EVALUATION OF A PROPOSED TECHNIQUE FOR IDENTIFYING MARTIAN CAVES IN THEMIS INFRARED IMAGES.

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Introduction: Caves can provide shelter against the inhospitable surface conditions on Mars, protecting not only possible past life, but also potentially protecting humans in future exploration missions [1]. The key to being able to utilize caves on Mars begins with finding them. Images of cave-like features from various visible-wavelength cameras unfortunately do not show sufficient detail to unequivocally identify caves. Here, we evaluate a potential technique for identifying cave skylights on Mars in orbital thermal infrared (IR) images, which relies on the hypothesis that these features should not exhibit the same diurnal thermal behavior as the surrounding land surface.

Background and Method: Cushing et al. [2] have identified seven possible skylight entrances into Martian caves on the volcano Arsia Mons, dubbed the "Seven Sisters," using IR images from the Mars Odyssey Thermal Emission Imaging System (THEMIS). These features were found to exhibit diurnal temperature variations that were smaller than their surrounding surfaces [2].

Here, we expand on this observation in an attempt to define a systematic method for locating caves in THEMIS night IR image data. Our method is based on the hypothesis that the geologic materials in cave openings may not exhibit typical diurnal thermal patterns because their temperatures are influenced by additional factors, such as contact with potentially large volumes of air below the surface. Thermophysical models for Mars (*e.g.*, [3]) typically assume horizontal surfaces, with temperatures solely controlled by insolation, the albedo, and the thermal inertia of the surface materials. In practice, the results from such models are constrained with measured quantities to derive the thermal inertia of the surface: surface temperature measurements (*e.g.,* from THEMIS IR images), albedos (from visible observations), and the observing circumstances are used to select from a family of different possible model-generated diurnal thermal curves associated with different thermal inertias.

Figure 1 shows an example family of different modeled diurnal thermal curves from [4] for a set of surfaces that differ only in their thermal inertias. To the extent that the model accounts for all relevant physics, the temperature of a typical homogeneous, horizontal Martian surface would be expected to follow a single diurnal curve because the thermal inertia of a surface should not change on that timescale. If there are factors influencing the temperature of the surface that are not accounted for in the model - for example, contact with a reservoir of subsurface air inside a cave (either cold-trapped in the winter or warm-trapped in the summer) - it is possible that the temperature of the affected surface might not follow a single diurnal curve predicted by the model. Put another way, if temperature measurements of the same surface from two different times of day yield two different thermal inertias, this would be taken as evidence of anomalous thermal behavior, suggestive of unaccounted factors influencing the surface temperature. Identification of such anomalous thermal behavior by itself would not be sufficient to identify caves because other factors not included in this model (*e.g.*, diurnal sublimation/condensation of volatiles) exist. However, taken together with photogeologic evidence for features possibly associated with cave entrances, such thermal behavior would be very suggestive.

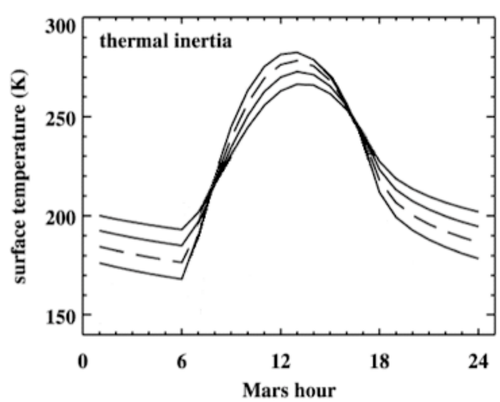

Figure 1: Sample diurnal thermal curves for different thermal inertia surfaces that are otherwise identical (adapted from [4]).

To test the proposed method of cave detection, THEMIS IR images of candidate cave features taken at two different times during predawn hours were used to calculate thermal inertia images using the model of [3] in the jENVI THEMIS analysis software suite (which also takes into account seasonal differences in the observations and atmospheric

conditions). The two thermal inertia images were then registered to each other and subtracted to create a differenced thermal inertia image. Surfaces that conform to the model will report approximately the same thermal inertia at both times, leading to a value near zero in the differenced image (within the uncertainties of measurement, quantified by [5] as total ~65 J m^{-2} K^{-1} $s^{-1/2}$). Surfaces that have temperatures influenced by non-standard factors could have anomalously bright or dark areas in the differenced image because the thermophysical model would report two different
thermal inertias at the two times of day.

VIS Image ID	Center Latitude	Center Longitude	Incidence Angle
V07946019	8.48 °N	162.60°E	77.540
V10456019	20.41	123.82	67.399
V11478007	15.74	161.83	71.590
V12041006	21.18	121.69	71.686
V12066009	21.55	120.57	71.638
V12877003	21.71	125.51	74.162
V14225010	22.93	120.07	83.794
V14462024	19.97	122.98	85.830

Table 1

Data: The proposed technique was applied to three of the Seven Sisters targets (Abby, at 240.54° E, 6.713°S, and Nikki, at 240.55°E, 6.708°S, and Wendy, 240.32°E, 7.84°S) where sufficient quality data were available at two pre-dawn times, as a check of the method where cave identifications are relatively well-established. A recent survey of over 40,000 THEMIS visible images [6] produced a list of 54 targets with morphological evidence potentially related to caves. Eight of these targets (Table 1) have good quality THEMIS night IR images at two pre-dawn times, which were also processed in the method described above.

Results: The example thermal inertia difference image in Figure 2 (containing the Abby and Nikki features from the Seven Sisters [2]) show no bright or dark areas that stand out against the background at the geographic locations of the features. The putative cave features analyzed from the list of [6] also have thermal inertia differences that were no different than the surrounding surface material. For all features examined, the proposed cave-related features all but disappear into the surrounding terrain (Figure 3).

Discussion: The failure of our proposed method for identification of cave-related features using thermal inertia anomalies has several possible explanations, including: 1) The features examined so far are not true caves, but rather pit craters, fissures, or other shallow features without deep reservoirs of trapped air; 2) Some of the features may be true caves with deep reservoirs of trapped air, but it has insufficient thermal mass and/or airflow to strongly influence the temperature of geologic materials at the putative entrances; 3) The uncertainties associated with calculation of thermal inertias are larger than the magnitude of the proposed effects.

Some of the candidates of [6] with the best photogeologic evidence for features associated with possible caves could not be analyzed due to the insufficient quality/timing of the THEMIS IR coverage. We will continue to test the method as better data of these targets are acquired by THEMIS.

References:

[1] Wynne, J. J. et al., (2008) *EPSL, 272*, 240-250. [2] Cushing, G. et al., (2007) *GRL*, *34,* L17201. [3] Mellon, M. T. et al., (2000) *Icarus, 148,* 437-455. [4] Putzig, N. E. et al., (2007) *Icarus*, *191,* 68-94. [5] Fergason R. L. et al. (2006) *JGR*, *111*, E12004. [6] Cabrol, N. et al., (2009) *LPS XV,* Abstract #1040

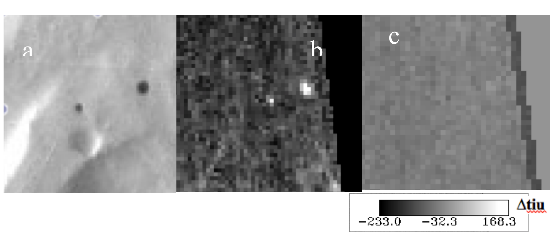

Figure 2. Images for of proposed caves Abby and Nikki from [2]: a) Visible THEMIS image V17716001; b) Night IR THEMIS image I15151011; c) Thermal inertia difference image made using image in b) and image I01309002. For scale, individual pixels seen are in b) and c) are 100m. Units of Δtiu are J m^{-2} K^{-1} $s^{-1/2}$.

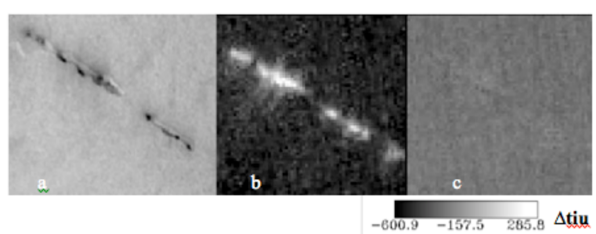

Figure 3. **(a)** Visible image of candidate cave or cavity feature (THEMIS Image V07946019) from [6]. **(b)** Thermal inertia images of same region from THEMIS Image I07703013. **(c)** Difference of thermal inertias from THEMIS images I07703013 and I18910003. For scale, individual pixels seen are in b) and c) are 100m. Units of Δtiu are J m^{-2} K^{-1} $s^{-1/2}$.