KILAUEA PIT CRATERS AS MARS ANALOGS: A New Direction for Cave-detection Techniques. G. E. Cushing and T. N. Titus, U.S. Geological Survey, 2255 N. Gemini Dr. Flagstaff, AZ 86001, gcushing@usgs.gov

Introduction: Detecting most of the caves that are likely to exist on Mars is difficult because their entrances must face skyward and be wide enough (>100 m) to be confirmed by THEMIS thermal-infrared observations [1]. Here we discuss the possibility of using THEMIS data to indirectly detect cave entrances that may exist in a small number of anomalous Martian pit craters.

First identified in Kilauea volcano's rift zones and named as such by *Wilkes* (1845), pit craters are circular, elliptical or trough-shaped depressions that result from the collapse of surface-layer materials into large subsurface void spaces [2,3]. By their lack of elevated rims, ejecta patterns, or associated lava channels, these pits are both visibly and morphologically distinct from impact craters or effusive volcanic vents (Figs. 1 & 2).

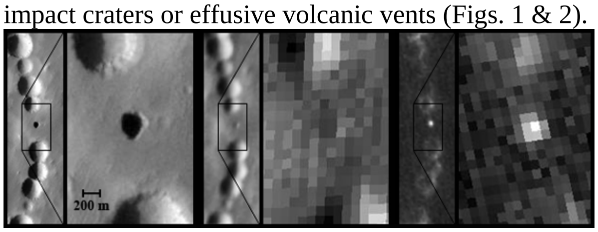

Figure 1: From [4], THEMIS visible (left), afternoon infrared (center) and predawn infrared (right) observations of a Martian APC that formed within a chain of typical pit craters. The APC is both thermally and morphologically distinct.

On Mars, typical pit craters are often clustered in linear or curvilinear chains (Fig. 1), have diameters ranging from less than 100 m to more than 4 km, and are generally bowl-shaped with floors that curve gradually upward to the upper rims [3]. Predawn THEMIS thermal-infrared observations indicate little or no thermal-inertia difference between typical pit-crater interiors and their surrounding surfaces (except for exposed bedrock along their upper rims, Fig. 1) [4].

Anomalous Pit Craters (APCs): A small number of Martian pit craters exhibit morphologies (Figs. 1, 2-A) and thermal behaviors (Fig. 1) that are clearly distinct from typical pit craters because: 1) compared with their diameters, APCs are deeper than most typical pits. 2) From orbital observations, APCs appear to have cylindrical (rather than bowl-shaped) interiors, with either vertical or overhanging inner walls strong enough to extend 245 m or more beneath the surface [5]. 3) APCs are invariably circular or near-circular in plan view, though this may be a function of a smaller APC size distribution (<400-m diameters). 4) APCs exhibit thermal behaviors that are strikingly different from those observed in typical pit craters (Fig. 1) [4].

The difference in thermal behavior between APCs and typical Martian pit craters may be highly significant. In Figure 1, an APC lies directly in the center of the chain of typical pit craters. Notice how this feature is slightly cooler than the surrounding surface in the afternoon (though not as cool as shadowed areas in the adjacent pit craters), while at night it is considerably warmer than all other surfaces within the scene. This behavior shows that APCs experience smaller amplitudes of diurnal temperature variations, suggesting the subsurface controls, or at least heavily damps, APC temperature variations. Typical pit-crater temperatures, on the other hand, are dominated by solar insolation. *Wynne et al.*, (2008) investigated diurnal and annual temperature variations in several terrestrial cave systems [6] and recorded behaviors (Figure 3) that are consistent (damped variability compared to surface temperatures) with those shown in Figure 1.

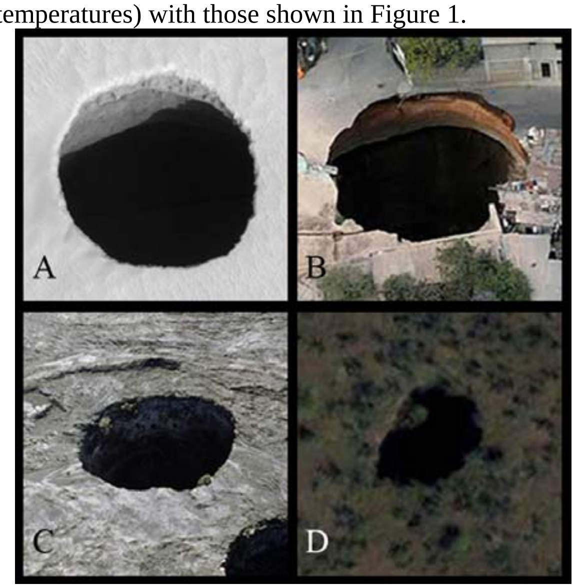

Figure 2: Pit-crater examples: Panel-A is a HiRISE observation [7] of a Martian APC ~165 m across with an overhanging rim and a depth of *at least* 245 m [5]. Panel-B shows a human-caused sinkhole that looks similar, but is not analogous to [A]. Panels C & D are terrestrial SWRZ pit craters that may be analogous to Martian APCs. Panel [D] is shown in cross-section in Figure 4.

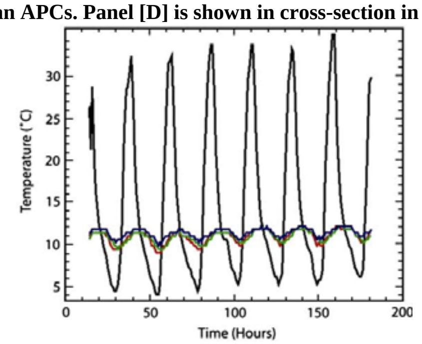

Figure 3: From [6], temperature variations over several days for several points within a terrestrial cave (colored) and for the nearby surface (black). Cave temperatures are minimally influence by solar insolation, and variations are significantly damped.

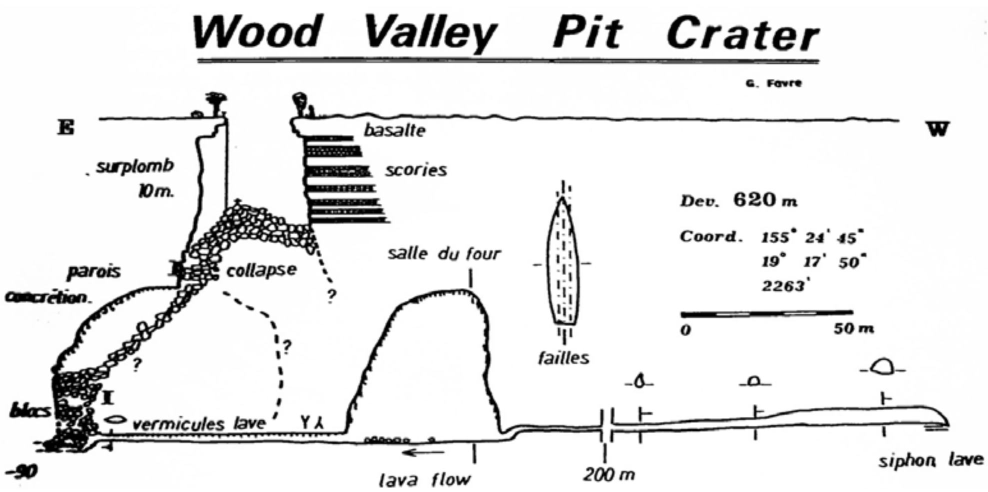

Figure 4: Cross-section diagram of the SWRZ Wood Valley pit crater [8] (also shown in Figure 2-D). The base of this pit provides access to an extensive system of underground caverns and lava-tube caves. If these void spaces significantly affect the surface pit's thermal behavior, then comparable behaviors in the Martian APCs may indicate the presence of other subsurface systems.

Terrestrial Pit Craters: Kilauea volcano's Southwest Rift Zone (SWRZ) contains several pit craters that appear morphologically comparable to the Martian APCs (*e.g.*, Figures 2-C & 2-D) because they formed via collapse processes in basaltic lava, are generally circular (though SWRZ pits tend to be more irregular), and have either sheer or overhanging interior walls. Though some terrestrial collapse features seem to appear similar to the APCs found on Mars, they are not necessarily analogous. The large sinkhole shown in Figure 2-B appears visibly similar to the Martian APC in 2-A, but formed via human-induced surface/water interactions and is not considered as a Mars analog.

The SWRZ pits are of considerable interest (assuming they are indeed analogous to Mars' APCs) because some are known to contain access points into significant subsurface void spaces such as large caverns and lava-tube caves [*e.g.*, 8,9]. Figure 4 shows a diagram of the SWRZ Wood Valley pit crater, whose rim overhangs the floor, and whose base contains access to two large subterranean caverns and several hundred meters of lava-tube caves [8].

Because Mars' APCs exhibit thermal behaviors that are unique on Mars, but similar to those recorded in terrestrial cave systems (Figures 1 & 3), and because they appear (at least visibly) to be morphologically comparable to some of the SWRZ pits (some of which contain cave entrances; Figures 2 & 4), we suggest a strong likelihood that at least some of the APCs on Mars provide access to subsurface void spaces such as cracks, caves or caverns. If the subsurface void space (into which a collapse event occurs) extends beyond the diameter of the pit, then access points into that void may exist at the pit's base [9].

If connected to a Martian APC, the low-amplitude nature of a cave's thermal variations may cause it to behave as a giant thermal capacitor—effectively damping the APC's overall thermal variations. Future observations of selected SWRZ pits, both possessing and lacking cave entrances, may allow thermal distinctions between them to be characterized. Such an understanding may allow future investigations to indirectly determine which of Mars' APCs may contain cave entrances of their own. Though we know that Mars' APCs show clearly distinctive thermal behaviors, such data have yet to be recorded in the SWRZ pits.

Caves are important targets to the Mars exploration community because of their habitat potential for future human visitors, and because caves may be among the only places on Mars that contain preserved evidence of any past or present microbial life [10].

References: [1] Christensen, P. R., *et al.* (2004) *Space Sci. Rev.*, 110(1), 3985-4015. [2] Wilkes, C., (1845) *Narr. of U.S. Explor. Expd.*, Vol. 4. [3] Wyrick, D. and D. A. Ferrill (2004) *JGR*, 109, E06005. [4] Cushing, G. E., *et al.* (2007) *GRL*, 34, L17201. [5] Cushing, G. E. *et al.* (2007) *LPSC XXXIX*, Abstract #2447. [6] Wynne, J. J., *et al.* (2008) *Earth & Planet. Sci. Lett.*, 09298. [7] McEwen, A. S. *et al.* (2007) *JGR*, 109, E05S02. [8] Favre, G. (1982) *Proc. of the 3rd Int. Symp. on Vulcanospeleology*, 37-41. [9] Okubo, C. H. and S. J. Martel (1998) *J. Volc. & Geotherm. Res.*, 86, 1-18. [10] Boston, P., *et al.* (2004) *AIP Space Technol. Appl. Int. Forum*, 699, 1007-1018.