THRESHOLDS OF DETECTION AND IDENTIFICATION OF HALITE NODULE HABITATS IN THE ATACAMA DESERT USING REMOTE IMAGING.

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Introduction: The guiding theme of Mars exploration is shifting from global and regional habitability assessment to biosignature detection [1]. To locate features likely to contain biosignatures, it is useful to focus on the reliable identification of specific *habitats* [2] with high biosignature preservation potential. Proposed chloride deposits on Mars [3,4] may represent evaporitic environments conducive to the preservation of biosignatures. Analogous chloride-bearing, salt-encrusted playas (salars) are a habitat for life in the driest parts of the Atacama Desert [5,6], and are also environments with a taphonomic window [7-9]. The specific geologic features that harbor and preserve microorganisms in Atacama salars are sub-meter to meter scale salt protuberances, or halite nodules (Fig 1) [7,10]. This study focuses on the ability to recognize and map halite nodules using images acquired from an unmanned aerial vehicle (UAV) at spatial resolutions ranging from mm/pixel to that of the highest resolution orbital images available for Mars [11].

Geologic Background: The hyperarid core of the Atacama Desert in northern Chile lies between 19ºS and 27°S and is flanked by the Coastal Range to the West and the Cordillera de Domeyko to the East. This region has experienced extreme and continued dryness for the past 10 – 15 Ma [12], and represents a terrestrial dry extreme for photosynthetic activity [13, 14], serving as an analog for evaporitic environments of late Noachian to early Hesperian Mars.

The field location for this study was located in Salar Grande at 21°8'57''S, 70°0°58''W. Like other salars in the Atacama, the surface of Salar Grande is covered in halite nodules formed via deliquescence and efflorescence over timescales of years to decades from originally flat salt polygons [6]. Halite nodules host endolithic cyanobacteria, which have a high likelihood of preservation within the halite crystals [8]. Halite nodules, if they were to be identified within Martian chloride deposits, would likely be high priority targets for study and sampling.

Methods: Visible images at five different spatial resolutions were used to explore the effects of image resolution on a human analyst's ability to recognize and map halite nodules. The images used were collected with a visible light camera (CMOS sensor, $f = 2.8$) onboard a UAV at 10 m flight altitude for a ground sampling distance (GSD) of 0.4 cm/pixel. Images were resampled to 1.7, 6.9, 27.6 cm/pixel using idealized modulation transfer functions (MTF), and to 55.2 cm/pixel using the MTF of the High-Resolution Imaging Science Experiment (HiRISE) camera on the Mars Reconnaissance Orbiter.

Figure 1: Halite nodules at Salar Grande. Microorganisms that inhabit the interior of nodules are occasionally exposed near nodule crests.

An orthophotomosaic of images at 0.4 cm/pixel was used to define a reference map unit of halite nodules over a 464.403 m^2 area of Salar Grande using the Interactive Data Language Environment for Visualizing Images (IDL/ENVI) software (Fig 2). Mapping efforts at the higher GSDs, specified above, were completed over the same area and compared against the reference map unit. Halite nodules were mapped based on the following characteristics: relief, brightness, and morphology. The parameters used to quantify these characteristics are presented in Table 1.

Nodules form at salt polygon edges, and rise, some gradually, others abruptly, to a typical relief of 0.10 – 0.30 m. The crests of most nodules are bright relative to their surroundings because pure halite is

Table 1: Definitions of parameters used to map nodules.

Brightness Parameter	[(avg. DN value of mapped unit) - (avg. DN value of reference map unit)] / (StdDev of reference unit DN values)
Accuracy Parameter	(# pixels in mapped unit that overlap with reference map unit) / (# pixels in reference map unit)
Precision Parameter	(# pixels in mapped unit that overlap with reference map unit) / (# pixels in mapped unit)
Area Parameter	(# pixels in mapped unit) / (# pixels in the scene)
Relief Parameter	avg.[tan(solar elevation angle) * (shadow lengths)]

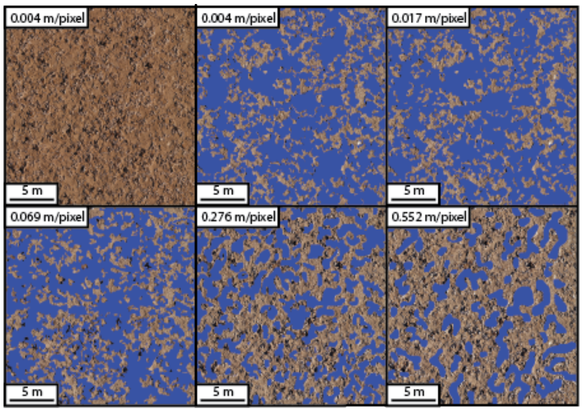

Figure 2: Panel 1 is the scene used to map nodules for this study. Blue areas are halite nodule map units at each GSD overlain on the full resolution scene. These are the "mapped units" referenced in table 1.

visible breaching the red/brown detrital ground cover [e.g., 7]. Nodules range in extent and morphology, from decimeter-scale, rounded, individual nodules to decameter-scale, furrowed, nodule clusters. Individual features are rarer (in terms of areal extent) than nodule clusters, as nodules typically merge at polygon vertices and edges.

Results: A summary of the results is presented in Fig 3. We found that halite nodules cannot be reliably mapped at GSDs of 27.6 cm/pixel or coarser. As resolution decreases it becomes more difficult, or impossible, to identify nodules, and increasingly bright regions are mapped, reducing the area mapped as nodules. Additionally, the mapping accuracy and precision parameters decrease as resolution coarsens.

Discussion: This work exemplifies how studies of terrestrial habitats can be used to guide measurement requirements for future Mars missions. We propose two regimes of feature recognition based on our data: *detection* and *identification*. We defined a threshold of *detection* as the spatial resolution necessary to notice the presence of a characteristic, and we defined a threshold of *identification* as the spatial resolution necessary to recognize a uniquely diagnostic set of characteristics and reliably infer the presence of a feature, such as a halite nodule. Even at the coarsest resolution explored in this study (55.2 cm/pixel) some characteristics of halite nodules were detectable but the nodules could not be reliably identified. That is, it was recognized that some features were present on the surface, but the margins, extent, morphology, and characteristics of the features were not reliably mapped, and a positive identification of the features could not be made. Our study indicates that features like halite nodules, if they exist on Mars, may be *detectable* with HiRISE, but not *identifiable*.

Reference: [1] Mustard, J.F., et al., *Report of the Mars 2020 SDT* 2013. [2] Cabrol N. *Astrobiology*, 2018. **18**(1). [3] Osterloo, M.M., et al., JGR: Planets, 2010. **115**(E10). [4] Osterloo, M.M., et al., Science, 2008. **319**(5870). [5] Wiertzchos et al., *Astrobiology*, 2006. **6**(3). [6] Davila et al., *JGR*, 2008. **113**(G01028). [7] Artieda, O., et al., Earth Surface Proc. and Landforms, 2015. **40**(14). [8] Summons, R.E., et al., *Astrobiology,* 2011. **11**(2): p. 157. [9] Fernández-remolar, D.C., et al., JGR*:* Biogeosci., 2013. **118**(2). [10] Chong-díaz, G., *Lecture Notes in Earth Sci*. 1988, Springer. [11] McKay, C. P., et al. (2003). Astrobiology 3(2): 393. [12] Houston, J. and A.J. Hartley, Int. Jour. of Clim., 2003. **23**(12). [13] Stan-Lotter, H., Novel Res. Results and App. 2012, Springer Vienna. [14] Warren-Rhodes, K., et al., Micro Ecol, 2006. **52**(3).

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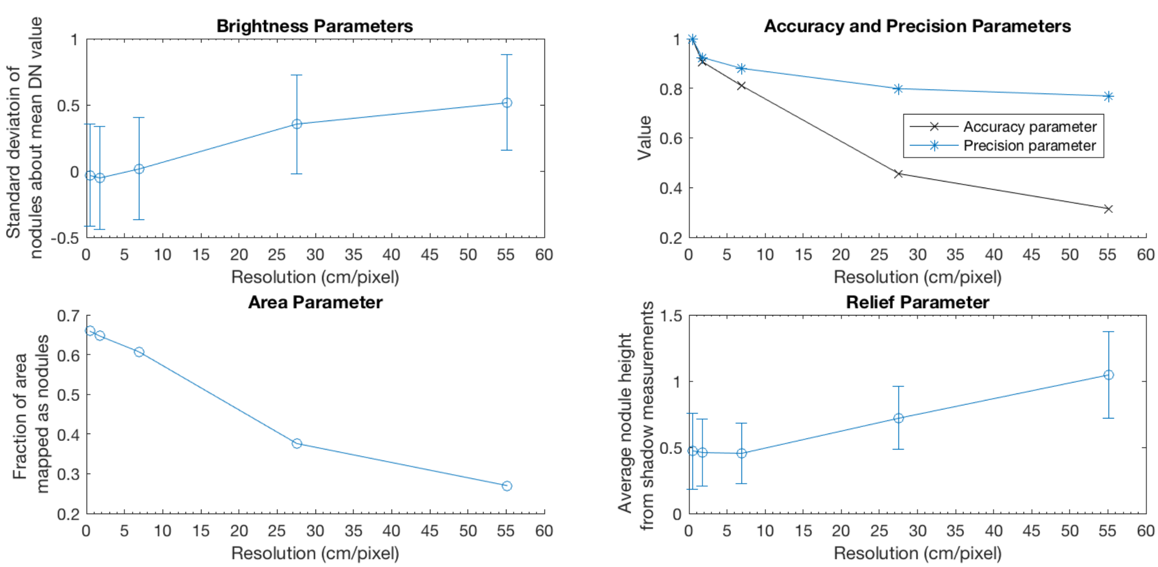

Figure 3: Plot of parameters defined in Table 1. Brightness parameter captures how the brightness of the mapped regions changes with GSD for the R, G, and B bands. Accuracy and precision parameters decrease with coarsening resolution. Area parameter is the fraction of the scene mapped as nodules. Relief parameter is average height of nodules measured with shadow lengths. Error bars = 2σ.