DETECTION OF CAVES AND CAVE-BEARING GEOLOGY ON MARS. N. A. Cabrol[1,2], E. A. Grin[1,2], and J. J. Wynne[2,3]. 1. NASA Ames Research Center, Space Science Division, MS 245-3. Moffett Field, CA 94035-1000.; 2. SETI Carl Sagan Center, 515N. Whisman Road, Mountain View, CA 94043; 3. Merriam-Powell Center for Environmental Research, Department of Biological Sciences, Northern University of Arizona, Flagstaff, AZ 86011. Email: Nathalie.A.Cabrol@nasa.gov.

Overview: The objectives of the Earth-Mars Cave Detection Project is to identify regions on Mars likely to contain caves and/or cave-bearing geology through (1) the analysis of multispectral imagery from past and current orbital missions and other orbital assets (e.g., radar), and (2) the investigation of terrestrial analogs for the identification of associated thermal, and geo-signatures. The project's deliverables include (*a*) the localization and characterization of potential caves and pits on Mars and their classification; (*b*) for terrestrial analogs, the identification of geosignatures and texture images, Energy Dispersive Spectra (EDS), and other signatures, and the classification of mineral suites to be expected under sets of conditions. The end product is a database of morphological, geological, mineralogical, signatures of significant astrobiological relevance for future mission searching for the past and present signatures of life on Mars and for human exploration.

Rationale: If early Mars once supported life, organisms may have retreated underground to escape the increasingly inhospitable surface conditions [*e.g.,* 1-4]. If subsurface life does exist on Mars, energy would either be derived heterotrophically or chemoautotrophically [5]. Numerous cave-dwelling chemoautothrophic microbes considered as analogues for Mars have been identified [6]. These organisms fix carbon from the air or rocks, live on oxidizable hydrogen sulfide [7] or can process methane, carbon dioxide, or sulphate ions [8]. It has been suggested that caves may provide access to water resources on Mars [2,3,9]. Identification of water and ice is central to both the search for life and for future manned-missions. Whether from orbit or from the ground, data now abounds to support the presence of liquid water and ice throughout Martian history. Recent gullies plausibly formed by shallow and deep aquifers were identified [10-11]. Phyllosilicates and other abundant other hydrated minerals [12] support the hypothesis of surface bodies of water; groundwater and surface drainage have been suggested [e.g., 13-16]. The MER mission has also identified an acidic shallow water environment at Meridiani, which may be conducive to cave formation [17].

Future human exploration and possible follow-on establishment of a permanent human presence will not only need water for survival and fuel; it will also require construction of suitable shelters and will provide near-complete protection against inhospitable surface conditions [2]. Potential future use as human habitats will first require detection of caves. To be efficient, such detection must be performed in a systematic fashion and with a high-degree of reliability. There is currently no tool, methodology, models, or instruments dedicated to the detection of caves for planetary exploration while their identification responds to NASA's highest priorities related to science (water and search for life) and human exploration (*e.g.,* Exploration Vision: help advance the plans for humans on Mars in 30 years).

Project Description: In response to this issue, we developed a project with an overall goal to define mission and instrumentation requirements for detecting caves on Mars using thermal infrared imagery. Specifically, the two main objectives are to:

(a) Characterize cave thermal behavior and evaluate the potential to differentiate thermal signatures of deep caves from shallow caves and collapse pits at Mars analog sites (Atacama Desert, Chile and Mojave Desert, California) where thermal data for both caves and non-cave features is collected in order to determine cave signatures and the differences between various types of caves. It also quantifies the signatures of false positives and false negatives;

(b) Develop models for martian caves that simulate atmospheric and environmental conditions using thermal behavior data and structural characteristics from terrestrial caves. We model surface and subsurface temperatures of caves and surrounding terrain, Mars atmospheric conditions (lower pressure, density, and heat capacity), entrance structure, albedo associated with martian geological formations where caves are likely to occur, and varying surface temperatures to reflect seasonality and diurnality. The objective is to identify the optimal detectability of a cave given structure type and geological substrate. The developed model is used to identify times to conduct overflights using the Quantum Well Infrared Photodetector (QWIP), a thermal imaging sensor developed by NASA Goddard Space Flight Center (GSFC). Overflights will be used to determine detectability and resolvability of each cave in the thermal infrared.

(c) Map potential caves and cave-bearing geology on Mars by surveying the existing missions databases. The results presented here relates to this objective.

Typology of Martian Caves: The geological diversity and evolution of Mars suggest that cave-types may be as varied as on Earth. The existence of caves from microscale to macroscale structures is predicted from Mars geology and climate history. A first level approach is to consider caves as a result of aqueous (water and ice), volcanic, and aeolian activity (individually or combined). Another approach is to consider processes, *i.e.,* tectonic and chemical activity, and erosion. **Tables 1 and 2** summarize plausible martian cave types and their formation processes [after 18-19].

Table 1. Cave Formation Independent of Host Environment Chemical Composition

Cave Type	Process	Morphology	Host Environment
Tectonic	Mass mov. in regolith	Fossae	Cohesive, low water content
Sink Hole	Soil piping	Chamber	Fine-grained, non-cohesive
Subsurface Erosion	Water drainage	Underground conduit	Water-rich, porous
Valley and Talus	Slope processes	Interconnected holes	Coarse-grained clastics
Channel bank	Flow scouring	Longitudinal excavation	Cohesive
Lake shoreline	Wave scouring, ice-push	Shore leveled excavation	Fine-grained, non-cohesive
Aeolian	Wind scouring	Holes	Loosely Cohesive

Table 2. Cave Formation Dependent on Host Environment Chemical Composition

Cave Type	Process	Morphology	Host Environment
Dissolution	Chemical	Holes, chambers	Soluble material
Lava blister	Exsolved away gas	Pockets	Basalt
Fracture	Mechanical pressure	Ridges, fossae, fractures	Varied materials
Lava tubes	Roof cooling	Shallow depth conduit	Lava flows
Ice	1. Steam from volcanic origin 2. Tension, wind ablation	1. Opening in dynamical equilibrium 2. Ice cracks, grooves, subsurface fluid-filled "lakes"	Ice
Glacial potholes	Ice melt blocks	Isolated cavities	Ancient segregated ice environment
Pseudo-karsts	Thermokarst, pressure or temperature induced melting	Collapsed structures	Poorly consolidated sediment

Preliminary Results: 40,116 THEMIS images were examined into the first year of the project. They cover the Olympus, Chryse, Elysium, Hellas, Argyre, and Memnonia regions of Mars. Among those, 1.7% (N = 677) show features of interest ranging from possible lava tubes, deep cavities associated with pit chains morphology, faulting, sink holes near ancient channels, ancient deep volcanic vents, and other cavity-like features associated with periglacial processes. Among those, 7.4% (N = 50) present characteristics making them high-priority cave or cavity candidates i.e. **Figure 1**.

Our poster will show the location of these features, their morphology, and type. Next steps include completing the survey of the THEMIS imagery and, where available, the compilation of images taken at different times of the day for high-priority candidates in order to assess depth and morphology; and to initiate the survey of imagery from other missions i.e. MRO, MGS, MEx. When completed, this project will provide a catalogue that identifies the most promising targets for astrobiology and human mission concept studies and a first-level assessment of their interest and reachability.

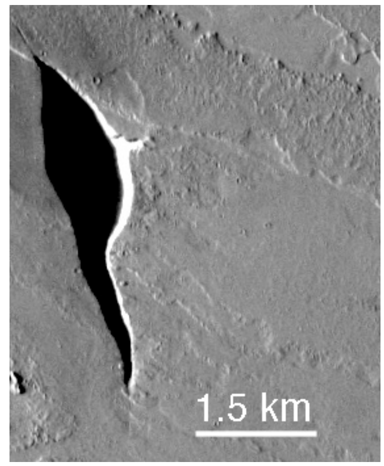

Figure 1: THEMIS image ID V05709015 (subsample), 18m/pxl resolution.

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