Earth-Mars Cave Detection Program, Phase 2 – 2008 Atacama Desert Expedition
Explorers Club Flag Report (Flag #52)

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NOTE: The team members listed above are part of a three year study cave thermal behavior in the Atacama Desert, Chile and Mojave Desert, CA; this team received a three-year grant to conduct this project under NASA's Exobiology program. During Year 1, only Wynne, Chong and Titus will be participating in fieldwork with the assistance of a cave mapping team and other personnel.

The Atacama Desert expedition is part of a broader three year study to: (1) characterize thermal behavior of both caves and non-cave features at two Mars analogue sites: the Atacama Desert, Chile and Mojave Desert, California (only the Atacama work will be discussed in this proposal); (2) evaluate the potential to differentiate thermal signatures of deep caves from shallow caves, as well as deep caves from impact craters and collapse pits; and, (3) develop models for Martian caves that simulate Mars atmospheric conditions using thermal behavior data from terrestrial caves. Our overall goal is to define mission and instrumentation requirements for detecting caves on Mars using thermal infrared imagery.

Potential Importance of Martian Caves: (A) Caves may be important in detecting evidence of extraterrestrial life because they offer protection from low surface temperatures, unfiltered ultraviolet radiation and violent windstorms, which may degrade and decompose organic materials. (B) A manned mission to Mars will require access to significant H2O deposits for drinking water, oxygen and liquid hydrogen fuel. Caves may provide the best access to these resources without the added expense of developing rover enabled augers and drilling equipment. (C) Future human exploration and possible establishment of a permanent settlement on Mars will require construction of living areas sheltered from harsh surface conditions. Caves with a protective rock ceiling would provide an ideal environment where these shelters may be built.

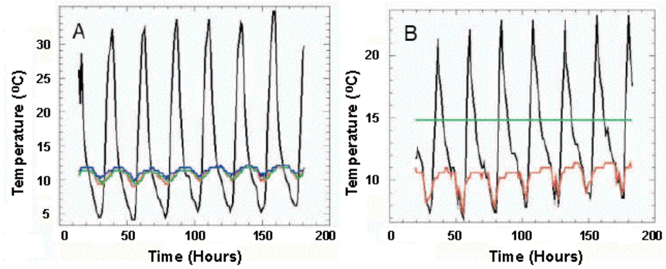

Fig. 1: Thermal behavior data of Cavernas de Quitor (A) with lateral (red) and sinkhole (green) entrances, midpoint (blue), and surface (black) temperatures, and Cueva Mina Chulacao (B) with entrance (red), dark zone (green) and surface (black) temperatures. Data collected from 19 - 30 June 2006, Atacama Desert, Chile. From *Wynne et al.* [2008a].

Terrestrial Cave Detection: Rinker [1975] provided the baseline for detecting caves in the thermal infrared, and suggested caves could be detected by identifying the thermal signal associated with the mass of air at the entrance contrasted against the surrounding ground surface. We suggest temperature contrast between the rock walls within the cave entrance and external surface rock will be the basis for cave detection [*Wynne et al.,* 2008a, b]. Internal cave surface temperatures represent the mean annual ambient temperature [*Cropley* 1965; *Pflitsch and Piasecki* 2003] while ground surface temperature, influenced by direct solar insolation and to a lesser extent by ambient air temperature, fluctuates diurnally and seasonally [*Wynne et al.*, 2007, 2008b]. Optimal thermal detectability will occur when differences between thermal radiance of the cave walls at the entrance and ground surface are greatest.

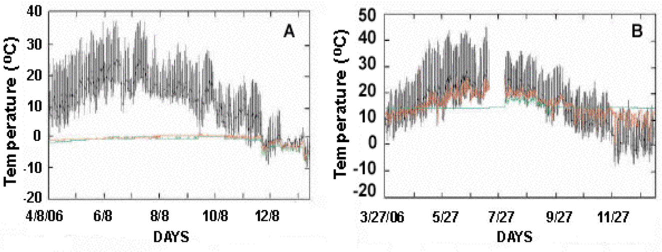

Fig. 2. Hourly temperature data of entrance (red), dark zone (green), and surface (black) for Ice Cave, New Mexico (A) and Cathedral Cave, Arizona (B). *Wynne et al. unpublished data.*

During Phase 1, we collected hourly temperature data and thermal imagery at two caves in the Atacama Desert, Chile [Wynne et al., *2008a, b*] and nine southwestern U.S. [*Wynne et al.*, 2008b] to characterize thermal behavior and identify detection times. Thermistors were placed at the entrance, dark zone and surface. For the Atacama caves, optimal detection times were ~1200 and ~1400 hr for Quitor (**Fig. 1A**) and Chulacao (**Fig. 1B**), respectively.

We collected longer term datasets for southwestern U.S. caves. For Ice Cave, western New Mexico, greatest thermal contrast occurs from spring through early fall when this cave exhibits a ~30° C difference between entrance and surface (**Fig. 2A**). Cathedral cave, northern Arizona is most detectable late spring through mid-summer at midday with a maximal temperature difference of a ~20° C between entrance and surface (**Fig. 2B**).

Thermal image capture has also been successful in approximating detection times. However, because images have been taken during late fall to early winter, seasonality cannot be assessed and thus interpretations may be limited. For thermal images collected over a 24-hour period at Xenolith Cave, western New Mexico, thermal contrast is greatest in the late evening (**Fig. 3A**) and predawn images (**Fig. 3B**) when the effects of solar insolation are diminished to nonexistent, and surface temperatures are driven largely by ambient temperatures [*Wynne et al.* unpublished data].

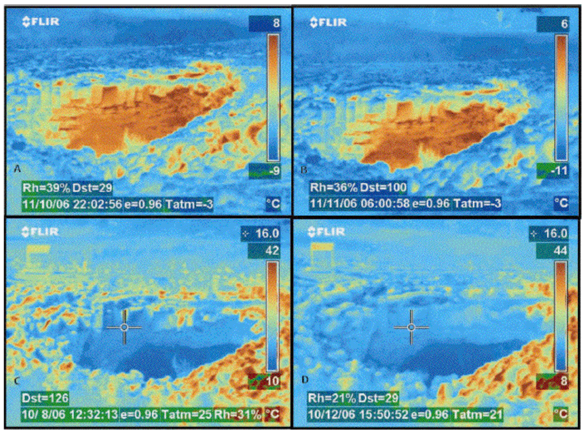

Fig. 3. Imagery of Xenolith Cave, NM captured over a 24 hour window from early morning to late afternoon. A FLIR Therma CAM™ B20 HSV infrared camera was used to collect images. A. Late-evening; B. Pre-dawn; C. Early Afternoon; D. Late-Afternoon. FLIR camera courtesy J. Thompson, FN05. *Wynne et al. unpublished data.*

Thermographic Detection on Mars: Atmospheric and surface conditions on Mars fluctuate more dramatically as compared to Earth. On Mars, large diurnal [*Kieffer et al.*, 1976; *Ye et al.*, 1990; *Larsen et al.,* 2002] and seasonal temperature variations [*Larsen et al.*, 2002] have been documented. Additionally, Martian air has lower pressure, density, and heat capacity than Earth's atmosphere. Thus, much larger amplitudes of diurnal and seasonal temperature shifts are expected on Mars. Because these shifts would occur widely and internal cave temperature is expected to be relatively constant, Martian cave detection is feasible using imagery at the appropriate wavelength and spatial resolution [*Wynne et al.*, 2008a]. We anticipate this will influence signal strength of Martian cave entrances resulting in a stronger thermal signal than their terrestrial counterparts.

Cave-Like Features on Mars: Finding and evaluating caves for their potential to harbor life on Mars is not a new concept [*Grin et al.,* 1998, 1999; *Boston,* 2000; *Boston et al.,* 1992, 2001, 2003]. As part of our proof-of-concept study, several possible cave-like features (a.k.a. the seven sisters) were identified on the northern flank of the Arsia Mons volcanic field [*Cushing et al.,* 2007]. Surrounding topography for most of the features is characterized by collapse pits and grabens [*Ferrill et al.*, 2003; *Wyrick et al.*, 2004]. On Earth, collapse pits are often associated with lava tubes and form when the cap rock subsides and the rock and sediment collapse into the void. Most candidates occurred in proximity to or within collapse pit chains, and likely formed similarly. They are characterized by dark circular features and are consistent with large vertical walled pits.

We used a combined visual-thermal imagery interpretation approach to analyze the feasibility of these features as cave sinkholes. **Figs 4B** and **4C** shows an example of such feature (Annie) characterized by a warmer temperature signal than the shadows of adjacent collapse pits during the afternoon, and remains warmer than the surface in the morning.

This result is consistent across all these features, and is consistent with the terrestrial analog imagery captured at night and early morning. To further investigate these features, we used photoclinometric routines to estimate subsurface topography. Our results indicate these seven features range in depth from 53 to 130m.

Recent imagery captured by HiRISE on board the Mars Reconnaissance Orbiter suggests at least one of the "Seven Sisters" (Jeanne) is unlikely to be an impact crater [*HiRISE Operations Center 2007*]. According to the HiRISE team, the best interpretation is that this is a collapse pit into a cavern or at least a large pit with overhanging walls. Furthermore, interpretations from the imagery suggests the walls are either perfectly vertical, extremely dark or more likely, overhanging [*HiRISE Operations Center* 2007]. *Halliday and Wynne* [2008] suggest the seven sisters are actually pit craters similar to those on the Big Island, Hawaii.

Hypotheses: Our goals are to (1) better understand thermal behavior of both terrestrial and Martian caves, their optimal detection time of day and season; and to (2) ultimately be able to differentiate caves from non-cave features, and potentially inferring cave volume from the thermal signal of a cave entrance. To that end, our project will test several hypotheses (H): (H1) Cave structure, geospatial location, topography and geology will influence thermal capacity and affect cave signature, thus detection capabilities in the thermal infrared; (H2) Strength of thermal signal of cave entrances is directly correlated to volume and horizontal length; (H3) Non-cave features will have thermal behaviors distinct from cave entrances, enabling us to discern caves from non-cave features; and, (H4) Due to the low atmospheric pressure and wide diurnal temperature fluctuations on Mars, we expect signal strength of cave entrances to be stronger as compared to Earth.

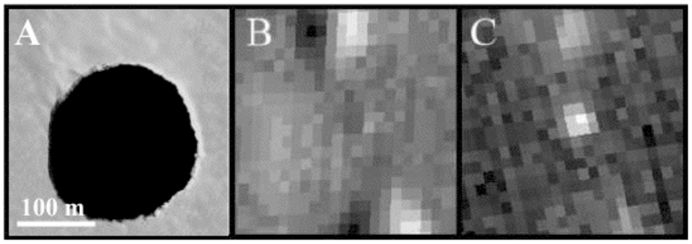

Fig. 4. A. HIRISE image (23 cm/pxl) of "Jeanne" released in May 2007 (PSP_003647_1745 sub-image); (B) THEMIS afternoon (~1500 hrs) IR image of and (C) early morning IR image (~0400 hrs) of "Annie". "Annie" resolvable at center of image C. From *Cushing et al.,* [2007].

Data Collection: We deployed sensors at sample 8 caves and 7 non-cave features in the Atacama as a baseline. Hourly temperature data and barometric pressure is currently being collected at each cave for two years using HoboPro© remote data loggers.

Temperature data will be required to best model cave thermal behavior and to best understand when caves may be most detectable in the thermal IR. Barometric pressure data will provide us with an additional metric to better understand why caves are detectable at certain times and not others. For example, as cave air temperature and surface temperatures equilibrate due to barometric pressure shifts, this air movement may influence the walls of the cave entrance and thus ultimately influence detectability.

Appropriate Times for Cave/ Non-Cave Detection: Data will be retrieved in June 2009. These data will be used to investigate the relationships of thermal behavior temperature data collected for ground surface, the cave entrances and deep zones. This will enable us to: (a) conduct best-fit regression analysis to identify optimal temperature contrasts between surface and the cave entrance. The latter approach is a time series technique equivalent to a Fast Fourier Transform [*Wynne et al.,* 2007, 2008a, b]. Using this approach, we will model hourly temperature data by fitting temperature series as a function of local time of day. Output from these routines will identify both optimal and off-peak times for detection.

Thermography of Cave/ Non-Cave Features: In Year 3, we will use the thermal behavior data to guide aircraft platform collects of thermal imagery. Thermal behavior data will be used to identify optimal and off-peak times for cave detection. Because, in a given region, these study sites will not be optimally detectable at the same time, imagery acquisition will be scheduled during times when most of the study sites are both optimally and least detectable. Imagery collected at caves during non-peak times will serve as a sensitivity test. We will collect thermal imagery using NASA's Quantum Well Infrared Photodetector (QWIP) placed within the fuselage of a fixed-wing aircraft. Depending on weather conditions, attempts will be made to maintain a resolution of 2 to 10 m for all flight passes. This sensor is equipped with an onboard GPS, which will be used to georeference each flight line. For daytime overflights, we will also operate a high-resolution visible imager. Additionally, we will use a handheld QWIP thermal imaging sensor to obtain close range ground-based thermograms at select caves and non-cave features.

Expedition Accomplishments: All mission critical objectives were met for the 2008 Atacama Desert expedition. We (1) deployed temperature and barometric pressure data loggers at eight caves and seven non-cave features in the Cordillera de la Sal region of northern Chile, (2) developed and refined cartographic techniques for deriving cave volume and high resolution maps, and (3) mapped two caves and two non-cave features using these newly developed techniques.

Preliminary Findings: We also identified two additional areas of inquiry that may be relevant for the targeting and ultimate exploration of Martian caves. (I) A few of our study caves are characterized by multiple entrances and skylights (> 2 entrances). We referred to these sites as “leaky sieve” caves. Consequently, our initial thoughts were these features may be (a) poor representations of a buffered cave environment and thus may be an insufficient analogue for this work, and (b) difficult to model the thermal behavior given multiple entrances. Through our investigations, we discovered areas within these caves that may serve as buffered environments. If correct, Martian caves with multiple entrances may still be important as potential targets to search for evidence of life. We will be analyzing data from these caves in Year 2 to determine whether these areas are thermally different (and thus potentially a buffered environment) from other areas within these caves. (II) Water was observed in a side passage of one of our study caves. This observation may be significant because the Atacama Desert is hyper-arid, and subsurface standing water was found several miles from the nearest known water source. An additional arm of this research will involve investigating the significance of this observation. We will investigate (a) whether this is a unique finding for Atacama Desert caves, (b) the genesis of the water deposition, and (c) whether this observation is significant from a Mars-analogue perspective.

Expected Results (upon project completion): Through our efforts, we will: (1) identify times when differences between cave entrances and surface control stations are optimal and schedule thermal data collection overflights accordingly; (2) compare the thermal behavior of caves to non-cave anomalies, and; (3) populate simulation models of the thermal dynamics of Martian caves and surface. Additionally, this project will result in the: (*i*) development of a systematic approach for terrestrial and extraterrestrial cave detection; (*ii*) establishment of a thermal signature library of terrestrial caves of various structure types; (*iii*) designation of optimal times for detection of caves on a per structure basis for Earth and Mars; and (*iv*) identification of instrumentation and mission requirements for detecting Martian caves.

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Table 1: 2008 Atacama Desert Expedition Team

Team Member	Affiliation	Role
Jut Wynne	SETI-CSC, NAU	Expedition lead; Sensor placement
Guillermo Chong	UCN	Logistics Chief
Tim Titus	USGS	Sensor placement
Christina Colpitts	Independent contractor	Safety Officer; Cartographer
John Dedecker	Charlottesville Astronomical Society, VA	Cartographer
Lynn Hicks	Southeast Georgia Health System, Brunswick	Expedition Doctor
Knutt Peterson	University of New Mexico, Albuquerque	Cartography Chief
Peter Polsgrove	Northern Arizona University, Flagstaff	Field Engineer
Dan Ruby	Fleischmann Planetarium, Univ. Nevada, Reno	Communications Officer; Cartographer

Sitting left to right: Dick Araya (Chilean caver), Christina Colpitts, and Tim Titus. Back row from left to right: Lynn Hicks, Dan Ruby, Knutt Peterson, Jut Wynne, John DeDecker, and Pete Polsgrove.

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