Orbital Observations of Martian Cave-entrance Candidates: G.E. Cushing[1], T.N. Titus[1] and E. Maclennan[1]
[1]U.S. Geological Survey, Center for Astrogeology, 2255 N. Gemini Dr. Flagstaff, AZ 86001, gcushing@usgs.gov

Introduction: From the time Oberbeck et al. (1969) first proposed that some lunar rilles might be collapsed lava tubes, the existence and potential utility of extraterrestrial cave systems have been discussed—particularly for the Moon and for Mars [e.g., 1,2]. Considering the behavior of basaltic volcanism is generally analogous between the Earth and Mars [e.g., 3], volcanic caves may be common on Mars as well [*1*,*4*].

Here we present a general discussion about orbital observations of cave-entrance candidates on Mars. Candidates were identified by the THEMIS VIS (18 m/pixel) and CTX (6 m/pixel) visible-wavelength cameras. Since their identification, many candidates have been targeted by the HiRISE camera at extremely high resolution (25-50 cm/pixel) to reveal important morphologic details. We have thus far identified three different cave types in Mars' volcanic regions.

Lava Tubes: Many Martian lava-flow features appear consistent with orbital views of terrestrial inflated tube-fed lava flows. These are often characterized by low (10-20 m), sinuous topographic crests with laterally spreading flanks that often form chains of either tumuli or vent structures (Figure 1, Top). In many cases, a fracture or channel (<60 m across) runs axially along their crests. This specific morphology is a telltale indicator of a tube-fed system emplaced by inflation, which can be a dominant pāhoehoe emplacement mechanism across low slopes [5]. Although sometimes identified as completely collapsed lava-tube ceilings, it is important to emphasize that axial trenches along inflated tube-fed flows may be dilational fractures or the surfaces of former channelized flows. These trenches do not necessarily indicate subsurface tube characteristics such as void diameter, whether internal collapse has occurred, or even whether the tube system ever drained to form an empty tunnel. However, we suggest that the skylight entrances discussed here (being considerably deeper than their associated axial trenches) indicate that drainage did occur at those locations, and that evacuated tubes are likely to remain at least partially intact beneath the surface.

Volcano-Tectonic Fractures: These structures (Figure 1, Center) show evidence of both volcanic and tectonic formation mechanisms, and are clearly different from the axial trenchess associated with tube-fed lava flows in several ways. These are wider (100-200 m) than the trenches found along the crests of tube-fed flows and are composed of 10-20 km linear segments that cut across numerous pre-existing lava flows and intersect each other at sharp angles of 95º-110º. These

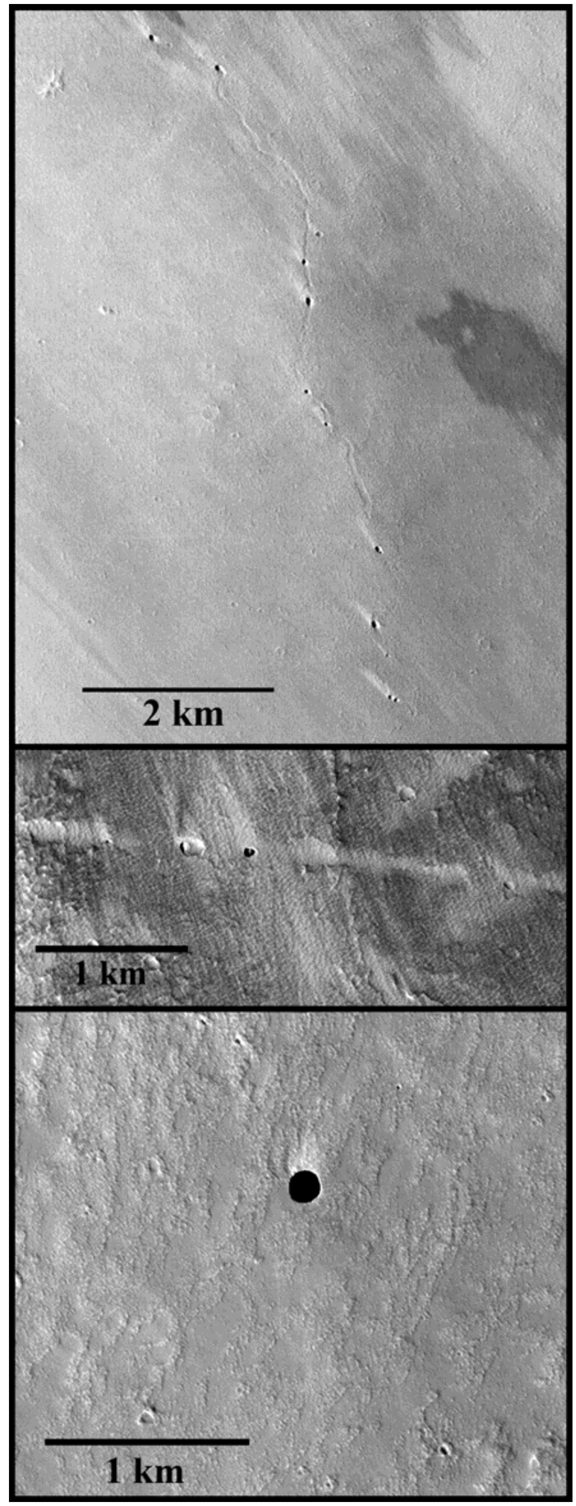

Figure 1: Martian examples of Tube-fed lava flow with skylights (Top); Volcano-tectonic fracture with skylight (Center); Atypical Pit Crater (APC, Bottom).

conjoined fractures can extend more than 100 km in length and sections show evicence of viscous outflow activity. Unlike axial fractures in tube-fed flows, the rims of these trenches are level with the local topography, and their floors are broad and flat with no apparent vertical offset between opposing walls. A regional dust mantle (up to several meters thick) masks evidence of any parallel normal faults that could indicate whether a graben-type collapse occurred. The lengths, segmentation, location and orientation of these fractures (between Arsia Mons and Pavonis Mons, and aligned with the Tharsis-ridge volcanic system) suggest they may have formed through deep tectonic processes associated with the Tharsis regional uplift [*6*,*7*]. Tectonic fractures of this magnitude could have been intruded and widened by magma, thus inducing formation of the observed grabens and skylights at the surface. Unlike lava-tube caves (which tend to be sinuous, remain relatively near the upper surface and follow regional slopes), volcano-tectonic caves could extend deeply into their host fractures and branch into subsurface networks. A suitable terrestrial analog to these volcano-tectonic fractures may be the 'Great Crack' in Kīlauea volcano's southwest rift zone, which hosts a number of deep and extensive caves, some of which have been explored to depths exceeding 180 m [*D. Coons*, personal communication, 2009].

Atypical Pit Craters (APCs): Terrestrial analogs to these features commonly contain cave entrances at their bases. These pits are proportionately deeper than common pit craters, are cylindrical or conic in form, have vertical or overhanging walls and often have flat smooth floors (Figure 1, Bottom) [8]. APCs do not form within linear surface depressions, and are nearly always circular with diameters of ~50-300 m. HiRISE data show that some APCs extend laterally beneath overhanging rims for unknown distances [9]. *Haruyama et al.* (2009) recently discovered lunar features that look identical to Martian APCs, and suggest they may be skylight entrances into deep lava tubes [10].

APC Thermal Behaviors: Cave entrances in APCs may be difficult to visibly observe if they are out of view beneath overhanging rims, although they may exert a thermal influence on the overall pit. Knowing local surface temperatures from THEMIS TIR data, we can estimate APC floor temperatures from the ratio of sub-pixel mixing between the floor and nearby surface for each pixel that covers part of an APC. We calculate floor areas in VIS images by fitting ellipses (diameter, eccentricity and rotation) to the pit rims. We then 'super-register' the TIR image to the VIS image by re-projecting the TIR (100 m) to VIS resolution (18 m), and then shifting the TIR image across the VIS-derived ellipse until a best fit is achieved. This re-projection and super-registration of TIR to the VIS data allows us to define the pit's edge and to estimate the areal ratio of floor and surface contained within each (100 m) TIR pixel. If we assume that the floor is spatially isothermal, a best-fit temperature can be calculated. Surface temperatures are assumed to be the median local temperatures of the surrounding areas.

APC diurnal temperature variations are strongly damped in amplitude compared with those of the surface (Figure 2) and adjacent common pit craters (which are each dominated by solar input) suggesting that subsurface thermal conductivity is likely the control for APC floor temperatures. On Mars, this particular thermal behavior appears to be unique to APCs and is generally consistent for all candidates large enough to be resolved by THEMIS TIR. Temperature variations observed in APCs are comparable to behaviors recorded in terrestrial cave entrances [11], and if some APCs are thermally influenced by cave systems, then damped (and probably phase delayed) diurnal temperature ranges should be expected. However, all APCs resolved by THEMIS TIR exhibit this same general thermal behavior, and it is unlikely that all of these contain cave entrances. APC floor temperatures appear to vary in accordance to the subsurface diurnal thermal wave, and detecting thermal evidence of cave entrances will require instruments with improved spatial and temporal resolution. We expect cave entrances inside APCs to exaggerate (and slightly phase-delay) the damped behaviors already observed, and extreme examples (such as floor/surface differences > 50 K) lead us to suspect the presence of additional physical influences that warrant further investigation.

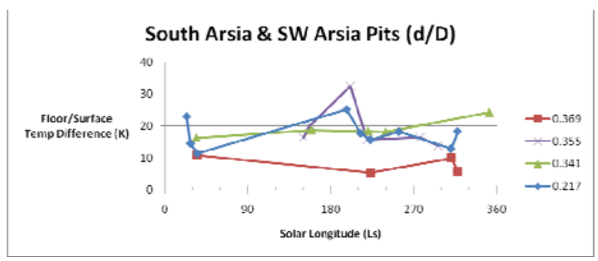

Figure 2: Plots of pre-dawn THEMIS floor/surface temperature differences vs. season at different locations.

References: [1] Horz (1985) *Bases and Sp. Activities of the 21st Cent.* pp. 405-412. [2] Boston et al. (2003) *Grav. and Space Bio. Bulletin*, 16(2). [3] Glaze et al. (2005) *JGR*, 110, B08202. [4] Cruikshank and Wood (1972) *Moon*, v. 3, pp. 412-447. [5] Kauahikaua, et al. (2003) *USGS Prof. Paper* #1676. [6] Barendt (1990) *Mars*, p. 249-297. [7] Philips (1990) *JGR* 95, B4, pp. 5089-5100. [8] Cushing et al. (2007) *GRL*, 34, L17201 [9] Cushing et al. (2008) *LPSC abst.* #2447. [10] Haruyama et al. (2009) GRL, 36, L21206. [11] Wynne et al., 2008, *Earth and Planet. Sci. Lett.*, 272, 1-2, 240-250.