The Ice Towers of Mt. Erebus as analogues of biological refuges on Mars N. Hoffman[1] and P. R. Kyle[2], [1]White Mars Research Program, School of Earth Sciences, University of Melbourne, Email nhoffman@unimelb.edu.au [2]Dept of Earth & Environmental Science, NM Bureau of Geology and Mineral Resources, New Mexico Tech, Socorro, Email kyle@nmt.edu

Introduction: The past three years have seen an explosion of speculation about flow features on modern Mars, based on physical evidence including the Malin and Edgett gullies [1] and dark dust streaks [2]. In parallel, supporting work has shown that liquid water is temporarily stable on the surface of Mars for the necessary period of minutes to hours to form these features [3]. Although alternative non-aqueous models have been proposed [4, 5], a majority of authors prefer a model of ephemeral liquid water to explain the features - especially the gullies, for which Arctic analogues exist [6, 7, 8]

Nonetheless, what is lacking in the studies to date is an appreciation of how water will behave under arid and cryogenic conditions, when it is close to the triple point. Under these circumstances, water will vaporize easily and large amounts of transport can take place in the vapor phase.

In this contribution we draw attention to Mount Erebus, on Ross Island, Antarctica, where unusual volcanic fumaroles form hollow icy towers, under conditions that are almost as cold and dry as Mars. We suggest that the search for active liquid water on present-day Mars can be targeted at these towers which have obvious thermal and albedo anomalies, and a characteristic surface expression and pattern of occurrence.

Under the harsh surface conditions of Mars, these icy fumarole towers represent a warm environment with high water vapor saturation and partial UV shielding – perhaps the most benign surface environment imaginable on modern-day Mars. Unfortunately, the analogue environment on Earth does not contain significant occurrences of liquid water, but the concept is nonetheless significantly attractive in the search for bioactivity on Mars.

We illustrate this search by an example from Hellas Basin that appears to represent a chain of geothermal anomalies or "hot spots". These are elevated by some 20-40K above the ambient temperature, based on Themis IR data, and should be checked with high-resolution visible imagery to look for the characteristic albedo signature of ice towers.

Nearby, two extended patches of thermal anomaly are also of interest and could represent surface escape of fluids and vapor. The search for additional sites is continuing.

"Water" on Mars: Odyssey Neutron data shows that much of Mars' surface is underlain by permafrost, so there is no lack of available H_2O. The physical form of this H_2O is ice, not water, and the average surface temperature of ~216 K is far below the melting point of even the most caustic eutectic mixture. However, the evidence of gullies [1] has led many authors to speculate that near-surface water may be reasonably common on Mars, at some orbital inclinations, especially if geothermal heating raises the local ground temperature.

Under these conditions, we note that any solid or liquid H_2O in the shallow regolith will be very close to the triple point, and hence to the vapor phase. We will explore here the consequences of this for the transport and deposition of H_2O, near to a geothermal hot spot.

Clifford [9] introduced the concept of vapor phase transport of H_2O within a cryoregolith on Mars. He envisaged a deep liquid reservoir gently adding vapor to the regolith pore space, which percolated upwards until it cooled and froze within the regolith, forming a thick permafrost layer without the need for atmospheric cycling of H_2O. We draw on that concept, and on a fascinating terrestrial example of low-temperature vapor-phase transport to suggest the likely form of active H_2O sites on Mars.

Mount Erebus and its Ice Towers: Situated on Ross Island, Antarctica, this ~3800m active volcano is unusual both in terms of its chemistry, and its fumaroles [10]. The summit region is composed of porphyritic anorthoclase phonolite, with crystals commonly 7-8cm in length. A lava lake occupies the summit crater, which has been continuously active since 1972. Small Strombolian outbursts are common and the crater is somewhat hazardous. In 1992, the Dante robot explorer entered the crater, with the goal of sampling volcanic gases, but a failure of the winch system aborted the mission.

The fumaroles of Mount Erebus are quite unique on Earth. Normally, volcanic fumaroles are marked by small accumulations of spattered lava, and mineral species precipitated out of the volcanic gas stream, such as sulfur and sulfates, zeolites, and other exotic crystals. Note that these are the components of the volcanic gas that solidify at surface temperatures (or retrograde reaction products as the gases cool and mix with ambient air and rock). Other gaseous emissions such as CO_2, SO_2, H_2S, and H_2O are dispersed into the atmosphere.

On Mount Erebus, notably, at the prevailing temperature of the summit (~235 K), H_2O forms a solid phase – ice. Since H_2O is one of the most common constituents of volcanic gas, the potential exists to form large fumarolic constructs of almost pure ice (Figure 1).

In some regards, the morphology of these chimneys is similar to that seen at the "black smokers" of mid-ocean ridges where submarine vents release highly mineralized water. Here, the volumetrically important species that can form framework solids are metal sulfides and other ore minerals and these create spires and chimneys up to 30m in height, centered on and focusing the hot fluid vent.

On Mount Erebus, a similar hollow ice chimney forms, up to 10m high, atop a broader mound of ice formed by debris collapsing off the spire. In local fumarole fields, chains of ice towers are aligned along subsurface fissures. The mounds may be 10-30m across and the chimneys have a diameter of a few metres. It is possible to ascend the chimneys by ice climbing and descend into the interior (Figure 2).

Under some towers is a grotto – a cave like hollow under the perpetual ice of Antarctica. This grotto arches over the actual surface vent of the fumarole – typically a fissure in the lava. Daylight is attenuated and colored by its passage through the ice to produce an eerie blue dimness, sheltered from the howling winds outside (Figure 3). A local microclimate prevails inside the grotto which is tens of degrees warmer than the outside air, and sheltered and "moist". (The term "moist" should be used with caution, since temperatures are still substantially subzero, and ice plates onto the roof of the grotto, but relative humidity ranges to 96%).

The ground surface under the grotto is remarkably dry and ice-free, and still generally at sub-zero temperature unless a strong local outgassing vent warms the ground. Even here it remains dry because if any liquid water was present in the regolith, it would rapidly evaporate, as would ice sublime. Thus, the heat of the fumarole acts to drive H_2O out of the regolith, and into the arch of the grotto, and up the chimney to form the tower. However, as temperature within the grotto fluctuates, the cave roof may undergo thawing or freezing, generating local liquid water.

Ice Towers on Mars?: By analogy with Mount Erebus, we argue that geothermal hot spots on Mars are unlikely to emit liquid water, unless they are exceptionally active, or newly formed - when the extensive permafrost might melt for the first and only time. Instead, under equilibrium conditions the effect of a hot spot will be to drive vapor-phase transport of H_2O. The regolith will become desiccated, and H_2O-rich vapor will be expelled upwards. At the surface, a similar grotto-and-chimney style of ice tower is anticipated.

Unlike Antarctica, most of Mars is not covered by permanent surface ice. Therefore a tower and mound of clean, bright, water ice will be superposed on the dull ochre dust of Mars. A broadly circular or elongate white spot 10-30m across is anticipated. Although this feature will be close to the limit of resolution for most satellite imaging systems, its high albedo contrast represents a significant imaging target. We anticipate towers to grow taller under the lower gravity of Mars, for the same base diameter. Towers 30m or more in height appear possible, and under appropriate low-sun lighting conditions, a visible shadow may also be detectable if metre-scale resolution imaging is employed.

As a further characteristic, we anticipate that multiple hotspots and associated towers will occur along the line of a single fissure and be elongated in a preferred direction, as is the case on Erebus. Therefore we can search for not just a single white dot, which could be an artifact, but a chain or cluster of dots, which is unambiguous.

To date, we have not identified any such features in high-resolution Viking or MOC visible images which have the required resolution to identify these anomalies. However, a very interesting pair of Odyssey InfraRed images from Hellas Basin is worth attention.

The daytime IR image I01047002 identifies two areas of thermal anomalies (Figure 4). Only one IR band is shown here, but the features are emissivity anomalies on all 9 IR bands, suggesting that they are not patches of unusual mineral composition with reflectivity in one or more bands. Furthermore, the location of the bright patches in shadowed hollows and backslopes suggests that the daytime emissivity is not simple reflection of solar radiation, or local ground warming of sun-facing slopes.

The two areas are rather different – one has a couple of extended patches some 2 km across, while the other shows an elongate cluster of pixel-scale (i.e. 100m or less) dots and blobs. The latter exactly fits the expected distribution of a cluster of hotspots along a fracture set.

The thermal anomalies are confirmed by night-time image I01228002 which still shows a 20-40K thermal contrast, although nighttime temperatures are substantially colder across the scene, and terrain-related anomalies have all but dissipated. The two images are overlain in Figure 5, which uses "hot" colors for the nighttime IR, and "white" intensity for the daytime IR to show terrain shape from shading. The coregistered images show that daytime and nighttime anomalies exactly coincide.

Despite a search of the MOC image archive, high-resolution visible images have not been found to confirm the visible albedo of these features. We cannot therefore be sure that we have found actual ice towers on Mars, but we do appear to have located geothermal anomalies – a major search target for multiple investigations. Clearly, this area deserves further study and additional imaging.

Biological Implications: Although it is unlikely that any extant biota survive on the Martian surface, ice towers represent a significant protective environment that could act as a refuge for microorganisms. The grotto and the inside of the chimney are substantially shielded from UV radiation by the icy structure of the chimney and mound. Temperatures inside the grotto will be stable, and warmer than ambient.

At some locations inside the grotto, transient films of liquid water are possible. Therefore, microorganisms *might* have some chance of survival in such a location.

Since ice towers present such a striking and obvious visual target, and since the pattern of IR anomalies expected from a cluster of thermal vents is also distinctive, we recommend additional searches of existing imagery for the characteristic signatures described here.

Once a reasonably extensive search has been conducted for these new classes of target, we can begin to understand their surface distribution in terms of the tectonics and geologic history of Mars, and prioritize areas for future orbital imaging and possible precision landers.

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Figure 1: A steaming fumarole on Mount Erebus with a 10m ice-tower precipitated from H_2O-rich volcanic gas

Figure 2: Climbing to the chimney entrance of an ice-tower.

Figure 3: Inside the grotto below an ice-tower. Note the bare, dry rock underfoot and the filtered light.

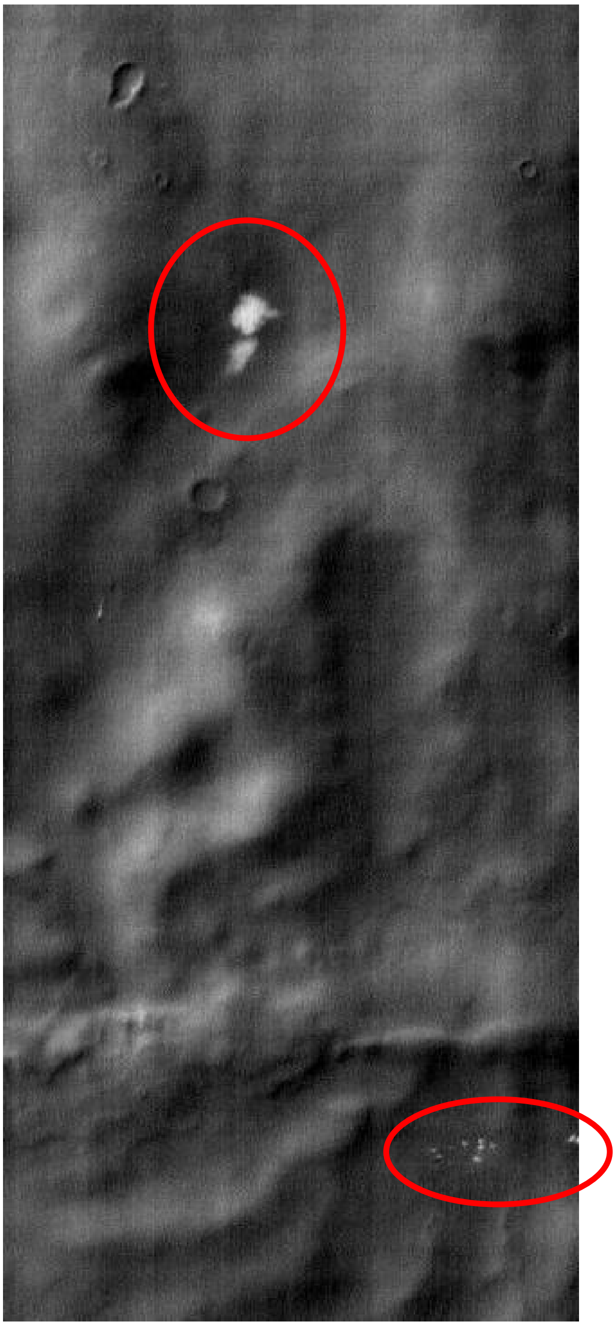

Figure 4: Daytime Odyssey IR image I01047002 in Hellas Basin, showing two areas of anomalous emissivity **not** associated with sun-facing topography. Both areas are in full or partial shade, in shallow depressions or on the back-slope of a ridge.

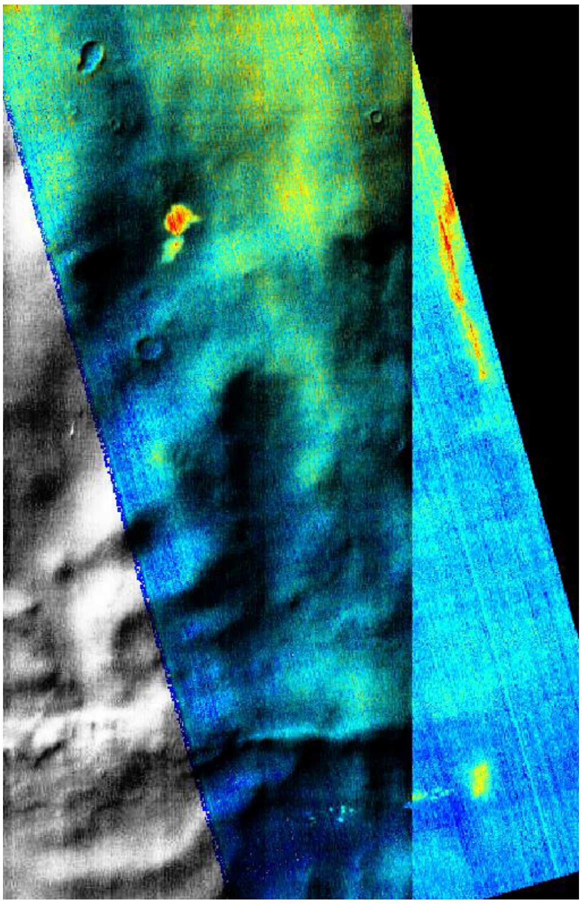

Figure 5: Overlay of nighttime IR image I01228002 showing "hot" colors associated with 20-40K thermal anomalies during day and night over these anomalous areas. Elongate anomaly at centre-right is a rock-rich crater rim that received a large sunlight budget. In contrast, the anomalous areas were in shade during daytime.