HALE CRATER – ANCIENT WATER SCIENCE, CONTEMPORARY WATER RESOURCE.

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Uniqueness: We chose Hale crater as a human landing site (LS)/exploration zone (EZ) primarily because of the ease with which liquid water can be extracted from Recurring Slope Lineae (RSL) found on the slopes of its central peak complex. Furthermore, the Hale EZ can address most or all of the astrobiology, atmospheric, geosciences, cross-cutting, and resource objectives.

Introduction: Hale crater is a complex impact crater (125 × 150 km located at 35.79°S, 323.68°E; **Fig 1**). Hale formed in the Amazonian (>1 Ga) and released ~10 km^3 of liquid water, fluvially modifying nearby channels [2]. The impact occurred on the Argyre basin periphery, and appears to be superposed on the long outflow system comprised of Uzboi, Ladon, & Morava Valles (ULM [3]; **Fig. 1**). ULM transported an estimated ~150,000–450,000 m^3/s of water during the late Noachian through the early Hesperian [3].

Hale's general mineralogy suggests deep mantle and primordial crustal material, while parts of the crater rim have been altered via impact-induced hydrothermal activity [4]. Minerals in the EZ may have recorded at least 3 impulses of activity: post-Argyre (~3.9 Ga [5]), post-Bond, and post-Hale (1-3 Ga [1,2]).

Within the last 10 Ma, hundreds of gullies were carved in the steep slopes of the central peaks and rim of Hale [6]. While gullies can be modified by the sublimation of CO_2 [7], it is generally accepted that gullies are a result of flowing water released during an epoch with a significantly different obliquity [8].

Currently, hundreds of RSL occur in the large uplifted mountains of the crater's central peak. These low albedo, narrow (<5 m) features incrementally lengthen down slopes (25–45°) from L_s 171±23° to 336±6° (270±50 sols from spring to summer), fade during the colder season, and recur the following year [9]. Water-based hypotheses best match observations that correlate incremental lengthening with higher surface temperatures [9-13]. Hale RSL begin flowing when surface maximum temperatures are significantly below 273 K. These flows are therefore briny, and likely originate from a confined aquifer [9].

Landing site: Many of the ~200 sites on Mars with RSL [9] present significant LS challenges. In contrast, Hale offers smooth, flat areas for landing and shallow slopes (<30°) for brine/water access. Our proposed LS (35.30°S, 323.14°E, elevation of −1621 m) is to the northwest of the central peak (**Fig. 2**).

Resource Regions of Interest (ROIs): We have located the LS and surface field station to allow access (<5 km) to the west- and southwest-facing slopes of the central peak. These slopes are covered in RSL during the spring and summer. While the spring-like sources that RSL emanate from are on steep slopes of 45°, most RSL extend onto smooth, shallower slopes (~25°). Modeling indicates that brine occupies the top 4-10 cm of these RSL. This brine could therefore be collected and sent downhill via a pipeline to a water treatment facility. Tapping a single RSL would likely provide 100 MT of water over the duration of the active RSL season.

Engineering material could be acquired from the lower scree slopes of the central peak or from the ponded and pitted material [2] in the center of the crater. The latter material may have a low rippability, allowing machinery to more easily move the material.

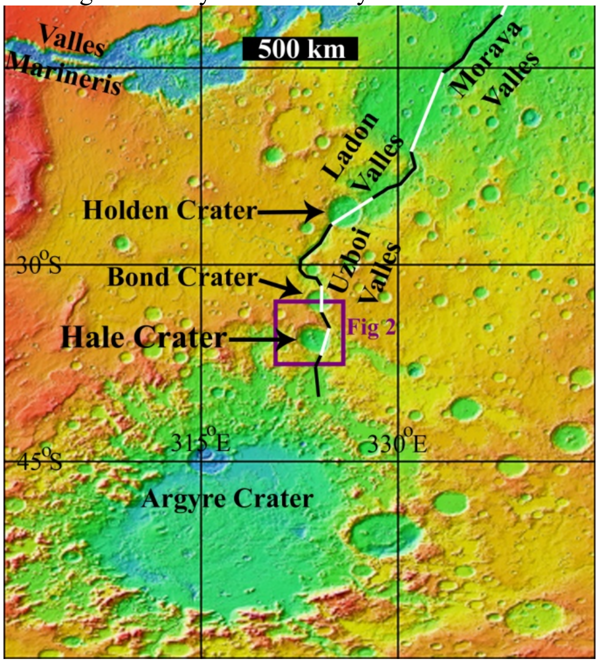

Figure 1. MOLA topography, showing Hale crater's location along the ULM outflow system and proximity to Argyre. Preserved ULM channels (black lines) and presumed lost morphology (white lines) trace the path that water took from Argyre or a lake on its rim to a basin within Margaritifer from ~3.8 to 3.5 Ga [3].

Scientific ROIs: While the nearby RSL-covered slopes would be used for resources, RSL-bearing slopes further to the southeast could be studied to better understand RSL and the dynamic local micro-environment(s) that they create. This would address the extant life and chemistry Astrobiology science objectives: A3, A4, A5, and A6.

The search for extant life within RSL should be a major priority. The RSL in Hale must be so briny (very low water activity values) that no known terrestrial life can respire there. This reduces the impact of cross-contamination by terrestrial life (i.e., reduced planetary protection). However, martian life may have either evolved a way to live in such an environment, or may be living within the depths of the RSL source regions.

Study of the gully science ROIs would address the diverse geologic processes Geoscience objective G3. Furthermore, Atmospheric science objective B5 (previous climate states) could be addressed by better understanding how/when the gullies were formed.

The ancient channel and hydrothermal mineralogy science ROIs would allow investigation into the formation of two pre-existing channels and hydrothermally-altered mineralogy. These channels may have been linked to a large outflow network (ULM; **Fig. 1**) and the hydrothermal environments may have once been habitable. Thus, these science ROIs could address the past life Astrobiology science objectives A1 and A2. Fluvial ejecta from Hale have partially filled these external channels. Subsurface imaging (using tools such as ground penetrating radar) could allow for a better estimate of the dimensions of these channels before Hale crater was emplaced, yielding better estimates of the amount of discharge needed to form these channels in the late Noachian to early Hesperian. Furthermore, understanding the impact-generated, fluvially-modified ejecta will improve our knowledge of surface conditions when Hale formed, as well as other similar craters such as Mojave, Tooting, and Sinton. Together, these science ROIs address the geologic and paleoenvironment evaluation Geoscience objective (G1) and additional questions about surface/ground water (Q8).

No well-constrained absolute ages of Mars' surface exist. Instead the lunar chronology (only marginally-constrained itself) is used along with dynamic arguments to estimate absolute ages on Mars. Argyre represents a significant stratigraphic event (modeled to ~3.9 Ga [14]) and significant structural work has been done to map its stratigraphy relative to major surrounding features [e.g., 4,14]. Additionally, since the formation of Hale postdates the likely end of major aqueous activity (the active channels), dating Hale would put a lower limit for this important epoch of Martian history. Radiometric age measurements of drill-collected impact melt material or in-place shocked minerals from the ROI could reveal two distinct ages, allowing us to anchor both of these events, significantly increasing our understanding of Mars' chronology and addressing the age Geoscience objective, G2.

Atmospheric stations at the field station and science ROIs would allow monitoring of the regional and intracrater water vapor, dust, and sediment transport, addressing Atmospheric science objectives B1 and B3.

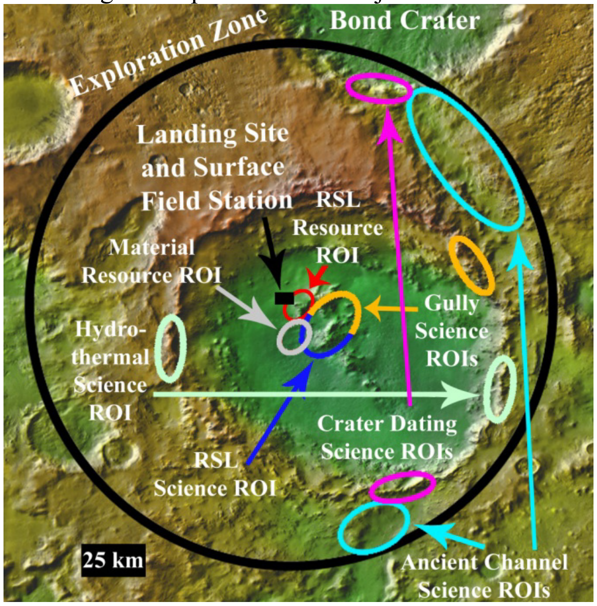

Figure 2. Proposed Hale LS/EZ.

Conclusions: The Hale EZ would allow easy access to liquid water via RSL. This EZ also exhibits a long history of water activity from the Noachian to today. The science ROIs meet the threshold criteria of allowing *access to deposits with a high preservation potential for evidence of past habitability and presence of sites that are promising for present habitability* via RSL, ULM channel, and hydrothermal exploration; *access to outcrops with morphological and/or geochemical signatures indicative of aqueous processes or groundwater/mineral interactions* via RSL, ULM channel and hydrothermal exploration; and *identifiable stratigraphic contacts and cross-cutting relationships from which relative ages can be determined* via dating, helping bound the ages of ULM system and Argyre.

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