EXPLORING *RECURRING SLOPE LINEAE:* SURFACE MISSION ARCHITECTURE AND FIELD EXPERIENCE.

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Introduction: *Recurring Slope Lineae*, or *RSL*, are narrow, discolored, linear streaks that appear on steep slopes on Mars [1]. Unlike slope streaks, which have been attributed to randomly occurring dust avalanches [2], *RSL* recur in the same place in subsequent years and appear to progressively lengthen throughout the summer season [1,3]. Their appearance is correlated with warm temperatures, and they appear on slopes with different aspects depending on the time of year [4]. These characteristics lead *RSL* to be attributed to the action of liquid water [1,3]. Attempts to corroborate this hypothesis with additional evidence of liquid water have been met with difficulty, however: *RSL*-covered slopes do not show a significantly different thermal inertia than *RSL*-less slopes [5], and only a few *RSL* run out on slopes lower than the angle of repose, as one might expect of a liquid water flow [6]. Ojha et al. reported the discovery of perchlorate salts associated with *RSL* [7], but these detections may also have been due to a data artefact [8]. A surge in *RSL* in the wake of the MY24 dust storm supported the hypothesis that the *RSL* were dust-related [9]. However, hypotheses explaining *RSL* as purely dry flows encounter difficulty explaining why *RSL* behave differently from slope streaks (for example, their seasonal occurrence) [see summary in 10].

RSL hypotheses can be divided into three major categories: wet flow, volatile-triggered flow, and dry flow (**Figure 1**). The goal of further *RSL* research is to distinguish between these three hypotheses. Once this determination is made, the goal would be to distinguish between sub-hypotheses—for example, if *RSL* were determined to be the result of wet flows, we would then want to know where the water came from, how it became liquid, whether or not it can constitute a habitable environment, and whether anything is currently living therein.

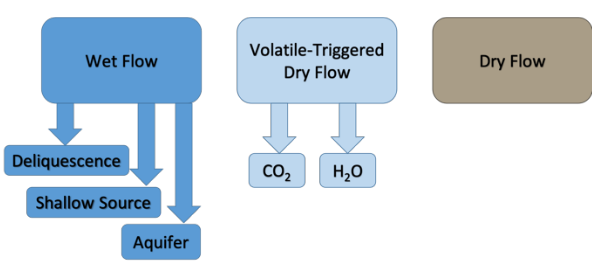

Figure 1. Hypotheses for *RSL* formation

In this contribution, we summarize the results of a three-year effort to determine what additional information would be needed to fully understand how *RSL* form, including what types of measurements would be needed, how they could be achieved, and where on Mars they would need to be collected [11].

Measurement Approaches: *RSL* observations have so far been made from orbit, mostly by the HiRISE instrument [12] on the Mars Reconnaissance Orbiter (MRO), which can best resolve them (<5 m across). Our understanding of *RSL* from orbit improves as we take more observations over a longer amount of time (improving our statistics). New instruments, such as a high spatial resolution multispectral camera, or new observing strategies, such as a HiRISE-class camera in a time-shifting orbit would improve our chances of detecting hydration features (in the first case) or observations of sources of water such as fog or frost (in the second case).

Still, many observations would remain ambiguous if made from orbit. Only a snapshot of *RSL* activity is possible as the orbiter passes overhead. We observe *RSL* "lengthening" over a summer season, but because we are not watching the *RSL* continuously, we do not know if these events are sudden (characteristic of an avalanche) or gradual (more like seeping liquid water).

Even if water *was* detected from orbit, we would not definitively know where it was coming from (e.g., deliquescence, near surface, aquifer, etc.). The distribution of water, ice, or CO_2 in the shallow subsurface would be needed to fully understand the *RSL* process. Finally, measurements assessing the level of water activity (how much is available to be used by living organisms), or whether the *lineae* are already inhabited are not possible from orbit.

Given the challenging terrain, we explored a large trade space for obtaining improved measurements of *RSL*, which included surface and aerial access as well as contact and non-contact science options [11]. The most favorable option was to access *RSL* from the rim side (hillslope), measure it with contact instruments to determine hydration state and the role of salts and to get below the surface to detect any moisture at depth.

Field Test: To investigate the aforementioned access option, we developed the second generation DuAxel; a JPL-developed rover with two rappelling Axels capable of accessing and conducting science investigations in *RSL*-like terrains [13]. We fitted the Axel rover with an instrument payload: stereo cameras (for context), a microscope (for close context), a near infrared point spectrometer (for measuring water and salt), and a dielectric probe, for measuring water with depth by electrical spectroscopy [14]. In August, 2019, we fielded the instrumented rover in Mojave, California, where we explored an artificial *RSL* created at a crater-wall-analog slope. A typical scenario included the rover traveling to the edge of the slope in a 4-wheeled configuration (**Figure 2**), anchoring, and then allowing one two-wheeled Axel robot to descend the slope (**Figure 3**), deploying the instruments sheltered within its wheel well.

Figure 2. Two 2-wheeled Axel robots dock to a central module to form a 4-wheeled rover called DuAxel.

Figure 3. Axel rover rappelling down the slope, testing dry talus, wet talus, and wet talus with added salt to determine if its payload was sufficient to distinguish them.

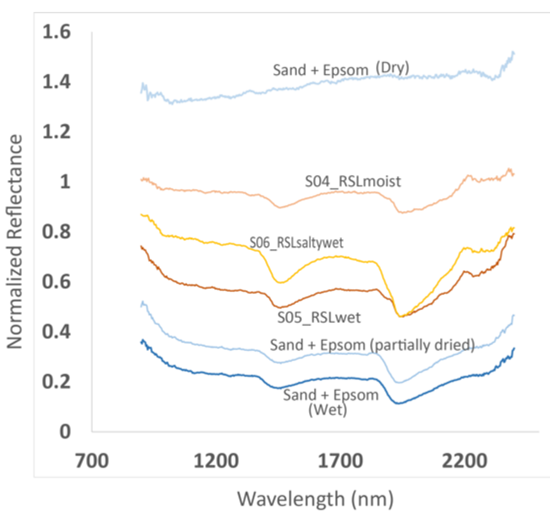

Figure 4. The NIR spectrometer could distinguish between dry, moist, wet, and salty *RSL* end-members.

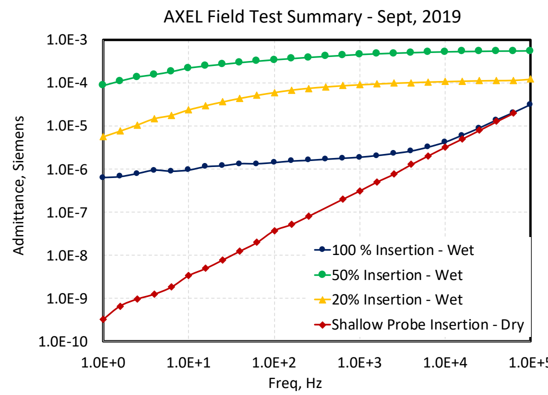

Figure 5. Results of dielectric probe measurements. In this case, water had flowed across the surface but not infiltrated fully to depth. The dielectric probe was able to capture this detail by inserting the probe to different depths. The surface was dry (red), the subsurface at 20% probe insertion was wetter (yellow), the subsurface at 50% probe insertion was wettest (green), and the deeper subsurface was dryer again (blue). The probe operator was able to draw this conclusion with no knowledge of the *RSL* set-up.

We conducted trials across five days using Mars-like operations to inform the science investigation, instrument operations, mobility access of extreme terrains and remote operations using an anchoring/rappelling rover. The rover traversed a total distance of 150 m across five days with remote and autonomous operations. Using remote operations, the rover rappelling 57 m on 30° average slope (with local slopes reaching vertical) with a total odometry of 75 m. Measurements with the full instrument suite were acquired on discolored and non-discolored slopes, during day and at night, with the dielectric probe acquiring measurements below the surface at 2 cm, 5 cm and 9 cm depth.

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