RECOGNITION CRITERIA OF SPRING DEPOSITS ON MARS AT ALL SCALES: EVIDENCE FROM THE DALHOUSIE SPRINGS ANALOG (AUSTRALIA).

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Introduction: Potential martian spring deposits are of considerable interest [1, 2] as indicators of water and the nature of the subsurface environment and as possible sites for preserved evidence of microbial communities. They are therefore attractive targets for exploration with Rovers, sample return missions [3], and eventually crewed exploration.

The Dalhousie Springs Complex (DSC) in central Australia is arguably one of Earth's largest groundwater discharge features, and is part of the Great Artesian Basin (GAB). The discharge points are marked by spring mounds of precipitated and trapped sediment. The hydrology, geomorphology, and deposits of the DSC therefore hold considerable significance as potential Mars analogues [4, 5, 6].

Recognition of spring deposits: Deposits at the DSC have a suite of distinctive characteristics evident at a range of scales that allows their recognition. These characteristics are found in all large scale spring deposits of the GAB [7] and but are also found elsewhere [8, 9] suggesting that they may have wider applicability. These are organized below from largest to smallest scale features [10]:

1. 10^4-10^2 m (medium resolution satellite images): Spring deposits form disconformable to unconformable surface caps that may be topographic highs. This may be due to their formation as constructed mounds of precipitated groundwater salts or because the well cemented deposits have become relativaly elevated through lowering of the surrounding landscape (Fig. 1). Apical pits are sometimes present and their margins can be precipitous.
2. At the same scale (10^4-10^2 m), compositional contrasts between the surrounding rocks and the spring deposits are likely (for example carbonate over silicate) and should be visible in medium to high resolution hyperspectral data, unless obscured by surface dust coatings (Fig. 1).
3. 10^3-10^1 m (high resolution satellite and ground level images): spring deposits will be generally conformable to the surface but locally cross-cutting. (Fig. 2). Convex-upward layering may be evident. Onlap point source deposits may be present on the original mound flank.
4. 10^0-10^{-3} m (close range, ground level, images): Mineral assemblages are apparent and include features such as: vein stock works, cavities, internal sediments, laminated, botryoidal, and mammaliated crusts and cavity fills, vugs are also common (Fig. 3).
5. 10^{-3}-10^{-4} m (close up images, low-power microscopy): Spring deposits show highly complex internal textures with cross cutting stratigraphic relationships (Fig. 4).

Figure 1: IKONOS multi-spectral image of the DSC showing compositional contrast between areas of spring deposits (white) and surrounding bedrock (red). The complex is ~20 km N-S and ~9 km E-W.

Figure 2: Small mesa ~5 m high - a morphological residual of a spring mound.

These relationships and textures are largely independent of composition. While the deposits of the DSC are predominantly calcite, with minor gypsum and pyrolusite, similar textures can be found in most mineral precipitates associated with springs and hydrothermal vents, for example spring deposits composed of fine-grained silica and sulfides [11], opal [12], and iron oxides [13]. This suggests that despite the composition of the martian springs, these textures and relationships will assist in the detection of spring deposits on Mars.

Figure 3: Brecciated and cavernous thermal vent limestone with internal cements and manganese sediments.

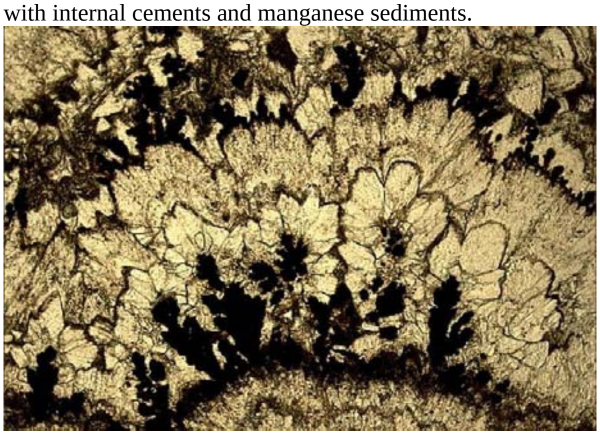

Figure 4: Microstromatolitic calcite and pyrolusite formed as thermal vent precipitates (2.5 mm wide).

Spring deposits on Mars: Previously hypothesized spring deposits include: pitted cones in Acidalia, Cydonia, and Utopia [10], light-toned deposits in Valles Marineris, chaotic terrains and several large craters [14], and several locations in Arabia Terra [3]. Other interpretations of the pitted cones include pingoes or rootless cones, and resolution of the genesis of all these features will likely require ground truth.

Hydrothermal silica deposits have been encountered by the *Spirit* Rover in the Columbia Hills [15]. Nearby features informally named "Crossfield" and 'von Braun" may represent fossil spring deposits. Some of the textures outlined here may be present in outcrop at these sites and visible in any future Rover imaging (Fig. 5).

Implication for Mars Exploration: In confirming the presence of spring deposits on Mars, Orbital images (e.g., HiRISE) continue to be important as they provide the regional context for features. They also allow identification of their architecture and mineralogy. However, ground truth by Rovers is essential. But hazardous steep tracks may limit observations to allochthonous blocks on the slopes surrounding ancient spring deposits, rather than accessing *in situ* material.

Figure 5: Crop of HiRISE image PSP_008963 _1650 showing possible spring deposits Crossfield (top right) and von Braun (bottom right).

We find that much of detailed fabric of spring deposits and thus their formation history can only be identified on a scale where the field of view is a few millimeters or less and the resolution is a few microns. The key features for identifying spring deposits are at the micron scale and are best detected used using transmitted light microscopy. The return of spring deposits to Earth is thus essential for detailed characterization.

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