hosted habitable microenvironments.

Conclusions and Future Work: The 2022 RAVEN rover mission at the Holuhraun lava flow-field involved a successful traverse from the older lava flow to the margin of the younger lava flow, during which a cache of four samples and supporting images and compositional data were acquired from each of the main features of interest to address questions regarding habitability, aeolian science, and volcanology. The findings of this study will provide a basis for comparison for the upcoming combined UAS–rover mission, with the goal of determining the most effective means of doing remote mission operations utilizing both robotic systems. Overall, scientific results highlight the importance of rover payload capabilities toward ground-truthing orbital-scale hypotheses and resolving the fine-scale features within a landscape.

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References: [1] Golombek et al. (2021). *LPSC LIII*, abstract #2156. [2] Barnes et al. (2021). *Planetary Sci. Journal*, 2(4), 130. [3] Bonny et al. (2018). *JGR: Solid Earth*, 123, 5412–5426. [4] Basu, U. et al. (2022). *LPSC LIII*, abstract # 2362. [5] Hamilton, C. W. et al. (2018). *JGR: Planets*, 123, 1484–1510. [6] Langley et al. (2012). *Proc. Of Int. Symp. on A.I. Robotics & Automation in Space.* [7] Osinski et al. (2019). *Planetary & Space Sci.,* 66, 110-130.

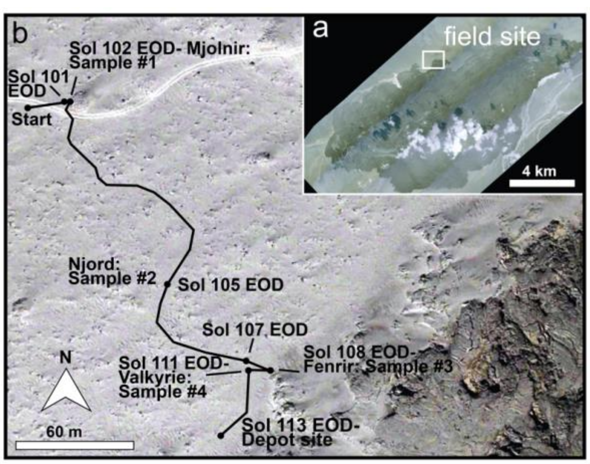

Fig. 1. (a) Map of Holuhraun flow-field and field site (white box). (b) Expanded view of field site & sol path.

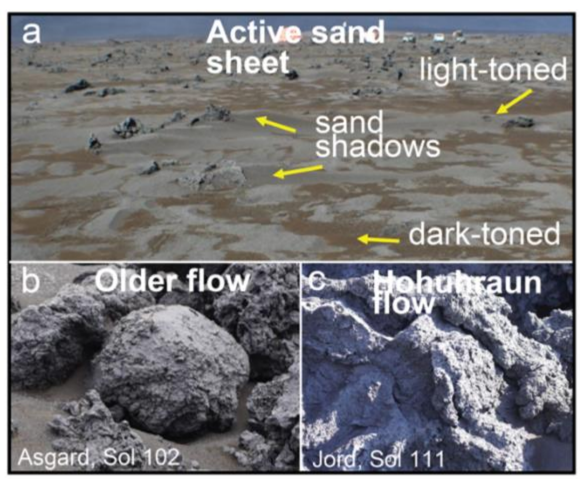

Fig. 2. (a) Light-toned aeolian ripples & sand shadows overlying dark-toned substrate. (b) Exposure of older lava flow. (c) Exposure of Holuhraun flow.